Managing Water in the 21st Century: Challenges and Opportunities

Proceedings of the 8th Rosenberg International Forum on Water Policy

Alberto Garrido & Ayman Rabi
Editors

Rosenberg International Forum on Water Policy
University of California

Managing Water in the 21st Century

Challenges and Opportunities

Proceedings of the 8th Rosenberg International Forum on Water Policy

Alberto Garrido and Ayman Rabi

Editors

Rosenberg International Forum on Water Policy

Professor Soroosh Sorooshian

Chair

ISBN 978-1-60107-970-1

The University of California prohibits discrimination against or harassment of any person in any of its programs or activities on the basis of race, color, national origin, religion, sex, gender, gender expression, gender identity, pregnancy (which includes pregnancy, childbirth, and medical conditions related to pregnancy or childbirth), physical or mental disability, medical condition (cancer-related or genetic characteristics), genetic information (including family medical history), ancestry, marital status, age, sexual orientation, citizenship, status as a protected veteran or service in the uniformed services (as defined by the Uniformed Services Employment and Reemployment Rights Act of 1994 [USERRA]), as well as state military and naval service.

UC policy prohibits retaliation against any employee or person in any of its programs or activities for bringing a complaint of discrimination or harassment. UC policy also prohibits retaliation against a person who assists someone with a complaint of discrimination or harassment, or participates in any manner in an investigation or resolution of a complaint of discrimination or harassment. Retaliation includes threats, intimidation, reprisals, and/or adverse actions related to any of its programs or activities.

UC is an Equal Opportunity/Affirmative Action Employer. All qualified applicants will receive consideration for employment and/or participation in any of its programs or activities without regard to race, color, religion, sex, national origin, disability, age or protected veteran status.

University policy is intended to be consistent with the provisions of applicable State and Federal laws.

Aridity and the Fate of Agriculture

Henry Vaux Jr., Chair, 1996–2016

Rosenberg International Forum on Water Policy

The Rosenberg International Forum on Water Policy was created with an endowment gift from the Bank of America to the University of California to honor Bank Chairman Richard Rosenberg on the occasion of his retirement. Chairman Rosenberg had rallied the California business community to address the drought of 1987–1992 and has maintained an abiding interest in sound water policy and good water management practices. The forum is held every two years at different locales around the world. To date, forum venues have included San Francisco, CA; Barcelona, Spain; Canberra, Australia; Ankara, Turkey; Banff, Canada; Zaragoza, Spain; Buenos Aires, Argentina; and Aqaba, Jordan.

Participation in the forum is limited to fifty water scholars and senior water managers. Typically 25 to 30 countries are represented around the table. Participants are asked to read the papers in advance of the forum and come prepared to engage in interactive discussions that are at the heart of each forum. Forum themes are identified by a nine-member advisory committee that provides advice and oversight. The editors of this volume, drawn from the membership of the advisory committee, were Dr. Alberto Garrido, from the Botin Foundation Water Observatory and the Technical University of Madrid, and Dr. Ayman Rabi, who directs the Palestinian Hydrology Group. For this eighth edition of the Rosenberg Forum, the advisory committee chose the theme "Managing Water in the 21st Century: Challenges and Opportunities."

One basic objective of the Rosenberg Forum is to promote the use of science as a base upon which to build effective public policies. That theme is taken up again in the 8th edition of the forum in both the opening and closing sessions. In the keynote session, three high-level policymakers discuss water scarcity and the potential use of science in addressing it. Two of the presenters were former prime ministers of Jordan and the third was a high-level, distinguished diplomat at the United Nations. The two prime

ministers are perhaps best qualified about the existing and potential manifestations of water scarcity, living as they do in one of the most arid countries in the world. The third view focuses on the array of challenges within which water scarcity is embedded. What emerges is documentation of the urgent need to address water scarcity; the equally urgent need to develop and rely upon science in fashioning policies to address water scarcity; and the need to facilitate interaction between scientists and policymakers in order to make the best possible use of existing and developing science.

The last session of the forum also focuses on the science–policy nexus. In both the panel presentations and the discussion that follows, there is consideration of what might be characterized as the prevailing pathologies that constrain the effectiveness of the relationships between scientists and policymakers. Further, these constraints are seen to attenuate the use of science in policymaking, a failure that carries high social costs. The closing discussion includes development of recipes for improving the interactions of scientists and policymakers and underscores the importance of doing this if we are to be successful in meeting the future challenges posed by water scarcity.

The intervening sessions include scientific contributions on two topics that represent both challenges and opportunities for water management in the twenty-first century. First, the institutional arrangements for managing water resources are frequently ineffective or only partially effective. One explanation lies with the fact that political jurisdictional boundaries rarely coincide with watersheds, the fundamental hydrologic element on which integrated watershed management should be based. The session on regional planning and management explores a variety of issues that bear on the prospects for effective water management across international and interregional boundaries. The importance of design, context and participation is highlighted. However, cautionary lessons show that institutional arrangements need to be tailored to individual circumstances. One size does not fit all. The importance of language in addressing the resolution of water disputes between disparate parties who may possess differing degrees of political and economic power is also highlighted. The Israeli-Arab water agreements are employed to illustrate the various concepts and findings that emerge from this work.

A second set of challenges and opportunities emerges in the final scientific session that focuses on the fate of agriculture in dry or drying climates.

There are two challenges. Global population growth means that there will be more than two billion additional mouths to feed by mid-century. Yet, both irrigated and rainfed agriculture appear to be approaching their limits of extent. And global warming is anticipated to reduce water supplies in some areas where irrigated agriculture is virtually essential for production. The fundamental issue is, how agricultural production can be expanded to feed the expected additional population in the face of increasingly binding constraints on land and water resources. Here, forum participants were invited to examine the outlook in the Middle East/North Africa (MENA) region, where water supplies are already quite scarce and population is growing. The prospects of existing techniques and technologies for producing food in dry regions are also evaluated, and several encouraging but limited prospects for the future are identified. Finally, the consequences of growing population, agriculture under stress, and other sources of instability are examined from the perspective of rural areas in the MENA region.

In the remainder of this volume, the written contributions of the forum speakers are presented in the order in which they were programmed. All of the papers were subjected to editorial review and revision. The scientific papers were subjected to rigorous peer review, and authors were required to respond to those reviews with appropriate changes and modifications to their papers. Thanks go to all of the authors for a job well done. Thanks also go to all of the forum participants for a particularly rich and enlightening set of discussions that were at the heart of this forum.

Part 1

Keynote Papers: Views of Top Policymakers

1

Bridging Science and Policy in the Domain of Water: A Middle-Eastern Perspective

H.E. Dr. Abdel Salam Majali, FIAS

Former Prime Minister of Jordan

President, Islamic World Academy of Sciences, Amman, Jordan

Excellencies and Eminent Guests,
Ladies and Gentlemen

Water is vital for the life and health of people and ecosystems and is a basic requirement for the development of countries. Muslims believe that water *is* life. The Qur'an declares: "We made from water every living thing." But around the world, women, men, and children today lack access to adequate and safe water to meet their most basic needs. Water resources, and the related ecosystems that provide and sustain them, are under threat from pollution, unsustainable use, land-use changes, and climate change.

Nearly a third of the world's population will face severe water shortages in 25 years' time, increasing the danger of conflict over water supplies. Unless we change our ways, we will soon be facing a more serious water crisis. Consequently, competing claims to water between users within countries and between countries must be managed in a cooperative rather than a confrontational fashion. *Integration* rather than *segregation* should be the key policy. The needs of future generations must be safeguarded and issues of quantity and quality of water must be addressed.

Let me first talk about the Middle East.

The Middle East is one of the most water-insecure regions in the world. This already scarce natural resource has the potential to spark local and interstate conflicts, particularly as many of the region's central waterways

are shared by several riparian states. In this respect, the most likely hotspots are the Nile drainage basin, the Tigris-Euphrates Rivers, and the Jordan River basin. Jordan, of course, ranks eleventh out of twenty states in '"extreme risk.'"

All of these potential sites of conflict involve several countries. For the development specialists, the three regions represent three models of water-related development phenomena: water management for poverty eradication, as in the case of the Nile; water management for food security, as in the case of the Tigris-Euphrates river system; and water management to halt environmental degradation (and, more important, to promote regional peace), as in the case of the River Jordan.

From the outset, disputes related to water resources have formed part of the Arab-Israeli conflict. In 1949, peace negotiations after the first Arab-Israeli war broke down, in response to Israeli demands to keep control over the economically important Lake Tiberias and the Jordan River. The water issue resurfaced again in the early 1960s after Israel announced plans to divert water from Lake Tiberias to the Negev. The Arab states strongly denounced the plans, which would have reduced the share of Israel's Arab neighbors of water for drinking and for agriculture. The Arab response was a counter-plan that aimed to considerably reduce the amount of water reaching Israel from the tributaries of the Jordan River.

The above conflicting water-diversion projects by Israel were a significant contributor to the 1967 Six-Day War.

More recently, there is evidence to suggest that the long-standing political dispute between Israel and Syria could have been effectively addressed if water rights were discussed during the peace negotiations between the two countries after the Madrid peace conference in 1991; in fact, the last outstanding issue in the negotiations was whether Syria should have access to Lake Tiberias or not.

Moreover, water disputes contributed also to the failure of peace talks between Tel Aviv and the Palestinian Liberation Organization (PLO).

On the other hand, a successful example exists of two adversaries in the region sharing the precious little they have in terms of water resources for the sake of peace. Israel and Jordan signed their famous peace treaty in 1994. It was signed by Abdel Salam Majali on behalf of Jordan and Yitzhak Rabin on behalf of Israel. The treaty had a major water-sharing component that addressed one of the most lingering difficulties between Jordan

and Israel. The treaty guaranteed Jordan an equitable share of water from the Yarmouk and Jordan Rivers, and outlined an elaborate arrangement whereby Jordan and Israel will share the Yarmouk and Jordan River waters. Moreover, Jordan and Israel agreed to cooperate in finding sources for the supply to Jordan of an additional quantity of 50 million cubic meters (MCM) per year of water of drinkable standard.

This led to Israel agreeing to transfer additional water supplies to Jordan.

Nevertheless, water is still one of the central problems facing Jordan. A problem that many successive governments of the country have had to deal with, including two governments which I have headed. Military conflicts in the region have resulted in the movement into Jordan of people from Palestine, Lebanon, Iraq, and Syria. This human flood places increased strain on the already meager water resources that Jordan has. It was recently announced that Jordan was hosting over 1 million Syrian refugees within its borders. This is equivalent to the UK hosting 7 million refugees or the US hosting 30 million. You can imagine the nightmare that agencies responsible for the provision of safe drinking water have to put up with, and indeed, those extra finances that have to be found by the government for the purpose.

Today, in Jordan and the region, we face the challenge of saving the Dead Sea, which is vanishing with severe negative consequences on the area. For years, Israel and the Arab governments have diverted up to 95% of southward flow of the Jordan River, which replenishes the Dead Sea. A very creative solution is suggested today to save the sea: a project to create a pipe-canal system connecting the Red Sea to the Dead Sea through building a 180-km pipeline across Wadi Araba. This three parties project (Jordan, Israel, and the Palestinian Authority) could restore most of the Dead Sea water level over time. Moreover hydroelectricity generated from the water coursing down the gradient would power large desalination plants.

The project represents an innovative—yet calculated—leap forward in the region's attempt to address its water and energy needs as well as create an ecosystem in which the involved countries have a stake in its longevity. The project is thus as important for food and energy security as it is for human security: the security of the Israelis, Palestinians, and Jordanians. Unlike other national proposals, the Red-Dead Canal will not only save the Dead Sea from extinction but also provide desalinated water to Israel and the Palestinians, as well as Jordan. Further, such an undertaking has been

stipulated in Article VI of the Jordan-Israel Peace Treaty that Jordan and Israel shall cooperate in developing plans for the purposes of increasing water supplies and improving water use efficiency, within the context of bilateral, regional, or international cooperation.

As a decision-maker, I think that this project is innovative and forward looking and is a potential peace asset that contributes to regional interdependence and security.

The 1997 UN Watercourses Convention is a global framework agreement with the goal to '"ensure the utilisation, development, conservation, management and protection of international watercourses'" (see the Convention's website, www.unwatercoursesconvention.org). Achieving sustainable and peaceful management of the more than 500 international watercourses in various parts of the world is one of the major challenges in the immediate and long-term future. The three central issues that arise in this context are legal entitlement, framework for allocation, and compliance with the agreed watercourse regime. Such complex issues require more than a legal response. I think they need a political response as well as a scientific one. The input of the water experts, across the entire horizon of water resources management, including engineers, hydrologists, economists, and social scientists, is equally important.

New concepts such as "green" water and "virtual" water could be further developed and employed effectively in the response to transboundary water problems. But at the very end it is the will of politicians that will have the final word. The legal response to water scarcity has a solid foundation in the UN Watercourses Convention. However, years after the adoption of this Convention, it is not yet in force, a fact that endorses the point of view of those who say that water crisis is a crisis of governance, not one of scarcity.

Clearly, there is a problem when it comes to the relationship between scientists and technologists on the one hand and politicians on the other. Few politicians appreciate the possibilities of science. They do not understand the limitations of science or the long time scales it can take to develop an idea into a product or a service. Nor do the majority of scientists understand the restrictions of political office or have a clear idea of political processes. They do not appreciate the pressures or the time scales politicians work to. Both sides, the scientists and the politicians, recognize the importance of each other. But there is no natural dialogue between the two sides, because they come from different worlds.

We need to bridge the gap and make politicians understand the importance of science by creating better communications between the science and non-science worlds, between the scientific and the political communities.

Politicians judge the policy position action first and foremost on its policy merits, not on its morality. So if we want a politician to adopt a position relative to supporting science or scientists, or the incorporation of science into some other decision, it is not enough to present the research that supports this position or to spell out the policy administrative or legislative terms. The message must be framed first and foremost in its politically communicable form.

I think this is one of the reasons why the InterAction Council has taken a serious interest in water issues. IAC Members are eager to learn about the water-related problems afflicting the world today. This was evident at the last two meetings of the IAC, in Quebec city and in Tianjin (China), as well as the earlier preparatory meeting, which took place in Toronto in March 2010.

So what can we do to bridge the gap between the two parties? As a scientist turned politician, I can propose some ideas:

1. Scientists must take an interest in politics and must understand the particular challenges politicians face. We must aim at a social relationship developed over time between scientists and politicians.

2. Scientists should not view politicians as mere media or PR experts, because they can really help. The communication staffs of science organizations (academies of sciences in particular) and political offices can help. More could be done to "pre-test" science messages being delivered to political receivers and to teach effective follow-up. Some scientists are good communicators (Bruce Alberts, of the U.S. National Academy of Sciences, and Ahmad Zewail, winner of the Nobel Prize in chemistry, are good examples) and they could be held up as role models and encouraged to share their expertise with others.

3. Finally, perhaps the best place to begin bridging the divide is to get more of those with scientific expertise working in political positions of influence. For this to happen, politics has to become a more acceptable trajectory for young people in science and less of an "alternate career choice."

Due to the fact that politicians are still far from understanding the water problems the world is facing, some experts believe that the world water crisis is a crisis of governance, not one of scarcity.

For the majority of the developing countries of the South, water is a matter of survival. Countries of the North, which happen to be industrialized and developed, are richly endowed with this precious resource; thus, it is seen as a secondary problem despite the sincere efforts of caring environmentalists and politicians to address the issue.

Only until we realize that we are all in the same boat—that is, politicians and scientists, and people from the South and people from the North—and that we all face a transnational water crisis, will we be able to realize a water-secure future for our children and grandchildren.

Thank you.

2

Bridging Science and Policy in Water Management

H. E. Dr. Adnan Badran

Former Prime Minister of Jordan

Professor and President of University of Petra, Amman, Jordan

President of Arab Forum of Environment & Development (AFED), Beirut, Lebanon

Introduction

There is no doubt that problems with water management are becoming more complex due to rapid population growth, climate change, and the growing demands of industrial and agricultural development. The problems of water scarcity therefore become more acute, and, simultaneously, science becomes more crucial in providing the basis of sound governance and a holistic approach to enlightened policy and water management. The potential of modern science to contribute to the resolution of water scarcity is unlimited. The major challenge to sustainability is how to use science to overcome uncertainty of Agenda 21 on environment development.

Water scarcity has many causes, among them a crisis of water management, fragmented institutions, and inadequate policies, legal systems, and political will. Yet the gap between science and policymaking at the national, regional, and global levels continues to widen. Training scientists in water research will require political commitment, sustainable funding, and international outreach.

Effective water governance will require broad stakeholder participation, a transparent sharing of information between scientists and "policymakers," and a balanced sharing of authority between the government and nongovernment sectors. Effective institution-strengthening and appropriate legal frameworks to guide the public-private partnership will be needed.

Water for Life

Water is an integral part of life, the environment, and development. Yet it is not equally available to all. Currently, one-third of world's population is living in water-scarce or water-short areas. Moreover, it is estimated that 12% of the global population uses 85% of its freshwater. Water supply resources are being stretched to their limits. By 2050 an additional three billion people will be born mostly in countries already suffering from water shortage. Climate change will likely mean that as much as one-half of the global population will be living in water-scarce or water-short areas. With the advent of climate change, the water-stressed areas in the Middle East and North Africa (MENA) region will likely face extreme water scarcity as projected rainfall declines of 20% and temperatures increases of 2° to 3°C would lead to large losses of water resources, increases in the likelihood of intensifying scarcity of basic food supplies, and increases in the extent of increased poverty.

The improvement of water management techniques and technologies needed to cope with the projected increase in water scarcity will require new water science as well as extensive use of existing water science. Future water policies will have to be well informed by science if they are to be effective. Many existing water policies are not based on sound science and are aimed at goals other than ensuring that water is used efficiently, protected from qualitative degradation, and maintained for future generations. The potential of science to contribute to the resolution of current and foreseeable water problems is virtually unlimited. There are numerous examples.

At the global level the developments from nanoscience can help in a variety of ways. Development of more effective ways of cloud seeding, development of nanomembranes for cleaning polluted water, and improvements in diffusion technology, which will lower the costs of desalination, are important examples. Development of small scale solar technology can improve energy generation and thus lower the cost of desalination. The importance of such a development can be illustrated by reference to the MENA region, where solar energy falling on 1 m^2 of surface annually is the BTU equivalent to one barrel of oil. Currently, the Arab region, with 5% of world population, produces 50% of the world's desalinated water (AFED 2010). Technology can help to extend the application of desalination and other water-cleansing techniques to other areas throughout the world.

At the regional level, scientifically based management of shared water resources, whether surface or groundwater, should be placed high on the

agenda of countries with shared water basins. Effective bilateral and/or multilateral agreements should lead to stronger economic and political ties among countries with shared water basins, obviating the potential for conflict. The importance of dealing effectively with shared water is almost self-evident. This is particularly true in the MENA region where "of all renewable water resources . . . two-thirds originate from sources outside the region" (AFED 2010).

At the national level science can contribute to the acquisition of knowledge about possible new water sources and about the application of techniques for using existing sources more efficiently. Thus, for example, agriculture accounts for 85% of water use in Arab region as compared with a world average of 70%. On-farm irrigation efficiency remains at 35%, so there is clearly room for improvement at the farm level (AFED 2010). Science can also contribute to the development of new crop strains that better tolerate both aridity and salinity. Rain-harvesting systems and efficiency improvements in science-based agricultural practices to achieve water savings should be emphasized. Other policy reforms leading to a new political economy of water management could focus on the acquisition of water "virtually" through imports of crops "from water-rich countries, while allocating scarce water resources to low-water-consuming, high-value crops that can generate foreign exchange" (AFED 2010). In this way, food security may be achieved through set of well-balanced trade and water management policies.

One potential new source of water is recycled wastewater. Wastewater generated by domestic and industrial sectors in the Arab region totals 10 km^3/year, of which 5.7 km^3 undergoes treatment. Of this volume of treated wastewater, only one-third is reused. However, wastewater treatment plants currently handle waste loads that exceed their capacity limits. The untapped potential of wastewater should be the focus of appropriate policy interventions, including national water management strategies for water reuse.

The Role of Science in the Domain of Water

Background

The focus of this section is on the importance of science in fashioning enlightened water policies to manage the intensifying global water scarcity. In the following section, the importance of water in sustaining life,

the environment, and economic development is discussed. Subsequently, the decline of available water resources is characterized. The final sections focus on the importance of water science to fashioning solutions to the global water crisis, the needs to build scientific competence and capacity, and issues related to making science based water policy. An important underlying theme that runs throughout the chapter is that the existing water scarcity in the arid and semiarid Arab countries lies at the extreme edge of the global water scarcity picture. Moreover, it offers to other parts of the world, particularly those that are arid and semiarid, a picture of the future water situation likely to be visited upon them if the current situation is neglected.

Water for Life

Freshwater is tiny proportion of the water resources on earth, with salt water accounting for 97.5% of planetary waters and freshwater for only 2.5%. Currently, 70% of the freshwater is tied up in polar caps, glacial ice, and groundwater at inaccessible depths. This means that 30% of available freshwater, or only 0.75% of total water supplies, are available to humans for various uses (Shiklomanov 1997). Human water endowments, which are found in lakes, rivers, and accessible ground are but a tiny proportion of the total planetary water endowment. As documented by Vorosmarty et al. (2010) and others, that water endowment is distributed unevenly around the globe in both spatial and temporal terms. This means that there are times and places where water is especially scarce as well as times and places where it is reasonably plentiful. This is shown in figure 2-1, where it can be seen that renewable freshwater is relatively scarce in the MENA region and South Asia regions and relatively plentiful in the Americas, Australia, and New Zealand. It is also important to recognize that there is significant variability within each region, exhibited by water-sparse and water-rich locales.

The importance of water in sustaining life, the environment, and development has been acknowledged in the Dublin-Rio water principles (Assaf 2010). In addition, Article 25 of United Nations Declaration of human rights stated in 1948 that "Everyone has the right to a standard of living adequate for the health and well-being of himself and his family, including food, clothing, housing and medical care and necessary social services and the right to security."

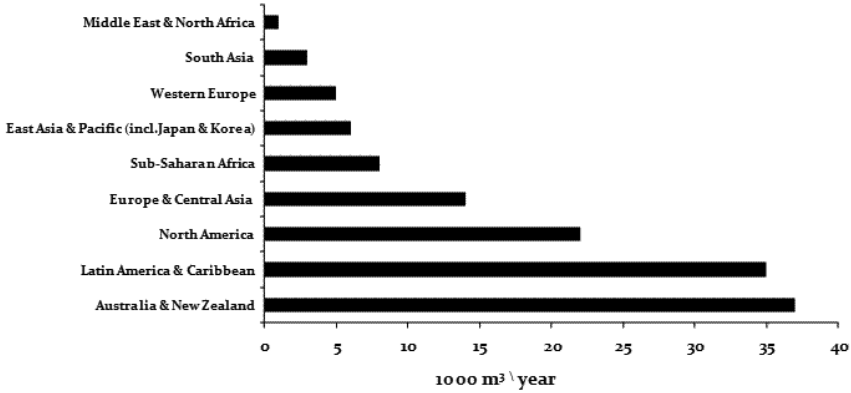

Figure 2-1. Actual renewable freshwater resources per capita, by region.
Source: World Bank 2007.

Although water is not acknowledged explicitly, it is a crucially important part of the daily human diet and sustains life. It should be recognized that some efforts to manage water sustainably have unintended side-effects that could have been predicted. A case in point is the treatment of water as a commodity, a practice which threatens the poor. Privatization of water resources has reduced the availability of fresh, sanitary water. Two in three people survive on less than $2 a day and are simply unable to pay for water for simple washing, cooking, and sanitation needs. One proposal for dealing with the problem is to create an escalating price system based on the quantities of water used. Under this system, costs to the poor are minimal since they use small amounts. This proved to be an effective social package policy related to poverty.

As resources are decreasing in quality and quantity, water policies promoted by developmental agencies with governments have concentrated on a comprehensive, integrated ecosystem of water management. Expanding demands for domestic, agricultural, and industrial water uses have made water a scarce resource in some countries in the Middle East, where total water withdrawals exceed renewable water resources. In fact, most Arab countries are already below the water scarcity level (Plan Blue UNDP Database 2005–9).

Therefore, thoughtful, science-based water policies, strategy, and management regimes are crucial if supplies, demands, and allocations among stakeholders are to be met in a balanced fashion that incorporates fairness and efficiency.

Freshwater Scarcity

The UN and UNESCO classify rich-water countries as those who secure 8,000 m^3 of water per capita per year. The global average is estimated to be 6,000 m^3 per capita per year. Water-scarce countries are defined as those with annual allocations below 1,000 m^3 per capita, while allocation of below 500 m^3 per capita per year constitute severe water scarcity. Annual per capita endowments of renewable water resources are shown for the 25 most populous countries in the world in figure 2-2. Global per capita renewable freshwater resources are declining at significant rates. Rayne & Forest (2013) reported "substantial reductions of global per capita stock of 54% between 1962 and 2011. There was a decrease of 75% in sub-Saharan Africa, 71% in the Middle East & North Africa (MENA), 64% in South Asia, 61% in Latin America and the Caribbean, 52% in East Asia & the Pacific, and 41% in North America". At current rates of depletion, global per capita renewable internal freshwater resources are project to decline from levels observed for 1962 by 65% by 2020. Thirteen Arab countries are among the 19 most water-scarce nations in the world. Per capita water availability of eight of those countries is below 200 m^3, less than half of the level that the UN defines as severe scarcity. Per capita annual renewable freshwater resources for the MENA region are expected to decline from 1962 values by 80% in the year 2020.

The reasons for this decline are many, and the importance of each varies by region. Population growth, which has occurred in all regions, is an obvious reason. Declines in the availability of the water resource also account for diminishing per capita availability. The world-wide trend of declining water quality means that less water is available for consumptive uses. Declining water quality reduces available supplies just as surely as drought. Lower per capita endowments also result over time when nonrenewable resources of water are persistently utilized as long-term supplies. Fossil groundwater and quantities of water that are over-drafted from renewable aquifers are the most obvious examples of nonrenewable supplies. Persistent withdrawal of such supplies depletes them to the point where demand pressures (that were previously supplied by nonrenewable sources) fall on renewable sources that are physically substitutable. A final source of explanation is climate change, which has occurred in the past and is expect to occur in the future. This means that for some regions water is less available than it was historically.

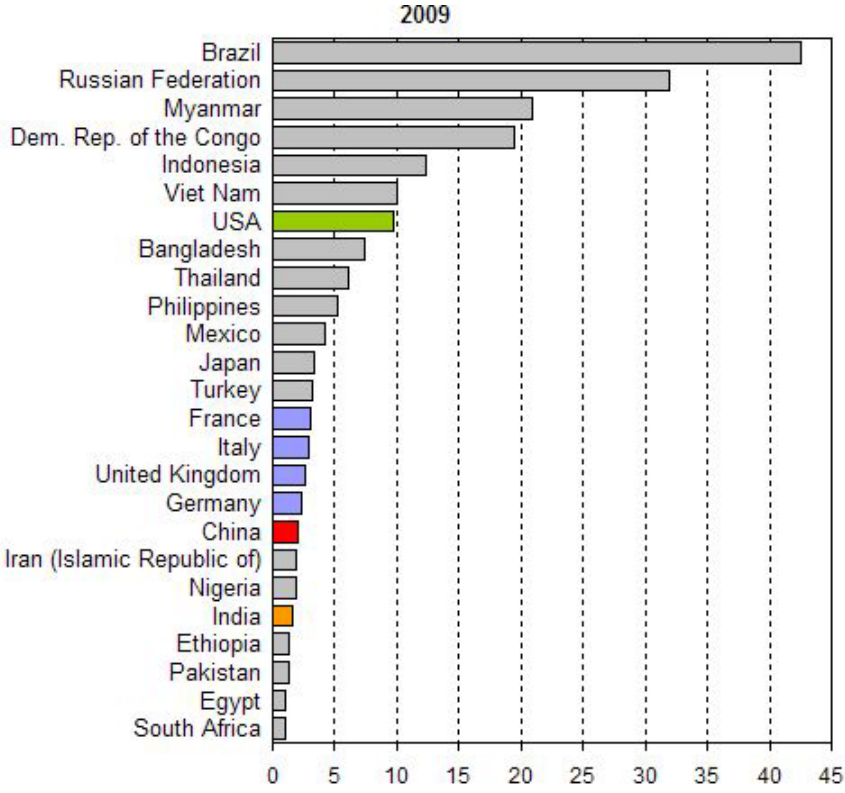

Figure 2-2. Total renewable water resources per capita for the 25 most populous countries in 2009 (in 1,000 m^3 per person per year). Among the 25 most populous countries in 2009, South Africa, Egypt, and Pakistan are the most water-limited nations. India and China, however, are not far behind, with per capita renewable water resources of only 1,592 and 2,103 m^3 per person per year. Major European countries have up to twice as much renewable water resources per capita, ranging from 2,288 (Germany) to 3,032 (France) m^3 per person per year. The United States of America, on the other hand, has far greater renewable water resources than China, India, or major European countries: 9,753 m^3 per person per year. By far the largest renewable water resources are reported from the Russian Federation and Brazil, with 31,929 and 42,496 m^3 per person per year, respectively. Without an increase in available water resources, Ethiopia, due to population growth, would become the most water-limited country in 2050, with only 633 m^3 of renewable water resources per person per year, followed by Egypt, Pakistan, South Africa, and Nigeria. Due to the projected population decline, per capita renewable water resources in some European countries would slightly increase, from 2,288 to 2,667 m^3 per person per year in Germany and from 2,954 to 3,146 m^3 per person per year in Italy. *Source:* Population: UN DESA 2008; water resources: CIA 2009.

The picture that emerges, then, is one of intensifying scarcity. The fundamental cause of the intensifying scarcity is bound up in the fact that demands for water are growing at the same time that available supplies of water of appropriate quality are shrinking. Some of that scarcity is self-inflicted owing to the absence of effective water policies and management regimes. Some of that scarcity can be avoided by employing existing science in the making of policy and in the fashioning of improved techniques and technologies that will permit water to be used more efficiently and more extensively than it has been in the past. Commitments to programs of research and development will also be required as a basis for the public policies and innovative technologies that will be necessary to confront and manage the emerging global water crisis.

How Can Science Help?

There is little argument that science will need to be at the foundation of the policies needed to address the intensifying water scarcity. Nevertheless, while existing science and science to be developed in the future will be crucial, science by itself will not be sufficient to resolve global and regional water problems. Other needed elements will include the process of adapting scientific findings for use in managing water resources and building the necessary institutional linkages to facilitate the use of science in the making of policy.

As shown in figure 2-3, worldwide spending on research and development has grown from $522.5 million in 1996 to $1.275 trillion in 2009. Most of the growth was accounted for by OECD countries. Additionally, total spending on R&D as a percentage of gross domestic product ranged from 1.2% (Spain) to 3.37% (Sweden), as shown in figure 2-4. This figure also shows that the private sector contributes more than the the public sector for the countries listed.

These figures mask several important facts about the investment in scientific research related to water. First, water research is not a large or even constant percentage of the research budgets of any of the nation's considered. Moreover, it is not unreasonable to assert that water research budgets have not grown in parallel to the total R&D budgets over the period in question. Thus, for example, in the United States public spending on water research in real terms (adjusted for inflation) was at the same level in 2000 as it had been in the late 1970s and did not grow in parallel with the

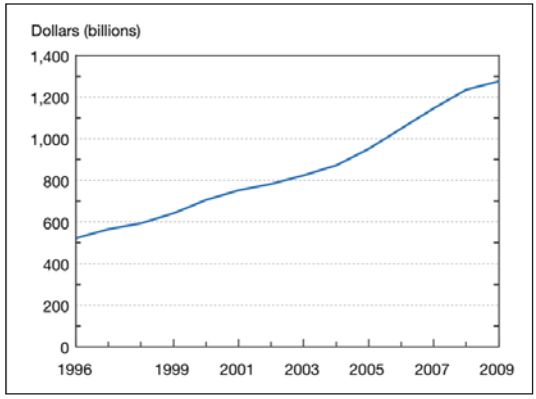

Figure 2-3. R&D expenditures worldwide, 1996–2009.
Source: National Science Foundation 2011; UNESCO 2012.

Year	Dollars (billions)
1996	522.5
1997	564.0
1998	594.2
1999	641.4
2000	704.5
2001	752.4
2002	782.1
2003	822.2
2004	872.1
2005	951.0
2006	1,048.4
2007	1,144.5
2008	1,234.8
2009	1,275.2

Expenditure on R&D: The contribution of the private sector vs. the public sector

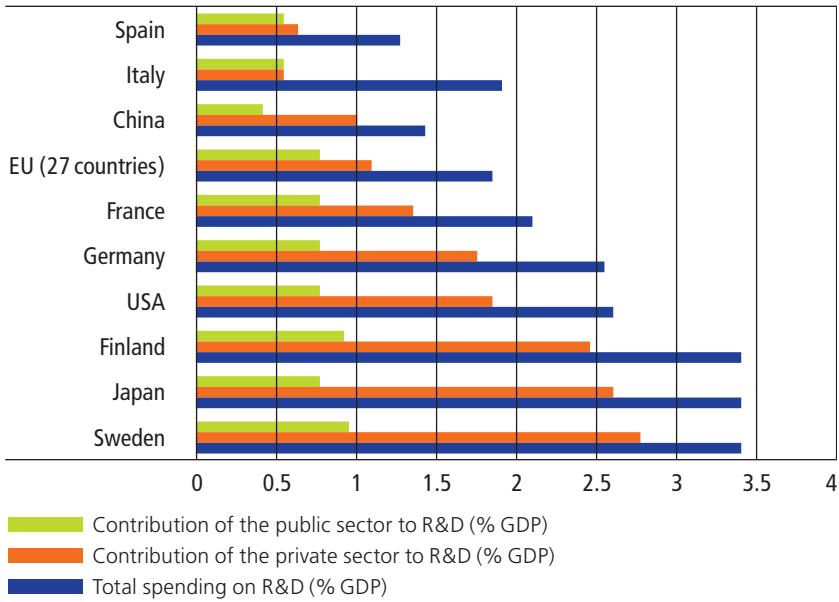

Figure 2-4. *Source:* National Science Foundation 2011; UNESCO 2012

substantial growth of general R&D over the same period (National Research Council 2004).

A second important fact about investment in R&D generally and water research specifically is that there is a great deal of variation between countries and regions. In a comprehensive review on the state of science in the Arab region, Badran (2005) concluded that the region exhibited poor performance in science and technology. This was attributed to political turmoil, low-quality education, and inadequate R&D infrastructure. In short, the region has failed to deliver high-quality science and has failed to build capacity in R&D. This has resulted in low rates of innovation and a below-average evolution to a knowledge-based economy compared with the rest of the world. The results are summarized in figures 2-5 and 2-6, which indicate that the scientific research personnel per million inhabitants varies but is low in the Arab states. Only Africa has fewer scientists per million inhabitants. Figure 2-7 shows that in the Arab region only 0.2% of GDP is directed to R&D, and most of that is public.

This measure of research capacity contrasts with the general levels of water availability and the effectiveness of water management in the region. With the exception of Sudan and Iraq, all Arab countries are water poor. In agriculture, there is an effort to utilize technology for saving water in irrigation, but the effort needs expansion. Also, the International Centre for Biosaline Agriculture (ICBA) in Dubai is developing sustainable crop production by using saline water (Badran and Zou'bi, 2010), and this effort also needs to be built upon. In another area, research-based universities in the MENA region have started to give priority to research focused on the nexus of water and energy for a sustainable model of technical knowledge and a system linking technology with policy. Badran (2011) has found a strong connection between human rights, levels of R&D, and rates of innovation. Indicators have shown a strong correlation between human rights as a contributor to effective science and technology among Islamic (OIC) and Arab countries. Globally, the World Bank found effective performance of water research in various sectors such as agriculture but concluded that very little of this was being conducted in the Arab region (World Bank 2007). In another report (2005) the Bank concluded that when compared with other regions, water science was at a low level in the Arab region. Demand for water research is not yet an integral part of water policy in many countries in the region. There are, however, a few bright and promising sports, such

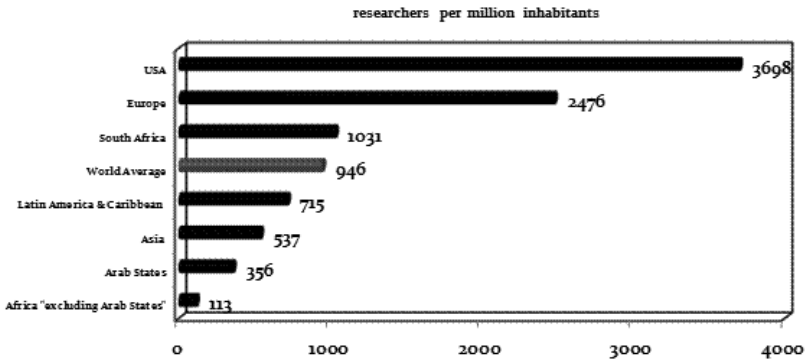

Figure 2-5. Researchers in selected regions of the world. *Source:* UNESCO 2012.

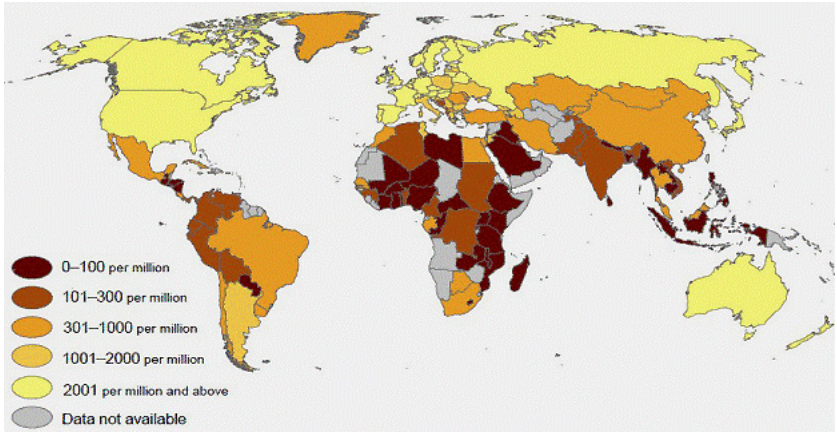

Figure 2-6. Researchers per million Inhabitants, 2010. *Source:* UNESCO 2012.

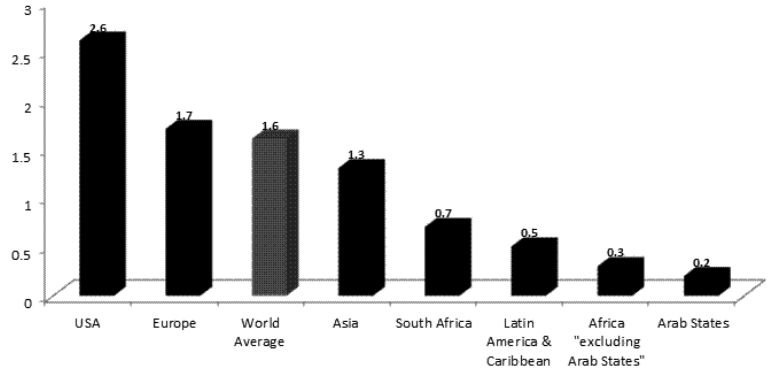

Figure 2-7. Gross expenditure on research and development (GERD) as a percentage of gross domestic product (GDP). *Source:* UNESCO 2012.

as the Masdar Institute in Abu Dhabi, King Abdullah University of Science and Technology (KAUST) in Saudi Arabia, and the Qatar Foundation (Badran and Zou'bi 2010). Taylor et al. (2008) identified constraints on the ability of science to influence policy in water management in Middle East and North Africa (MENA) region as follows.

- The unavailability of a critical mass of competent researchers in the region.
- The management and leadership of research organizations are ineffective.
- The linkages between research and policy communities are not established.
- Career opportunities in the region for researchers may not be compelling enough to retain them.
- Limited connectivity to international research communities hampers professional growth, learning, and exposure to new ideas, all of which are vital to the success of careers in research.
- Many organizations in the region lack an internal research agenda that is "owned" by the organization itself. Many research organizations feel obliged to follow donors' agendas, which are not necessarily aligned with community or national needs. Consequently, researchers may feel "sub-contracted" to pursue the agenda of others, leading to frustration and a sense of disempowerment.
- Organizations whose primary goal is to influence policy will often resort to recruiting well-connected and reputable researchers in order to increase policymakers' confidence in their research. However, reputation in the Arab region seems to be closely associated with seniority rather than performance in terms of relevant, high-quality research. The importance of seniority appears to make it difficult for young researchers to attract funding or support for their own research ideas.

Building Scientific Capacity and Infrastructure

In regions where science needs to be more fully available to support water policymaking, the scientific community needs to identify research priorities. The research itself should be conducted in an integrated and interdisciplinary fashion that will allow scientists to find solutions to complex problems arising from an increasingly dynamic environment. The international water

research community should be involved in strong partnerships to the extent appropriate and feasible. Simultaneously efforts should be made to improve and expand the educational opportunities for young scientists with interests in hydrology and related water disciplines. An interdisciplinary approach should be part of the educational and training effort. It no longer suffices for water research to be done exclusively by agricultural schools or civil engineering departments, as has been the case in the past. Rather, water science needs to be viewed for both educational and research purposes as a integrated and interdisciplinary field of endeavor.

In Germany, there are 500 institutes conducting research on water and related fields. The resulting fragmentation of the research structure can be attributed to the heterogeneous funding system for universities and research institution. To combat this, a "water science alliance" was begun in 2009 with the aim of joining and strengthening existing competence in water research and creating a framework for complex research in water sciences over the foreseeable future. The alliance is a tool for bringing together and interlinking leading groups and institutions in "thematic clusters" to conduct research leading to concrete solutions to water problems. The alliance will bring synergy and added value by integrating different disciplines (Teutsch and and Krueger 2010). This model has great promise in reducing fragmentation and creating integrated programs of water research.

In Australia, South East Queensland (SEQ) has faced intensive pressures on its water resources, which may be compounded by climate change. Here an alliance for scientific research on water as established as a partnership between the Queensland provincial government, the Commonwealth Scientific and Industrial Research Organization (CSIRO), the University of Queensland, and Griffith University. The resulting partnership is to tackle problems of uncertainty and development of a strategic plan for managing the water resources of SEQ. It is supported with a $50 million appropriation over a period of 5 years (Clayden et. al, 2010). Specific elements of the task include

- ensuring the reliability and safety of recycled water.
- identifying needed infrastructure and developing needed technology for recycling waste water and storm water.
- building scientific knowledge into the procedures for planning and management of water supply systems.

- developing methods for increasing public confidence in water supplies of the future.

Integrated water management analyses have shown that coordinated development of water, land, and related resources cannot be solved by structural measures alone but require linkages of knowledge with action for sustainable development (Clark 2007). Institutional and organization structures that effectively link scientific knowledge to decision-making contribute to problem-solving and innovation for integrated urban water systems (Davis 2010).

Also needed are business-based models for technology transfer. These can be established by research managers in the form of incubators and science parks. Funding mechanism that are mostly governmental tend to be inadequate and not sustainable. Although external funding has contributed importantly to meet water research challenges, the emerging research agendas were not based on national needs but on the donors' agenda. High-quality research requires a national science and research agenda, political endorsement, outstanding research managers, and sustainable funding and linkage between research and policy (Laarmani Salih 2010). Ultimately, water decision makers must employ the results of carefully targeted research and development in establishing water policy or the most important water challenges are unlikely to be addressed.

Bridging Science and Policy

Interactive knowledge sharing in the development of policy for the sustainable management of water resources is sometimes hampered by stakeholders who oppose certain policies on political or ideological grounds. Solid scientific knowledge can provide the basis for a credible common ground among stakeholders that leads to effective science-based water policies. The key element in linking science to policy is a governmental requirement that research be used in the formulation of policy (Carden 2009). Taylor et al. (2008) found in a survey that building institutional relationships between independent or private research organizations and policy-making bodies is difficult to sustain.

A UNESCO conference held in 1977 on the multiple uses of water and integrated water management is seen by many as the genesis of integrated water management. Many countries, including the United States, South Africa, Australia, and the United Kingdom, have adopted integrated

watershed management as the fundamental approach to water policy. Powerful environmental movements in North America and Europe in the 1980's confronted existing governmental policies that concentrated exclusively on economic growth. In their place were substituted additional objectives that were equity and sustainability.

Global efforts that resulted in the development of the Dublin-Rio water principles for a holistic approach for integrated water management (Assaf 2010) gave further voice to the notion of integrated watershed management.

- First principle: Freshwater is both of finite quantity and essential to sustain life, development, and environment. Freshwater is needed to maintain all forms of life and for human socioeconomic development.
- Second principle: Management should include participation of stakeholders, users, and policymakers.
- Third principle: Women should be purposefully involved in the making of water policy and in water management. Women in rural areas can spend most of their time looking for water and carrying it over long distances.
- Fourth principle: Water has an economic value and should be structured as a commodity.

The last principle, which leads to pricing of water, is not popular unless the poor are secured and consumers understand the value of water, so as not to pollute or waste it. Still, in many countries, water is perceived as a public good. Withal, research for water policy should be conceived of within the framework provided by the notion of integrated watershed management.

The concepts of green water, blue water, and virtual water also need to inform the research-policy interface. Green water is the soil moisture within 2 m of depth that is made available for absorption by the root systems of plants. Additionally, it contributes to water vapor in the atmosphere through direct evaporation or transpiration from plants. To conserve green water, soil ploughing, particularly for rainfed summer crops, and fallowing is practiced. Also, the use of plasticulture to conserve soil moisture has been found effective as a water-management technique. Engineered crops that use less water and sometimes are subject to moisture stress is another way to conserve green water. The management and manipulation of green water is a highly promising area for water research and development.

Blue water is found in rivers, lakes, aquifers. It includes transboundary waters, whether surface waters or aquifer waters. Globally, blue water is

becoming fully appropriated. This means that research should be directed at means of economizing on blue water but also at economical ways of using green water. Protecting blue water from pollution and from diversions that are not renewable are other ways to conserve blue water.

Virtual water is water embodied in foodstuffs and other commodities that can be imported. It permits water-short countries to acquire water from water-rich countries and use internal supplies to grow high-value crops that will generate foreign exchange.

Scientists and Policy-Making

Scientists in the labs and the field largely believe that their mandate is to create knowledge and disseminate it through publication in peer-reviewed journals, and that other professionals should take the task of bridging scientists with policy and decision makers. The missing link in politics is to bridge science output with policy. Carden (2009) suggested the creation of knowledge brokers, whether IGOs or NGOs. The National Water Research Center of Egypt is an ideal mechanism. The Royal Water Commission in Jordan, or the higher council for water and climate in Morocco are other examples.

Policy-science interaction (PSI) in the water sector aims to bridge the science–policy gap with different types of knowledge brokering instruments (KBI) at national and regional levels. KBI aims to increase the quality of science–policy interactions by positioning the public to learn about the complexity of the issue and by understanding the impact of driving forces affecting their future.

The major challenge to sustainability is how to use science to overcome uncertainty in basic issues of Agenda 21 related to environment and development (Grubb and Grubb 1992). These are complex issues that cannot be addressed except through alliances and interdisciplinary, holistic approaches of physical, life sciences (e.g., hydrology, ecology, agriculture, human food and health) and social sciences (e.g., policy, social sciences, economics, human development). An approach of this type will lead to physical and social agenda for the use of natural resources linked with managerial skills responsive to stakeholders.

Escalating pressure on less than 1% of the world's total supply of water is made more difficult to manage by population increases that are exacerbated by climate change and degradation of water quality. In

addition, research activity is fragmented and poorly linked to policy and management needs. UNESCO and WMO set up HELP (Hydrology for the Environment, Life and Policy) initiative to deliver social, economic, and environmental benefits through sustainable use of water by deploying hydrological science to achieve and integrated catchment area. The objective is to form a global network to bring together hydrologists, water resource managers, and policy and legal experts to address water issues defined by local stakeholders (see www.unesco.org\water\ihp\help). Twenty-five basins were established from different climatic, social, and economic regions around the world. These basins will serve as "outdoor labs." The main outcome is to integrate hydrological, socio-economic, and legal research responsive to water policy. HELP has created a platform for dialogue among physical and social scientists, water resource managers, and policymakers.

Jordan's Water Situation: A Snapshot

In Jordan, there is a strict policy on national (as opposed to transboundary) water aquifers. Hydrological studies and geological surveys have provided the basic data needed to manage groundwater. In 1993, the Jordan Ministry of Water and Irrigation established a bylaw prohibiting the drilling of new wells in most parts of the country, and since no new licenses have been offered for drilling water wells, with few exceptions for university campuses and hospitals (El-Naqa and Al-Sayeb 2008). All wells are controlled and supervised by the water national authority, and meters have been installed and are monitored very closely. The amount of water pumped from underground is measured and actions are taken accordingly.

The landscape of water resources in Jordan is as follows:

Rainfall distribution of water in Jordan

- 8,200 million m^3 annual rainfall, 80% loss to evaporation
- 1,640 million m^3 annually left: (Haddadin 2011)
- 510 million m^3 blue water–surface
- 200 million m^3 groundwater blue water–aquifers
- 860 million m^3 soil moisture green water–soil moisture
- 70 million m^3 reclaimed water recycled water

- Jordan's share of transboundary annually (blue water):
  80 million m^3–Yarmouk transboundary basin (original 296 million m^3) according to Johnston plan of distracting between Syria, Israel, and Jordan
  60 million m^3–Tiberias
  68 million68 million m^3–Syrian–Jordan underground basins
  100 million m^3–Saudi–Jordan basin underground (the Disi aquifer)

Total: 1948 million m^3 annually (314 m^3/capita/yr), which puts Jordan, according to UN classification, as a severely water scarce country. Virtual water is hard to calculate since there are imports of meat, grains, fruits, and vegetables as well as exports of fresh produce.

Jordan has been facing the problem of demand that has exceeded the limits of supply. Many of the wells that were licensed before 1993 are overdrafted, and some wells are turning brackish. Recycling waste water is one solution for increasing the efficiency of water-reuse. Another is using ROs in desalinating brackish water for irrigated crops and utilizing tolerant genomic biosaline plants.

Research aimed at developing technologies and techniques for exploiting green water, conserving blue water, and identifying economical opportunities to acquire virtual water is needed.

Finally, demand management policies that emphasize rationing or economizing on water have not been fully utilized, though many of them have a strong basis in science. Any research that can increase the public acceptability of demand management policies will be helpful.

Conclusion

Analyses of links between science and policy in water management in the MENA region show that water research is not part of water policymaking. There is an absence of cutting-edge scientific research, and linkage of knowledge to policy is not well-developed. There is a lack of national science and technology policy and coordination. Agendas may be dictated by donor agencies, and water policy is influenced by the politics of interest groups more than by science-based discourse. Capacity building in training scientists to excel in water research is needed. This requires a national agenda that includes water research priorities, political commitment, sound

research management, sustainable funding, and a manpower plan to attract outstanding scientists and to send outstanding graduates abroad on scholarships for PhD and postgraduate studies to develop a critical mass in water research nationally.

Conferences and other interactions between scientists, planners, communicators, managers, and public officers should bring water science to policy making process for water management. Stakeholders should be engaged in water policymaking and should use knowledge in overcoming differences. Universities and research centers should develop water science research groups to tackle the priorities of the water sector. This will develop an interdisciplinary approach, pool resources, and develop a critical mass of the know-how to attract funding for joint proposals related to the priority of the water national agenda.

National water agendas should not be subjected to the whims of outsiders, but international scientific cooperation with world-class research institutions should be encouraged and maintained. Scholars should produce tangible scientific results that are perceived by government as credible. Research must be placed at the center of water policy, and governments should implement sustainable water policies to rationalize demand to ensure efficient use. Government's role should be shifted from being exclusively a provider to being an effective regulator and planner.

A report from the Economist Intelligence Unit (2012) on challenges to meet water supply in 2030 emphasized that shortage and stress will yield scientific innovations. The report cited a few promising technologies:

- Lower-cost water desalination: from carbon nanotubes with membranes to radial deionization for removing salts from water.
- Better wastewater reuse: research and development is reducing energy by 30 to 45%.
- Managing aquifers recharge; storing surplus water.
- With the political will and consumer backing, water stress will force technology development and innovation in all phases of the water cycle.

References

AFED. 2010. *Arab Environment: Water: Sustainable Management of a Scarce Resource*. Beirut, Lebanon: www.afedonline.org.

Assaf. H. 2010. *Integrated Water Resources Management*. Beirut, Lebanon: 2010 AFED Report, chap. 6, pp. 92–105.

Badran, A. 2005. *S&T in the Arab Region*. Paris: UNESCO Science Report 2005.

———. 2011. The Science and Technology and Human Rights Nexus in the Arab World. Paper presented at 18th IAS conference, Doha, Qatar, 22 October.

———. 2013. Excellence in Higher Education for Building S&T Proficiency: A Global Perspective. Paper presented at the 19th IAS conference, Dhaka, Bangladesh, 6–9 May.

Badran. A, and M. R. Zou'bi. 2010. *Arab State*. UNESCO World Science Report 2010.

Carden, F. 2009. *Knowledge to Policy: Making the Most of Development Research*. Ottawa, Canada: International Development Research Center (IDRC).

CIA (United States Central Intelligence Agency). 2009. World Factbook 2009. https://www.cia.gov/library/publications/the-world-factbook/fields/2201.html.

Clayden, G., et al. 2010. *Action Systems for Integrated Water Management: Implications for S.E. Queensland, Australia*.

Clark, W. 2007. Sustainability Science: A Room of Its Own. Proceedings of the National Academy of Sciences, 104 (6): 1737–1738.

Davis, M. L. 2010. Water and Wastewater Engineering. Rome: Food and Agricultural Organization of the United Nations.

Economist Intelligence Unit. 2012. W*ater for All? A study of Water Utilities' Preparedness to Meet Supply Challenges to 2030*.

El-Naqa, A., and A. Al-Sahyeb. 2008. Groundwater Protection and Management Strategy in Jordan. *Water Resources Management* 23:2379–2394.

Global Issues. 2010. *Water & Development*. www.globalisones.org.

Grubb, M. and M. Grubb. 1992. Earth Summit Agreements: A Guide and Assessment. An Analysis of Rio '92. Rio de Janeiro: United Nations Conference on Environment and Development.

Howari, F. ed. 2008. *Bridging the Gap between Water Science and Policymaking*. Water Policy in GCC Countries conference, Kuwait. April.

Jagannathan, N. V., et al. 2009. Unbundling Water Management in MNA Countries. In *Water in the Arab World*.

Laarmani, H., and A. Salih. 2010. Linking Water Research & Policy. *AFED Report*, chap. 12. 190–199.

National Research Council 2004. Confr*onting the Nation's Water Problems: The Role of Research*. Washington, D.C.: National Academy Press.

National Science Foundation. 2011. National Center for Science and Engineering Statistics, Special Tabulations (2011) of Organization for Economic Co-operation and Development, Main Science and Technology Indicators (2011-1 and previous years).

Rayne, S. and K. Forest 2013. *The Decline of Global per capita Renewable Internal Freshwater Resources*. Saskatchewan Institute of Applied Sciences.

Shiklomanov, I. 1997. *Assessment of Water Resources and Water Availability in the World*. Geneva, Switzerland: World Meteorological Organization.

Taylor, et al. 2008. *Researcher Perceptions of Capacity for Adaptiveness & Management of Research Organizations in the MENA Region*. Cairo: IDRC.

Teutsh, G., and E. Krneger 2010. *Water Science*. Alliance White Paper: Priority Research Fields. Helmholtz, Germany.

United Nations Human Development Report. 2006. Universal Declaration of Human Rights, Dec. 10, 1948.

UN DESA (United Nations Department of Economic and Social Affairs). 2008. World Population Prospects. UN Department of Economic and Social Affairs Population Division.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2012. UNESCO Institute for Statistics Science and Engineering Indicators 2012.

Vorosmarty, C. J., P. B. McIntyre, M. O. Gessner, et al. 2010. Global Threat to Human Water Security and River Biodiversity. *Nature* 468: 334. doi:10.1038 /nature09549,

World Bank 2007. *Making the Most of Scarcity: Accountability for Better Water Management in the Middle East and North Africa*. Washington, D.C.: World Bank.

———. 2008. *Agriculture for Development: World Development Report*. Washington, D.C.: World Bank.

3

The Importance of Water Management in a Changing Global Waterscape

The Honorable Margaret Catley Carlson

When we talk, as we often do, about the importance of effective water management in a changing world, the first question we should ask is, "What is changing?" The answer to that question is, "A lot." Beginning in 1750, human enterprise began to dramatically alter the world. Since 1950 that activity has accelerated exponentially. When we examine patterns of growth in a broad range of human-related activities, as James Gustave Speth did in his book *The Bridge at the Edge of the World: Capitalism, the Environment and Crossing from Crisis to Sustainability*, we see how the pace of change has accelerated between 1750 and the present. We see clearly the enormous influence that global population growth, urbanization, and increasing wealth have had on water use, dam development, agricultural production, fertilizer use, paper production, and automobile availability. We also see the consequences of accelerating growth in these areas on the atmospheric concentrations of carbon dioxide, nitrous oxide, and methane. Similarly, the combined effects of population increases, land-use change, and greenhouse emissions on atmospheric temperatures, the number of extreme flooding events, ocean biogeochemistry, fisheries decline, and species extinctions are also illustrative. The Earth is indeed undergoing rapid and accelerating change, and this change is reflected in the global waterscape.

Water stress is typically defined as the ratio of total freshwater withdrawals compared with the annual renewable freshwater supply. High levels of water stress are an indication that socioeconomic demand for freshwater is approaching or exceeding annual renewable supply. If we project current trends forward to 2025 we see that even with only a moderate degree of climate change many highly populated places in the world

will face seasonal or permanent water stress. It is important to note that when looking at such maps that the aggregation of stress trends in larger countries like China, India, Russia, the United States, and Canada can mask the risk of social disruption due to water stress at regional and local levels.

When we examine per capita renewable water resources on a regional basis, we see clearly that areas such as the Middle East and North Africa are going to suffer disproportionately as water stress intensifies in the coming decades. We also see that there is a nexus at which water, food, and energy are interlinked. On average it takes a liter of water to produce every calorie we eat. The pending crisis becomes apparent when we examine how much more water and energy will be required to grow cereal grains to meet the doubled global food demand that we expect by 2050. Without productivity gains, water and related energy needs will double by midcentury.

Water and energy are engaged in inextricably linked interplay. It takes a lot of water to produce energy. Water is a crucial input at all stages of the power generation cycle, not just in hydropower production but also in processes of the mining and refining of energy minerals and coal and gas liquefaction and gasification. Abundant water is also required for processing of crude oil, tar sands, oil shale, natural gas, coal, and uranium. Water is a vital input in the growing and processing of biofuels, in thermoelectric cooling, in the transportation of energy products, and in emissions controls and carbon sequestration.

It also takes a great deal energy to produce water. Energy is required to abstract, purify, and distribute water for use and to transport it through pipes and canals. It is also required for extracting water from underground aquifers, for managing and treating wastewater for reuse, and for desalination of brackish waters and seawater to provide new water sources.

Regarding potential consequences of climate change, with each degree of projected atmospheric warming, new risks emerge or increase. We have already observed that with a global temperature rise of only 1°C, small mountain glaciers are disappearing and water supplies are being threatened in some areas. At between 2°C and 4°C we should expect significant decreases in water availability in many areas, including the Mediterranean and South Africa. Beyond 4°C, patterns of crop production shift globally, and sea level rise threatens many of the world's largest coastal cities. Rises in temperature of the same range also directly affect agriculture. The rising intensity of storms, droughts, flooding, and heat waves is

already hampering growth in agricultural productivity in many developed countries. While increased yields may be possible in some higher-latitude regions, temperature increases beyond 2°C are projected to stall if not reverse growth in agricultural productivity in many important food-producing areas. It may only be a matter of time before water scarcity and disrupted climatic patterns bring about the next food crisis. We could soon be facing annual losses equivalent to the entire grain crops of India and the United States combined.

An impressive array of activities are already underway that may be helpful in fashioning strategic responses to increasing climatic variability. Globally, some of the contemporary agricultural research focuses on development of new seeds for drought-resistant crops, water-saving crop management schemes, and devising incentives for reducing water use. Attention is also being devoted to developing crop types that can flourish in saline water. But it is not just agriculture that is concerned about growing climate variability: other industries are focusing on likely consequences of changing climate variability for their operations. The insurance industry has observed that between 1980 and 2008 the frequency of major flooding disasters and highly damaging windstorms have increased by 8% and 4% respectively, with commensurate increases in insured losses. These observations are a harbinger of even greater increases in weather-related damages in the future.

Key players in the public sector are also worried about the changing global waterscape. The United States National Intelligence Council recently released an assessment of the security implications of a growing global water crisis (Intelligence Community Assessment 2012). The bottom line of the report was that "during the next 10 years, many countries important to the United States will experience water problems—shortages, poor water quality, or floods—that will risk instability and state failure, increase regional tensions, and distract them from working with the United States on important U.S. policy objectives. Between now and 2040, freshwater availability will not keep up with demand absent more effective management of water resources. Water problems will hinder the ability of key countries to produce food and generate energy, posing a risk to global food markets and hobbling economic growth. As a result of demographic and economic development pressures, North Africa, the Middle East, and South Asia will face major challenges coping with water problems" (National Intelligence Council 2012)."

A second report published by the National Research Council in the United State entitled *Climate and Social Stress: Implications for Security Analysis* arrived at the same conclusions. The report notes that: "Changes in the availability of water resources may play an increasing role in political tensions, especially if existing water management institutions do not evolve to take better account of the social, economic, and ecological complexities in the region. Agreements will likely reflect existing political relations more than optimal management strategies. The most dangerous situation to monitor for is a combination of state fragility (encompassing, e.g., recent violent conflict, obstacles to economic development, and weak management institutions) and high water stress" (National Research Council 2012)." The lack of effective management strategies for the changing global waterscape may become a global security threat.

It is no secret that water is badly managed—or simply not managed at all—in many places. Most water problems are problems of governance. For most governments, management of water is a difficult political problem. It is a matter that is expensive to address and fraught with emotional, no-win issues. Governments have tended to play safe with water issues, relying on traditional infrastructure and capital projects that can be perceived publicly as high-visibility solutions. Most governments, however, are far better at creating and announcing policies than they are at implementing them.

The question becomes, How do we deal with this? How do we govern in a far more water-, food- and energy-stressed world? What does the extraordinary pressure we are putting on the water-energy-food nexus do to power relations? What trumps what? Do urban concerns trump rural concerns? Is energy more important than water?

A significant amount of technical and scientific research is available on changing global and regional hydroclimatic conditions and their impact on the water-energy-food nexus. However, there is very little new research directed at questions of how to design and implement effective governmental institutions that can address issue of water, energy, and food, as well as the interactions among them.

The prospects for change in this situation are not good. International cooperation appears to be declining in this new century. The Rio+20 outcomes, for example, were characterized by some observers as "the longest suicide note in global history." What appears to be happening globally is that we are going backward toward fragmentation.

Three big changes in particular are making governance more difficult. These include the explosion of global water demand; new and emerging contamination threats; and rapidly accelerating urbanism. In addressing these concerns it is important to note that the large-scale conference diplomacy through which solutions to such matters were typically negotiated in the twentieth century no longer works. New forms of negotiated cooperation over the management of water, such as the European Water Framework Directive, are emerging, but they remain at odds with multicentered, multispectral, decentralized forms of government—coalitions of the willing that typify the global fragmentation of governing institutions.

There appears to be a huge gap between awareness of these problems and the amount of policy attention they receive. Each year the World Economic Forum evaluates the threats posed by fifty global economic, environmental, geopolitical, societal and technological risks of concern in the immediate and long term. In 2012, the World Economic Forum ranked water-related issues fifth in terms of their likelihood of slowing economic performance globally. In 2013, the global water supply crisis was ranked fourth among threats generally but second in terms of its potential to impact the performance and survival of businesses in many sectors of the global economy. Despite this, governments around the world give these threats little or no policy attention or, as in the case of countries like Canada, ignore the threat completely while gutting legislation created by earlier governments that does attempt to protect the basic resource.

Most countries do not have policies that treat water, food, and energy in an integrated, interrelated fashion. Such policies will be essential in the future, however. Increasingly, energy production competes with agriculture for water. New energy-producing technologies such as hydrological fracturing, or "fracking," will change the water using characteristics of the energy sector. These changes will have significant consequences for the interrelationships of energy with water and energy with food.

Increasing competition for scarce water resources has become a growing business threat and a major economic issue that cannot be ignored. The private sector, therefore, is now being forced to strengthen the hand of government to act on these issues in order to prevent water-related issues from becoming serious threats in their sectors. Strengthening the hand of the government with respect to water policy is also seen as vital to the competitive advantage in business and in some cases vital to sector survival.

The global water supply crisis in tandem with food and energy security issues is creating new players and new managerial roles in water governance. This appears to be leading to increased attention to the development and implementation of effective water policy. Such policies must call, in the first instance, for effective water resource monitoring and data management, a fundamental prerequisite for effective management. Development of workable regulatory frameworks, risk management, water and energy conservation, and synergy and training and investment require increased attention if current and prospective water management problems are to be addressed successfully.

Water quality is also becoming more critical because degradation of water quality limits available supplies just as surely as does drought. The need to monitor water quality parameters significantly increases the magnitude of needed monitoring and data management. Big data requirements are also leading to big changes. Once the exclusive responsibility of national governments, processes of data collection, assembly, and access are today being privatized. Highly transparent, decentralized, multilayered information depositories help both business and government but also enable civil society to know about and act upon water issues on a local, regional, and national basis. Satellite data are becoming crucial to the emergence of financial transparency with respect to water management. Smart meters translate integrated water and energy consumption data into information governments need to set new standards in water and energy efficiency. Organizations like the International Water Association are demonstrating how a minimal improvement of 20% in the energy efficiency of municipal water and wastewater systems compared to 1990 can be achieved by 2020. Efforts are being applied to reduce the costs of desalination continue. Large-scale food processing plants that recycle virtually all of their water are beginning to appear in places like Canada. Additionally, new technologies now allow energy to be produced from wastewater through codigestion of biodegradable wastes. These advancements and technologies make a big difference at the water, energy, food interface. More will be needed, however.

It is in cities that the changing global waterscape needs the greatest attention. By 2025, global municipal water demand will increase by 40%. The condition of urban water infrastructure globally has been in decline for some time. It has been estimated that the water-related infrastructure

deficit between 2005 and 2030 could be as much as US $22.6 trillion. Effective action by new players, including corporatized utilities, financial houses, public-private partnerships, and other governance innovations, will be required to remove these deficits from the public balance sheet. But fixing urban infrastructure will not be enough. A new urban hydrosocial water contract needs to be negotiated globally. That contract needs to link water security to public health protection; flood protection; social amenity and environmental protection; sustainable management of limited natural resources; and intergenerational equity and resilience to climate change.

The global waterscape has changed dramatically in the past 250 years. More places are becoming water stressed, and more will become so in the coming decades. Water governance is becoming far more difficult. Many governments lack the capacity to take on the kinds of difficult reforms that are required. New technologies, new management tools, and growing public and private sector pressure provide ever-stronger demands and support for public efforts to improve water policies. For the purposes of this forum, three lessons emerge from an examination of where we have been and a look forward to the water management imperatives of the future.

- First, growing water stress is a serious global social, economic and environmental threat. Addressing that threat will require building bridges between scientists and politicians. Without such bridges, crisis and conflict are a real possibility in places of increasing water stress like the Middle East and North Africa.
- Second, the action in terms of scientific, policy, and political change should be focused on the water-energy-food triangle and its various interrelationships.
- Third, strengthening the government hand with respect to water policy is increasingly seen as vital to competitive advantage in business and in some cases to sector survival. It is also vital in promoting intergenerational equity and the social and environmental resilience that will be required to sustain us as the global waterscape redefines itself around emerging new hydroclimatic realities.

References

Intelligence Community Assessment. 2012. Global Water Security. ICA 2012-08, 2 February 2012.

National Research Council. 2013. *Climate and Social Stress: Implications for Security Analysis*. J. D. Steinbruner, P. C. Stern, and J. L. Husbands, eds. Washington, DC: National Academy Press.

Office of the Director of National Intelligence. 2012. *Global Water Security: Intelligence Community Assessment ICA-2012-08*. http://www.fas.org/irp/nic/water.pdf.

Speth, J. G. 2008. *The Bridge at the Edge of the World: Capitalism and the Environment and Crossing from Crisis to Sustainability*. New Haven: Yale University Press.

Part 2

Scientific Contributions

Regional Planning and Management

Aridity and the Fate of Agriculture

When Regionalism Works: An Exploration of Design Elements and Contexts

Dr. Andrea Gerlak

University of Arizona

Abstract

In the past two decades, there has been a notable rise in cooperative efforts at the river basin level aimed to promote joint management and protection of international rivers. This paper examines a variety of comparative examples from around the world to ascertain characteristics of effective regionalized water management. The purported benefits of regionalism and approaches to the study of performance in regional water management are explored. We examine the presence and absence of four important design elements—transparency, scientific learning, conflict resolution, and public participation—in a variety of illustrative cases from around the globe. We uncover a gap in performance in regional water management. In part, this gap may be explained by unrealistic expectations around the effectiveness of river basin organizations and the widespread promotion of models of best practices that may be inappropriate in particular contexts. We conclude that a design features approach to understanding regionalized water management can benefit from an integration of political, economic, and social contextual factors.

Introduction

Regional cooperation around water resources is not new! Nations have been signing treaties, forming regional cooperative organizations, and engaging in joint water programs for centuries. Since the first international water treaty was signed concerning navigation rights on the Danube between Austria and Turkey in the early 1600s, more than 400 international water

treaties have been signed between riparian countries (Wolf 2004). Regional cooperation may be further institutionalized by the creation of river basin organizations (RBOs) designed to govern aspects of transboundary water resources management.

The idea of river basin management received considerable zeal with industrialization and development of technology for multipurpose river development (White 1969) and became manifest in 1933 with the Tennessee Valley Authority. This expert-driven model spread throughout the world (Mukhtarov 2007), and by the 1950s, RBO discourse came to be framed in the ideals of democracy, modernity, economic development, and part of the larger fight against communism (UN 1970; Ekbladh 2002; Turton et al. 2004). As non-navigational uses expanded in the latter half of the twentieth century, regional organizations acquired new responsibilities related to dam construction, water allocation, and pollution (Wescoat 1996).

Since the 1990s, there has been a notable rise in cooperative efforts at the river basin level aimed to promote joint management and protection of international rivers (Conca et al. 2006; Gerlak and Grant 2009). In the past two decades, both domestic and international RBOs have been established in virtually every region of the world (Barrow 1998; UNECE 2009; OECD 2011). There is great variety in the form and function of international RBOs around the world, constituting commissions, committees, and authorities (Lautze et al. 2013). River basin organizations are promoted by a host of international organizations, including the Global Environment Facility, the World Water Council, and Green Cross International (Cosgrove and Rjsberman 2000; Green Cross 2000; Uitto and Duda 2002; Gerlak 2004). Under the UN 1997 Convention on the Law of the Non-navigational Uses of International Watercourses, states are encouraged to establish joint mechanisms or commissions to facilitate transboundary cooperation. The Berlin Rules also promote basin-wide joint agencies or commissions to undertake the integrated management of international waters.

Regionally, there is also movement to promote river basin organizations in many parts of the world. For example, in South Africa, the South African Development Community (SADC) Water Protocol on Shared Watercourses (1995) calls for the establishment of river basin institutions. River basin institutions are on the rise in Europe today as well, as a result of the 1999 European Union Water Framework Directive, which aims to standardize water management practices in the region, and the UNECE Convention

on the Protection and Use of Transboundary Rivers and International Lakes of 1992, which mandates multilateral agreements and the establishment of joint bodies (Barraqué and Mostert 2006; UNECE 2009). To promote exchange between river basin organizations and facilitate regional networks of basin-level organizations, the International Network of Basin Organizations (INBO) has emerged in recent years. Based in Paris, the network is hosted by the Office International de l'Eau, an organization mainly funded by the French water industry and the government (Molle 2008: 141).

In the wake of growing fragmentation and diffusion in water management (Hoff 2009; Gupta 2011), the creation of RBOs represent efforts to promote more centralized regional water management around transboundary rivers. To better understand the relative strengths of regionalized water management, this chapter examines a variety of comparative examples from around the world. By doing so, we are able to ascertain characteristics of effective regionalized water management.

The first section of the paper examines the purported benefits of regionalism and how benefits have been historically framed based on the dominant discourse and governance trends of the day. The second section outlines questions of effectiveness and performance in regional water management. To better understand regionalized water management in practice, we then examine the presence and absence of four important design elements—transparency, scientific learning, conflict resolution, and public participation—in a variety of illustrative cases from around the globe. In the final section, we discuss the gap in performance uncovered by this research and suggest how a more contextual approach might help us to better understand gaps in performance that stem from variations in design and implementation. Ultimately, this understanding can better inform regionalized water management.

Unpacking the Benefits of Regionalism

Regional water management organizations at the river basin level are purported to offer a variety of benefits. They are thought to promote cooperation between upstream and downstream states, help standardize water policies across states, and serve as a form to bring between areas like flood protection, regional planning, wastewater treatment, water supply, and hydropower generation (Pahl-Wostl 2007: 55). If they appropriately coincide

with the boundaries of the river basin, they can help overcome many of the collective action problems associated with transboundary resource management and promote information sharing (De Lange et al. 2005). In addition, regional cooperation over water resources is thought to provide significant ecological and pollution control benefits (Sadoff and Grey 2002).

The benefits of regionalism are relative to the degree and depth of cooperation and institutionalization. Broadly speaking, RBOs vary in their form and function, representing advisory committees, authorities, associations, commissions, councils, corporations, tribunals, trusts, and federations (Gupta 2009). In the Danube River basin, for example, the highly institutionalized International Commission for the Protection of the Danube is credited with helping to facilitate cooperation among riparian states, lessen the divide between states in a post–Cold War political climate, and strengthen democratic institutions in the former communist bloc (McNally and Tognetti 2002: 21).

Historically, benefits of regionalism have been framed based on the dominant discourse and governance trends of the day. Today, RBOs are in good currency; the belief in the utility of RBOs is firm and RBOs are prominent in the contemporary debates on water governance (OECD 2011). Generally, the appeal of RBOs is broad. In part, it reflects a renewed interest in the river basin as the ideal scale for water management (Barrow 1998; Molle and Wester 2009: 5). According to engineer and international water scholar Peter Rogers (1997: 45), RBOs are popular in economic and planning literature because they reflect the notion of internalizing externalities by analyzing the river basin as a single unit.

The promotion of RBOs as a tool for regional water management also reflects notions of good governance. Some recent research examining global water discourse and governance highlights the role of transnational policy entrepreneurs, particularly global knowledge networks, in producing and maintaining the global discourse of RBOs through the development of knowledge, development assistance projects, global water meetings and publications (Mukhtarov and Gerlak 2013). For example, the International Law Association, a global knowledge network composed of academics and practitioners, promotes RBOs as central to good governance practices, including transparent decision-making, the rule of law, and non-state participation (Hildering 2004: 89). For others, like the Global Water Partnership, the World Water Council, and numerous academics, institutions at

the river basin level help achieve Integrated Water Resource Management (IWRM), an approach to water management that aims at holistic and multi-level governance of water and related resources (Hooper 2005, 2010; Global Water Partnership 2000; Serageldin et al. 2000). The World Water Council (2012) recently reported that strengthening regional cooperation can better achieve water security and economic development.

International environmental NGOs, like the World Wildlife Fund, Green Cross International, and the International Union for Conservation of Nature, also advance RBOs as a vehicle for conservation and integration (McNally and Tognetti 2002; WWF 2002; Green Cross 2000: 14; Aguilar and Iza 2011). An important attraction of RBOs to NGOs is the potential participatory venue, or vehicle for bottom–up planning (Warner et al. 2008: 131; NGO Forum 2005). In many regions of the world, the appeal is quite simply money. IGOs and government-based development organizations, as well as global knowledge networks, leverage material and nonmaterial incentives such as donor conditionality to get actors "buy into" the RBO discourse and governance approaches (Mukhtarov and Gerlak 2013).

Effectiveness and Performance in Regional Water Management

Effectiveness and performance often fall short of promise in the eyes of both practitioners and scholars. There remains no single approach to studying effectiveness in regional water management. At its best the case research is descriptively rich and detailed. At its worst, it is narrowly construed and piecemeal, capturing mere snapshots in time. Although it has been more than a decade since international relations scholar Thomas Bernauer (2002: 2) observed that we have very limited knowledge of the nature and extent of variation in the performance of existing international river management schemes, the finding remains largely true today. Governance mechanisms and their effects in international water management are still not well understood (Riekerman et al. 2006).

The case research reveals some notable limitations in regionalized water management. In the case of the Joint Technical Committee in the Euphrates-Tigris River basin, researchers have found that it has been limited in its achievements and has not fulfilled its expressed aim of coordinating the development and use patterns of the three riparians, leading to further

conflict and crises in the basin (Kibaroglu and Ünver 2000; Mostert 2005: 33; Islar/Ramasar 2009: 12). The Niger Basin Authority has been criticized as a paper tiger, meeting few of its stated goals over the past two decades (Bernauer 1997: 159; Lautze et al. 2005: 26; Rangeley et al. 1994: 18). So too has the Indo-Bangladesh Joint Rivers Commission, a commission between India and Bangladesh dating back to the early 1970s to help manage and resolve disputes along the Ganges River, been criticized for failures in implementation (Nishat and Faisal 2000: 299; Kliot et al. 2001: 306). Some argue that the Mekong River Commission has been unable to effectively manage water development (Backer 207: 44; Ha 2011: 125); others point to worse ecological conditions in the Mekong River Basin, despite the long-standing presence of transboundary cooperation (Sneddon and Fox 2006: 183).

Over the past decade, some momentum has been building toward more comparative studies designed to more fully understand effectiveness in regionalized water management (e.g., Nakayama 1997; Kliot et al. 2001; Marty 2001; Rieckermann et al. 2006; Verwijmeren and Wiering 2007; Siegfried and Bernauer 2007; Dombrowsky 2008; UNEP 2009; Schmeier 2012). Schmeier (2012), for example, takes an institutionalist approach to examine the effectiveness of river basin organizations that includes a comparative look at the nature of the problem, the constellation of actors, and factors of institutional design. Dombrowsky (2008) studies a smaller number of RBOs to better understand the depth of integration including questions of RBO membership and scope. Siegfreid and Bernauer (2007) offer an approach that focuses on causal effects and problem solving, and produces quantitative assessments that are comparable across cases of river management. Even some more traditional studies of river treaties in international relations scholarship are calling attention to questions of institution design (Stinnett and Tir 2009).

As a result of this evolving body of research, we are learning that both the presence and absence of particular governance features help to explain effective regional water management. Notably, there is a growing recognition that institutions can perform effectively only when they include certain governance mechanisms for conflict resolution, allow for public participation, include access to reliable expert knowledge to address the issues at hand, and incorporate rules or mechanisms that acknowledge uncertainty or are flexible under changing circumstances (Rogers and Hall 2003; Wolf 2007; Raadveger 2008; Bernauer and Kalbhenn 2010). The absence of such

mechanisms may lead to inflexible or unenforceable decisions that fail to garner local support (Cassar and Mock 2003). Further, how elements, like legitimacy, representativeness, leadership, and comprehensiveness, are performed and how their interaction is coordinated are thought to be of critical importance in terms of effectiveness in water governance (Pahl-Wostl et al. 2013).

Increasingly, scholars are calling attention to the broader context in which institutions are shaped and governance plays out. According to Oran Young (2002: 5), the institutional design needs to be compatible with the bio-geophysical systems in which they operate. The design must also be "sensitive to and reflective of" the political, economic, and social contexts in which they operate (Myint 2003: 292). For Helen Ingram (2011), a contextual approach to water management takes into account the "history, culture and sense of place, and suggests that mixed strategies that appeal to multiple values and fit into local circumstances are more appropriate." There is growing recognition in water governance research that context shapes collaboration, innovation, and on-the-group implementation of projects and policies (De Boer et al. 2013). In terms of regionalized water cooperation, a contextual approach may better inform variation in design and implementation and call attention to interrelationships between factors related to performance.

A Process-Design Approach

Drawing from a diverse literature on social and ecological systems, international institutions, common-pool resources, and international waters, some recent research (Berardo and Gerlak 2012) explores conditions under which institutions are more likely to foster meaningful cooperation in the management of shared rivers. Effectiveness can be examined at two levels: first, a broader level focused on the interstate agreement itself; and second, a level addressing the process design elements.

The first level of effectiveness speaks to the interstate agreements that commonly govern international rivers, which in turn structure and shape the relationships among all parties involved in the use of the common resource. Interstate agreements may establish RBOs to serve as venues for state interaction and assist with information exchange and the achievement of settlements (Haftendorn 2000: 66–67; Schmeier et al. 2013). Under

this first level of effectiveness we also include process design, which refers to the complex internal negotiations that usually take place inside new institutions to decide how, when, and under what conditions the parties interact. Various studies highlight different "process" dimensions that affect the nature of adopted rules and regulations in the context of interstate agreements around shared waters (Hamner and Wolf 1998; Jägerskog and Phillips 2006; Kistin et al. 2009; Stinnett and Tir 2009; Gerlak et al. 2011).

Process design in turn affects how states shape the design elements at the second level of effectiveness, which can also be thought of as process challenges that must be continuously faced to ultimately achieve collaborative solutions to problems in the river basin. Process design elements associated with effectiveness in river basin management include transparency, scientific learning, conflict resolution, and public participation.

To better understand regionalized water management in practice, it is important to examine the presence and absence of these four design elements in a variety of cases. The goal is to examine a broad array of cases from around the globe to probe for common patterns or insights that can better inform regionalized water management. Next, we delve deeper into the four design elements and offer illustrative case examples.

Transparency

In the context of transboundary watercourses, public access to information ensures that citizens and other members of civil society have the ability to request from governmental and intergovernmental authorities information on the status of the watercourse and its tributaries (including water flow and water quality), factors that could affect the watercourse or its tributaries, and norms, policies, and management plans that shape activities relevant to the watercourse (Bruch 2000). Increasing transparency is a fundamental step to tackle noncompliance among member states (Mitchell 1994) and also to give private citizens in some parts of the world recourse to redress on unfair actions or incompetence of the executive authority (Asian Development Bank 1995).

In the context of institutions that deal with complex water issues that cross political boundaries, transparency increases the ability of multiple participants to understand the inner workings of the decision-making process that affects the management of the natural resource. This means that in an institutional setting where a given watercourse is managed, information

of a technical and legal nature should be available to all interested parties (Bruch 2000). Transparency allows for all actors involved, including policy makers, scientists, and the public, to have the potential to examine the functioning of the organization (Berardo and Gerlak 2012).

Several water reports in the past decade highlight concerns about transparency in water governance. According to UNESCO (2009: 57), the water sector has been historically plagued by "lack of political support, poor governance, under resourcing and underinvestment" which is manifested in nontransparency and lack of accountability. Transparency International's *Global Corruption Report 2008* chronicles limited oversight capacity and widespread corruption in water development projects. Capacity building activities should be based on a principle of openness and accessibility, according to the UNDP (2008: 8). New tools are needed in the contracting process to provide for a transparent and accountable process that is free from corruption (Water Integrity Network and Transparency International 2010). In the context of regionalized water management, transparency in management and decision-making can mean transparency of public investments and monitoring of government and RBO activities.

In some cases there is a good deal of transparency in terms of annual reporting, access to meeting minutes, and organizational reports. The International Commission for the Protection of the Danube River, for example, has a fairly extensive and accessible website (http://www.icpdr.org/main/danube-basin) that includes summaries of meetings and many subgroup reports and papers. Member states of the International Commission for the Protection of the Rhine report regularly to the ICPR on the legislative, regulatory, and other measures, and the ICPR submits an annual activity report to the member states and informs the public on the state of the Rhine and the results of its work (Burchi and Spreij 2003: 44). In contrast, the Joint Rivers Commission, created by India and Bangladesh for sharing the Ganges River, reports very little information about their operations or activities publicly (Nishat and Faisal 2000: 301). Further, even when there is fairly good public access and transparency in operations, as in the case of the Mekong River Commission, negotiations and deals made outside of the forum of the RBO hinder transparency. For example, announcements of bilateral agreements in recent years between several states in the Mekong River basin (including between Lao PDR and Thailand and between Lao PDR and Viet Nam) for dams on the main stem of the river along with

private contracts agreed by these states have called into question the lack of transparency in planning processes (Molle et al. 2009).

Transparency can also be exhibited by the monitoring of financial expenditures and records. Public expenditure reviews are one tool to review spending and increase the accountability and transparency of results (UNESCO 2009: 10). Financial transparency, by way of access to banking records of multinational companies involved in water development projects of the Lesotho Highlands Development Authority, proved critical in prosecutions there (Stålgren 2006; Earle and Turton 2005). The Project represents the largest international water transfer in the world, designed to provide extra water to the city of Johannesburg, South Africa, by transferring water from the Orange to the Vaal River. In this instance, the chief executive of the Authority was ultimately charged and convicted (with an 18-year prison term reduced to 15 years, on appeal) on bribery and fraud charges for the way construction contracts were awarded for the project. The state of Lesotho subsequently brought charges against several foreign construction companies working on the project, several of which have been successfully convicted of bribery. Ultimately, transparency in financial practices is an important and necessary element of financial sustainability as part of larger RBO performance and effectiveness (Hooper 2005: 31).

Scientific Learning

Another factor involves the production and dissemination of scientific knowledge. Fostering the development of a base of commonly accepted scientific knowledge is one of the most important contributions that governance arrangements can make, since scientific learning is critical for the successful management of complex ecosystems (Rogers and Hall 2003; Wolf 2007; Underdal 2008; Bernauer and Kalbhenn 2010; Gunderson and Holling 2002). Design features that support information management processes and the flow and production of information are thought to be important design features (Eakin and Lemos 2006). Jointly managed and integrated databases, often organized around GIS mapping, common monitoring protocols, and jointly developed ecosystem models, provide the technical platform for the scientifically informed knowledge base that is characteristic of successful ecosystem management initiatives (Karkkainen 2006: 229).

The sharing of data is thought to develop collaboration and friendship between experts and technicians in the basin (Nishat and Faisal 2000: 300).

Further, joint and transparent information acquisition and interpretation can help to develop a sense of reciprocity between states and mutual assurance of joint compliance (Burton and Molden 2005) and diminish asymmetries in information that can undermine cooperation (Sadoff et al. 2008: 31). Open access to information and data sharing processes are essential to monitoring practices (Stinnett and Tir 2009) and to adaptive, integrated management of water resources (Timmerman and Langaas 2004).

The production and dissemination of scientific knowledge is necessary to promote scientific learning in regionalized water management. Under the Okavango River Basin Water Commission (OKACOM) Protocol on Hydrological Data Sharing (2010), OKACOM monitors water level, water discharge, water quality, sediment transport, and meteorological data of the Okavango River, aiming at using it for "sustainable integrated river basin planning, decision making and management" (OKACOM Protocol, Preamble). In the Lake Victoria Basin, the Lake Victoria Basin Commission (LVBC) Protocol requires the LVBC and member states to exchange information with the public and promote awareness of sustainable water resources use, which they do so through National Focal Points (LVBC Protocol, Articles 24 and 37). If a member state receives a request from another for information that is not readily available, the requesting member state can be asked to cover the costs associated with collecting and processing the data. Further, the exchange of information or data does not extend to information that is protected under the laws of the member states or any international treaty to which a member state is a party (LVFC Protocol, Article 24).

One of the more established practices for scientific learning can be found in the Rhine River basin. Here, under a detailed framework, the International Commission for the Protection of the Rhine (ICPR) monitors the state of the basin, gathering information on water pollution levels measured by more than 100 monitoring stations along the river (ICPR 2007). This allows for tracing the intrusion of pollutants into the river and observing changes in the river's pollution level. But in some cases, like for the Joint River Commission along the Ganges-Brahmaputra-Megna System between India and Bangladesh, regular collection and sharing of data is lacking, which results in ineffectual management, among other things, in suboptimal flood forecasting (Nishat and Faisal 2000).

But it is not just a process that is necessary to support scientific learning. Political support and capacity are critical elements to scientific learning.

Consider the Mekong River Commission, an RBO characterized by a highly developed data and information sharing system that allows for gathering, processing, and disseminating data (Backer 2006; Schmeier 2012). The MRC is credited with data and information exchange for both ecological issues related to hydrology, biodiversity, fisheries and socioeconomic and development in the basin in the form of the State of the Basin reports. Its flood-specific early warning systems are well-respected. Yet, limited capacity in some states, such as Laos and Cambodia, hampers data acquisition and analysis. Moreover, data and information sharing with nonmember states has proven particularly difficult, significantly hindering integrated river basin governance in the Mekong River basin. The lack of data from upstream stretches of the river has presented an obstacle to basin-wide modeling (Schmeier 2012).

Conflict Resolution

Conflict resolution mechanisms are seen as important for ensuring that institutional actors can address their differences, overcome conflict, and sustain cooperation (Ostrom 1990; Hansen et al. 2008). Once an initial agreement is reached among states on the need to jointly manage an international river, successful implementation is dependent not only on the terms of the agreement but also on an ability to enforce those terms (Wolf 1997; Stinnett and Tir 2009). Better enforcement of rules reduces transaction costs, which in turn "frees" resources that can be used for the establishment of cooperative activities (Hensel et al. 2006).

Many times, however, the terms that govern the interactions among actors are contested or are not clear enough for a plurality of participants in the institution. When this happens, conflict is likely to erupt and institutions must overcome it through the use of effective conflict-management techniques (Hansen et al. 2008). Conflict resolution mechanisms can support robust institutions because they can foster adaptive governance (Dietz et al. 2003). This is because these mechanisms allow actors to evaluate and interpret rules, and ultimately revise them to better meet new or changing conditions, clarify ambiguous agreements and thereby, promote greater compliance (Chayes and Chayes 1995). Further, the ability to draw on conflict resolution mechanisms can guide members through periods of high tension (Zawahri 2008: 466). While mechanisms to settle disputes can be varied, the most common are direct negotiations, nonbinding mediation, or

binding arbitration or adjudication by an international institution (Elhance 2000; Cosgrove 2003).

Conflicts in regionalized water management tend not to be isolated and rare. But the mere presence of a river basin organization is not enough to preclude conflict between states. Consider the Ganges River basin, where conflicts date to the 1970s following the creation of the IBJC, well into the 1990s, and more recent years around diversions and water development schemes (Gleick 2009). In the case of the Euphrates–Tigris River basin, meetings of the Joint Technical Committee on Regional Waters (JTCW) failed to provide workable solutions and conflict resolution (Islar 2009). In part, some researchers suggest this is the result of inadequate financial and technical capacities (Kibaroglu 2002).

The Permanent Indus Commission (PIC) offers an example of effective conflict resolution design and implementation. The PIC has detailed conflict resolution mechanisms where the commissioners first attempt to resolve disputes that arise (IWT, Articles VIII, IX; Annexures F and G). If they are unable to resolve the dispute, the matter is deferred to the member states' foreign secretaries for negotiation and then, if necessary, to a neutral expert for resolution and perhaps an appointed court of arbitration. In her research of the PIC, Zawahri (2008: 468) reports that since its formation, the PIC has resolved all but a couple of questions. This includes the size of agricultural land India can irrigate from the western tributaries, as well as a new method by which flood warnings are delivered to Pakistan. In a couple of matters, including the construction of the Salal dams and the Baglihar dam, the foreign secretaries and a neutral expert, respectively, helped the parties reach resolution.

Public Participation

Finally, effective water governance depends on ensuring wide participation throughout the collective process (Marty 2001; Rogers and Hall 2003: 28). Prior research suggests that it is through deliberation that divergent parties can develop trust and social capital, which are necessary conditions for collaboration (Adger 2000: 359; Bruch 2000; Gunderson et al. 2006). Mechanisms that allow for actors to share and deliberate new ideas and information with actors external to the institution, such as through public participation and advisory bodies, are thought to facilitate the adaptability of common pool resource and social-ecological systems (Ostrom 1990; Lebel et al. 2006), and

lead to more flexible decisions that are also easier to enforce (Cassar and Mock 2003; Wester et al. 2003). A lack of public participation may result in limited support for any agreement reached or may challenge implementation (Mostert 2003). Multiple design choices are available to address public participation (Fung 2003), but in transboundary water governance these mechanisms may range from the informal submission of comments at different stages of the decision-making process to more formal mechanisms that require public input as a component of planned management actions.

Nonstate actors, like community groups, community and individual rights holders, or water users, have historically been excluded from transboundary water governance (UN 2013: 7). In most cases, international organizations, international donors, and other government bodies have only observer status in river basin organizations (Mostert 2003). There are, however, a few exceptions to this, where international and national NGOs play a greater role in active discussions with the organization. Most of these instances are isolated to river basin organizations in Europe and North America (Schmeier 2012). For example, the ICPR along the Rhine is mandated to cooperate with NGOs relevant for the RBO's activities by sharing information and providing observer status at commission meetings (Rhine Convention, Article 14). The International Commission for the Protection of the Elbe organizes annual meetings between the RBO and NGOs from both member states.

Some research around public participation in RBOs suggests that they fail to provide a forum for public participation, offering little access to information and few mechanisms for broader stakeholder participation (Milich and Varady 1999; Schmeier 2012). For example, in the Orange River basin there are concerns that water management is too technocratic and top-down (Pahl-Wostl 2007). In our research of the pulp mills controversy along the Uruguay River, we uncovered the river basin organization's failure to channel in constructive ways the growing public sentiment (particularly on the Argentine side) that the mills could be pernicious for the health of the river's ecosystem (Berardo and Gerlak 2012: 114). In this case, the Administrative Commission of the Uruguay River, formed initially in 1975, did not provide a mechanism for public participation. In the wake of mounting public pressure and social protests over the construction of paper mills on the Uruguay side of the Uruguay River (i.e. the blocking of bridges between the two countries), the commission was unable to

adapt and provide a forum to resolve the conflict. Ultimately, the conflict reached the International Court of Justice. But the case highlights the need for change and adaptation in the organization's modus operandi to equip it better to face modern challenges. Like previous studies on water management have shown, collaborative practices that lead to cooperation heavily depend not so much on making sure all interests are represented, but on making sure all interests are represented before the decision-making process starts (Scholz and Stiftel 2005). Further, different forms of engagement are often necessary for different types of stakeholders (Sadoff et al. 2008).

A Gap in Performance in Regionalized Water Management

In examining several key design elements associated with effective regional water management, we can observe how the presence or absence of these factors plays out and ultimately impacts regional cooperation along transboundary rivers. Overall, this review reveals a mixed record. It finds that it is not the relative presence or absence itself that often makes the difference but rather the effective—or ineffective—implementation of the design feature in practice. Process design features are effective only to the extent that they are implementable. Implementation of process design elements like those studied here require the requisite political support as well as the appropriate administrative and technical capacity. Further, treaty design elements, associated with the first level of effectiveness, influence the implementation of the process design elements of transparency, scientific learning, conflict resolution, and public participation. As Fischhendler's (2008: 132) research points out, ambiguity in treaty design can be constructive by helping to bring a dispute to temporary closure but can also leave unresolved critical issues that negatively impact the relations between parties during the implementation and management phases of agreements.

The examples highlighted here from the diverse case research around transboundary waters suggest that the cases do not always bear out the purported benefits. This is partly because expectations for RBOs as a vehicle for regionalized water management may be too high. The expected functions of RBOs may simply be too ambitious or unrealistic (Jouravlev and Solanes 2008; Rangeley et al. 1994). In part, this tendency to overpromise and then under-deliver is the result of an inability to recognize important contextual factors that influence effectiveness. As Ruth Meinzen-Dick (2007: 15200) writes, "Over the past 50 years, a series of institutional

arrangements has been presented as panaceas to improve water management . . . Each of these approaches has failed to live up to expectations, largely because the variability of local situations and the difficulty of transplanting institutions from one place to another."

This belief in a magic formula or panacea is manifest in the promotion of models of regional river basin management. Models of '"best practices"' demonstrate that a certain institutional design can serve as a blueprint for implementation. In the case of river basin organizations, the adoption of a model that has been successful elsewhere is more politically conducive than innovation (Molle 2008: 146). These models are attractive to national officials in that they offer possible solutions to complicated and problematic water management problems, and perhaps more importantly, they frequently come with significant donor investment (Molle 2008; Chambers 1997). Models also bring perceived legitimacy and thus may be used to justify a particular political agenda. For example, the French model for basin management has been used to support a pollution tax in Indonesia and new administrative budgeting processes in Brazil (Mollinga and Bolding 2004; Rap 2006). Historically, the Tennessee Valley Authority represents a classic best practice model, promoted by the U.S. Army Corps of Engineers and applied in various parts of the globe (Priscoli 2007; Ekbladh 2002). The Australian federal government widely supported the Murray-Darling River Basin Commission model thereby influencing developments in countries such as China, Sri Lanka, and Vietnam and contributing to the creation of the Mekong Basin Commission and its ongoing operations (Molle 2005).

This blind promotion of models of river basin management in part explains the gap in performance revealed in this paper. This Field of Dreams—"if we build it, they will come"—approach where donors and other transnational policy actors promote the argument that one organizational design and approach can be exported to other parts of the world sets up unrealistic expectations that are often not matched by on-the-ground outcomes. In his study of effectiveness in regional water management along the Rhine River, Erik Mostert (2009: 148) makes the argument that experiences along the Rhine cannot simply be applied or exported to other regions because of the role of critical contextual factors in the region, including regional economic cooperation, domestic legislation and technological innovation. He contends that the Rhine Action Plan worked in the basin only because the "low legal status was more than compensated by the political

and social pressure on the different Rhine governments to implement the plan" (Mostert 2009: 149). Myint (2003: 312) also explains the success of the Rhine in part due to how well the Rhine Action Plan fits with the political, social, and economic contexts in which it operates, particularly in contrast to earlier, less successful initiatives in the basin. Indeed, such a domestic context varies substantially in other parts of the world.

The design elements approach outlined in this paper helps to highlight general organizational principles on a more macro level that we know are important in the context of river basin planning and management. It offers a set of design elements specific to the context of transboundary, regionalized water management to be considered as we evaluate regional planning and management processes, design new processes and institutional structures, and modify or adapt existing institutions. The mixed record reported here suggests that the next steps might be to move beyond the general design criteria to ask, What are the contextual situations where one or more of these design features are important in supporting effective regionalized water management?

A more contextual approach can help us to better understand gaps in performance that stem from variations in the design and implementation of particular elements. Consider public participation, a design feature that has received considerable attention and support from those in the international water community in recent years. It is inconceivable to imagine anyone arguing against broad public participation in regional water management. Yet political scientists have long understood there to be decision rules around who participates—and how they participate—that are politically driven (Blomquist and Schlager 2005). Moreover, participation may be compulsory, top-down, or merely symbolic (Cooke and Kothari 2002). A more contextual approach would help uncover power differentials among populations of peoples and cultural barriers, allowing us to see differences in design and implementation that shape effectiveness. Or it might reveal the role of national or sub-national entities in contributing to the establishment of trust among stakeholders, leading to greater technical cooperation and improving coordination over shared waters once institutions are established (UN 2013: 8).

Scientific learning will also play out differently in varying river basin contexts. This is because knowledge processes are specific to particular communities and the context itself can support or undermine laws, institutions, and processes (Brugnach and Ingram 2012). In some cases lack

of capacity may hinder effective river basin management (UNDP 2008). This lack of capacity may result from an inadequate and unstable financial investment, but it may also stem from failures and gaps in technology and innovation (Le Marquand 1977; Kliot et al. 2001; Nakayama 1997). A more contextual approach would better reveal flaws in design or implementation around the production and dissemination of scientific knowledge given realties in capacity.

With regard to conflict resolution features, a contextual approach would allow us to think about how this design feature plays out differently in some basins versus others. For example, given that the upstream-downstream externality problems are more difficult to solve than collective (common pool resource) problems (Le Marquand 1977; Marty 2001), we might expect the conflict resolution mechanisms to be quite important in these basins to help even the playing field or minimize asymmetric challenges in the basin.

Similarly, the design and implementation of transparency features matters greatly based on the context. As Helen Ingram (2011) argues, "In situations of excessive bureaucratic control, designs with greater transparency and public participation are appropriate. However, transparency and openness are not by themselves useful in contexts of great economic and social inequity where the resources necessary to participate are out of reach to the disenfranchised." Rather, as Ingram argues, other strategies and capacity building mechanisms would be necessary in such a context. Further, a more contextual approach to transparency may highlight the role of regime type in implementation, for example, suggesting that even in cases where the public has access to information, political systems at the national level may not provide proper mechanisms for voices to be heard.

Finally, in looking at context, we might begin to see interrelationships between design elements. In looking at the various cases presented here we can see how transparency in reporting and public access can help to heighten greater public participation. Similarly, public participation may improve transparency in reporting. Scientific learning and monitoring can also support public participation and transparency and may serve to minimize conflict.

But admittedly, a contextual approach makes the conversation and the commensurate research more challenging. Practically, it may well mean more mixed strategies and approaches to motivating behavioral change (Ingram 2013: 11). In terms of scholarly research, a more integrated,

contextual approach to design elements in effective transboundary water management requires better data and research around design features in practice. This research needs to be more comprehensive across temporal and spatial scales and more comparative in nature. As long-time water scholar and professional Asit Biswas (1008: 5) notes, one of the greatest challenges for the twenty-first century is how to develop and manage transboundary water resources "sustainably and efficiently in full agreement and cooperation between the appropriate co-basin countries so they result in a win-win situation for all the parties concerned." To meet this challenge, we will need to better understand similarities and differences in design features across various economic, social, and political contexts.

References

Adger, W. N. 2000. Social and Ecological Resilience: Are They Related? *Progress in Human Geography* 24(3): 347–364.

Aguilar, G., and A. Iza. 2011. *Governance of Shared Waters. Legal and Institutional Issues.* Gland, Switzerland: International Union for Conservation of Nature.

Asian Development Bank. 1995. *Governance: Sound Development Management: Policies and Strategies.* Manila, Philippines: Asian Development Bank.

Backer, E. B. 2007. The Mekong River Commission: Does It Work, and How Does the Mekong Basin's Geography Influence Its Effectiveness? S*udostasien aktuell: Journal of Current Southeast Asian Affairs* 31–55.

Barraqué, B., and E. Mostert. 2006. *Transboundary River Basin Management in Europe*. New York: UNDP.

Barrow, C. J. 1998. River Basin Development Planning and Management: A Critical Review. *World Development* 26(1): 171–186.

Berardo, R., and A. Gerlak. 2012. Conflict and Cooperation along International Rivers: Crafting a Model of Institutional Effectiveness. *Global Environmental Politics* 12(1): 101–120.

Bernauer, T. 1997. Managing International Rivers. In O. Young, ed., *Global Governance: Drawing Insights from the Environmental Experience*. 27–63. Cambridge, MA: MIT Press.

———. 2002. Explaining Success and Failure in International River Management. *Aquatic Sciences* 64:1–19.

Bernauer, T., and A. Kalbhenn. 2010. The Politics of Freshwater Resources.

In R. A. Denemark, ed., *The International Studies Encyclopedia*. 5800-5821. Oxford: Wiley-Blackwell Publishers.

Bernauer, T., and P. Moser. 1996. Reducing pollution of the River Rhine: The influence of international cooperation. *The Journal of Environment & Development* 5:389–415.

Biswas, A. K. 2008. Management of Transboundary Waters: An Overview. In O. Varis, C. Tortajada, and A. K. Biswas, eds., *Management of Transboundary Rivers and Lakes*. 1–20. Heidelberg, Germany: Springer-Verlag.

Blomquist, W., and E. Schlager. 2005. Political Pitfalls of Integrated Watershed Management. *Society and Natural Resources* 18(2): 101–117.

Bruch, C. 2000. *Charting New Waters: Public Involvement in the Management of International Watercourses.* UNU Workshop on Southern African International Waters, Sandton, South Africa, 25 and 26 September.

Brugnach, M., and Ingram, H., 2012. Ambiguity: The Challenge of Knowing and Deciding Together. *Environmental Science & Policy* 15: 60–71.

Burchi, S. and M. Spreij. 2003. *Institutions for International Freshwater Management*. Paris: UNESCO.

Burton, M., and D. Molden. 2005. Making Sound Decisions: Information Needs for Basin Water Management. In M. Svendsen, ed., *Irrigation and River Basin management: Options for Governance and Institutions.* 51–74. Massachusetts: CABI Publishing.

Cassar, A., and G. Mock. 2003. Transboundary Environmental Governance: The Ebb and Flow of River Basin Organizations. In *World Resources 2002–2004*. Washington, DC: World Resources Institute.

Chambers, R. 1997. *Whose Reality Counts? Putting the First Last*. London: ITDG Publishing.

Chayes, A., and A. H. Chayes. 1995. *The New Sovereignty: Compliance with International Regulatory Agreements.* Cambridge, MA: Harvard University Press.

Conca, K. 2006. *Governing Water: Contentious Transnational Politics and Global Institution Building.* Cambridge, MA: MIT Press.

Conca, K., F. Wu, and C. Mei. 2006. Global Regime Formation or Complex Institution Building? The Principled Content of International River Agreements. *International Studies Quarterly* 50(2): 263–285.

Cooke, B., and U. Kothari. 2002. *Participation: The New Tyranny?* London: Zed Books Ltd.

Cosgrove, W. J. 2003. *Water Security and Peace: A Synthesis of Studies Prepared under the PCCP–Water for Peace Process.* Paris: UNESCO.

———. 2009. Public Participation to Promote Water Ethics and Transparency. In. M. R. Llamas, L. M. Cortina, and A. Mukherji, eds., *Water Ethics: Marcelino Botin Water Forum 2007*. London: Taylor and Francis Group.

Cosgrove, W. and F. Rijsberman. 2000. *World Water Vision: Making Water Everybody's Business*. London: Earthscan Publishers.

De Boer, C., J. Vinke-de Kruijf, G. Özerol, and H. Th. A. Bressers, eds. 2013. *Water Governance, Policy and Knowledge Transfer: International Studies on Contextual Water Management*. Abingdon, UK: Routledge.

De Lange, M., D. J. Merrey, H. Levite, and M. Svendsen. 2005. Water Resources Planning and Management in the Olifants Basin of South Africa: Past, Present and Future. In M. Svendsen, ed., *Irrigation and River Basin Management: Options for Governance and Institutions*. 145–168. UK: CABI Publishing.

Dietz, T., E. Ostrom, and P. C. Stern. 2003. The Struggle to Govern the Commons. *Science* 302(December 12): 1907–1912.

Dombrowsky, I. 2007. *Conflict, Cooperation and Institutions in International Water Management: An Economic Analysis*. Cheltenham, UK: Edward Elgar.

———. 2008. Integration in the Management of International Waters: Economic Perspectives on a Global Policy Discourse. *Global Governance* 14: 455–477.

Eakin, H., and M. Lemos. 2006. Adaptation and the State: Latin America and the Challenge of Capacity-Building under Globalization. *Global Environmental Change* 16(1): 7–18.

Earle, A., and A. Turton. 2005. No Duck No Dinner: How Sole Sourcing Triggered Lesotho's Struggle against Corruption. Presentation at Can We Meet International Targets without Fighting Corruption? seminar. *World Water Week* (Stockholm), 20–26 August.

Ekbladh, D. 2002. Mr. TVA: Grass-Roots Development, David Lilienthal, and the Rise and Fall of the Tennessee Valley Authority as a symbol for U.S. Overseas Development, 1933–1973. *Diplomatic History* 26(3): 335–374.

Elhance, A. P. 2000. Hydropolitics: Grounds for Despair, Reasons for Hope. *International Negotiation* 5(2): 201–222.

Fischhendler, I. 2008. When Ambiguity in Treaty Design Becomes Destructive: A Study of Transboundary Water. *Global Environmental Politics* 8(1): 111–135.

Fung, A. 2003. Recipes for Public Spheres: Eight Institutional Design Choices and Their Consequences. *Journal of Political Philosophy* 11(3): 338–367.

Gerlak, A. K. 2004. The Global Environment Facility and Transboundary Water Resource Management: New Institutional Arrangements in the Danube River and Black Sea Region. *The Journal of Environment & Development* 13(4): 400–424.

Gerlak, A. K., and K. A. Grant. 2009. The Correlates of Cooperative Institutions for International Rivers. In Thomas J. Volgy et al., eds., *Mapping the New World Order,* 114–147. Oxford: Wiley-Blackwell.

Gerlak, A. K., J. Lautze, and M. Giordanp. 2011. Water Resources Data and Information Exchange in Transboundary Water Treaties. *International Environmental Agreements* 11(2): 179–199.

Global Water Partnership. 2000. *Integrated Water Resources Management*. Stockholm: Global Water Partnership.

Green Cross International. 2000. *National Sovereignty and International Watercourses.* Geneva: Green Cross International.

Gunderson, L. H., and C. S. Holling, eds. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems.* Washington, DC: Island Press.

Gunderson, L. H., S. R. Carpenter, C. Folke, P. Olsson, and G. D. Peterson. 2006. Water RATs (Resilience, Adaptability, and Transformability) in Lake and Wetland Social-Ecological Systems. *Ecology and Society* 11(1): 16.

Gupta, J. 2009. Driving Forces in Global Freshwater Governance. In D. Huitema and S. V. Meijerink, eds., *Water Policy Entrepreneurs: a Research Companion to Water Transitions around the Globe*. 37–61. Cheltenham: Edgar Elgar.

———. 2011. An Essay on Global Water Governance and Research Challenges. In M. R. van der Valk and P. Keenan, eds., *Principles of Good Governance at Different Water Governance Levels.* Delft: The Netherlands National Committee IHP-HWRP.

Ha, M. L. 2011. The Role of Regional Institutions in Sustainable Development: A Review of the Mekong River Commission's First 15 Years. *Consilience: The Journal of Sustainable Development* 5(1): 125–140.

Haftendorn, H. 2000. Water and International Conflict. *Third World Quarterly* 21 (1): 51–68.

Hammer, J., and A. T. Wolf. 1998. Patterns in International Water Resource Treaties: The Transboundary Freshwater Dispute Database. *Colorado Journal of International Environmental Law and Policy* 9: 157–177.

Hansen, H. E., S. McLaughlin Mitchell, and S. C. Nemeth. 2008. IO Mediation of Interstate Conflicts: Moving Beyond the Global versus Regional Dichotomy. *Journal of Conflict Resolution* 52(2): 295–325.

Hensel, P. R., S. McLaughlin Mitchell, and T. E. Sowers. 2006. Conflict Management of Riparian Disputes. *Political Geography* 25(4): 383–411.

Hildering, A. 2004. *International Law, Sustainable Development and Water Management*. Delft: Eburon Publishers.

Hoff, H. 2009. Global Water Resources and Their Management. *Current Opinion in Environmental Sustainability* 1: 141–147.

Hooper, B. 2005. *Integrated River Basin Management: Learning from International Experience*. London: International Water Association Publishing.

———. 2010. River Basin Organisation Performance Indicators: Application to the Delaware River Basin Commission. *Water Policy* 12: 461–487.

Ingram, H. 2013. No Universal Remedies: Design for Contexts. *Water International* 38(1): 6–11.

———. 2011. Beyond Universal Remedies for Good Water Governance: A Political and Contextual Approach. In A. Garrido and H. Ingram, eds., *Water for Food in a Changing World*. 241–261. Abingdon, UK: Routledge.

Islar, M. 2009. *Crisis of Water: Interrogating Neo-Liberal Water Discourses in Turkey*. Paper presented at Third IIPPEE International Research Workshop.

Islar, M., and V. Ramasar. 2009. *Security to All: Allocating the Waters of the Euphrates and Tigris*. Paper presented at Earth System Governance Conference.

Jagerskog, A., and D. Phillips. 2006. *Managing Transboundary Waters for Human Development*. New York: UNDP.

Kistin, E. J., P. J. Ashton, A. Earle, D. Malzbender, et al. 2009. An Overview of the Content and Historical Context of the International Freshwater Agreements that South Africa has Entered into with Neighboring Countries. *International Environmental Agreements* 9(1): 1–21.

Karkkainen, B. C. 2004. Post-Sovereign Environmental Governance. *Global Environmental Politics* 4: 72–96.

Kibaroğlu, A. 2002. *Building a Regime for the Waters of the Euphrates-Tigris River Basin*. New York: Springer Publishers.

Kibaroğlu, A., and O. Ünver. 2000. An Institutional Framework for Facilitating Cooperation in the Euphrates-Tigris River Basin. *International Negotiation: A Journal of Theory and Practice* 5 (2): 311–330.

Kliot, N., D. Shmueli, and U. Shamir. 2001. Development of Institutional Frameworks for the Management of Transboundary Water Resources. *International Journal of Global Environmental* 1 (3–4): 306–328.

Lautze, J., K. Wegerich, J. Kazbekov, and M. Yakubov. 2013. International

River Basin Organizations: Variation, Options, and Insights. *Water International* 38(1): 30–42.

Lautze, J., M. Giordano, and M. Borghese. 2005. *Driving Forces behind African Transboundary Water Law: Internal, External, and Implications.* International workshop on African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa, Johannesburg, South Africa, 26–28 January.

LeMarquand, D. G. 1990. International Development of the Senegal River. *Water International* 15: 223–230.

Lebel, L., J. M. Anderies, B. Campbell, C. Folke, et al. 2006. Governance and the Capacity to Manage Resilience in Regional Social-Ecological Systems. *Ecology and Society* 11(1): 19.

Marty, F. 2001. *Managing International Rivers: Problems, Politics, and Institutions*. Bern, Switzerland: Peter Lang.

McNally, R., and S. Tognetti. 2002. *Tackling Poverty and Promoting Sustainable Development: Key Lessons for Integrated River Basin Management*. London: WWF.

Meinzen-Dick, R. 2007. Beyond Panaceas in Water Institutions. *PNASS* 104(39): 1500–1520.

Milich, L. and R. Varady. 1999. Openness, Sustainability, and Public Participation. *New Designs* 258–306.

Mitchell, R. 1994. Regime Design Matters: Intentional Oil Pollution and Treaty Compliance. *International Organization* 48(3): 425–458.

Molle, F. 2005. *Irrigation and Water Policies in the Mekong Region: Current Discourses and Practices.* Colombo, Sri Lanka: International Water Management Institute.

———. 2008. Nirvana Concepts, Narratives and Policy Models: Insight from the Water Sector. *Water Alternatives 1.*

Molle, F., T. Foran, and M. Käkönen, eds. 2009. *Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance*. London: Earthscan.

Mollinga, P., and A. Bolding, eds. 2004. *The Politics of Irrigation Reform: Contested Policy Formation and Implementation in Asia, Africa and Latin America*. Aldershot: Ashgate Publishing Ltd.

Mostert, E. 2003. Conflict and Co-operation in International Freshwater Management: A Global Review. *International Journal of River Basin Management* 1 (3): 1–12.

———. 2005. *How Can International Donors Promote Transboudary Water Management?* Bonn: Deutsches Institut fur Entwicklungspolitik.

———. 2009. International Co-operation on Rhine Water Quality 1945–2008: An example to follow? *Physics and Chemistry of the Earth* 34: 142–149.

Mukhtarov, F. 2007. Intellectual History and Current Status of Integrated Water Resources Management: A Global Perspective. In C. Pahl-Wostl, P. Kabat, and J. Möltgen, eds., *Adaptive and Integrated Water Management: Coping with Complexity and Uncertainty*. Heidelberg: Springer Verlag,

Mukhtarov, F. and A. Gerlak. 2013. River Basin Organizations in the Global Water Discourse: An Exploration of Agency and Strategy. *Global Governance* 19: 307–325.

Myint, T. 2003. Democracy in Global Environmental Governance: Issues, Interests, and Actors in the Mekong and the Rhine. *Indiana Journal of Global Legal Studies* 10(1): 287–314.

Nakayama, M. 1997. Successes and Failures of International Organizations in Dealing with International Waters. *Water Resources Development* 13(3): 367–382.

Nishat, A., and I. M. Faisal. 2000. An Assessment of the Institutional Mechanisms for Water Negotiations in the Ganges-Brahmaputra-Meghna System. *International Negotiation* 5(2): 289–310.

NGO Forum. 2005. Running Dry: Does the ADB Stand for "Water for All"? *Synthesis Report of the Civil Society Organisations to the Implementation Review of the Asian Development Bank Water Policy*. NGO FORUM on ADB, Quezon City, Philippines, 18 November.

O'Hara, S., ed. 2003. *Drop by Drop: Water Management in the Southern Caucasus and Central Asia*. Budapest: Open Society Institute Press.

Organisation for Economic Co-operation and Development (OECD). 2011. *Water Governance in OECD Countries: A Multi-level Approach*. Paris: OECD.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge University Press.

Pahl-Wostl, C. 2007. Transition Towards Adaptive Management of Water Facing Climate and Global Change. *Water Resources Management* 21(1): 49–62.

Pahl-Wostl, C., K. Conca, A. Kramer, J. Maestu, and F. Schmidt. 2013. Missing Links in Global Water Governance: A Process Orient Analysis. *Ecology And Society* 18(2): 33. http://dx.doi.org/10.575/ES-05554-180233

Priscoli, J. D. 2007. Five Challenges for Water Governance. In Anthony R. Turton et al., eds., *Governance as a Trialogue: Government-Society-Science in Transition*. Berlin: Springler, 2007.

Priscoli, J. D. 2009. River Basin Organizations. In J. Delli Priscolli and A. T.

Wolf, eds., *Managing and Transforming Water Conflicts,* 135–168. Cambridge: Cambridge University Press.

Raadgever, G. T., E. Mostert, N. Kranz, E. Interwies, and J. G. Timmerman. 2008. Assessing Management Regimes in Transboundary River Basins: Do They Support Adaptive Management? Ecology and Society 13(1): 14.

Rap, E. 2006. The Success of a Policy Model: Irrigation Management Transfer in Mexico. Journal of Development Studies 42(8): 1301–1324.

Rangeley R., B. M. Thiam, R. A. Andersen, and C. A. Lyle. 1994. *International River Basin Organizations in Sub-Saharan Africa*. Washington, DC: World Bank.

Rieckermann, J., H. Daebel, M. Ronteltap, and T. Bernauer. 2006. Assessing the Performance of International Water Management at Lake Titicaca. *Aquatic Sciences* 68(4): 502–516.

Rogers, P. 1997. International River Basins: Pervasive Unidirectional Externalities. In P. Dasgupta, K.l-G. Maler, and A. Vercelli, eds., *The Economics of Transnational* Commons, 35–76. Oxford: Clarendon Press.

Rogers, P., and A. W. Hall. 2003. Effective Water Governance. *TEC Background Papers No. 7.* Stockholm: Global Water Partnership.

Sadoff, C., and D. Grey. 2002. Beyond the River: The Benefits of Cooperation on International Rivers. *Water Policy* 4: 389–403.

Sadoff, C., T. Greiber, M. Smith, and G. Bergkamp. 2008. *Share—Managing Water Across Boundaries.* Gland, Switzerland: IUCN.

Schmeier, S. 2011. *Resilience to Climate Change-Induced Challenges in the Mekong River Basin. The Role of the Mekong River Commission*. Washington, DC: World Bank.

Schmeier, S., A. K. Gerlak, and S. Schulze. 2013. *Who Governs Internationally Shared Watercourses? Clearing the Muddy Waters of International River Basin Organizations.* Earth System Governance Working Paper No. 28.

Scholz, J. T., and B. Stiftel, eds. 2005. *Adaptive Governance and Water Conflict: New Institutions for Collaborative Planning.* Washington, DC: Resources for the Future.

Sehring, J. 2009. Path Dependencies and Institutional Bricolage in Post–Soviet Water Governance. *Water Alternatives* 2 (1): 61–81.

Serageldin, I., et al. 2000. A Report of the World Commission on Water for the 21st Century. *Water International* 25(2): 284–302.

Siegfried, T., and T. Bernauer. 2007. Estimating the Performance of International Regulatory Regimes: Methodology and Empirical Application to

International Water Management in the Naryn/Syr Darya Basin. *Water Resources Research* 43(W11406): 1–14.

Sneddon, C. and C. Fox. 2006. Rethinking Transboundary Waters: A Critical Hydropolitics of the Mekong Basin. *Political Geography* 25: 181–202.

Solanes, M., and A. Jouravlev. 2006. *Water Governance for Development and Sustainability*. Santiago, Chile: UN.

Stålgren, P. 2006. *Corruption in the Water Sector: Causes, Consequences and Potential Reform*. Stockholm: Stockholm International Water Institute.

Stinnett, D., and J. Tir. 2009. The Institutionalization of River Treaties. *International Negotiation* 14(2): 229–251.

Timmerman, J. G., and S. Langaas. 2004. *Environmental information in European transboundary water management*. London: IWA Publishing.

Transparency International. 2008. *Global Corruption Report 2008: Corruption in the Water Sector*. Cambridge, UK: Cambridge University Press.

Turton, A., R. R. Meissner, P. M. Mampane, and O. Seremo. 2004. *A Hydropolitical History of South Africa's International River Basins*. Report to the Water Research Commission. Pretoria: University of Pretoria African Water Issues Research Unit.

Uitto, J. I., and A. M. Duda. 2002. Management of Transboundary Water Resources: Lessons from International Cooperation for Conflict Prevention. *Geographical Journal* 168: 365–378.

Underdal, A. 2008. The Organizational Infrastructure of International Environmental Regimes. In U. Sverdrup and J. Trondal, eds., *The Organizational Dimension of Politics,* 186–205. Oslo, Norway: Fagbokforlaget.

UN (United Nations). 1970. *Integrated River Basin Development: Report of a Panel of Experts*. New York: UN Department of Economic and Social Affairs.

———. 2013. *Water Security and the Global Water Agenda*. A UN-Water Analytical Brief. Ontario, Canada: United National University.

UNDP (United Nations Development Programme). 2008. *Performance and Capacity of River Basin Organizations: Cross-case Comparison of Four RBOs*. Washington, DC: UNDP.

UNECE (United Nations Economic Commission for Europe). 2009. *River Basin Commissions and Other Institutions for Transboundary Water Cooperation: Capacity for Water Cooperation in Eastern Europe, Caucasus and Central Asia*. New York and Geneva: UN.

UNEP (United Nations Environment Programme). 2009. *Hydropolitical Vulnerability and Resilience along International Waters*. Nairobi: UNEP.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2007. *State of the Art Review on IWRM*. Paris: UNESCO-IHP.

———. 2009. *United Nations World Water Development Report 3: Water in a Changing World*. Paris: UNESCO.

Verwijmeren, J., and M. Wiering, eds. 2007. *Many Rivers to Cross: Cross Border Co-operation in River Management*. Delft: Eburon Publishers.

Warner, J., P. Wester, and A. Bolding. 2008. Going with the Flow: River Basins as the Natural Units for Water Management? *Water Policy* 10(2): 121–138.

Water Integrity Network and Transparency International. 2010. *Integrity Pacts in the Water Sector: An Implementation Guide for Government Officials*. Berlin: Water Integrity Network and Transparency International.

Wescoat, J. L., Jr. 1996. Main Currents in Early Multilateral Water Treaties: A Historical-Geographic Perspective. *Colorado International Environmental Law and Policy Journal* 39: 1648–1949.

Wester, P., D. J. Merrey, and M. de Lange. 2003. Boundaries of Consent: Stakeholder Representation in River Basin Management in Mexico and South Africa. *World Development* 31(5): 797–812.

White, G. F. 1969. *Strategies of American Water Management*. Ann Arbor: University of Michigan Press.

Wolf, A. T. 2007. Shared Waters: Conflict and Cooperation. *Annual Review of Environment and Resources* 32: 3.1–3.29.

WWC (World Water Council). 2012. *A New Water Politics: World Water Council 2002–2012 Strategy*. Marseille, France: World Water Council.

WWF (World Wildlife Fund). 2002. Pricing as a Tool to Reduce Water Demand. *WWF Spain/ADENA's Alcobendas: Water City for the 21st Century: A Demonstration Project*.

Young, O. R. 2002. *The Institutional Dimensions of Environmental Change: Fit, Interplay and Scale*. Cambridge, MA: MIT Press.

Zawahri, N. 2008. Designing River Commissions to Implement Treaties and Manage Water Disputes: The Story of the Joint Water Committee and Permanent Indus Commission. *Water International* 33(4): 464–474.

The Role of Creative Language in Addressing Political Asymmetries: The Israeli-Arab Water Agreements

Dr. Itay Fischhendler

Hebrew University of Jerusalem

Dr. Aaron T. Wolf

Oregon State University

Dr. Gabriel Eckstein

Texas Wesleyan University School of Law

Abstract

International water agreements are often used as mechanisms for fostering and institutionalizing political cooperation. Yet, since water resources in many places are being driven to the edge of their natural limits, a number of international organizations have formulated legal principles and norms aimed at helping states resolve water disputes. While states have been urged to adopt these principles, it seems that they often embrace other less-traditional alternatives that may better address their own political needs. The aim of this study is to examine why states fail or decline to adopt several of the general principles of customary law formulated by these international organizations and to investigate how creative language is often adapted instead. The principles examined include basin-wide development and management; the appropriation of water according to clearly defined water rights; and joint management of shared water resources. The study focuses on three contemporary case studies centering on Israel, Jordan, and the Palestinian Territories. It concludes that the negotiation over the legal terminology of agreements between these parties exemplifies the

power struggle and asymmetries between Israel and its neighbors. Much of the deadlock in the negotiations was resolved when the parties moved from their adversarial positions to address the underlying interests, in which a compromise was forged that captured elements of international law while still addressing the needs of the dominant riparian. These results indicate that under asymmetric settings, there is a need for creative legal discourse rather than an entrenchment of international water law, which has found to be a recipe for failure.

Introduction

Since water resources are being driven to the edge of their natural limits, today even the most cooperative neighboring states find it difficult to achieve mutually acceptable arrangements over shared water resources (McCaffrey 2001). As a means for helping states negotiate resolutions to water disputes, a number of international bodies have formulated general legal principles and norms focusing on basin-wide development and management, the appropriation of water according to clearly defined water rights, and joint management of shared water resources (Benvenisti and Gvirtzman 1993; Conca et al. 2006). These principles and norms are intended to change the behavior of states by introducing new principles and norms of conduct. Among these international bodies are the International Law Association, which developed the 1966 Helsinki Rules and the 2004 Berlin Rules, and the International Law Commission. Today, nearly all states agree that the numerous water treaties and other international legal instruments testify to the existence of customary international law for transboundary water resources (Dellapenna 2006).

While states are being urged to adopt these principles and norms (Hayton and Utton 1989), emerging trends in transboundary water regulation suggest that, in fact, states tend to embrace other less-traditional principles that may better address their own political needs. For example, Conca et al. in their study on whether governments are converging on common principles for governing shared river basins found that there is only weak evidence for the actual adoption of common principles for regime formation (Conca et al. 2006). Also, Kliot and Shmueli (2001) determined that very few of the institutions they examined corresponded to the ideal model of institutions for the management of transborder water

resources, namely, a basin-wide multipurpose institution that treats the whole basin as a single unit and equitably integrates all riparians. Yet many of these institutions were nevertheless found to be effective in managing the shared resource. Treaties in basins with multiple riparians are still often bilateral, and many of these treaties are based on needs rather than rights, as stipulated by customary law, and the coordination achieved is limited. In some cases it seems that even if the language of international law does appear in treaties, it actually has a different meaning there. Such was the case in the 1995 Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin (1995 Mekong River Treaty) that, although employing the term "basin" treaty, often meant a watercourse, which is a smaller spatial unit of jurisdiction than a basin (Sneddon and Fox 2006).

The aim of this study is to examine why states fail or decline to adopt several of the general principles of customary law formulated by these international organizations and to identify the creative language that is adopted instead. The principles to be examined are 1) basin-wide development and management; 2) the appropriation of water according to clearly defined water rights; and 3) joint management of water resources by all basin riparians.

To this end, a comparative research design is offered. Three case studies will be examined in detail, including the water components of the 1994 Treaty of Peace between Israel and Jordan, the 1995 interim water agreement ("Oslo II") between Israel and the Palestinian Liberation Organization (PLO); and the 2005 agreement between Israel, the Palestinian Authority and Jordan to conduct feasibility studies for a canal project between the Red and Dead Seas.

The study first examines the emergence of three core principles in international water law and their potential ability to address asymmetries. Next, through the three case studies, it seeks to understand why these so-called "ideal" principles are often not adopted and what alternative principles might replace them. Finally, it discusses the limits and limitations of the three principles vis-à-vis their ability to reconcile a negotiation process steeped in conflict.

Principles of International Water Law and Addressing Asymmetries

The Principle of Basin-Wide Management

At the beginning of the twentieth century, the basin became the recognized unit for developing and managing water resources in individual multipurpose projects. But it was during the 1960s that the concept became widespread in water development (Teclaff 1996). Basin-wide institutions are now pitched as the most appropriate unit for internalizing all externalities associated with water-land-human interaction. Such water institutions include river basin councils, commissions, and authorities.

In the last few decades, legal scholars have also agreed that the critical unit of analysis for international water resources is that of the international drainage basin. For example, the International Law Association, already in 1951, began endorsing the integrated basin principle (Teclaff 1996). This was followed the 1966 Helsinki Rules that promoted a holistic approach to water management at a basin level. In 1986, the scope and definition was widened by the ILA to encompass interrelated transboundary surface and groundwaters as well as transboundary aquifers that are completely dissociated from any surface water resources (Seoul Rules 1986).

The Principle of Water Rights

Most legal systems today recognize and protect the property aspects of water rights (Solanes 2001). International law strives to delineate those riparian state rights to international water resources (Benvenisti and Gvirtzman 1993). The underlying rationale for establishing water rights is that a clear definition of who is entitled to use the water will reduce uncertainty and conflict (Pradhan and Meinzen-Dick 2001). This is in line with neoclassical economics, which see property rights as a fundamental concept of development (Molle 2004). Thus, the "right" terminology has penetrated many of the legal instruments that seek to articulate or establish international water law. For example, the Helsinki Rules put forth the notion of legal rights to water in many of its clauses (Helsinki Rules 1966). Similarly, the Watercourse Convention stresses the right of watercourse states to utilize the watercourse (Article 5). The Berlin Rules, though not setting rights as a guideline for appropriating water, stress the right to have access to water (Berlin Rules 2004).

The Principle of Joint Management

Navigation laid the groundwork for a legal or administrative unity of the river basin in politically divided basins. This sense of management unity was built upon as the non-navigation demands and the technological means to meet those demands grew. Indeed, in the United States from the 1940s to the 1970, a series of river basin commissions were established. During the 1940s and 1950s, basin authorities emerged throughout the world: in India, Sri Lanka, Brazil, Colombia, Ghana, Australia, and other countries. These took a variety of forms. Some only coordinated planning while others established a joint mechanism to govern the basin. In a coordinated structure each party has its own institutions that coordinate some of their activities. In a joint structure the activities were carried out by a joint institution to which the parties delegated authority (Haddad et al. 1999).

Acknowledging the benefits of cooperative water management, it seems that the international community has often advocated a high intensity of cooperation in the form of joint management structure. For example, the 1997 Watercourse Convention establishes the general obligation to cooperate (Article 8), and the management required for cooperation (Article 24) called for the establishment of joint mechanisms or commissions. Similarly, the Berlin Rules call for the establishment of a joint management arrangement to ensure equitable and sustainable use of water (Article 64).

These water law principles were developed to create a more level playing field and offset local asymmetries. To some extent, this position comports with the international legal theory that states are equal under international law, and, because of that equality, they are supposed to cooperate and negotiate in good faith. By requiring states to recognize the equality of sovereigns, and by obligating them to cooperate and negotiate in good faith, international law ensures that weaker states are dealt with fairly and justly by their "bigger siblings."

The next section examines in detail three case studies in order to understand the applicability of these "ideal" principles to an asymmetrical setting and alternative principles that might replace them if these principles are not adopted.

Middle Eastern Water Agreements

Background on the Israeli-Arab Water Agreements

Most of Israel's water resources are transboundary. Israelis, Jordanians, and the Palestinians share the lower basin of the Jordan River (see fig. 5-1), whose main flow comes from tributaries located in Lebanon and Syria that discharge some 1,250 million cubic meters (MCM) annually (Soffer and Kliot 1988). These waters are used both as a potable water supply of the metropolis of Amman, through the King Abdullah Canal, and for the water supply in Israel, through the Israeli National Water Carrier, built in 1964. Israelis and the Palestinians also share the Mountain Aquifer, which supplies 672 MCM per year, according to the Oslo Interim Agreement. Israel uses nearly 80% of the water in this aquifer, and the Palestinians use the remainder (Trottier 1999). The Mountain Aquifer provides pristine water to both sides, although it is highly susceptible to pollution due to its karstic structure; thus, its management requires a high degree of cooperation (Haddad et al. 1999). Finally, there is the Coastal Aquifer, the southern tip of which underlies the Gaza Strip. Until the 2005 disengagement process, it provided water to both the Palestinian population and the Jewish settlements of the Strip. Today it is the only water source for the Palestinians in Gaza.

Despite the shared nature of the resources, both Israel and Jordan, in the 1950s, announced unilateral plans to develop the Jordan Basin. Israel planned the diversion of the northern Jordan River, through the construction of a carrier, to the Coastal Plain and Negev Desert (Naff and Matson 1984). Jordan opposed this out-of-basin water transfer and instead announced its intention to irrigate the Jordan Valley by channeling the Yarmouk River into the King Abdullah Channel, which is part of the same basin. As Israel started implementing its plan, a series of border clashes erupted between Israel and Syria; these clashes escalated to an armed conflict in 1953 (Wolf and Ross 1992). But even earlier the United States sent Eric Johnston as a special envoy to the region with the mission of reaching regional agreement between the riparian states on the division of the waters of the Jordan and Yarmouk Rivers. Johnston's 1951 proposal was rejected by all countries, as was his 1955 version. Within a decade, the tension over water, coupled with the regional border dispute, led to numerous political clashes over water between Israel and Jordan, some of which developed into significant military confrontations.

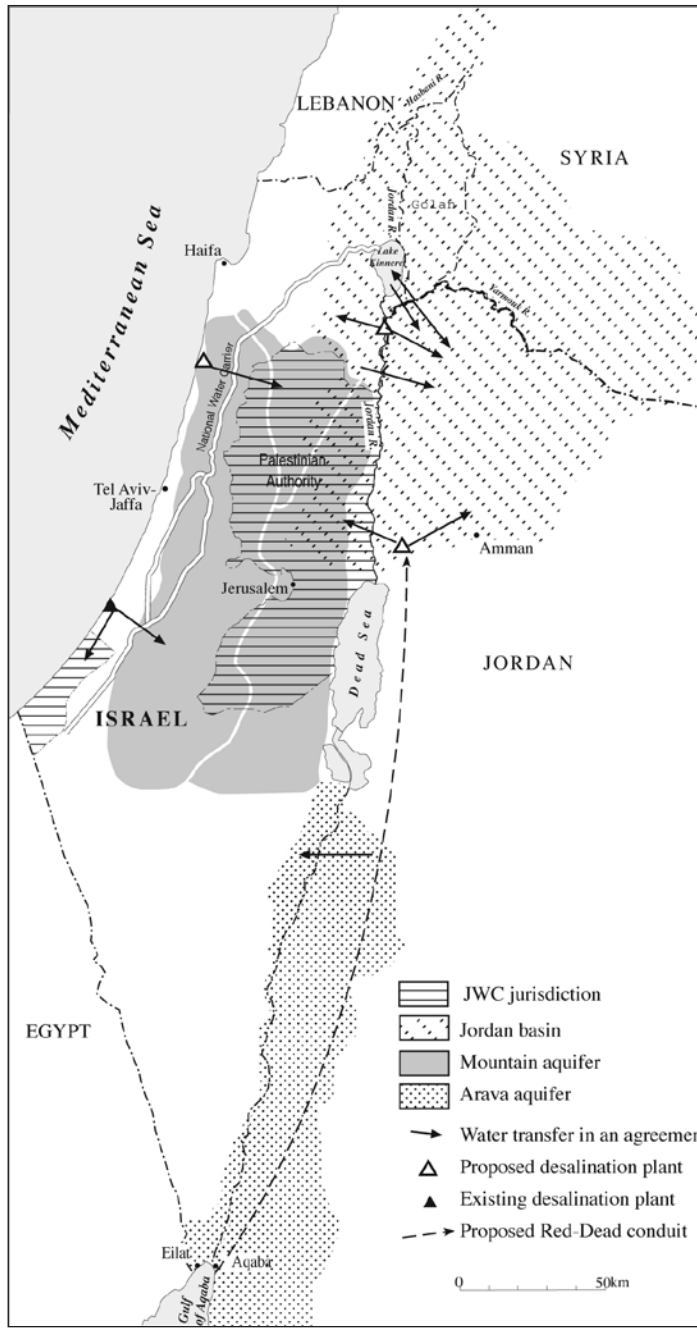

Figure 5-1. The geopolitical units in the Jordan River basin.
Source: Soffer and Kliot 1988.

After the Six-Day War of 1967 the geopolitical map of the Middle East changed dramatically. Apart from Israel's victory in terms of land and borders, it also gained water resources by acquiring two of the three Jordan River headwaters, as well as winning control over the Mountain Aquifer previously held by Jordan. Israeli military rule extended to all civilian affairs in the territory of the West Bank, including water (Tal 2002). This meant that drilling any well in the West Bank required an Israeli permit. Israel granted only 23 of these to Palestinians from 1967 to 1990 (Awartani 1992). In contrast, during the same period Israel exploited this water to address the growing political pressure of its agricultural sector. Israel has also gradually increased its use of the Yarmouk and during the 1970s and '1980s had plans to revive the Mediterranean Sea–Dead Sea Canal first visualized a century earlier by the Zionist movement (Varadi 1990).

While Israel was developing the resource, Jordan and Syria did not sit idly by. In the mid-1970s, as Jordan faced water shortages in its main cities of Amman and Irbid, it revived its plan to jointly build a large storage facility on the Yarmouk with Syria. The plan for a "Unity Dam" was again discussed by the two at the end of the 1980s and '90s, causing considerable tension in Israel, which initially opposed its construction (Hof 1995; Keinan 2005). As all freshwater use has reached the limits of its availability in Israel, the West Bank and Gaza Strip, and Jordan, tensions over scarce water have increased.

The Madrid peace conference in 1991 and the many negotiations that followed marked a turning point in water relations. In Madrid, two parallel negotiating tracks—the bilateral and multilateral—were established. The former referred to direct negotiations between Israel and each of its immediate Arab neighbors, with the exception of the Palestinians, who, at the time, were included in the Jordanian delegation at the insistence of Israel (Rubinstein 2004). The latter focused on key issues that concerned the entire Middle East and that might generate confidence-building measures (Peters 1996). Each track was divided into groups that included the water issue. While the work on both tracks was progressing, Israel and the Palestinians initiated a secret negotiating track outside the framework of the Madrid conference that resulted in the Oslo I Accord, signed in September 1993. That accord, which announced the establishment of a Palestinian interim authority, also noted the need for cooperation in the field of water. Subsequent to Oslo I, Israel and the Palestinian Liberation Organization (PLO)

in September 1995 signed the Oslo II Interim Agreement, in which article 40 of Annex III addressed issues of water and sewage.

The moment it became clear that Israel and the PLO were about to sign Oslo I, the bilateral talks between Israel and Jordan intensified. Water was the last and most contentious issue resolved in those negotiations, which came to an end with the signing of the Israeli-Jordanian peace treaty in October 1994; Annex II of the treaty pertains to the two countries' shared water.

The Israel-Jordanian agreement set in motion the plan to develop the Dead Sea area; both sides declared the Jordan Rift Valley a development zone and established the Trilateral Economic Committee and Jordan Rift Valley (JRV) Steering Committee. Finally, in April 2005, after 3 years of negotiations, a feasibility study was signed for the environmental and social assessment of the Red Sea–Dead Sea Water Conveyance study.

The next section examines briefly the negotiations over the language negotiated and adopted in each of the three agreements.

Negotiating International Language

The Israeli-Jordanian agreement

A Jordanian demand that Israel reorganize their respective water rights was raised in 1992 while both countries discussed the common agenda for the coming water negotiations. Water rights were important for Jordan, whose use of the Jordan River had been diminished by Israel's extensive use of that water (Haddadin 2001) and in light of the Palestinians obtaining reorganization of their own water rights in talks with Israel (Izraeli 2005). Water rights are based on several factors, such as hydrology, geography, and historical use and needs; the weight of each factor is not determined universally but rather based on the circumstances of each case. It was thus clear to Israel that setting the allocation on the basis of disputable algorithms would result in long-term disagreements (Shamir 2003). Even if the weight of each factor were agreed upon, Israel feared that Jordan's water needs in the future would change, which may result in a demand for adjustment (Sabel 2005). Finally, Israel was concerned that recognizing its water rights on the Yarmouk might allow its neighbor to raise counter-claims on the Jordan River, which Israel wished to leave as an exclusively Israeli water body (Izraeli 2005). Instead, Israel preferred a clear division of water based on a definition of the water source and location, quantities, qualities, and pricing (Shamir 2003). The disagreement was resolved by both sides putting forward the notion of securing

their respective "rightful water share," the meaning of which was left to be defined in the next phase of negotiation (Common Agenda 1993).

As the controversy over water rights continued, the technique of incorporating both sides' needs in the treaty language defused the deadlock. This occurred only when the formula of "rightful allocation" was introduced at the late stages of negotiations. "Rightful allocation" implies that the Jordanian rights are the allocation both sides agree upon (Rizner 2005). This term served to provide a psychological reference to "rights" that was important to Jordan while basing the allocations on what is specified in the agreement, which was important to Israel (Shamir 2003).

Next, there was a need to clarify the meaning of "rightful allocation" and to divide the water between the two states accordingly. Jordan's interpretation of its respected water rights was to receive from Israel 200 MCM per year of potable water from the Jordan River, half of it from the Sea of Galilee, also known as Lake Kinneret (Haddadin 2001), on the basis that the lake is an international watercourse where Jordan is a riparian (Rizner 2005). Israel, in contrast, argued that Jordan is not riparian to the lake itself (Katz-Oz 2005). Thus, Israel opposed including any reference in the treaty to the Jordan River as a "shared basin" (Sabel 2005) and insisted that the term "Lake Kinneret" not appear in the treaty language (Shamir 2005). As a result, although it was clear that the source of some of the water provided to Jordan is the lake itself, the lake's name was not mentioned in the treaty, nor was there any reference to the Jordan River as a shared basin. Instead, it stated that the source would be "from the Jordan River directly upstream from the Deganya gates on the river" while the meaning of "Jordan River" was deliberately left ambiguous (Sabel 2005).

Finally, there was a need to set the degree of cooperation and dependency required to execute the treaty provision. Israel was concerned that setting up a joint management structure in which both countries share and develop the basin resources might put the burden of droughts and funding new water resources on it, as it has more water alternatives (Rizner 2006). It was also concerned about any interpretation that might describe the treaty and its institutions as a symbol of Israel's control in the basin (Shatner 2005). Consequently, the Joint Water Committee (JWC) was set up to oversee the treaty implementation and established coordination mechanisms rather than a joint or a cooperative framework. These were restricted to cooperation in developing plans for purposes of increasing water supplies and

improving water use efficiency within the context of bilateral, regional, or international cooperation.

Figure 5-2 presents the language employed by both sides and how the differences in jargon were reconciled in the negotiation process.

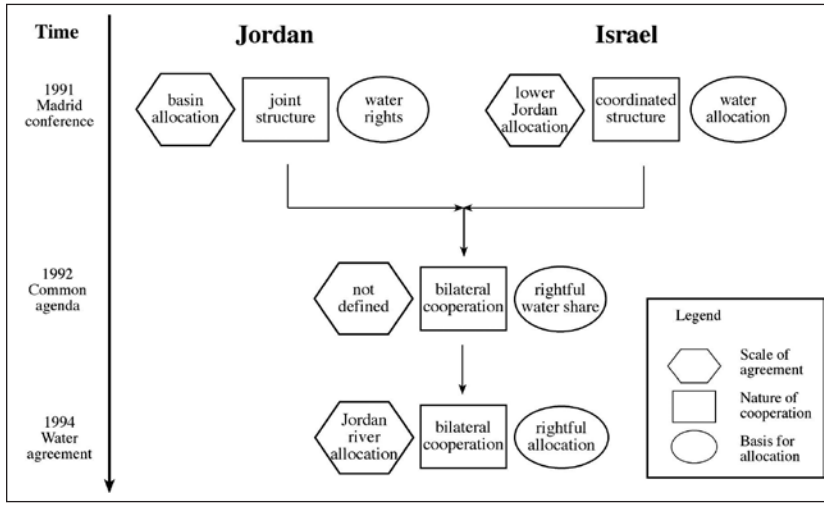

Figure 5-2. Language evolution in the Israeli-Jordanian negotiations.

The Israeli-Palestinian agreement

While Jordan consented to discussing "allocations," the Palestinians insisted on the division of water based on water rights (Shamir 1998). As a result, when the multilateral water group met in Geneva just after the Madrid conference to discuss regional water issues, the Palestinians insisted that their water rights be negotiated; in response, Israel argued that this was a political topic that was outside the multilateral and technical scope of the discussion (Izraeli 2005). Instead, Israel suggested that until this issue was discussed during the permanent negotiations phase, both sides should adopt a "pragmatic approach" of dividing the water according to the future needs of the Palestinians (Kantor 2005). The Palestinians refused to discuss water needs independently of water rights and left the multilateral water group until this issue returned to the agenda (Haddad 2004).

The Israeli objection to discussing Palestinian water rights based on the "reasonable and equitable" criteria originates with the fear that this term was not quantifiable (Kinarti 2006), and thus may build great expectations

on the Palestinian side (Rizner 2005). Israel was further concerned about water rights providing the Palestinians fixed entitlement to water even during a regional drought (Kantor 2005). The Palestinians, on the other hand, opted for water rights as leverage for land rights (Haddad 2004).

Another point of disagreement was the Palestinians' wish that the agreement include "joint" management over the entire basin and a reference to them as riparian to the Dead Sea (Sabel 2005). For the Palestinians, terminology commonly used in international law was assumed to assure them the support of the international community (Attili 2006). Furthermore, attaining a joint basin-wide agreement and even a joint water utility might have provided the Palestinians with the power to reallocate existing water uses, which were dominated by Israel outside the West Bank (Attili 2004). Thus, not surprisingly, Israel opposed such terminology and opted for a coordinated management structure over the West Bank that would better reflect the existing status quo. Yet, it also suggested augmenting the Palestinians' water supply through a desalinization plant on the Israeli coast at Hadera (Katz-Oz 2005).

A breakthrough for the Palestinians occurred when Abraham Katz-Oz, the head of the Israeli negotiation team in the multilateral talks, agreed to acknowledge the Palestinians' water rights on an equitable basis as well as their affinity to the Dead Sea. Once this was accepted there was no return and these issues were included in the Declaration of Principles (DOP) on the interim self-governance arrangements signed in Washington on September 13, 1993 (Annex III, Article 1). Yet many of the Israeli negotiators who were against acknowledging the Palestinians' water rights decided on a strategy of postponing the clarification of the meaning of "equitable water rights" to the permanent status negotiations. In the meantime, the Israeli strategy was to continue to advance water allocation based on the pragmatic approach (Kinarti 2006).

Next, in 1994 the Cairo Agreement was signed, Annex II (Article II) of which touched on shared water in the Gaza Strip. The agreement announced that a subcommittee would deal with water issues of mutual interest while its scope and scale were restricted, allowing the water sovereignty of each side to be maintained. The Cairo Agreement was followed by intensified negotiations that led, a year later, to the Taba Agreement, often called Oslo II, Article 40 of which addressed water and sewage. The clash between allocation based on rights versus allocation based on pragmatism was resolved in

the negotiations only when a third approach was adopted: negotiating the Palestinians' interim water needs on the basis of population patterns and irrigation needs. Once the allocation was agreed, the Palestinian allotment was to be presented in the negotiated agreement as water rights based on reasonable and equitable criteria, again without clarifying what "reasonable and equitable" actually meant (Rizner 2005).

At Israel's insistence the scale of the agreement was restricted to the West Bank rather than the entire basin (see fig. 5-1). Narrowing the scale prevented the Palestinians from gaining control of the major water source of Israel, located on the western fringe of the Mountain Aquifer outside the West Bank zone. To ensure that the agreement would not affect the Kinneret or the Jordan River, Israel made sure that it did not recognize the Palestinians as riparian to the Jordan basin; the agreement did not even mention this water resource (Rizner 2005). Instead, it said that "various" water resources would be negotiated in the permanent status negotiations, without clarifying the meaning of "various."

Finally, to address the Israeli demand, a coordinating mechanism was set up to administer the agreement, with decisions made on a veto basis. Coordination should be understood in this context as an alternative to joint management. "Joint" would suggest ownership and "management" of a resource versus coordination, which indicates that each side is sovereign in its domain but agrees that certain matters can be managed together. The only shared structure was the establishment of an enforcement arm

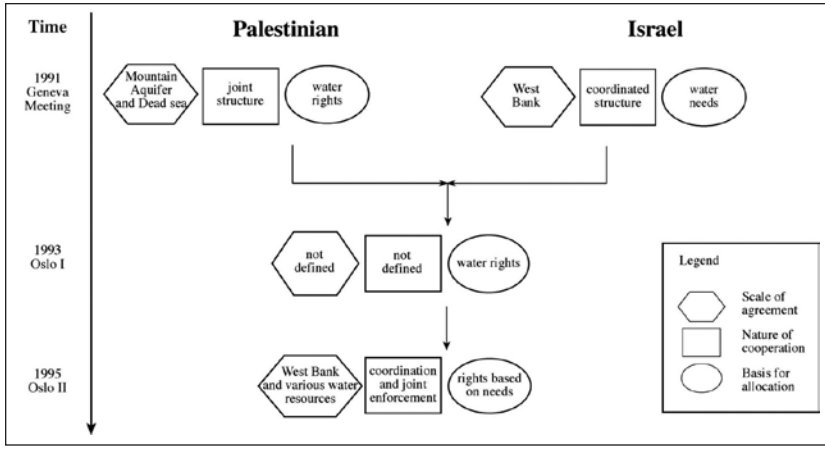

Figure 5-3. Language evolution in Israeli-Palestinian negotiations.

of the JWC, termed Joint Supervision and Enforcement Team (JSET). The assumption was that a joint structure for enforcement would be inevitable since this would be the only way to prevent disagreements.

Figure 5-3 presents the language advanced by both sides and how the differences in terms were reconciled in the negotiation process.

The Israeli-Palestinian-Jordanian agreement

Following a request by Jordan at the beginning of 2002, a World Bank Technical Assistance Mission visited the Hashemite Kingdom. The purpose of the visit was to assess the support of both Israel and Jordan for the Red Sea–Dead Sea Canal with the aim of saving the Dead Sea and providing desalinated freshwater to the region and especially to Amman (Red Sea–Dead Sea 2002a). The two countries agreed to establish a small joint steering committee that included the World Bank and that would prepare the Terms of Reference (TOR) required for the project (Red Sea–Dead Sea 2002b). Several months later, the principles for the TOR were submitted for acceptance by the Israeli Ministry of Regional Cooperation. The draft called for joint examination of the project by the two governments with the involvement of the World Bank, USAID, and/or the U.S. State Department. Both Jordan and Israel preferred a route entirely in Jordan. This would exclude some of the Israeli pressure groups that might oppose the project and would make it eligible for World Bank funding that only developing countries can receive (Benvenisti and Gvirtzman 1993). Yet the early draft addressed neither the scale of the examination nor the number of alternative routes to be examined (Israeli Government 2002). Following the early draft, the need to further advance the project was boosted by the Johannesburg World Summit on Sustainable Development and the Third Water Forum in Kyoto, both of which stressed the vision of saving the Dead Sea through the "peace conduit" (Johannesburg Summit 2002).

A year later, a more mature draft was issued by the World Bank. Following the Bank's insistence, the draft now included the Palestinians as riparians in the agreement along with Israel and Jordan (Blitz 2006). It also paved the way for an examination of the water resources of the entire Jordan basin and for establishing regional joint institutions to govern the TOR (Red Sea–Dead Sea 2003a). Finally, it acknowledged the need for consultation with the public and implicitly the entitlement of all basin parties (including the Palestinians) to water and land rights in the basin.

Broadening both the scale and scope of investigation raised strong objection on behalf of Israel, while the Palestinians insisted on these changes (Red Sea–Dead Sea Water Conveyance Project 2003b). For the Palestinians, an agreement that touched on water and land issues in the entire basin, with reference to international law, was assumed to provide them with leverage for obtaining their "reasonable and equitable" water and land share in the permanent status negotiations with Israel (Attili 2006). In contrast, for Israel such an agreement might prejudge the results of the permanent status talks with the Palestinians and might infringe on its sovereignty and water and land resources, including Lake Kinneret and the Dead Sea (Keidar 2005; Blitz 2006). Instead, Israel suggested that the Palestinians' participation be examined at a later stage, in accordance with the progress on the final negotiations and to decouple the TOR from the regional water use, the peace process, and the upper basin riparians (Alaster 2006).

Despite pressure from both Jordan and the World Bank to accept the early draft (Bein 2006), Israel's strong objection to the 2003 draft resulted in a revised draft published by the World Bank (Red Sea–Dead Sea 2004). The new version of the TOR excluded much of the customary law language found in the previous draft, including any reference to Lebanon and Syria as upper riparians, the option for a joint management structure governed by a regional institution, and the status of the Palestinians as riparians. Instead, the TOR included a statement that the agreement will not prejudice the riparian rights of any of the parties, that the nature of cooperation remains to be studied, and that the parties status would change from riparians to "beneficiary party" (Red Sea–Dead Sea 2004). The "beneficiary" language adopted satisfied the Israeli demand for the passive status of the Palestinians (Alaster 2006; Yinon 2006) while the term "party" addressed the Palestinians' needs for recognition as equal parties to the agreement (Attili 2006). The statement also addressed the Palestinians' wish that the agreement not infringe on the rights of Syria and Lebanon, which were not involved in the negotiations, while for Israel it enabled decoupling of the agreement from the final negotiations.

However, despite the many compromises reached in the 2004 TOR version, Israel still objected to it. Israel wished to modify the objective of the study from saving the Dead Sea to a technical study that focuses on examining only the convenience route preferable to Jordan and Israel (Blitz 2006). Reframing the objectives of the agreement would have lowered the

importance of an investigation into the management of the water uses in the entire basin, an issue that was problematic for both Jordan and Israel (Alaster 2006). However, the World Bank continued to insist on the need to see the TOR in a wider regional context that includes the peace and water management of the entire basin (Yinon 2006).

The breakthrough in the negotiations came just after the Israeli disengagement from Gaza in 2005 and with the help of some more creative drafting (Yinon 2006). In the fourth draft of the agreement, the basin water study was replaced by policy statements each country issued on water resources management indicating that the nature of cooperation was to be studied rather than pointing toward joint management (Red Sea–Dead Sea 2005). Finally, the objectives of the study were framed to take on the semblance of a technical agreement, as requested by Jordan and Israel. This affected the parties involved in the negotiations on the Israeli side: the professional environmental community that headed the negotiations was replaced by the Israeli Water Commission team that now also addressed the political realities of negotiations in a conflict area. Politicizing the negotiation process further excluded from the negotiation process the examination of other alternatives for the conveyance. Finally, in April 2005, the

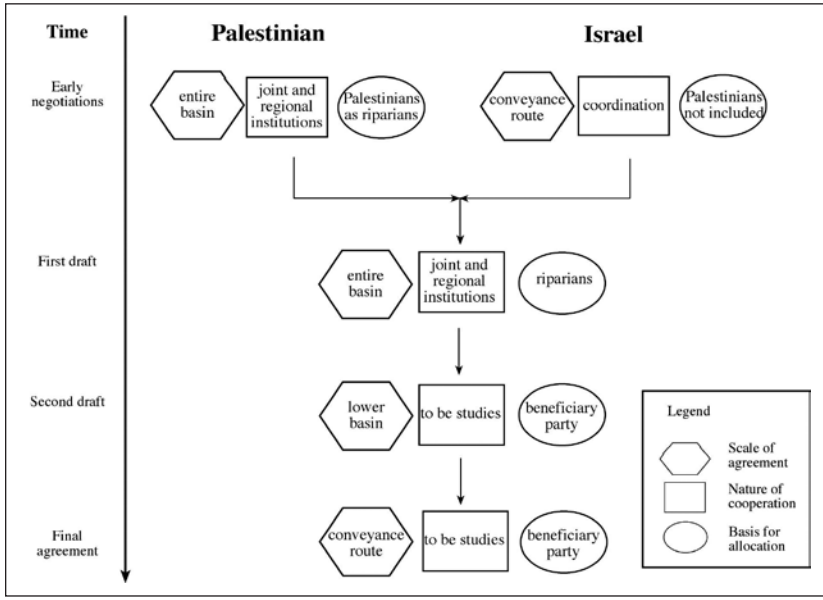

Figure 5-4. Language evolution in the Red–Dead negotiations.

three beneficiaries signed an agreement to launch a feasibility study for the environmental and social assessment for the Red Sea–Dead Sea Water Conveyance study.

Figure 5-4 presents the language advanced by both the Palestinians and the Israelis and shows how the differences in language were reconciled in the negotiation process.

Creative Language to Circumvent Political Realities

Water problems are often characterized as "wicked" problems that face multiple and conflicting interests over the use of integrated natural systems such as an aquifer or a watershed (Scholz and Stiftel 2005). To solve these problems in an equitable and optimal manner, certain principles of international water law call for a higher degree of physical and institutional integration, often at a basin-wide scale, and a clearer definition of water rights. These principles presuppose the easing of existing power asymmetries between parties and prevent unilateral development activities that ignore the rights of other basin riparians (Molle et al. 2006).

In our case study, by requiring Israel to allocate water according to clearly defined Palestinian water rights, all riparian water rights are recognized, regardless of their relative economic, military, or other power. That recognition, theoretically, would prevent a more powerful state from unilaterally negating or diminishing the water rights of a weaker riparian. Similarly, by requiring a multilateral approach (e.g., joint management) to the administration of the Jordan Basin and the Mountain Aquifer by all basin riparians, the objectives and designs of the more powerful state would be subject to the full cooperation of the weaker riparian.

Against this assumption, it seems that real-life experience often deviates from the ideal legal structures. For example, Kliot and Shmueli (2001), while analyzing nine major river basins, found that in only a minority of them a high level of cooperation in the form of joint management is gained and only a minority of the multipartite basins has multilateral organizations in place (Dombrowsky 2005). When it comes to adopting water rights the situation is not different. In many of the disputes that have been resolved, particularly on arid or exotic streams, the paradigms used for negotiations have not been "rights-based" at all—neither on relative hydrography nor specifically on chronology of use but rather "needs-based" (such as the case

of Egypt and Sudan in their Nile River agreement from 1929 and 1959). In the case of basin-wide approaches it seems that there is a gap between real and ideal legal principles. For example, in 1970 when the United Nations considered the Helsinki Rules, according to Biswas (1999), some states objected to the prominence of the drainage basin approach, which can be interpreted as an infringement on a nation's sovereignty.

The present study argues that it is unrealistic to expect a powerful riparian (in our case study, Israel) to relinquish its power advantage by accepting these three water principles, especially when the nature of the water dispute extends beyond water. Thus, a more traditional "bottom-up" approach is employed to adopt "creative terminology" as a means for circumventing the volatility inherent in these principles.

Both the negotiation over the legal terminology and the language adopted were found in themselves to be a manifestation of the power struggle and asymmetries between Israel and its neighbors. It was the weak riparians—the Jordanians and the Palestinians—that, in order to change the power balance and enhance their access to land and water resources, endorsed the language of international law, that is, calling for joint basin-wide management based upon water rights, while Israel sought alternative terminology that would uphold the status quo. This explains why drafting the water treaties was found to be a complex, lengthy, and often contradictory process, and one associated with high transaction costs. It also explains why the legal language that was finally adopted is rather ambiguous as ambiguity enabled virtual consent, which in turn allowed each side to assume that its own language dominates the treaty.

Much of the deadlock was resolved only when the parties moved from their adversarial positions to address the interests behind the positions, where a compromise was forged that captures elements of international law while still addressing the needs of the stronger riparian. For example, the adoption of rightful allocation terminology in the case of Israel and Jordan, and rights based on needs in the case of Israel and the Palestinians. The "rights" terminology came to satisfy the Jordanians or the Palestinians, while the "allocation" or the "needs" terminology came to address the Israeli needs. The Red–Dead talks also exposed an integrative stage of negotiation during which the parties started to add benefits to the agreements. This is the "beneficiary party" definition, which helped bypass any allocation and recognition based upon water "rights."

This evolution of water conflict negotiation under asymmetrical conditions explains why the language adopted deviated from the recommended international legal norms while still managing to address the needs of the weak riparian. The result was often in adopting only minimal and vague definitions that capture the spirit of international law principles but also allowing the freedom to tailor the agreements to the specific asymmetries of these case studies. Yet, it seems that while Israel was willing to compromise on the rights issue and the nature of cooperation, on the spatial scale the treaty's language still reflects its power inequities. In fact, in all three agreements the mandate of the regime does not go beyond parts of the basin that may endanger Israeli sovereignty and water and land control.

The Weakness of Creative Language

Although the study's aim is not to identify the ramifications of following these non-traditional language alternatives, attention should be paid to the long-term implications of the language adopted—especially given its abundant ambiguity and repeated failure to change the water status quo. In the case of the Israeli-Jordanian water agreement, this "creative ambiguity" was already found to be destructive, as both sides found it difficult to clarify under conflict (Fischhendler 2008). In the case of Israel-Palestinian agreement, due to the language adopted, some do not even consider their allocations under the interim agreement to reflect their water rights as based on reasonable and equitable criteria (Attili 2006). Some international scholars have also criticized many of the institutional components of the Israeli-Palestinian agreement as dressing up domination as "co-operation" (Selby 2003) or as an imposed-order regime that benefits the Israeli side at the expense of Palestinian water (Zeitoun 2007). Consequently, the Palestinians have stated that in the final negotiations they must not repeat the language mistakes made in the Oslo agreement (Husseni 2006). As a result, the 2000 water agreement draft agreed at Camp David (that was to replace the Oslo agreement) included more explicit language of international law, as it contains both references to "equitable and reasonable" and water rights language (Sher 2006). This entails the risk behind the use of such creative language in that it is still adopted in order to allow the more powerful state to cajole, or even force, the weaker state into submission. At the very least, by using its position of power, the

more powerful party can protect the status quo, which typically favors the stronger party.

Also in the case of the Red–Dead negotiations, many international and Israeli NGOs are dissatisfied with the exclusion of the entire basin, or at least the lower basin, from the feasibility study. As a result, many of these NGOs refer to the negative environmental externalities and inferior economic solutions that are adopted with the nonbasin approach (Bein 2011; Gavrieli et al. 2002).

Conclusion

Negotiations in conflict areas over water resources are often conducted between unequal partners, with each bringing to the negotiation table considerations that go beyond water (Lowi 1993). These conditions can often create conflicting patterns of interests such that under conflict conditions a basically nonpolitical issue, such as water allocation, can become politicized. These conditions, in addition to stochastic power asymmetry, were often found to impede cooperation in many environmental and especially water problems (UNEP 2006). This suggests that the Israeli-Palestinian-Jordanian case is not exceptional. A more realistic language that better reflects the political and power asymmetries but still acknowledges the importance of the existing rules of customary law turns the Middle Eastern example to a possible option for other regions facing water disputes.

This linguistic compromises forged are based on the fact that all players had specific objectives in entering into negotiations and that a failure to reach an accord would result in harm to both parties. This was clearly the case regarding the Dead Sea water conduit since such an agreement upon development would provide benefits to all parties.

While the solutions crafted by the parties have not been adopted by other states or regions, they constitute examples of creative decision making that might someday be adopted elsewhere under similar asymmetrical conditions. Ultimately, the Middle Eastern water experience teaches us that despite attempts to establish a "top-down" approach for the development of international water law for facilitating the drafting of water treaties, a broader approach that acknowledges the volatility, unique characteristics, and asymmetries inherent in these situations must be adopted. Otherwise the result may be no agreement at all. Yet, this study also highlights that

the negotiations do not occur in a vacuum but against the backdrop of asymmetrical power balance. This implies that the hegemonic state often is the one that set the tune in how the creative language would looks like.

Acknowledging the political realties in crafting legal language for agreements still leaves us asking who typically comes up with the alternative mechanism or alternative principle—the stronger or the weaker state? It can be argued that the weaker state has an incentive to be creative in its relations with its more powerful neighbor; however, we can also could argue that, because of its stature, the more powerful state is in a better position to formulate and suggest alternatives. The second explanation might fit with the conclusions of this paper, namely that Israel, as the hegemonic riparian, sought alternative terminology as a means of circumventing the Jordanian and Palestinian endorsement of traditional international law concepts.

At the same time, recognizing the importance of creative terminology implies that skillful negotiators and implementers able to exploit openings crafted by ambiguous language are assets that weaker parties need to cultivate.

References

Alaerts, G. J. 2003. Institutions for River Basin Management: A Synthesis of Lessons in Developing Cooperative Arrangements. In *Integrated Water Management at River Basin Level*, eds. G. Alaerts and G. Le Moigne. Washington D.C.: World Bank.

Alaster, Y. 2006. Legal Advisor for the Water Commissioner. Interview from February 13.

Attili, S. 2004. *Israel and Palestine: Legal and Policy Aspects of the Current and Future Joint Management of the Shared Water Resources*. Ramallah: The Negotiation Support Unit. Available online: www.nad-plo.org/nego/permanent/water/related/Shared%20water.pdf.

———. 2006. Palestinian Liberation Organization, Negotiation Support Unit. Interview from February 20.

Awartani, H. 1992. *Artesian Wells in Palestine, Present Status and Future Aspirations*. Jerusalem: Palestinian Hydrology Group.

Bein, A. 2006. Head of the Israeli Geological Survey for the years 1990–1995 and 2000–2005. Interview from February 13.

Bein, A., ed. 2011. *Altering the Water Balance as a Means to Addressing the Problems of the Dead Sea*. Jerusalem: The Jerusalem Institute for Israel Studies.

Benvenisti, E., and H. Gvirtzman. 1993. Harnessing International Law to Determine Israeli-Palestinian Water Rights: The Mountain Aquifer. *Natural Resources Journal* 33: 543–567.

———. 2006. Economic Advisor for the Minister of Finance for the years 1993–98. Jerusalem. Interview from February 11.

Berlin Rules. 2004. *The Berlin Rules on Water Resources*. International Law Association Berlin Conference, Water Resources Law. Available online: www.asil.org/ilib/WaterReport2004.pdf.

Biswas, A. K. 1999. Management of International Waters. *Water Resources Development* 15: 429–41.

Blitz, N. 2006. Head of Water Supply Department, The Water Commission. Interview from January 1.

Common Agenda. 1993. *The Middle East Peace Process, the Bilateral Peace Negotiations*. *Common Agenda*. Washington, D.C.: Embassy of Israel.

Conca, K., F. Wu, and C. Mei. 2006. Global Regime Formation or Complex Institution Building? The Principled Content of International River Agreements. *International Studies Quarterly* 50(2): 263–285.

Dellapenna, J. W. 2006. *Equitable Participation and the New Paradigm for International Water Law: The Key to Governance of the Global Water System*. Paper presented at the International Workshop on Governance and the Global Water System. Bonn, Germany, June 20–23.

Dombrowsky, I. 2005. Conflict, Cooperation and Institutions in International Water Management PhD dissertation 102(2005).

Fischhendler, I., 2008. When Ambiguity in Treaty Design Becomes Destructive: A Study of Transboundary Water. *Global Environmental Politics* 8(1): 115–140.

Gavrieli I., N. Lensky, N. Gazit-Yaari, and O. Aharon. 2002. *The Impact of the Proposed "Peace Conduit" on the Dead Sea* (Report GSI/23/2002), Geological Survey of Israel (GSI).

Haddad, M. 2004. *Politics and Water Management: A Palestinian Perspective*. Paper presented at the 2nd Israeli Palestinian International Conference. Turkey, October 10–14. Available online: www.ipcri.org/watconf/papers/marwan.pdf.

Haddad, M., E. Feitelson, S. Arlosoroff, and T. Nasseredin. 1999. *Joint Management of Shared Aquifers: An Implementation-Oriented Agenda (Final Report*

of Phase II). Jerusalem: The Harry S. Truman Research Institute for the Advancement of Peace and The Palestine Consultancy Group.

Haddadin, M. 2001. *Diplomacy on the Jordan: International Conflict and Negotiated Resolution*. Boston, Dordrecht and London: Kluwer Academic Publishers.

Hayton, R. D. and A. E. Utton. 1989. Transboundary groundwaters: The Bellagio Draft Treaty. *Natural Resources Journal* 29: 663–722.

Helsinki Rules. 1966. *The Helsinki Rules on the Uses of the Waters of International Rivers*. Report of the Committee on the Uses of the Waters of International Rivers. London: International Law Association. Available online: http://internationalwaterlaw.org/intldocs/helsinki_rules.html.

Hof, F. C. 1995. The Yarmouk and Jordan Rivers in the Israel-Jordan Peace Treaty. *Middle East Policy* 3(4): 47–56.

Husseni, H. 2006. Legal Advisor to the Palestinian Negotiation Team. Interview from March 12.

Israeli Government. 2002. The Ministry of Regional Cooperation. *Proposal: Principles for Terms of Reference (TOR): The Red Sea–Dead Sea "Peace Conduit" Project: Israel-Jordan.* World Bank. June 2.

Izraeli, M. 2005. Consultant to the Israeli Water Commissioner. Interview from January 3.

Johannesburg Summit 2002. *Jordan and Israel Announce Project to Save Dead Sea.* Available online: http://www.un.org/jsummit/html/whats_new/feature_story33.htm.

Kantor, S. 2005. Member of the Israeli Negotiation Team in the Israel-Jordan Peace Talks. Interview from July 31.

Katz-Oz, A. 2005. Member of the Israeli Negotiation Team in the Israel-Jordan Peace Talks. Interview from July 11.

Keidar, Y. 2005. Israel Multilateral Peace Talks Coordinator. Interview from June 25.

Keinan, E. 2005. Israel Ministry of Foreign Affairs, Deputy Director General and Legal Advisor. Interview from June 26.

Kinarti, N. 2006. Advisor for the Minister of Regional Cooperation and the Galilee. Interview from February 7.

Kliot, N., and D. Shmueli. 2001. Development of institutional frameworks for the Management of Transboundary Water Resources. *International Journal of Global Environmental Issues* 1(3–4): 306–328.

Lowi, M. 1993. *Water and Power, the Politics of A scarce Resource in the Jordan River Basin*. Cambridge: Cambridge University Press.

McCaffrey, S. C. 2001. *The Law of International Watercourses: Non-Navigational Uses*. Oxford, UK: Oxford University Press.

Molle, F. 2004. Defining Water Rights: By Prescription or Negotiation? *Water Policy* 6: 207–227.

Molle, F., P. Wester, and P. Hirsch. 2006. River Basin Development and Management. In D. Moden, ed., *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Chap. 17. London: Earthscan.

Naff, T., and R. Matson. 1984. *Water in the Middle East: Conflict or Cooperation?* Boulder: Westview Press.

Peters, J. 1996. *Pathway to Peace: the Multilateral Arab-Israeli Peace Talks*. London: The Royal Institute of International Affairs.

Pradhan, R., and R. Meinzen-Dick. 2001. *Which Rights Are Right? Water Rights, Culture and Underlying Values*. Paper presented at the meeting on water Resources, Human Rights and Governance. Kathmandu, Nepal, 26 February–2 March.

Red Sea–Dead Sea. 2002a. Red Sea–Dead Sea Water Conveyance Project. Ministry of Water and Irrigation/Jordan Valley Authority, Jordan and Ministry of Regional Cooperation, Israel: Summary of Discussion. April 18.

———. 2002b. The Red Sea–Dead Sea Water Conveyance Project. Hashemite Kingdom of Jordan, World Bank Technical Assistance Mission: Aide Memoire. April 8–23.

———. 2003a. The Red Sea–Dead Sea Water Conveyance Project. *Feasibility Study and Environmental and Social Assessment. Draft Terms of Reference and Annotated Comments:* Second Draft. October 7.

———. 2003b. The Red Sea–Dead Sea Water Conveyance Project. *Israel and Palestinian Comments:* First Draft.

———. 2004. The Red Sea–Dead Sea Water Conveyance Project. *Feasibility Study and Environmental and Social Assessment: Terms of Reference*. Third Draft. May.

———. 2005. The Red Sea–Dead Sea Water Conveyance Project. *Feasibility Study: Environmental, Technical and Economic and Environmental and Social Assessment, Terms of Reference*. April 19.

Rizner, D. 2005. Legal Advisor of the Israeli Negotiation Team in the Israel-Jordan Peace Talks. Interview from September 1.

———. 2006. Legal Advisor of the Israeli Negotiation Team in the Israel-Jordan Peace Talks. Interview from February 20.

Rubinstein. E. 2004. The Peace between Israel and Jordanian. In J. Nevo, ed., *Neighbors Caught in a Maze: Israel-Jordan Relations before and after the Peace Treaty*. 135–169. Tel Aviv: The Yitzhak Rabin Center for Israel Studies.

Sabel, R. 2005. Legal Advisor of the Foreign Ministry for Water Talks. Interview from May 14.

Scholz, J. T., and B. Stiftel, eds. 2005. Adaptive Governance and Water Conflict: New Institutions for Collaborative Planning. Washington, DC: RFF Press.

Selby, J. 2003. Dressing Up Domination as "Co-operation": The Case of Israeli-Palestinian Water Relations. *Review of International Studies* 29(1): 121–138.

Seoul Rules. 1986. *The Seoul Rules on International Groundwaters*. Adopted by the International Law Association at the Sixty-Second Conference Held at Seoul in 1986. Available online: http://internationalwaterlaw.org/intldocs/seoul_rules.html.

Shamir, U. 1998. Water Agreement between Israel and Its Neighbors. In J. Albert, M. Bernhardsson, and R. Kenna, eds., *Transformation of Middle Eastern Natural Environments*: *Legacies and Lessons*. 274–296. New Heaven, CT: Yale University.

——— U. 2003. The Negotiations and the Water Agreements between the Hashemite Kingdom of Jordan and the State of Israel. In M. J. Haddadin and U. Shamir, eds, *Jordan Case Study*. Paris: UNESCO-IHP.

———. Shamir, U. 2005. Member of the Israeli Negotiation Team in the Israel-Jordan Peace Talks. Telephone Interview from May 31.

Shatner, D. 2005. Member of the Israeli Negotiation Team in the Israel-Jordan Peace Talks. Interview from August 15.

Sher, G. 2006. *The Israeli-Palestinian peace negociation 1999–2001 within Reach*. London: Routledge.

Soffer, A., and N. Kliot. 1988. *Regional Water Projects in the Middle East*. Haifa: University of Haifa.

Solanes, M. 2001. Water Rights: Functions, Conditionalities, Administration. In E. Feitelson and M. Haddad, eds., *Management of Shared Groundwater Resources: The Israeli-Palestinian Case with an International Perspective*. Chap. 13. London: IDRC/Kluwer Academic.

Sneddon, C., and C. Fox. 2006. Rethinking Transboundary Waters: A Critical Hydropolitics of the Mekong Basin, *Political Geography* 25(2): 181–202.

Tal, A. 2002. *Pollution in a Promised Land: an Environmental History of Israel*. Berkeley: University of California Press.

Teclaff, L. A. 1996. Evolution of the River Basin Concept in National and International Water Law. *Natural Resources Journal* 36 (Spring): 359–391.

Trottier, J. 1999. *Hydropolitics in the West Bank and Gaza Strip.* Jerusalem: PASSIA.

UNEP. 2006. *Human Development Report. Beyond Scarcity: Power, Poverty, and the Global Water Crisis.* Basingstoke: Palgrave Macmillan, for United Nations Development Program.

Varadi, V. 1990. Historical Review. In V. Varadi and B. Beyth, eds., *Mediterranean-Dead Sea Project Bibliography.* Geological Survey of Israel Report GSI 9/90.

Wolf, A. T., and J. Ross. 1992. The Impact of Scarce Water Resources on the Arab-Israeli Conflict. *Natural Resources Journal* 32: 919–958.

Yinon, D. 2006. Legal Advisor for the Minster of Infrastructure. Interview from February 13.

Zeitoun, M. 2007. The Conflict vs. Cooperation Paradox: Fighting Over or Sharing of Palestinian-Israeli Groundwater? *Water International* 32(1): 105–120.

6

The Outlook for Food Security in the Middle East and North Africa

Dr. Mahmoud Solh

Director General, International Center for Agricultural Research in the Dry Areas (ICARDA)

Abstract

Soaring food prices have triggered worldwide concern about threats to global food security. The Middle East and North Africa (MENA) region is the most food import–dependent region in the world, and net food imports are projected to rise even further in the future. Thus the MENA region is particularly vulnerable to disruptions in global grain supplies and prices. Increasing resource constraints, growing environmental pressures, and the impacts of climate change exacerbate the problem. With farmland area expected to expand only slightly in the coming decade, future increases in production must come from increases in productivity per unit of water and land and by reducing existing productivity gaps. Actual farm yields of crops in the MENA region are far below their potential.

The paper examines the case of wheat, the staple food in the MENA region, accounting for some 37% of total food supply. The region imports almost half its wheat needs at an increasing cost. The analysis shows that, although there are regional differences in the potential of different agro-ecologies, crop yields can be increased by the promotion and adoption of existing, "on-the-shelf" technologies available with national and international research institutes. It is clear that the full potential of rainfed farming has not been exploited as yet. However, technological change does not translate into increased production until it is widely adopted by farmers. These gains in production will be achieved only if action is taken now to develop, adapt, and promote improved technologies that incorporate soil moisture conservation, supplemental irrigation, improved soil nutrient management,

high-yielding improved varieties, and integrated pest and disease management, coupled with more suitable policy environments and institutional support to encourage the adoption of the new technologies by farmers.

Global Context

Soaring food prices have triggered worldwide concern about threats to global food security. Up until 2006, the cost of the global food basket had fallen by almost a half. By mid-2008, international food prices had skyrocketed to their highest level in 30 years. This, coupled with the global economic downturn, pushed millions more people into poverty and hunger. From July to September 2010, wheat prices surged by 60 to 80% in response to droughts and crop losses in major grain-producing countries. Rice and maize prices also rose during that period. In December 2010, the FAO Food Price Index rose above its 2008 peak. The index dropped to an 11-month low in October 2011, but food prices still remain very volatile.

The United States is currently in the midst of a severe drought, its worst in 50 years. Half of all U.S. counties have been declared disaster areas, and the international prices of maize and soybeans have risen beyond the 2007–2008 peaks. The FAO Food Price Index, which measures the monthly change in the international prices of a basket of food commodities, climbed 6% in July 2012 after 3 months of decline, mostly driven by a surge in grain and sugar prices. International wheat quotations have surged by 19% amid worsened production prospects in Russia, Kazakhstan, and Ukraine—a region that accounts for nearly a quarter of global wheat exports—and expectations of increased demand for wheat for feed because of the shortage of maize supplies. Iran's wheat harvest was also affected by a severe drought. If the region's wheat harvest is further impacted, export controls may be imposed. Thus, the Middle East and North Africa—the world's biggest cereal importers—remain vulnerable to rising wheat prices (Bänziger, 2012; FAO, 2012).

High food prices pose a major threat to food security. The impact of high prices hits the poor hardest, as they spend a higher percentage of their income on food. But the crisis also raised the specter for import-dependent countries that, whatever the price, sufficient food may not be available on the international markets to satisfy their demands. The latest OECD-FAO Agricultural Outlook (OECD 2012) anticipates that agricultural output

growth will slow to an average of 1.7% annually over the next 10 years, down from a trend rate of over 2% per year in recent decades. Higher input costs, increasing resource constraints, growing environmental pressures, and the impacts of climate change will serve to dampen supply response. With farmland area expected to expand only slightly in the coming decade, additional production will need to come from increased productivity, including by reducing productivity gaps in developing countries.

The MENA Region

The increase in food prices had a major impact on the Middle East and North Africa since it is the largest food-deficit region in the world, with grain imports of about 65 million tons in 2010. In this paper, the Middle East and North Africa (MENA) region includes Algeria, Egypt, Libya, Morocco, Sudan and Tunisia in northern Africa, and Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, the United Arab Emirates, and Yemen in the Middle East (fig. 6-1).

The MENA region is the most water-scarce region in the world (fig. 6-2). Extraction rates are mostly unsustainable, and groundwater levels continue to fall. Most countries in the region will drop below the internationally

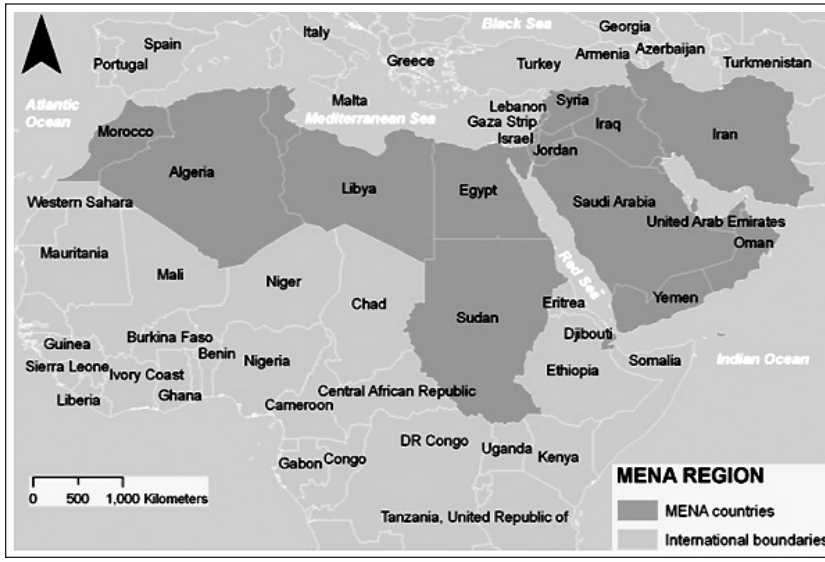

Figure 6-1. The MENA Region.

defined "water scarcity" level in the near future. Per capita water availability in the region is currently 1,100 m^3 per year, compared with a global average of 8,900 m^3 per year. Future projections suggest that this will fall to 550 m^3 by 2050 (IFAD 2009). The largest portion of available water is used for agriculture (fig. 6-3), but increasing competition from the domestic and industrial sectors is expected to reduce agriculture's share of water allocations, placing further limitations on agricultural production.

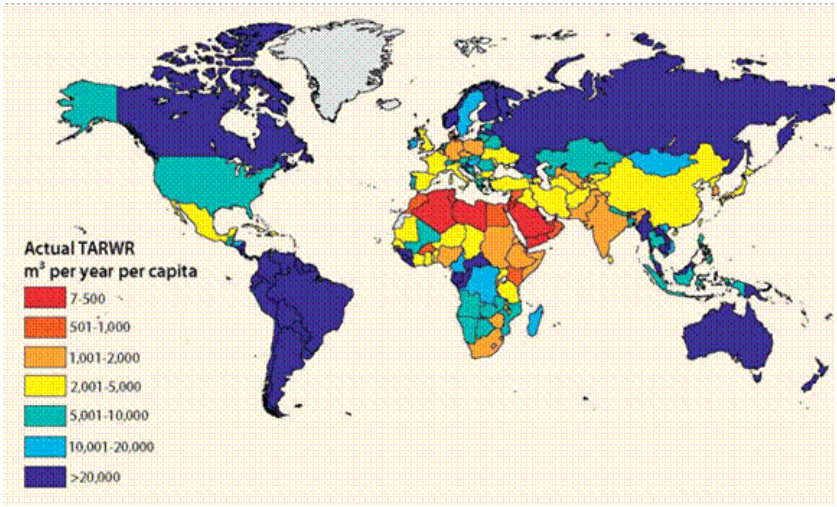

Figure 6-2. Per capita total annual renewable water resources. *Source:* FAO 2012c.

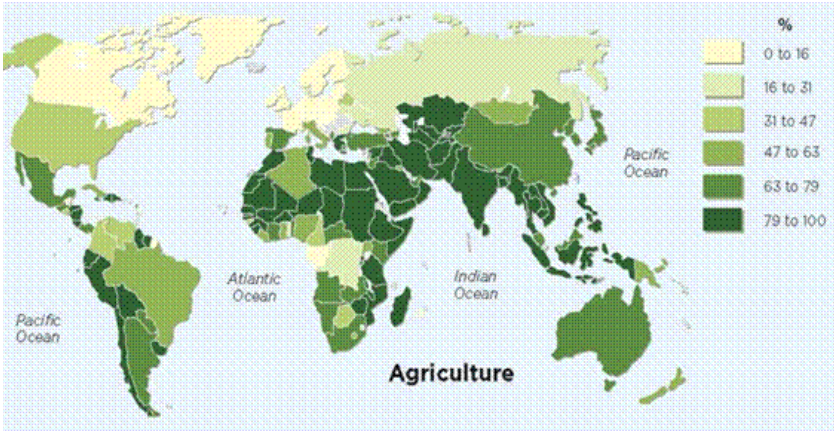

Figure 6-3. Percentage of freshwater used in agriculture. *Source:* UNESCO 2012.

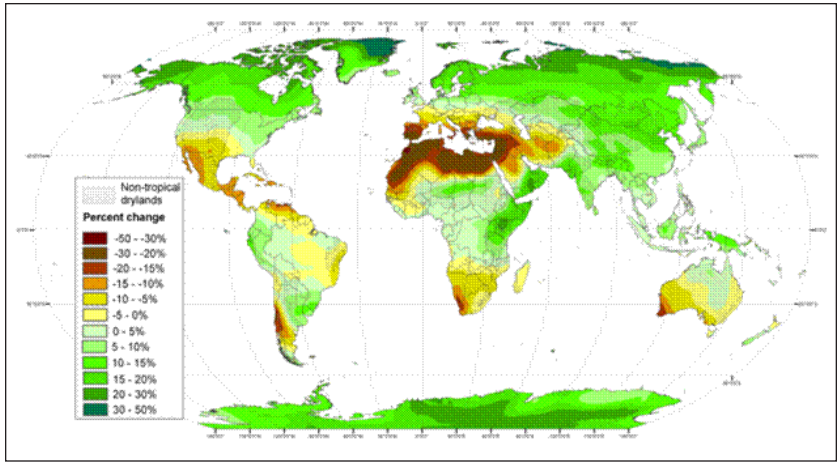

Figure 6-4. Relative change in mean annual precipitation, 1980/1999 to 2080/2099.
Source: GIS Unit ICARDA, based on partial maps from IPCC.

These problems will be exacerbated by climate change. Projections show that North Africa, the Middle East, and the Mediterranean will be hardest hit by climate change; precipitation is projected to decrease, while temperatures will rise, having serious implications for current agricultural production systems and driving even greater pressure on limited resources (fig. 6-4). Countries with predominantly rural economies and high dependence on dryland agriculture will be most at risk, as they are highly vulnerable to shifts in seasonal climatic patterns. The rural poor will be disproportionately affected by climate change because of their greater dependence on agriculture and their lower capacity to adapt to such changes.

Food Security in the MENA Region

The recent global food crisis of 2007–2009 with soaring commodity prices and shortage of food supplies in the international markets, has raised serious food security concerns about the potential fragility of the food security situation in the region. Recent research by the International Food Policy Research Institute (IFPRI) (Breisinger et al. 2011) has classified MENA countries according to their risk of food insecurity into five categories: low, moderate, serious, alarming, or extremely alarming (fig. 6-5). Except for the oil-rich countries of the Arabian Peninsula, which constitute less than 10% of the total population of the MENA region, most countries are facing risks

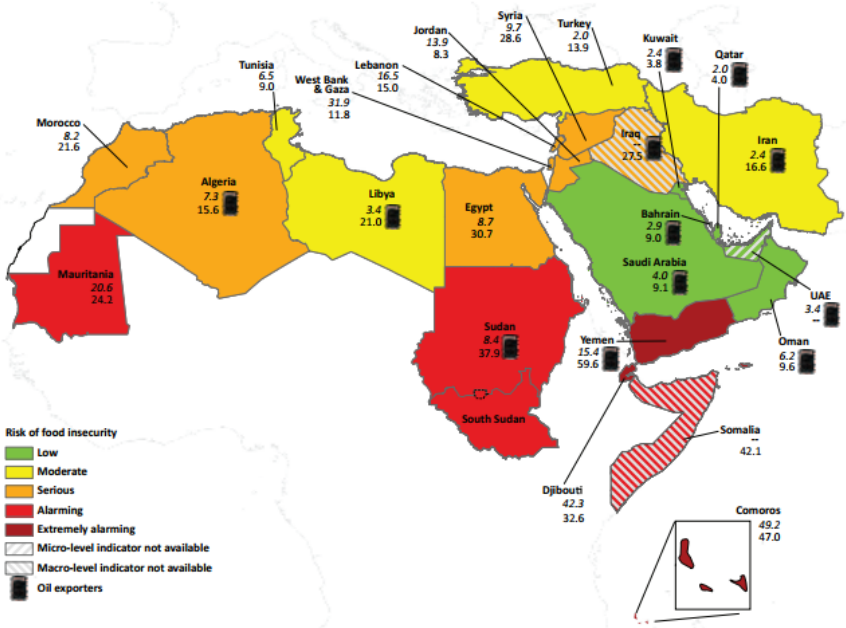

Figure 6-5. Risk of food insecurity in the Middle East and North Africa.
Source: Breisinger et al. 2012.

of food insecurity. Iran, Libya, and Tunisia exhibit moderate risk of food insecurity, whereas all other countries show serious, alarming, or extremely alarming levels of food insecurity risks. The countries at the highest levels of risk are Yemen and Sudan.

The MENA region is the most food import–dependent region in the world, and net food imports are projected to rise even further in the future. In 2000–2002, net food imports accounted for 25 to 50% of national consumption (fig. 6-6). MENA countries are very vulnerable to fluctuations in international commodity markets because they are heavily dependent on imported food. They are the largest importers of cereals in the world (fig. 6-7).

In 2010 the region imported 65.8 million tons of cereals compared with 58.8 million tons for Asia (in spite the huge difference population) and 18.0 million tons in sub-Saharan Africa. The expanding demand for cereals is expected to increase cereal net imports to 73.1 million tons by 2020. Wheat, in the form of bread and other products, is the staple food in most countries in the MENA region, and wheat imports alone will account for more than 50% of the total cereal net imports in 2020.

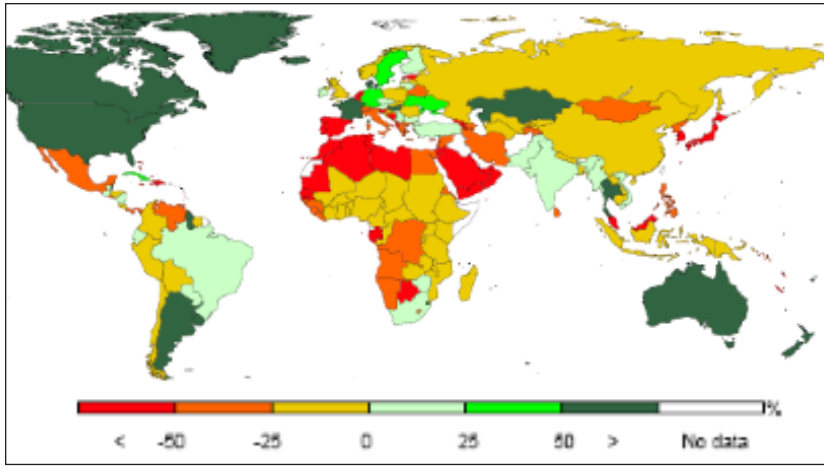

Figure 6-6. Net trade in food, 2000–2002. Net trade expressed as (exports-imports) / (calories consumed). *Source:* FAO 2004.

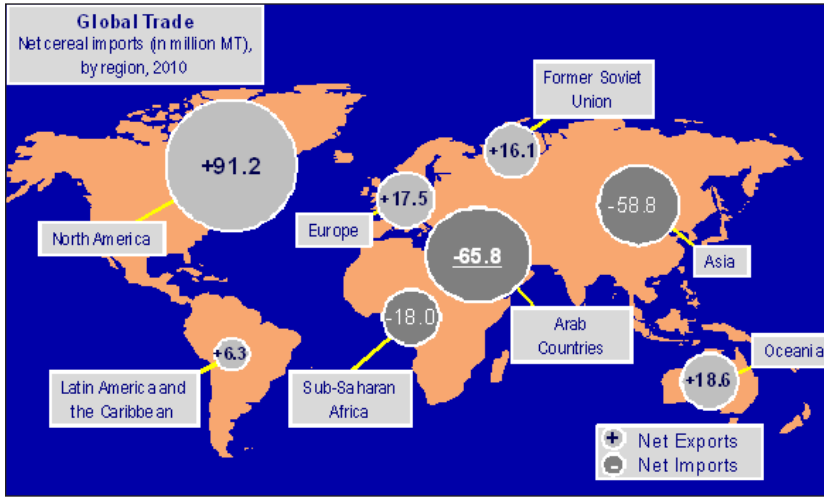

Figure 6-7. Arab countries are the largest net importers of cereal in the world (million metric tons, 2010). *Source:* Adapted from USDA 2011.

This high reliance on imported food can be attributed to both demand and supply factors. Demand factors include rising population and changing consumption patterns due to higher incomes. The MENA population has increased from 150 million in 1970 to 417 million people in 2010 and is projected to continue to grow at an annual rate of 1.7%. Shifting patterns of demand from staples to higher-value food products, combined with limited potential for land expansion, will further increase the region's food trade deficit. Supply factors include limited arable land and water resources, which constrain food production.

With limited scope for horizontal expansion, future increases in production must come from increases in productivity per unit of water and land. Following the food crisis, it became apparent that productivity gains in developing countries, and especially in the dry areas, have slowed. Actual farm yields of crops in the MENA region are far below their potential. One important and positive impact that the global food crisis has had in the region is that governments are now placing investment in agriculture high in their national priorities in an effort to ensure food self-sufficiency.

As the largest net importers of cereal, the countries of the MENA region are more exposed than other countries to severe swings in agricultural commodity prices, and their vulnerability will probably be exacerbated in coming years by strong population growth, low agricultural productivity, and their dependence on global commodities markets. Two forward-looking food-balance models, the IMPACT14 model created by IFPRI and an FAO model, project that demand for food in the region will grow substantially to the year 2030 and that production will not be able to keep pace, resulting in increasing dependence on imported food. Net cereal imports vary depending on population growth and availability of land and water resources. In some countries cereal imports will double, whereas in others they will remain constant or decrease. All, with the exception of Morocco, will remain net cereal importers through 2030 and beyond (table 6-1). The primary driver of increasing net cereal imports in the model is population growth, with income growth playing a smaller role. However, yields and production in some countries have already increased between 2000 and 2010, so these projections may need adjustment. The potential for increasing production is discussed below.

Table 6-1. Projected cereal imports in selected countries in MENA 2000–2030

Sub-region and country	Projected population growth 2000–2030 (%)	Projected income growth 2000–2030 (%)	Projected increase in net cereal imports 2000–2030 (%)
ARABIAN PENINSULA			
Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE, Yemen	105	190	89
NEAR EAST			
Iraq	95	24	48
Jordan	74	238	61
Lebanon	30	186	52
Syria	78	189	98
NORTH AFRICA			
Algeria	47	210	18
Egypt	59	168	137
Libya	57	211	72
Morocco	45	193	–17
Sudan	66	254	na
Tunisia	29	200	4

Source: World Bank et al. 2009.

The Case of Wheat, the Staple Food in the MENA Region

Wheat is the staple food in the MENA region, accounting for some 37% of total food supply. Consumption is highest in the Maghreb countries of Algeria, Morocco, and Tunisia, with average per capita consumption of 174 kg per year in North Africa, 158 kg in the Middle East, and 166 kg for the MENA region overall, compared with the world average wheat consumption of 66 kg per capita per year. The region imports almost half its wheat needs (fig. 6-8 and table 6-2) but at an increasing cost (fig. 6-9)

Rapid increases in wheat productivity were achieved in the late 1990s through 2006; the decline in yields and production in recent years reflect a series of drought years throughout the region (fig. 6-10). While total wheat area has declined over time, yields have increased by an average annual

Table 6-2. MENA self-sufficiency in wheat (%)

CHANGE FROM	1990–1994	1995–1999	2000–2004	2005–2009	1990–2009
Algeria	33.4	34.1	27.0	29.0	**–4.4**
Bahrain	0.0	0.0	0.0	0.0	0.0
Egypt	46.4	52.1	59.0	58.0	11.6
Iran	78.8	69.8	76.1	85.7	6.9
Iraq	64.8	50.3	39.5	43.9	**–20.9**
Jordan	10.0	7.1	5.5	2.9	**–7.1**
Kuwait	0.0	0.1	0.2	0.2	0.1
Lebanon	13.3	14.5	23.1	26.2	12.9
Libya	20.4	29.5	27.0	13.6	**–6.8**
Morocco	58.7	52.4	53.4	56.4	**–2.3**
Palestine	na	na	36.3	22.3	na
Oman	0.9	0.7	0.6	0.6	**–0.3**
Qatar	0.5	0.3	0.1	0.0	**–0.5**
Saudi Arabia	150.6	111.0	99.7	87.1	**–63.5**
Sudan	72.2	63.8	23.8	30.0	**–42.2**
Syria	92.6	113.2	111.1	114.9	22.3
Tunisia	61.7	48.7	44.3	49.3	**–12.4**
UAE	2.3	0.1	0.0	0.0	**–2.3**
Yemen	12.5	12.8	7.4	7.1	**–5.4**
MENA	64.2	57.8	57.0	57.8	**–6.4**

Source: FAO 2012c.

Note: Self-sufficiency = 100*[production]/[consumption] where consumption is the sum of production and net imports.

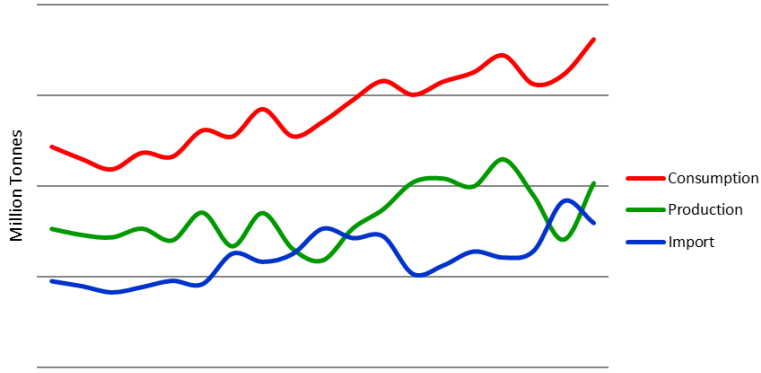

Figure 6-8. Wheat production, imports and consumption in MENA.

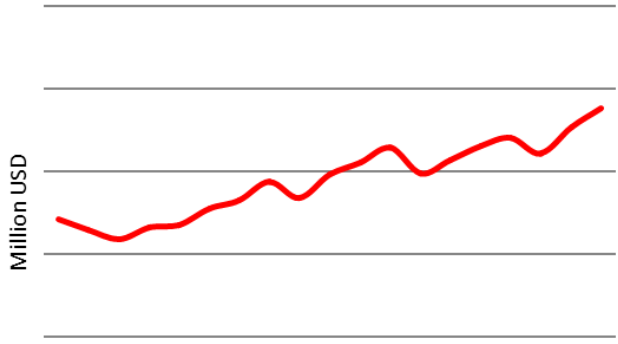

Figure 6-9. Wheat import value (USD million) in the MENA region.

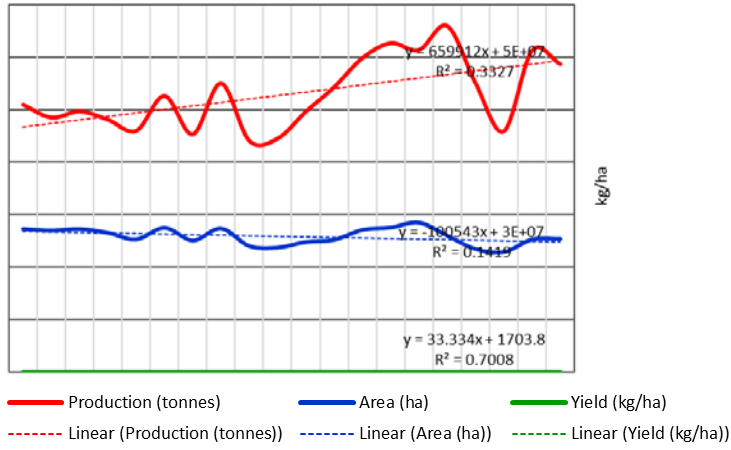

Figure 6-10. Wheat area, production and yield trends in the MENA region.

rate of 1.78%, resulting in an average annual growth in production of 1.29%. The average annual yield increase is similar to projected population growth rates in the MENA region of 1.77%. Thus, where the prospects for expanding the wheat area are limited, if production of wheat is to exceed population growth rates, yields must increase further.

Yield Gaps

To increase food security in the developing world, two parameters are used to explore the tradeoff between production intensification and the potential for land expansion of rainfed cultivated area at the country level (Fischer and Shah 2010):

1. **Yield gap:** the amount that actual yields, from either irrigated or rainfed areas, fall short of potential yields under optimum management; and
2. **Relative land availability:** the ratio of non-forested, non-cultivated suitable land area for rainfed production relative to what is actually cultivated.

It is apparent from table 6-3 that land availability in the MENA region is very limited; thus there is no potential for horizontal expansion in agricultural productivity except in the Sudan. On the other hand, actual farm yields of crops in the MENA region are far below their potential. Bridging the yield gap through vertical expansion in productivity is almost the only way forward to enhance food security.

Table 6-3. Potential availability of land for rainfed areas in different regions of the world (1,000 ha)

	Total area	Area <6 hr	Area >6 hr
Sub-Saharan Africa	201,761	94,919	106,844
Latin America and Caribbean	123,342	93,957	29,387
Eastern Europe and Central Asia	51,136	43,734	7,400
East and South Asia	14,769	3,320	11,450
Middle East and North Africa	2,716	2,647	71
Rest of the world	52,134	24,554	27,575
Total	445,858	263,131	182,727

Source: Deininger and Byerlee 2011

Note: Data reflects potential supply of land in areas with a population density less than 25/km^2

Most of the agricultural area in the MENA region is rainfed, and a large proportion of the region's agricultural production is based on dryland farming systems, with a variable annual rainfall in the range of 200 to 600 mm (fig. 6-11). The region has about 74 million ha of arable land, of which some 23% is sown to wheat (FAOSTAT 2012) (fig. 6-12). About 20 to 30% of the wheat area is irrigated, and the rest is grown under rainfed conditions. Productivity of wheat in rainfed areas is still low (0.8 to 2.0 t/ha) compared

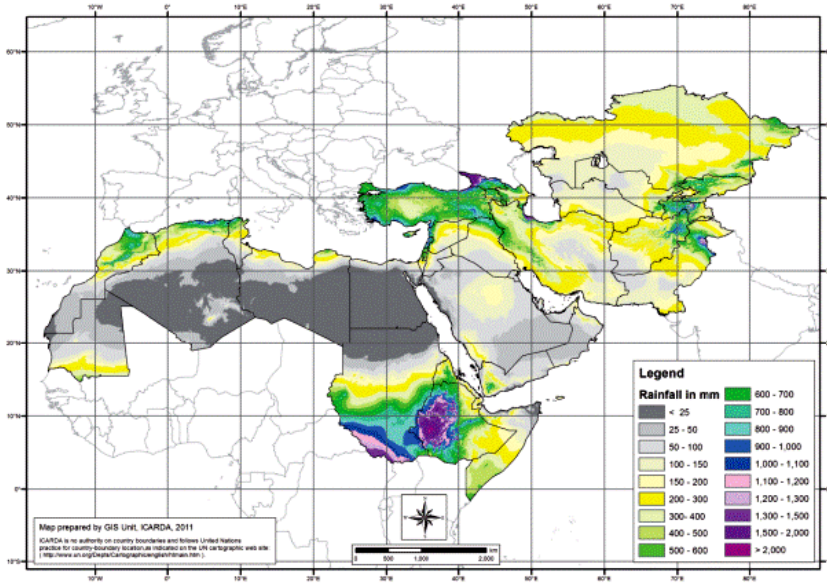

Figure 6-11. Rainfall zones of MENA region.

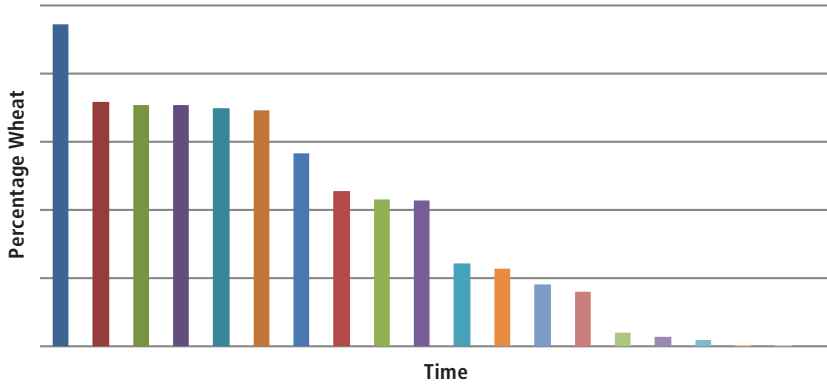

Figure 6-12. Percentage of arable area planted to wheat (average for 2006–2009).

with world averages. Rainfed production depends on low and extremely variable rainfall; therefore, productivity is low and unstable. This is further affected by frequent droughts and is likely to be exacerbated by climate change. However, higher and more stable yields have been achieved in experimental fields and in on-farm demonstrations. Analysis of potential yields and yield gaps show that the actual yields of food and other crops obtained by farmers are much below the potential yields that can be obtained with improved management. The analysis also shows that, although there are regional differences in the potential of different agroecologies, crop yields can be increased by the promotion and adoption of existing "on-the-shelf" technologies available with national and international research institutes. It is clear that the full potential of rainfed farming has not been exploited as yet.

Yield gap analysis by ICARDA (Pala et al. 2011) in key locations in Morocco and Syria, which represent major wheat production agroecologies, found that wheat yields could be substantially increased (fig. 6-13). The analysis used data obtained during the period of 1995 to 2004 on yields obtained under improved management at research stations or in on-farm demonstration trials; simulated potential yields using a cropping systems simulation model; and yields in farmers' fields in the vicinity of on-farm yield trials. The gap between yields in farmers' fields and research station yields in rainfed systems averaged 82% (fig. 6-14 and table 6-4).

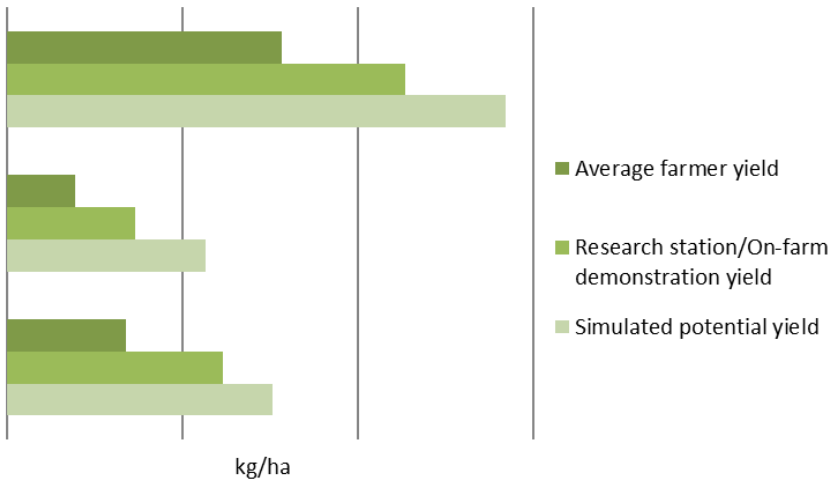

Figure 6-13. Yield gaps in Morocco and Syria: Mean yields for 1995–2004.

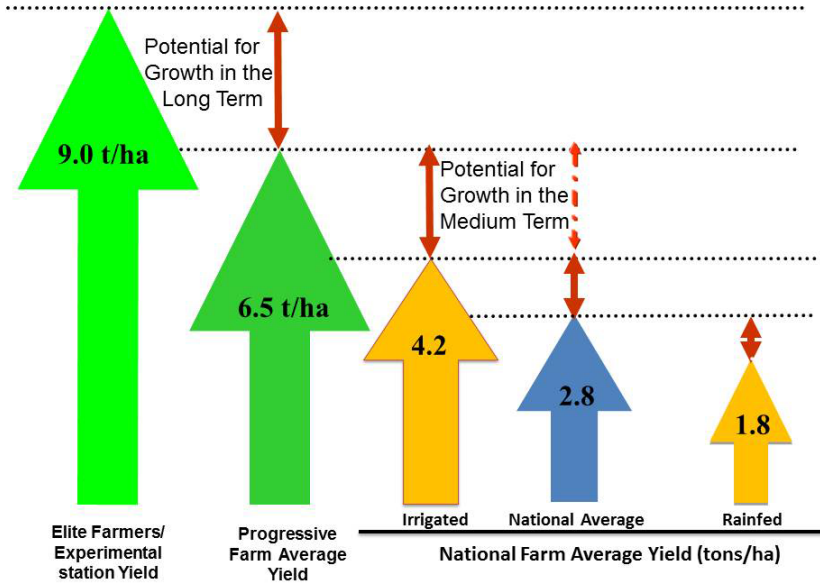

Figure 6-14. Yield gaps involving elite and progressive farms compared to national average, rainfed, and irrigated wheat crop in Syria.

Table 6-4: Yield gap analysis for Morocco and Syria

MEANS OF 1995–2004	Morocco Settat-Berrechid (rainfed)	Morocco Tadla (irrigated)	Syria (rainfed)
Rainfall (mm)	327	285	372
Average farmer yield (kg/ha)	1,163	4,685	2,020
Research station/on-farm demonstration yield (kg/ha)	2,190	6,800	3,675
Simulated potential yield (kg/ha)	3,390	8,510	4,540
GAP ANALYSIS			
Gap 1 (kg/ha)	1,028	2,115	1,655
Gap 2 (kg/ha)	2,228	3,825	2,520
Gap 1 (%)	88%	45%	82%
Gap 2 (%)	192%	82%	125%

Notes:

Gap 1 = difference between average farmers' yield and research station or on-farm demonstration yield.

Gap 2 = difference between average farmers' yield and simulated potential yield.

Thus, there is a large potential for increasing wheat production in the MENA region. Improved management practices along with improved varieties and supplemental irrigation can close the wide gaps between farmers' current yields and those achieved in research stations and on-farm demonstration trials.

The Case of Syria

In Syria, beside the apparent clear yield gaps between research and on-farm demonstration yields and farmers' yields, there is also a clear gap between the yields achieved by progressive farmers and those achieved by the average farmer (see fig. 6-14).

A collaborative program between the Ministry of Agriculture and Agrarian Reform and ICARDA in Syria has tackled the yield gaps in wheat. The program involved breeding for improved germplasm (with yield stability and drought and disease resistance/tolerance), supplemental irrigation, and research on improved crop management (agronomy, fertilization, and mechanization). The improved varieties and management practices were tested under farmers' conditions over multiple years and locations.

Figure 6-15 shows the impact of the adoption by farmers of improved wheat technologies. Wheat production was significantly increased (linear production trend), and Syria became more or less self-sufficient in wheat. The increased production resulted from the combined use of improved technologies and not from an expansion in area, which remained more or less constant (see the linear area trend). Production still varies with annual rainfall, but the graph also shows the higher responsiveness of improved wheat varieties to rainfall compared with the earlier period of 1977–90. The main technical reasons behind this impact include improved varieties, which contributed one-third of the increase in productivity, while supplemental irrigation and inputs (fertilizer, herbicides, etc.), each contributed one-third. All of this was supported by the government's enabling policy environment.

The strategy adopted in Syrian agriculture can serve as a model for development elsewhere and demonstrates that increases in staple food crop production are possible. The MENA region currently has a population of about 400 million, with an annual deficit of some 30 million tons of wheat, which is met by imports. By 2020, the population is expected to

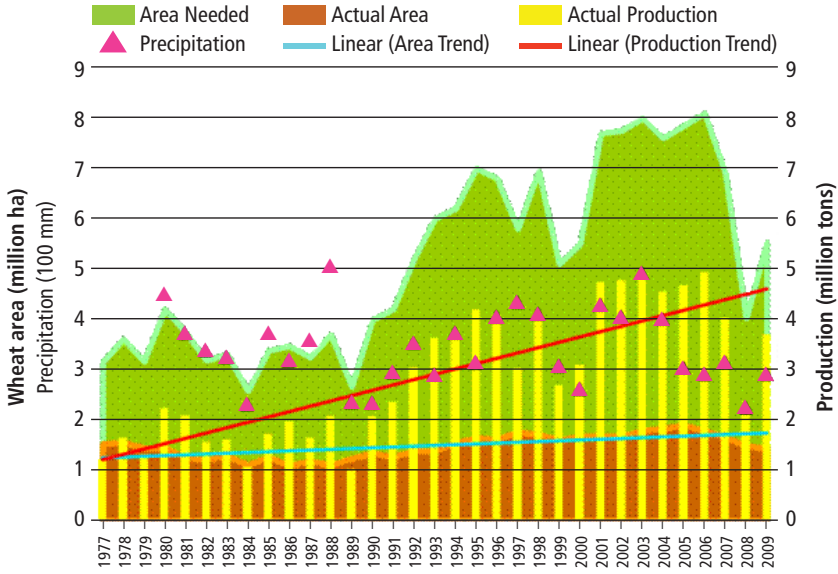

Figure 6-15. Adoption and impact of improved wheat production technologies in Syria.

reach almost 500 million, at an annual growth rate of 1.77%. Production of wheat needs to be kept above this rate of population growth if it is to meet the increasing demand. Land and water resources are already limited, so most of the increase in food production will have to come from increased productivity per unit area and per unit water. Assuming the same average per capita consumption of 166 kg per year, and the same wheat area, average wheat yields would have to increase by almost 1 ton, or 45%, in the 10 years to 2020 in order to meet demand without increasing imports above their 2007–9 current level (table 6-5). This is an average annual increase in yield of 3.15%.

Is such an increase achievable? The example of yield gaps above shows that such an increase is potentially achievable, being well within the difference between average farmers' yields and research station yields. However, technological change does not translate into increased production until it is widely adopted by farmers. Some individual countries may be able to achieve these gains, but only if action is taken now to develop, adapt, and promote improved technologies that incorporate soil moisture conservation, supplemental irrigation, improved soil nutrient management, high-yielding improved varieties, and integrated pest and disease management,

Table 6-5. Estimated average annual increase in yields required to meet the demand for wheat in 2020 without increasing imports

	Average 2007–2009	2020
Population	400,149	493,927
Kg/ha consumption	166.10	166.10
Consumption	66,465,209	82,041,774
Imports fixed at 2007-2009 level	31,436,022	31,436,022
Area fixed at 2007-2009 level	15,756,248	15,756,248
Production	34,886,552	50,605,752
Yield (kg/ha	2,214	
Yield required to maintain consumption (kg/ha)		3,212
Required yield increase		998
Average annual increase (%)		3.15%

coupled with more suitable policy environments and institutional support to encourage the adoption of the new technologies by farmers.

It should also be noted that these are the yield increases needed to simply maintain the current trade position of the MENA region; it will not reduce imports or achieve self-sufficiency in the region. Achieving self-sufficiency and reducing imports to zero would require average yields to be increased by almost 3 tons within 10 years, an unrealistic prospect. Many countries of the MENA region will therefore continue to be reliant on imports and the international market to meet their populations' demand for wheat. The global food crisis and ongoing instability in international food markets have raised questions about the reliability of international markets as suppliers of affordable food and have prompted many food-importing countries to pursue strategies focused on increasing self-sufficiency in staple foods as a way of becoming less reliant on food imports.

Enhancing Food Security in Arab Countries

The results of the first 2 years of a project on the Enhancing Food Security Project in Arab Countries clearly indicate that there is clearly potential

to increase food security in Arab countries. The project, which involves Egypt, Jordan, Morocco, Syria, Tunisia, Sudan, and Yemen, is supported by the Arab Fund for Economic and Social Development (AFESD), the Kuwaiti Fund for Economic Development (KFEAD), and the Islamic Development Bank (IsDB). The goal of the project is to contribute to achieving food security and agricultural sector growth with a focus on wheat-based production systems in the Arab countries under the challenging scenarios of climate change, the global economic crisis (increased food prices), and increasing population.

The project aims at increasing wheat production following an integrated, multidisciplinary research approach and technology transfer in whole provinces involving researchers, farmers' participation in planning, field days, farmers' fields schools, extension staff, and policymakers.

In the 2010–2011 season, production of wheat in Sharkia Province in Egypt was increased by 20%, with water savings of 20%, as result of improved wheat varieties, raised-bed plantation, and improved agronomic practices under irrigated conditions. In Tunisia, average wheat yields were increased by 12 to 20% as a result of adopting improved varieties under rainfed conditions in Janduoba Province; under irrigated conditions in Kairouan Province, yields were increased by 20 to 40%. In Syria, the wheat yields increased by 10 to 22% under drought conditions, while under supplemental irrigation, these increases were 20 to 40%.

Direct Investment in Foreign Agriculture: Is Land Acquisition a Viable Strategy?

The global food crisis and inflation in food prices in 2008 exposed the vulnerability of import-dependent countries to a volatile international market and raised the prospect of food insecurity for countries in the MENA region without much farmland, such as those in the Arabian Peninsula (Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates). Investment in foreign agricultural land is seen as one way to reduce the amount of food that these countries need to import at world prices. An increasing number of countries are engaging in foreign direct investment to ensure their national food security by buying or leasing land in other countries (a so-called "land grab"). The investor country acquires land and guaranteed access to the food produced on it, while the recipient country gets an

infusion of investment into its agricultural sector. Other possible benefits include the creation of jobs in rural areas and the development of rural infrastructure leading to economic development. The scale and terms of these investments and arrangements vary widely; some have no direct land acquisition but involve securing food supplies through contract farming and investment in rural and agricultural infrastructure, including irrigation systems and roads. However, for this to truly be a win-win arrangement, such investments should protect the recipient country's citizens from expropriation of their land, labor abuses, and loss of their own food security. Land investments can displace small-holder farmers or impact on the local food production in the target countries, especially if these countries face food security challenges of their own. FAO is now encouraging investors to support joint ventures with local farmers in poor nations rather than lease or buy land outright.

Toward Long-Term Food Security

Managing future food security at the national level requires strategic choices among a mix of domestic investments in agriculture and food stocks and international market arrangements. With limited arable land and water resources, there is limited scope for horizontal expansion in agricultural production; future increases must come from increases in productivity per unit of water and land. Against this background, the question is, what can make a difference in efforts to improve food production under land and water scarcity?

- An enabling policy environment and strong political will are critical. Policies are needed that support sustainable productivity growth in agriculture. Governments need to ensure that farmers have sustained access to quality seeds, fertilizers and tools as well as technical assistance, training, and credit; they also need to invest in rural infrastructure such as roads, irrigation systems, storage and market facilities. Reducing post harvest food losses could also contribute significantly to improving domestic supplies. Encouraging better agronomic practices; creating the right commercial, technical, and regulatory environment; and strengthening the agriculture innovation system (e.g. research, education, and extension) are essential steps.

- The dry areas must give greater priority to and investment in enhancing water productivity for sustainable agricultural and rural development, particularly in the vulnerable rainfed areas. Water is the fastest-depleting resource in the region, and managing the resource more effectively ("getting more crop-per-drop") and addressing impending issues of climate change is critical in the future.
- Advances in science and technology are crucial in overcoming or adapting to the challenges facing dry areas. An integrated approach is needed that addresses both agricultural productivity and the better management of the natural resources on which that productivity depends.
- Above all, greater investments are needed in agricultural research capacity development and institutional support. Strengthening the agriculture innovation system (research, education, and extension) is essential. Far greater investment is needed in developing a new generation of national scientists and technicians that will carry these efforts into the future.

The Role of ICARDA

With 35 years of applied research experience in the region, the International Center for Agricultural Research in the Dry Areas (ICARDA) is uniquely placed to provide the assistance needed in addressing the twin challenges of improving food crop production and conserving the natural resource base on which agricultural production depends. Collaborative research by ICARDA and its partners has contributed to significant gains in food security in dry areas. Ensuring food security in the future will require a long-term, multipartner, multisector strategy to deal with the challenges facing dry areas. ICARDA's research is directed toward improving food security and helping farmers adapt to climate change in dry areas.

Conservation and Use of Genetic Diversity

Researchers are using genetic diversity—germplasm from diverse sources—to develop improved, adapted crop varieties that can offer higher yields and simultaneously cope with climate change through better resistance to environmental constraints. The MENA region contains tremendous diversity, both in cultivated landraces and wild species. These provide an invaluable

resource for identifying new sources of resistance to temperatures, drought, diseases, and insect pests, as well as other adaptive traits.

Crop Improvement

ICARDA's mandate includes the improvement of wheat (the staple food crop in the MENA region), barley (a major livestock feed in the MENA region), and food legumes (chickpea, lentil, and fava bean), which are an important source of protein, especially for the urban and rural poor who cannot afford animal protein. ICARDA uses both conventional plant breeding and biotechnology to develop improved germplasm adapted to changing production systems with high yield potential and enhanced resistance to specific stresses. These, combined with improved crop management and integrated pest management (IPM) practices, are pivotal in ensuring food security and increasing agroecosystem resilience in the face of climate change.

Over the last 35 years, 880 improved varieties of wheat, barley, chickpea, lentil, fava bean, and forage crops developed by national research programs in collaboration with ICARDA have been released. About 86% were released in developing countries and 14% in industrialized countries. The estimated net benefit from these varieties is $850 million per year.

Improving Water Productivity

Water is the most critical limiting factor in dry areas. Irrigation accounts for 80 to 90% of water consumption in the MENA region. Thus, small improvements in on-farm water use efficiency can substantially improve water availability. Technologies and policy and institutional innovations are needed to improve water management in agriculture, increase productivity, and reduce production costs.

Climate change will exacerbate water scarcity in dry areas, many of which are already reaching critical levels of scarcity. Scientific innovation has led to several approaches for more effective management of water in agriculture. ICARDA's research focuses on increasing water productivity (the amount of crop or biomass produced per unit of water used) both at the farm and basin levels. ICARDA has also been studying the use of alternative water resources. For example, marginal-quality water and treated wastewater have been found useful for growing cotton, forages and trees. Conjunctive or blended use of drainage water with regular irrigation can optimize yields while conserving freshwater.

Diversification and Intensification of Production Systems

To cope with climate change, farmers will need to diversify their farming systems in order to improve ecosystem resilience, reduce risk, and simultaneously create new income opportunities. System diversification includes diversification of crop rotations, for instance by promoting the inclusion of legume crops in cereal systems, which also contributes to maintaining soil fertility, and also diversification into higher-value crops such as dryland fruit trees, protected (greenhouse) agriculture, and herbal, medicinal, and aromatic plants.

Reducing Production and Energy Costs

The fundamental driver of agricultural technology adoption by farmers is an increased return to their investment, either by increasing production or reducing costs. Conservation agriculture achieves both. It combines minimum soil disturbance (zero tillage), stubble retention, crop rotation, and early sowing of crops. It offers multiple benefits: savings in time, fuel, and machinery costs for land preparation; better soil structure; better soil moisture conservation; higher yield potential; and reduced soil erosion. While the practice has been widely adopted in other dryland areas (Australia, Latin America), a major bottleneck in the MENA region has been the lack of affordable planting equipment. This has now been resolved with the development of locally fabricated, low-cost zero-till seeders developed with local manufacturers and tested by farmers in Syria and Iraq. In the 2010–11 season, these machines were used by 400 farmers to plant almost 20,000 ha of zero-till crops, and the equipment and associated practices are being scaled out to other countries.

Capacity Development

In order for national research programs to meet the challenges of increasing agricultural production, they need a cadre of qualified researchers trained in the new and emerging research approaches needed to address the specific problems encountered by each country. Evidence shows that the MENA countries in general are facing a "skills gap"—an acute shortage of agricultural researchers. The Young Agricultural Scientists Program established at ICARDA is designed to bridge this skills gap by strengthening national research capacities and encouraging graduate careers in agricultural research.

References

Bänziger, M. 2012. Climate Conversations: How to Avoid Another Food Crisis. Alert Net, Thomson Reuters Foundation. 8 August. http://www.trust.org/alertnet/blogs/climate-conversations/how-to-avoid-another-food-crisis/

Breisinger, C., T. van Rheenen, C. Ringler, A. Nin Pratt, et al. 2010. *Food Security and Economic Development in the Middle East and North Africa: Current State and Future Perspectives*. IFPRI Discussion Paper 00985. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/sites/default/files/publications/ifpridp00985.pdf

Breisinger, C., O. Ecker, P. Al-Riffai, and B. Yu. 2012. *Beyond the Arab Awakening: Policies and Investments for Poverty Reduction and Food Securit*y. Washington, DC: International Food Policy Research Institute.

Deininger, K., and D. Byerlee. 2011. Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits? World Bank.

FAO (Food and Agriculture Organization of the United Nations). 2004. FAOSTAT 2004.

———. 2012. FAO Food Price Index, 9 August 2012. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/

———. 2012b. FAO Statistical Yearbook 2012. Food and Agriculture Organization of the United Nations, Rome 2012

———. 2012c. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, 2012. http://faostat3.fao.org/home/index.html

Fischer, G. and Shah, M. 2010. "Farmland Investments and Food Security, Statistical Annex", Laxenburg, Austria, Report prepared under World Bank IIASA contract - Lessons for the large-scale acquisition of land from an agricultural land use analysis.

OECD 2012. OECD-FAO Agricultural Outlook 2012, Organisation for Economic Cooperation and Development Publishing. http://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook -2012_agr_outlook-2012-en

Pala, M., T. Oweis, B. Benli, E. De Pauw, M. El Mourid, M. Karrou, M. Jamal, and N. Zencirci. 2011. Assessment of wheat yield gap in the Mediterranean: case studies from Morocco, Syria and Turkey. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, 2011.

Singh, P., P. K. Aggarwal, V. S. Bhatia, M. V. R. Murty, M. Pala, T. Oweis, B. Benli, K. P. C. Rao and S. P. Wani. 2009. Yield Gap Analysis: Modelling of

Achievable Yields at Farm Level. In S. P. Wani et al (eds). Rainfed Agriculture: Unlocking the Potential. CAB International 2009.

UNESCO. 2012. The 4th Edition of the UN World Water Development Report. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/

World Bank, FAO, and IFAD. 2009. Improving Food Security in Arab Countries. World Bank. January 2009.

7

Adapting Agricultural Water Management to Water Scarcity in Dry Environments

Dr. Theib Oweis

International Center For Agriculture in the the Dry Areas (ICARDA)

Abstract

The Middle East is experiencing severe and growing water scarcity. The impact of this scarcity on food security and the environment could potentially lead to sociopolitical instability and conflicts. There is limited potential to substantially increase water resources in this region because of several constraints, including climatic, political, cost, and quality issues. In fact, all global circulation models predict that precipitation, and hence water resources, in the Middle East will decline as a result of climate change in the coming decades. Agriculture, the largest user of water, receives a progressively smaller proportion of total water resources. However, food demand continues to rise as a result of rapid population growth and improved standards of living. Water availability for agriculture is one of the most critical factors for food security in many regions of the globe. It is, therefore, essential for countries across the region seeking stability and food security to produce more with less water—"more crop per drop."

Conventional approaches seek to increase crop yields (land productivity) while investing in modern irrigation systems, but this approach has major limitations. Higher crop yields generally require more water, which is not available. Modernizing irrigation systems may not result in substantial and real water savings; they increase the field and farm irrigation efficiency, but the overall water savings at the basin or landscape levels may not be proportional.

In water-scarce areas, where water is more limiting than land, the focus must shift from land productivity (yield per unit area) to water productivity, which is the returns (biological, economic, environmental, nutritional,

and/or social) per unit of water used. Research has shown that it is possible to double water productivity in many countries of the region in two decades. This is equivalent to doubling the available water resources. However, this will require major changes in the way we use and manage agricultural water; changes in cropping patterns, irrigation approaches, crop improvement strategies, policies, and institutions; and greater investment in research and capacity development.

Water productivity can be increased by improving crop water management and technologies, such as deficit irrigation, supplemental irrigation, and water harvesting. Simultaneously, countries may cultivate highly water-productive crops while importing crops with lower water productivity. Policymakers must make painful choices to rationalize water use while ensuring access to the poorest households. Resolving the crisis will require enduring progress toward political, social, economic, and administrative systems that shape the use, development, and management of water resources and water delivery in a more effective, strategic, sustainable, and equitable directions.

Background

Food security at the national level is the assurance that food is available and accessible to meet the current and future minimum requirements of all the people in a country. This, of course, may be achieved not only by producing food internally, but also by securing the resources and ability to import sufficient to cover the food deficit. Food insecurity is a major concern of all countries in the Middle East. Arab countries imported over 70 million tons of grains in 2011, more than half of their needs, and the gap between national needs and production is widening. A major concern arose during the 2007–2008 world food crisis, when wealthy countries in the Gulf were unable to buy wheat because of market shortages. Many countries started allocating resources to enhance food self-sufficiency, although at much higher costs and water consumption. Constraints are mainly associated with water scarcity but also unfavorable climate and/or degraded land resources and investment (Solh 2011).

The amount of water available for agriculture is one of the most critical factors for food security in many regions of the world. Strong relationships among water scarcity, food production, and food security were established

and will be clearer in the coming decades (Rosegrant and Cai 2001). Water scarcity and quality are potentially serious threats to food security and health in dry areas. There is a direct relationship between access to water and access to food and feed security. The proportion of the population without access to reliable, uncontaminated water is as high as 78% (ICARDA 2007). It may be noted that the food needs of a person with an average consumption of 2,500 calories per day would require, on average, about 2.5 m^3 of water to produce. This is equal to over 1,000 m^3 per capita per year, which is the water poverty level declared by UNESCO.

In the Arab countries, rapid population growth since the mid-1970s has caused a shrinkage in per capita renewable water resources from an average of 2,925 m^3/year in 1962 to 1,179.6 m^3/year in 1992. It shrunk further to an alarming 743.5 m^3/year in 2011, which is below the poverty line of 1,000 m^3/year and far below the world average of 7,240 m^3/year. Fifteen Arab countries already face water scarcity, with average water availability per capita below the poverty line. Twelve countries are under the 500 m^3/year threshold set by the World Health Organization for severe scarcity, and seven countries are below 200 m^3/year. By 2030, the effects of climate change will have reduced renewable water resources by a further 20% and increased the frequency of droughts as a consequence of decreasing precipitation and increasing domestic and agricultural water demand as temperatures rise. We will also experience expanding seawater intrusion into coastal aquifers as sea levels rise and groundwater overexploitation continues (UNDP 2013).

The second major conventional water resource in the region is groundwater. Shallow and deep groundwater resources, within or across national boundaries, are recharged by precipitation and by rivers. In several countries, groundwater contributes more than 50% of the total water withdrawals, and in some areas it is the only resource available. Nonrenewable or fossil aquifers are used mainly for agricultural expansion and development. Most Middle Eastern countries draw heavily on groundwater to meet rising demand. Their overexploitation and depletion have severe environmental consequences in addition to depleting national assets. Mining groundwater resources has resulted in rapid depletion of aquifer reserves, salinization, and deterioration in water quality. In addition they are threatened by pollution from agricultural, industrial, and domestic activities (UNDP 2013).

In many countries of the Middle East, securing water needs for domestic use—let alone for agriculture, industry, and recharge—is a serious challenge

(FAO 2011). Current water supplies will not be sufficient for economic growth in many countries of the region. Water scarcity has already hampered development in several countries and is increasingly affecting others. It is essential that we make major changes in the way water is managed to alleviate poverty, promote economic growth, and prevent conflicts. The recent UNDP report on water referred to the "water crises" in the Arab region and suggested that "resolving the crisis will require enduring progress towards political, social, economic, and administrative systems that shape the use, development, and management of water resources and water delivery in a more effective, strategic, sustainable, and equitable direction" (UNDP 2013).

About 80% of the total water resources in the region are used to produce food. With fast-growing populations and improvements in living standards, more water is diverted to other priority sectors, such as domestic and industrial consumption, leaving less water for agriculture. Ironically, as water for agriculture is declining, more food is needed and food security in the region is being increasingly threatened. If nonagricultural consumption continues to grow at the present rates, the share of agriculture in several Middle Eastern countries will drop to 50% in 25 years. In several countries, such as Jordan, marginal-quality water will soon become the major source of irrigation water (Al-Karaki 2011).

Despite its scarcity, water continues to be misused. New technologies allow farmers to extract groundwater at rates far in excess of recharge, rapidly depleting centuries-old aquifers. The productivity of water in the region is still low, but it varies depending on crop and country. Water scarcity and mismanagement will also accelerate environmental degradation through soil erosion, soil and water salinization, and waterlogging. These are global problems, but they are especially severe in the dry areas (Pereira et al 2002).

The objectives of this paper are to

- highlight the chronic water scarcity and the general misconceptions regarding water savings associated with current traditional practices and methodologies.
- present the recently formulated comprehensive framework on water productivity (WP) to properly describe true water use and benefits.
- suggest some promising ways of coping with increased water scarcity, especially for sustainable natural resources and agricultural development.

Untapped Water Resources: Limited

The majority of water resources in the dry areas—this includes surface and groundwater resources –are already tapped and used for various needs (UNDP 2013). The technical options listed below might provide additional water resources, but many constraints must be overcome.

Desalination

Desalination is a potential new water source but is costly and has negative environmental impacts. Half of the world's desalinated water is produced in oil-rich countries of the region. Of this, a large proportion is used in agriculture with very low economic willingness to pay. Desalination capacity has rapidly increased in the last decade because of the increase in water demand and a significant reduction in desalination cost as a result of technological advances. Under the most favorable conditions, the cost of desalinated seawater has fallen below $\$0.50/m^3$ while in other locations the cost is near or above $\$1.00/m^3$. (Ghaffour et al. 2013). The lower costs reported are largely associated with either energy subsidizes or with ignoring environmental costs. As new technologies develop, costs may eventually become feasible to use desalinated water for agricultural use, possibly using natural gas as a source of energy.

Marginal-Quality Water

The development and use of marginal quality water offer some promise. Potential sources include natural brackish water, agricultural drainage water, and treated sewage effluent. The Middle East has notable amounts of brackish water, mainly in groundwater aquifers, which can either be used directly in agriculture or desalinated at low cost for human and industrial use. Several freshwater aquifers have become brackish as a result of groundwater mining and seawater intrusion. Using brackish water in agriculture can contribute to food production and the environment, but it requires special scheduling to prevent land salinization and degradation of the ecosystem and to develop and select crops that can tolerate some level of salinity.

Treated effluent is an important source of water for agriculture in areas of extreme scarcity, such as Jordan and Tunisia, where it counts for about 25% of the country's water resources. In Egypt, 0.7 billion m^3 (BCM) per year of treated wastewater is being used in irrigation. It offers many advantages, as it lacks the uncertainties of surface water resources and can meet a

proportional share of the rising water demand from urbanization and population growth. Many factors prevent the expansion of wastewater reuse, however, including social barriers, technical obstacles, and institutional and political constraints (UNDP 2013).

Agricultural drainage is becoming an attractive option. In the last two decades, there has been considerable research on the reuse of drainage water in agriculture and its impacts on the environment. In Egypt, the drainage water from agricultural lands is collected by an extensive drainage network and recycled in the system after mixing with freshwater downstream until it becomes too saline for productive use. Currently about 5.5 billion cubic meters (BCM) of drainage water are being reused, and this is expected to increase to about 10 BCM by the year 2017 (Abdel-Shafy and Mansour 2013).

Rainwater Harvesting

This represents a real recovery of otherwise lost water and provides opportunities for decentralized, community-based management of water resources. In dry environments, hundreds of billions of cubic meters of rainwater are lost every year through runoff to salt sinks and evaporation from bare soil surfaces as a result of a lack of proper management and sustainable ecosystems development. ICARDA has demonstrated that over 50% of the otherwise lost water can be captured using water harvesting and can be used for agriculture (Oweis et al. 2012). The practice, principles, and methods will be elaborated later in this paper as it is also relevant to improving WP.

Water Transfers

Transfers between water basins and between countries have been extensively discussed in the Middle East over the last few decades. Several countries have considered importing water from other basins. Two projects were proposed, including transportation by pipeline (Turkey's proposed "peace pipeline") and by ships (big tanks or "Medusa" bags). Both options depend on economic, political, and environmental measures. Interbasin transfers may also have significant ecological impacts on both the transferring and receiving basins that are yet to be examined. Attempts have also been made to transfer water by balloons and tankers, but the cost is still too high for agricultural purposes. The peace pipeline project to transfer water from Turkey to the Middle East was unsuccessful because of financial and political constraints (Render 2007). As water scarcity in the region grows, the issues associated

with cross-boundary water resources become more relevant. Internationally agreed laws and codes of ethics need to be developed to ensure water rights and to open the way for innovative projects and better regional collaboration.

Traditional Coping Strategies

Over the last few decades, substantial resources have been spent to increase food production in water-scarce areas. The following strategies used to cope with water scarcity are no longer adequate or effective.

Increasing Yield Requires More Water

The Green Revolution transformed food production by increasing grain yields several-fold through improved cultivars, better fertility, and water management. Many examples illustrate large yield increases through the proper management of water and cropping systems. However, higher crop yields generally require more water use. While higher yields (production per unit area) reflect more efficient use of the resources, the relationship between biological yield and evapotranspiration is nearly linear (fig. 7-1a). When this relation is nonlinear, higher yields will need even higher rates of water use mainly because of increased evaporation associated with more irrigation and/or precipitation (fig. 7-1b). It is true that the relationships of other yield components, such as grain yield, differ from that of biological

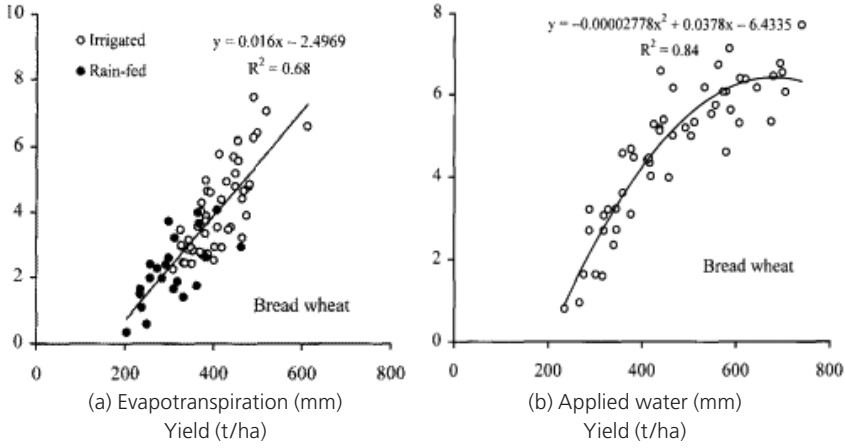

Figure 7-1. Relation between grain yield and evapotranspiration (a) and applied water (b) for bread wheat in Aleppo, Syria. *Source:* Zhang and Oweis 1999.

yield (as other factors affect the harvest index), but the relationships are generally positive. Increasing yields are still possible with improved crop varieties, better fertility and cultivation practices, and water management, but this will need a greater supply of water. This is not to say that there is no room for increasing a specific crop yield per unit of land without additional water, as this is possible by improving the harvest index and transpiration efficiency and by suppressing evaporation. But those potential increases are rather limited and may not contribute substantially to solving the water scarcity and food security issues of this region.

Farmers adopt three strategies to improve water use efficiency:

- reducing evaporation from the soil surface, deep percolation and residual water in the root zone.
- Improving the crop's transpiration efficiency.
- Increasing the harvest index.

The three processes are not independent, as targeting specific traits to improve one process may have detrimental effects on the other two, but there may also be positive interactions (Farquhar et al. 2004). Except for increasing the transpiration efficiency, the other processes require more water to increase yields. Drought-tolerant varieties, for example, yield better under drought conditions than water responsive varieties, but their higher yields may use more water.

Drought-tolerant varieties, among other factors, have deeper roots than other varieties, and thus can extract more water from the soil profile when the soil-water level is lower from deeper layers. The extra water taken by a drought-tolerant variety will not be available for crop use in the following season. This means that by increasing yields we do not necessarily save water proportionally. Breeders, especially under rainfed systems, often correlate yield increases with the total amounts of precipitation received during the season and usually do not measure or estimate the actual evapotranspiration. Ignoring residual water in the soil before and after the crop season and soil water movements during the season often underestimates actual crop water use. We usually use more water, which is hidden and not apparent to water users, and a false impression of water saving is often attributed to the crop or to the system.

Generally, substantial increases in crop yields require larger supplies of water, which may not be available. Thus, a yield-targeting strategy, alone, cannot solve the water shortage problem.

Improving Irrigation Efficiency: The Scale Issue

The term "efficiency" refers to the ratio of output to input. It is widely used in irrigation system design, evaluation, and management. Farm irrigation performance is based on four fundamental and interrelated efficiency terms: conveyance, application, distribution, and storage. The first two are the most relevant. Water conveyance efficiency is the ratio of water diverted from the source to that delivered to the farm. It reflects water losses from the conveyance system mainly through seepage, evaporation, and consumptive use by weeds. Irrigation application efficiency is the ratio of the water stored in the plant root zone to that applied to the field. It mainly reflects losses of water through deep percolation and runoff.

Water "losses" implied in the above efficiency terms are mostly not real losses. Seepage from irrigation canals and losses from field-level deep percolation are largely recoverable, as they normally join adjacent groundwater and springs. Runoff losses end up in fields downstream. Drainage water can also be recycled and used several times before becoming too saline, as has been done in Egypt (Van Steenbergen and Abdel Dayem 2007). Although most of these "losses" are recoverable, engineers strive to minimize them, as their recovery implies some costs to the user and other implications.

These efficiencies are essential for the design, monitoring, and performance evaluation of irrigation systems, but we must remember some caveats. Increasing application and conveyance efficiencies saves water at the farm level but not necessarily at the scheme or basin level, as lost water can be recycled and reused downstream. And higher irrigation efficiency implies better irrigation performance—but not necessarily higher agricultural production (Kijne et al. 2002).

Modernizing Irrigation Systems: The Fallacy

Many countries strive to convert traditional surface irrigation to modern systems, such as drip and sprinklers, which achieve higher water application efficiency. The lower efficiency of surface systems is mainly a consequence of low application efficiency. As indicated above, these losses occur at the field level, but often are partially or fully recovered at the scheme or basin levels by recycling drainage and runoff water or by pumping deep percolation losses from groundwater aquifers. (In some occasions these losses are not recovered, as they may join salt sinks or be

stored in unreachable locations.) Of course, these are important losses to the farmer, as the recovery has a cost—still, they are not total losses at the larger scale.

Reducing field losses by converting to modern systems will not create substantial additional water resources. In Egypt, individual farmers along the Nile and over the Delta lose on average about 55% of the water they apply through surface irrigation systems in runoff and deep percolation (an application efficiency of 45%). However, the lost water is continuously recycled through the drainage system and groundwater pumping. Only about 10% of the Nile water in Egypt is lost to the sea, which brings the system's overall efficiency to about 90%. Surface irrigation system losses must be understood in the context of scale to evaluate the real nature of losses across the system.

Modern systems such as sprinkler and drip irrigation are meant to be efficient. However, they can be efficient only if they are managed properly. Often they are no more efficient than traditional surface systems because of poor management. It was reported that the modern drip systems in the Jordan Valley are operated at an application efficiency of about 56% or less. Drip irrigation can be very efficient only if the system is well designed and maintained, and if irrigation scheduling is in accordance with crop water requirements. If management is lax, drip irrigation methods become very inefficient, as farmers operate the system much longer than necessary. Surface systems can perform very well if designed and operated properly (Shatanawi et al. 2005). Surge flow furrow irrigation can achieve over 75% application efficiency (Oweis and Walker 1990). Selection of the appropriate irrigation system may not depend solely on its application efficiency, but on physical and socioeconomic conditions at the site.

It is well established that modern irrigation systems can achieve higher crop productivity. But this is achieved not by reducing system losses in deep percolation and runoff, but rather through better control, higher irrigation uniformity, reduced irrigation frequency (less crop moisture stress between irrigations), better fertilization (fertigation), and other factors. In some modern systems, such as drip systems, real water savings can be achieved by reducing evaporation losses, where the wetted soil surface is limited and mulches can be used to further reduce evaporation. The increased land productivity, however, comes at a cost: higher capital, higher energy consumption, and more maintenance requirements. Successful

conversion requires a developed industry, skilled engineers, technicians, and farmers, and regular maintenance (Oweis 2012).

Modern systems are most successful in areas where water is scarce and expensive, so that farmers can recover the system cost by reducing irrigation losses and increasing productivity. Where water is cheap and abundant, farmers have little incentive to convert to modern systems. In fact, improving surface irrigation systems through land leveling and better water control may be more appropriate for most farmers in developing countries. The vast majority of irrigation systems worldwide are surface irrigation; this is unlikely to change in the near future. A wise strategy is to invest more in improving surface irrigation, while simultaneously encouraging the use of modern systems when conditions are favorable (Oweis 2012).

Managing Demand: Not Working

Although water is extremely scarce in the Middle East, it is generally supplied free of charge or at a low and highly subsidized cost (Cosgrove and Rijsberman 2000). Farmers have little incentive to restrict their use of water or to spend money on new technologies to improve the use of available water. International agencies, donors, and research institutes are advocating pricing schemes for water based on total operational costs. Although it is widely accepted in the region that water pricing would improve efficiency and increase investment in water projects, the concept of pricing presents enormous practical, social, and political challenges.

Traditionally, water is considered to be God's gift, to be distributed free to everyone. There is additional pressure from farmers for subsidized inputs. There is also a fear that once water is established as a market commodity, prices will be determined by the market, leaving the poor unable to buy water even for household needs. Downstream riparian countries fear that upstream countries may use international waters as a market commodity in the negotiations on water rights.

One cannot ignore these very real concerns. Innovative solutions are therefore needed to put a real value on water in order to improve efficiency but at the same time abiding by cultural norms and ensuring that people have sufficient water for basic needs. Subsidies for poor farmers may be better provided in areas other than water, so that the subsidies do not encourage inefficiency. Countries must strengthen the recent trend

to recover the running costs (operation and maintenance) of irrigation supply systems.

Water pricing and other tools of demand management will reduce the demand for water in agriculture but may not improve agricultural production or poor farmers' livelihoods. It will benefit other water use sectors, but will not contribute to increasing food security.

Water Productivity: A Comprehensive Framework

Improving irrigation efficiency, although necessary for the better performance of irrigation systems, does not reflect many aspects of agricultural water use, especially the returns to water used. Water productivity is the return or the benefits derived from each cubic meter of water consumed. This return may be biophysical (grain, meat, milk, fish, etc.), socioeconomic (employment, income), environmental (carbon sequestration, ecosystem services), or nutritional (protein, calories, etc.). Table 7-1 presents a range of water productivity values for selected agricultural products. It may be worth mentioning that for each product and productivity type, the range indicates the high and low performances of the production system.

It is important to distinguish between water depleted and water diverted or applied, because not all water diverted (or supplied) to irrigation is depleted. Recoverable losses (such as surface runoff, deep percolation, etc.) can be reused within the same domain or at a higher landscape scale. More specifically, depleted water includes evaporation, transpiration, water quality deterioration, and water incorporated into the product or plant tissues. Water recycled in the farming system may not be totally lost as implied by evaluating irrigation efficiencies. Water is defined not only by its amount but also by its quality and the time it is available. Various water qualities have different productivities, and it is necessary to establish some benchmarks and thresholds to standardize the unit of water for comparison. The timing of the application has a notable impact on water productivity. Here, the storage (in the soil, in groundwater aquifers, or in surface storage) plays an important role in applying water to crops in time to maximize water productivity.

It is now well understood that water productivity is a scale- or level-dependent issue requiring a multidisciplinary approach (Molden et al. 2010). Drivers to improve it vary with scale. At the field scale it is desirable

Table 7-1. Water productivity values (biophysical, economic, nutritional, and energy) of selected agricultural products

	WATER PRODUCTIVITY			
Product	**kg/m³**	**$/m³**	**Protein g/m³**	**Calories/m³**
CEREALS				
Wheat ($0.2/kg grain)	0.2–1.2	0.04–0.30	50–150	660–4000
Rice ($0.31/kg)	0.15–0.6	0.05–0.18	12–50	500–2000
Maize ($0.11/kg)	0.30–2.00	0.03–0.22	30–200	1000–7000
LEGUMES				
Lentils ($0.3/kg)	0.3–1.0	0.09–0.30	90–150	1060–3500
Fababeans ($0.3/kg)	0.3–0.8	0.09–0.24	100–150	1260–3360
Groundnut ($0.8/kg)	0.1–0.4	0.08–0.32	30–120	800–3200
VEGETABLES				
Potato ($0.1/kg)	3.0–7.0	0.3–0.7	50–120	3000–7000
Tomato ($0.15/kg)	5.0–20.0	0.75–3.0	50–200	1000–4000
Onion ($0.1/kg)	3.0–10.0	0.3–1.0	20–67	1200–4000
FRUITS				
Apples ($0.8/kg)	1.0–5.0	0.8–4.0	negligible	520–2600
Olives ($1.0/kg)	1.0–3.0	1.0–3.0	10–30	1150–3450
Dates ($2.0/kg)	0.4–0.8	0.8–1.6	8–16	1120–2240
OTHER				
Beef ($3.0/kg)	0.03–0.1	0.09–0.3	10–30	60–210
Fish (1.35/kg)	0.05–0.1	0.07–1.35	17–34	60–175

Source: Molden et al. 2007.

Note: $ = USD.

to maximize the biophysical water productivity of a specific crop or product. At the farm level, the farmer would like to maximize the economic return from the whole farm, involving one or multiple crops or products. At the country level, the drivers for improved water productivity are food security and exports. At the basin level, competition between sectors, equity issues, and conflicts may drive WP issues. It is important to note that the water productivity concept provides a standardized way

of comparing crops and production areas and for determining what to grow and where. Determination of cropping patterns should take into consideration drivers at all scales and all types of water productivity relevant to the population.

In water-scarce areas, water, not land, is the most limiting resource to agricultural development. Accordingly, the strategy of maximizing agricultural production per unit of land (land productivity) may not be appropriate for water-scarce areas. Instead, a strategy based on maximizing the production per unit of water is more relevant. Fortunately, practices for increasing water productivity also improve land productivity to some extent. A tradeoff needs to be made to optimize the use of both water and land resources (Oweis and Hachum 2009). This will require substantial changes in the way we plan and implement agricultural development, which will require a paradigm shift in national policies regarding water use and agriculture. These changes can be achieved in the following ways (Kijne et al 2003).

- Increasing the productivity per unit of water consumed through improved crop varieties; alternative crops (by switching to crops with lower water demand or to crops with higher economic or physical productivity); deficit, supplemental, or precision irrigation; improved water management with better timing of irrigation; and optimizing non-water inputs (such as agronomic practices, policy reform, and public awareness).
- Reducing non-beneficial water depletion by reducing evaporation from soil surfaces in irrigated fields and from fallow land; reducing water flows to sinks (such as salt lakes and the sea); minimizing salinization of return flows and shunting polluted water to sinks to avoid the need to dilute with freshwater; reusing return flows through gravity and pump diversions to increase the irrigated area.
- Reallocating water among uses, including from lower- to higher-value uses, which can dramatically increase the economic productivity of water; tapping uncommitted outflows to be used for productive purposes and improving the management of existing facilities; policy, design, management, and institutional interventions to reduce delivery requirements; adding storage facilities to store and regulate the use of uncommitted outflows.

Practices to Increase Agricultural Water Productivity

There is a great potential to increase agricultural water productivity, especially in developing countries. A wide gap exists between the biological crop returns to water in developed and developing countries (fig. 7-2). Narrowing this gap appears to be feasible and within reach.

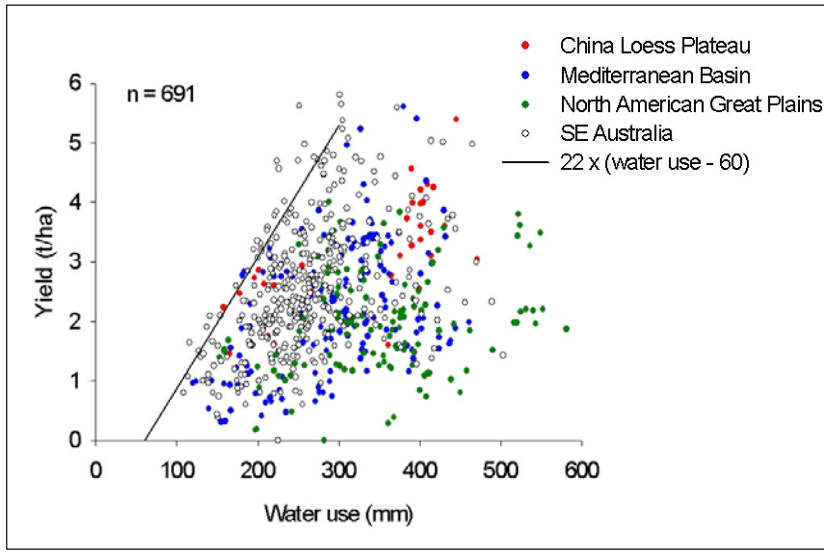

Figure 7-2. Variations between yield and crop water use for wheat in different regions of the world. *Source:* Adapted from Sadras and Angus 2006.

The potential increase is greatest in rainfed agriculture—where, in addition, greater public investment is the most feasible (Rockström et al. 2010). Research has shown that a cubic meter of water can produce several times the current levels of agricultural output through the use of efficient water management practices. This is especially relevant when considering benefits beyond the biophysical and including those of an economic and environmental nature (Ilbeyi et al. 2006).

The following sections describe practices that can substantially increase agricultural water productivity.

Deficit irrigation

Irrigation is usually scheduled to satisfy full crop water requirements to achieve the maximum crop yield per unit of land. Irrigation schedules in

water-scarce areas should be adjusted to maximize water productivity. Deficit irrigation is a practice in which irrigation is deliberately scheduled to provide less than full crop water requirements, exposing the plants to some moisture stress, and somewhat lowering the crop yield per unit of land (lower land productivity). It has been found, however, that if deficit irrigation is well scheduled, the percentage reduction in yield arising from the reduced amount of irrigation is smaller than that of the associated water saving. This means that more yield per unit of water used is achieved with deficit irrigation (higher water productivity) (fig. 7-3). The water saved could be used to irrigate new lands—as land is usually more limiting than water—and thus produce more food from the water available.

Results for rainfed wheat obtained from farmers' field trials in Syria show significant improvement in water productivity at lower application rates of supplemental irrigation than at full irrigation. This is especially clear as farmers, in general, tend to over-irrigate. The highest water productivity for applied irrigation was obtained at rates between one-third and two-thirds of that achieved with full irrigation, in addition to rainfall (Pereira et al 2002). One important merit of deficit irrigation in rainfed systems is the greater potential for benefiting from unexpected rainfall because of the higher availability of storage space in the crop root zone.

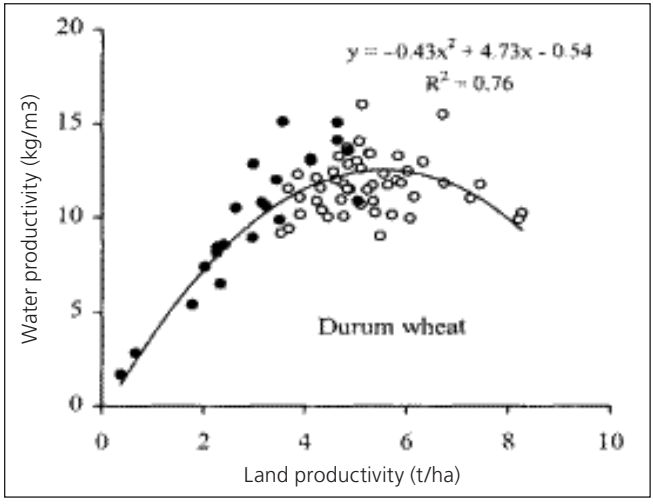

Figure 7-3. Relationship between water productivity and land productivity for durum wheat in a Mediterranean environment. *Source:* Zhang and Oweis 1999.

However, guidelines for crop water requirements and irrigation scheduling to maximize water productivity are yet to be developed for the important crops in dry areas. In particular, it is necessary to develop further the water production functions for various crops and work with economists on evaluating the merits of deficit irrigation and its optimization. National policies, however, need to be adjusted to reward farmers using deficit irrigation by maximizing their returns with improved supplemental irrigation

Supplemental irrigation

A shortage of soil moisture in rainfed agriculture often occurs during the most sensitive growth stages, affecting crop growth, yield, and water productivity. Supplemental irrigation can substantially increase yield and water productivity by applying limited amounts of water during critical crop growth stages to alleviate moisture stress during dry spells. Unlike full irrigation, this practice is used in rainfed areas where precipitation is the main source of water for the crops and farmers normally practice dryland farming if no water source for irrigation is available. Also, the timing and amount of supplemental irrigation cannot be determined in advance given the randomness of the rainfall. The average water productivity of rain in wheat cultivation in the dry areas of West Asia and North Africa ranges from about 0.35 to 1.00 kg of grain/m^3. However, water used in supplemental irrigation yields more than 2.5 kg of grain/m^3, i.e., in the same environment; supplemental irrigation gives a water productivity twice as high as full irrigation. (Oweis and Hachum 2009).

In the highlands, supplemental irrigation can be used to plant winter crops early, avoiding frost and improving yields. In the highlands of Turkey and Iran, early sowing with 50 mm of supplemental irrigation almost doubled the yields of rainfed wheat and barley and gave water productivity as high as 3 to 4 kg/m^3 (Ilbeyi et al. 2006). Clearly, water resources are better allocated to supplemental irrigation when other physical and economic conditions are favorable.

Rainwater harvesting

Precipitation in much of the dry areas is generally too low and poorly distributed for viable crop production. One potential solution is water harvesting, which is defined as the process of concentrating precipitation through runoff and storing it for beneficial use. This brings the amount of water

available to the target area closer to the crop water requirements, increasing water productivity and the economic viability of crop production. In areas with higher rainfall, much of the water flows as runoff, eroding fertile soils and leaving the soil profile with little moisture for plant growth. With climate change, rainfall intensities are expected to increase, making things even worse. Water harvesting reduces the runoff velocity and allows more time for infiltration, increasing soil water storage and combating land degradation (Oweis et al. 2012).

A wealth of information on traditional indigenous water harvesting practices is available. Indigenous systems, such as *jessour* and *meskat* in Tunisia, *tabia* in Libya, cisterns in north Egypt, *hafaer* in Jordan, Syria, and Sudan, and many other techniques are still in use. Modern practices based on indigenous knowledge, including contour ridges, semicircular bunds, runoff strips, etc., are now available for farmers to use. Water harvesting can provide water for crops, trees, domestic use, livestock, etc. Unfortunately, the introduction of systems that have been extensively tested under similar conditions elsewhere is usually not accepted by the target groups. Several other constraints hinder the wider development of water harvesting systems, including technology inadequacy, lack of community involvement, poor design and implementation, land tenure issues, inadequate institutional structures, and an absence of long-term government policies. Integrated watershed management approaches should be used in the planning of water harvesting where upstream-downstream interactions may be considered (Oweis et al. 2012).

Alternative cropping patterns

Current land use and cropping patterns must be changed if more food is to be produced from less water. New land use systems that respond to external as well as internal factors must be developed based on water availability. These systems should include greater use of water-efficient crops and varieties and more efficient crop combinations. The choice of alternative crops and farming systems should be based on a careful analysis of the biophysical factors as well as the returns from the water used, including income, social, and environmental aspects. New cropping patterns, in particular, must be introduced gradually and will often require policy support to encourage adoption (Molden et al. 2007). In cases of extreme water scarcity it becomes necessary to supplement national food

production with imports of "virtual water" in the form of products that are less water productive nationally.

Precision agriculture and irrigation

Precision agriculture is the close control of the amounts, timings, and variability of water application and other agricultural inputs to the crop and the system. It provides a way of monitoring the food production chain and managing both the quantity and quality of agricultural produce (Adamchuk and Gebbers 2010). Improved technologies that are currently available can at least double the amount of food produced—with no increase in water consumption—in other words, doubling water productivity. Implementing precision irrigation on laser-leveled land with uniform fertility and other techniques can substantially improve water application and distribution and result in high water productivity. Spatial variations, at the field level, of nutrients and soil-water can be minimized with precision agriculture, resulting in better management and improved outputs (Pereira et al. 2002).

The Challenge of Change

"Business as usual" is no longer an option for agricultural water management in the water-scarce Middle East. Unless strategic changes are made, the region will face increasing water and food insecurity. New thinking should drive new strategies and approaches backed by concrete action at the country and local levels. Regulatory and legislative reforms in the water sector are needed, rationalizing use and attracting more investment while protecting the most vulnerable sections of the population. Policy support and funding for research and building human and institutional capacity are essential to stimulate technological innovation. Local policies often contribute to the slow adoption of available technologies. Policy reforms can bring about a substantial change in the way we manage water resources. The region will soon face a water crisis unless several strategic changes are made.

- Change the emphasis from land to water. The traditional strategy of maximizing yield per unit of land is appropriate when land is the limiting resource for agriculture. Where water is the limiting resource, strategies should focus, instead, on maximizing water productivity. Policies should foster this change by creating an enabling environment for adoption whereby farmers maximize their profit.

- Change current land use and cropping patterns to more water-productive crops and cropping systems. New cropping patterns need to be studied—based on the comparative advantages of each agroecology—to replace inefficient crops, reduce water demand, and increase competitiveness.
- Change the way water is valued to truly reflect the conditions of scarcity. Since water is generally a common or shared resource, equity and sustainability issues must be carefully considered when policies are being developed.
- Change trade policies to import goods that have a high water demand. Large amounts of water cross borders as virtual water. This needs to be adjusted to reduce water demand and support existing farming systems and the associated socioeconomics.
- Change the attitude toward regional cooperation. Water productivity may be improved at the farm level, but it will not be maximized unless it is tackled at the basin level. This requires regional cooperation, particularly among countries that share river basins.
- Change from a disciplinary to an integrated approach. Narrowly focused or discipline-based research is not adequate to maximize water productivity. Developing productive, sustainable, agricultural systems requires integrating natural resource management with crop improvement and farming systems research.

References

Abdel-Shafy, H. I., and M. S. M. Mansour. 2013. Overview on Water Reuse in Egypt: Present and Future. *Sustainable Sanitation Practice* 14:17–25.

Adamchuk, V. and R. Gebbers. 2010. Precision Agriculture and Food Security. *Science* 327(5967): 828–831.

Al-Karaki, G. 2011. Utilization of Treated Sewage Wastewater for Green Forage Production in a Hydroponic System. *Emirates Journal of Food and Agriculture* 23(1): 80–94.

Cosgrove, W. and F. Rijsberman, ed. 2000. *World Water Vision: Making Water Everybody's Business.* London: Earthscan Publications.

FAO (Food and Agricultural Organization of the United Nations). 2011. *The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk*. Rome: FAO.

Farquhar, G., A. Condon, N. Richards, and G. Rebetzke. 2004. Breeding for High Water-Use Efficiency. *Experimental Botany* 55(407): 2447–2460.

Ghaffour, N., T. M. Missimer, and G. Amy. 2013. Technical Review and Evaluation of the Economics of Water Desalination: Current and Future Challenges for Better Water Supply Sustainability. *Desalination* 309: 197–207.

Ilbeyi, A., Ustun, H., Oweis T., Pala, M., and Benli, B. 2006. Wheat Water Productivity in a Cool Highland Environment: Effect of Early Sowing With Supplemental Irrigation. *Agricultural Water Management* 82: 399–410.

ICARDA (International Center for Agricultural Research in the Dry Areas). 2007. *Improving Livelihoods in Dry Areas: Strategic Plan 2007–2016*. Aleppo: ICARDA.

Kijne, J., T. Tuong, J. Bennett, B. Bouman, and T. Oweis. 2002. *Ensuring Food Security via Improvement in Crop Water Productivity. Background Paper 1: Challenge Program on Water and Food*. Colombo: International Water Management Institute.

Kijne, J., R. Barker, and D. Molden. 2003. Improving Water Productivity in the Dry Areas of West Asia and North Africa. In K. W. Kijne, R. Barker, and D. Molden, eds., *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. 179–197. Wallingford, UK: CABI Publishing.

Molden, D., T. Oweis, P. Steduto, et al. 2007. Pathways for Increasing Agricultural Water Productivity. In D. Molden, ed., *Water tor Food, Water for Life*. 279–310. London: Earthscan; and Colombo: International Water Management Institute.

Molden, D., T. Oweis, P. Steduto, P. Bindraban, M. Hanjra, and J. Kijne. 2010. Improving Agricultural Water Productivity: Between Optimism and Caution. *Agricultural Water Management* 97(4): 528–535.

Oweis, T. 2012. The Fallacy of Irrigation Modernization. *Revolve* (Special Issue 6): 42–43.

Oweis, T., and A. Hachum. 2009. Optimizing Supplemental Irrigation: Tradeoffs between Profitability and Sustainability. *Agricultural Water Management* 96: 511–516.

Oweis, T., and W. R. Walker. 1990. Zero-Inertia Model for Surge Flow Furrow Irrigation. *Irrigation Science* 11(3): 131–136.

Oweis, T., D. Prinz, and A. Hachum. 2012. *Rainwater Harvesting for Agriculture in the Dry Areas*. London: CRC.

Pereira, L. S., T. Oweis, and A. Zairi. 2002. Irrigation Management under Scarcity. *Agricultural Water Management* 57: 175–206.

Rende, M. 2007. Water Transfer from Turkey to Water-Stressed Countries in the Middle East. In H. Shuval and H. Dweikeds, eds., *Water Resources in the Middle East: Israel-Palestinian Water Issues, from Conflict to Cooperation*. 165–173. Berlin: Springer.

Rockström, J., L. Karlberg, S. P. Wani, J. Barron, et al. 2010. Managing Water in Rainfed Agriculture—The Need for a Paradigm Shift. *Agricultural Water Management* 79(4): 543–550.

Rosegrant, M. W., and X. Cai. 2001. Water Scarcity and Food Security: Alternative Futures for the 21st Century. *Water Science and Technology* 43(4): 61–70.

Sadras, V. O., and J. F. Angus. 2006. Benchmarking Water-Use Efficiency of Rainfed Wheat in Dry Environments. *Australian Journal of Agricultural Research* 57(8): 847.

Solh, M. 2011. Ensuring Food Security in a Changing Climate: How Can Science and Technology Help? In M. Solh and M. C. Saxena, eds., *Food Security and Climate Change in Dry Areas: Proceedings of an International Conference*. 5–12. Aleppo, Syria.

Shatanawi, M., A. Fardous, N. Mazahreh, and M. Duqqa. 2005. Irrigation System Performance in Jordan. In N. Lamaddalena, F. Lebdi, et al., eds., *Irrigation System Performance.* Options méditerranéennes, series B no. 52. 128–131. Bari, Italy: CIHEAM.

UNDP (United Nations Development Programme). 2013. *Water Governance in the Arab Region: Managing Scarcity and Securing the Future*. New York: UNDP.

Van Steenbergen, F., and S. Abdel Dayem. 2007. Making the Case for Integrated Water Resources Management: Drainage in Egypt. *Water International* 32(suppl. 1): 685–696.

Zhang, H. and T. Oweis. 1999. Water-Yield Relations and Optimal Irrigation Scheduling of Wheat in the Mediterranean Region. *Agricultural Water Management* 38: 195–211.

Climate Change and Increasing Aridity: The Fate of Agriculture and Rural Communities in the Middle East and North Africa

Dr. Lovell S. Jarvis

University of California, Davis

Dr. Jean Paul Petraud

University of California, Davis

Introduction

This paper reviews options for confronting the increasing aridity expected in the Middle East and North Africa (MENA) region as climate change progresses during the next century and as these changes affect agriculture and rural communities. The agricultural sector remains by far the largest user of water in the region, and it is certain to suffer from a significant decline in water availability. That decline will greatly reduce the welfare of those dependent on agriculture unless important measures are taken to improve water use efficiency, enhance economic growth, and directly attend to the needs of rural residents. Our paper assumes a goal of improving economic and social welfare, with particular interest in safeguarding the welfare of the poor, who are disproportionately employed in agriculture and/or are residents in the rural communities that depend on agriculture.

The MENA region is the most water-scarce region of the world, where scarcity is measured as the volume of water available annually to each resident. Total actual renewable water resources (TARWR) in the region averages less than 1,000 m^3 per year per capita. As shown in figure 8-1, 15 of 21 MENA countries fall below this level, with many falling well below. While 6 of 21 countries have more than 1,000 m^3 per capita per year, three of these countries have declining TARWR levels that are likely to soon fall

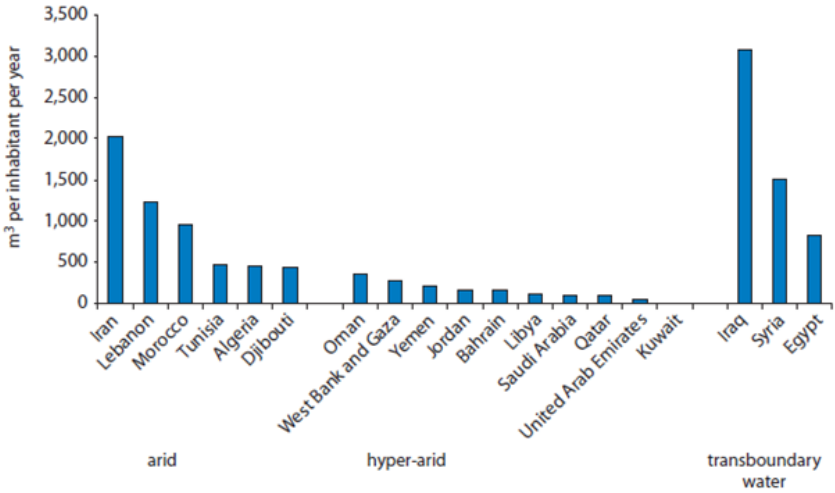

Figure 8-1. Total actual renewable water resources per capita in the MENA Region. *Source:* World Bank 2007.

below 1,000 m^3 as their populations increase (see table 8-1). MENA countries vary in terms of the sources of their water supply, the nature of water demand, and their economic resources, reflecting different levels of human and institutional development. Thus, some countries are better situated than others to confront the problems faced.

Climate change is expected to increase average temperatures, decrease precipitation, increase extreme climate events, and raise the Mediterranean Sea level, causing loss of coastal agricultural areas. Water availability will decline from traditional sources such as precipitation, surface catchment and storage, and underground aquifers. Simultaneously, population growth will increase the number of water claimants. As water availability shrinks and urban demand increases, history suggests that the amount of water available to agriculture and rural communities will decline. This is the harsh reality that must be faced. The question is how best to face this challenge.

The MENA region has competent water institutions and an extensive water infrastructure. However, policy has focused on increasing water supply rather than on managing water demand. This policy is no longer adequate. The opportunities for supply enhancement are decreasing, i.e., the cost of new water supplies is rising, even if desalinization and wastewater treatment can help provide additional sources for specific needs. We argue that the MENA region will benefit greatly from implementing water

Table 8-1. Total actual renewable water resources 2008–2012

	TARWR (10^9 m^3/yr)			TARWR per capita (m^3/inhab/yr)			AFED 2025 predictions
Algeria	11.67	I	2010	329	K	2010	261
Bahrain	0.12		2010	92	K	2010	106
Djibouti	0.30	I	2010	338	K	2010	260
Egypt	57.30		2010	706	K	2010	252
Iran (Islamic Republic of)	137.50		2010	1,859	K	2010	
Iraq	75.61	I	2010	2,387	K	2010	1551
Israel	1.78	I	2010	240	K	2010	
Jordan	0.94	I	2010	151	K	2010	98
Kuwait	0.02		2010	7	K	2010	4
Lebanon	4.50		2010	1,065	K	2010	919
Libya	0.70	I	2010	110	K	2010	67
Morocco	29.00	I	2010	908	K	2010	558
Oman	1.40	I	2010	503	K	2010	365
Occupied Palestinian Territory	0.84	I	2010	207	K	2010	
Qatar	0.06		2010	33	K	2010	40
Saudi Arabia	2.40	I	2010	87	K	2010	64
Sudan and South Sudan	64.50	I	2010	1,481	K	2010	1122
Syrian Arab Republic	16.80		2010	823	K	2010	550
Tunisia	4.60		2010	438	K	2010	373
Turkey	213.60		2010	2,936	K	2010	
United Arab Emirates	0.15		2010	20	K	2010	20
Yemen	2.10	I	2010	87	K	2010	120

Note:

I = AQUASTAT estimate

K= Aggregate data

and economic reforms to allow market forces to play a larger role guiding resource allocation, e.g., in crop production and water use in general. These reforms would create economic signals at the farm level to shift agricultural resources toward higher-value export crops, which are also more management and labor intensive. Simultaneously, economic reforms would create signals at the firm level in urban areas, leading to more rapid economic growth that would create attractive employment for rural-to-urban migrants. Although economic reforms would facilitate an agricultural transformation that leads to higher-value crops and that increases labor productivity, this transformation may not fully offset the loss of jobs that will occur as water scarcity rises. Regardless, it is unlikely that agriculture can absorb the additional workers that will appear in rural areas as a result of population growth. Thus, in addition to efforts to increase agricultural productivity, policy measures to facilitate rural-to-urban migration are essential if rural poverty is to be relieved. However, urban growth alone is insufficient. Policy changes to spur investments in agricultural and rural communities are essential.

Rising agricultural productivity and successful rural-to-urban migration will not be achieved unless education is improved and water demand management becomes a focus of policy in both rural and urban areas. Education must be improved for rural residents, as enhanced human capital will be a key input in modernizing agriculture and a requirement for obtaining productive employment in the urban sector for those who migrate. If water is used more efficiently throughout the economy, more can be produced from the scarce water available. Using water more efficiently in industry and in households will also free up more water for use in agriculture. Greater use of pricing mechanisms will be needed to achieve more efficient water use. The introduction of water pricing mechanisms will be politically difficult, but using water prices that increasingly reflect the opportunity cost of water is essential for achieving longer-run success.

Reform will be difficult, but the alternative to reform is bleak. Without economic reform, the economy will grow more slowly, fewer urban jobs will be created, and those jobs will be less productive. The urban-industrial sector will absorb more water regardless as the urban population grows, and the water available for agriculture will decline more sharply. Historically, whenever urban areas have lacked water, policy-makers have

immediately reduced water supplies for agriculture. In this situation, agricultural regions will produce less, generate less income, and offer fewer and less productive jobs, and the rural poor will be poorer and many will not have the resources to migrate successfully to urban areas.

This paper first presents evidence of increasing water scarcity in MENA countries and its likely consequences for agriculture and rural communities. We then explain why water-sector reform is necessary, why water reforms must also be accompanied by broader economy-wide reforms, and why establishing safety nets for poor farmers, agricultural workers, and investments in key rural communities are also essential. We end by recognizing the political challenges to this agenda and also the absence of good alternatives.

Predictions for Growing Water Scarcity

The MENA region is well known for having focused its efforts on increasing water supply. These efforts have successfully increased water availability, but at ever-rising cost, through the creation of dams and other catchment facilities for surface water and the exploitation of groundwater aquifers, including the construction of long-distance water conveyance and water distribution systems. More recently, major efforts are being made to increase treatment of wastewater for use in agriculture and desalinization for urban water consumption. Desalinization is becoming cheaper, making it another option, though water from the most efficient systems remains expensive at roughly $0.50 per m^3 and is thus not economically viable as a general supply for agriculture.

Three major factors are causing increasing water scarcity: population growth, a need to reduce aquifer overdrafts, and climate change. Population growth is currently about 1.8% annually (UN) and is predicted to decline only gradually. If population grows at an average rate of 1.3%, population will nearly double within 50 years. Rising population implies that water per capita will decrease sharply unless more water can be found.

Unfortunately, water availability is expected to decline, not increase. The MENA region has steadily increased groundwater extraction, but many of the aquifers contain fossil water and enjoy little to no recharge. The MENA region is already suffering from over-extraction of groundwater aquifers and aquifer water contamination due to saltwater and/or sewage

intrusion in some regions (Shetty 2006). Thus, many MENA countries are seeking to reduce rather than increase groundwater extraction. [Increasing supply from groundwater extraction has reached its limit.]

Climate change will cause acceleration of the hydrologic cycle that will also reduce the availability and the quality of water resources. Increasing surface temperature and declining rainfall will cause a decrease in surface water and a declining water table for groundwater. Rainfall will become less predictable, with greater frequency of drought and a higher probability of desertification in some regions, and, ironically, a higher probability of extreme climate events that will include flooding. Climate change will cause the Mediterranean Sea to rise, increasing coastal flooding and salt-water intrusion in coastal agricultural lands (Shetty, 2006; Sowers, et al., 2010).

Climate models predict a major reduction in precipitation in the MENA region, e.g., an average 10 to 25% decline by the end of the twenty-first century (UNDP 2007/08; Suppan et al. 2008). The effect is expected to be most severe in the eastern Mediterranean. The decrease in precipitation will combine with higher average temperatures to increase evaporation, reducing water availability to plants by even more. Oroud (2008) predicts the average water yield in Jordan will decrease by 45 to 60% due to a 10% decrease in precipitation and a temperature increase of 2°C, with similar expectations for Syria. Suppan (2008) predicts an increase of up to 4.5°C in mean temperature and a decrease of up to 25% in precipitation by the end of the century, with combined effects leading to a decrease of 23% of the Upper Jordan catchment. The Arab Human Development Report predicts that countries such as Lebanon and Morocco will experience a 10 to 15% decrease in water supply for every 1°C increase in mean temperature. Barghouti (2010) predicts the decline in the per capita TARWR index will be severe even by 2025, with that in Iraq decreasing by 35%, Morocco by 38%, and Yemen by 40%. Clearly, climate change is expected to have a strong negative effect on water and, thus, agriculture.

Water Scarcity and Agriculture

Agriculture varies in its importance across countries in the MENA region. As shown in table 8-2, agricultural value added as a share of GDP is less than 10% in 14 countries, but more than 20% in 2 countries. Six countries

Table 8-2. Share of agriculture 2008–2012

	Percentage of total country area cultivated (%)			Total economically active population in agriculture (1,000 inhab)			Share of agriculture (%)	Agriculture, value added to GDP (%)		
Algeria	3.54	E	2009	3175	E	2010	21	6.92	E	2010
Bahrain	5.00	E	2009	4	E	2010	1	0.86		1995
Djibouti	0.09	K	2009	285	E	2010	74	3.86	E	2007
Egypt	3.68	E	2009	6619	E	2010	25	13.99	E	2010
Iran (Islamic Republic of)	10.88	K	2009	6553	E	2010	22	10.06	E	2008
Iraq	10.91	E	2009	436	E	2010	5	8.57	E	2003
Israel	17.34	E	2009	51	E	2010	2			
Jordan	3.17	E	2009	113	E	2010	6	2.93	E	2010
Kuwait	0.84	E	2009	14	E	2010	1	0.46	E	2003
Lebanon	27.56	E	2009	28	E	2010	2	6.39	E	2010
Libya	1.17	E	2009	71	E	2010	3	1.87	E	2008
Morocco	20.28	E	2009	3008	E	2010	25	15.38	E	2010
Occupied Palestinian Territory	36.05	E	2009	110	E	2010	8	14.34	E	2003
Oman	0.44	E	2009	318	E	2010	29	1.86	E	2004
Qatar	1.29	E	2009	8	E	2010	1			
Saudi Arabia	1.60	E	2009	515	E	2010	5	2.58	E	2010
Sudan and South Sudan	8.14	E	2009	7124	E	2010	52	23.63	E	2010
Syrian Arab Republic	30.59	E	2009	1337	E	2010	20	22.93	E	2009
Tunisia	30.17	E	2009	805	E	2010	21	8.01	E	2010
Turkey	31.00	E	2009	8068	E	2010	32	9.60	E	2010
United Arab Emirates	3.16	E	2009	148	E	2010	3	0.97	E	2009
Yemen	2.75	E	2009	2314	E	2010	39	7.64	E	2010

Note:

E = External data

cultivate more than 20% of their total national area, while 12 countries cultivate less than 5% of total area.

Although agriculture accounts for a relatively small share of GDP in most countries, it accounts for 80% of total water use in MENA countries, reaching more than 90% in six of 19 countries (see table 8-2) Domestic (household) use ranges from 3 to 45%, but in 8 countries household use is less than 10% and in another 7 it is about 20%. These data show substantial scope for increasing water availability to domestic users and industry as population growth and urbanization occur, but with agriculture suffering a significant decline in water availability. For example, when water stress threatened water supply, Israel decreased water allocated to agriculture from 80% to 56% from 1985 to 2003 (Molle and Berkhoff 2006). Jordan, Morocco, and Tunisia have also begun to increase water use efficiency in agriculture and move water from agriculture to industrial and municipal uses (Shetty 2006).

The decrease in water availability will require a reduction in the area planted to crops. The combined effect of scarcer water and higher temperatures will also decrease crop yields. Many crops in the MENA region are already cultivated at the extremes of tolerance to heat and salinity, and yields of these crops are expected to decrease. For example, Eid et al. (2007) predict a decline of 9 to 19% in crop yields for a temperature increase of 2°C, which is the lower limit of temperature increase at the end of the twenty-first century predicted by climate models.

Declining cropped area and crop yields will reduce agricultural employment. Currently, agriculture accounts for a large share of regional employment (28% in Egypt, 44% in Morocco, 50% in Yemen) (WDI database), though the proportion varies widely, being less than 10% in 11 countries, more than 20% in 11 countries, and with 4 more than 30%. It is not unreasonable to anticipate that as water availability declines, agricultural employment will decline as well, even if not fully proportionately. In those MENA countries where agriculture is "small"—whether in terms of the shares of workers employed or output produced—adjustment will be easier if for no other reason than that the displaced workers and entrepreneurs will be a small part of the whole and thus more easily absorbed in other activities. The decline in agriculture, employment, and incomes and in the viability of agricultural communities will create stress, but these countries are more likely to achieve an attractive transition than are countries

where the adjustment will be large. In the latter, the number of displaced workers will be greater and they will be a larger proportion of the total labor force. In these countries, there is special incentive to begin planning now for transition.

Rural Communities and Rural-to-Urban Migration

Historically, in the economic development process most of the population is initially employed in agriculture and resident in rural areas. As economic development occurs, higher incomes lead consumers to spend a larger proportion of their incomes on manufactures and services, with consequent increase in the industrial and service sectors that are located mainly in urban areas. Workers in industry usually have higher productivity and earn higher wages than those in agriculture, and those higher wages are one factor causing rural workers to migrate to towns and cities. Accordingly, the proportion of workers active in agricultural activities and/or resident in rural areas steadily diminishes. The movement of workers from less-productive to more-productive jobs benefits both workers and the economy.

The MENA countries have been following a similar path for some decades. However, if agriculture declines as a result of growing water scarcity, rural workers may be "pushed" out of agriculture, moving in search of "any" job, not a better job, and the workers and the nation will be worse off as a result. Migration will be more difficult for those who leave and will be less likely associated with rising productivity and incomes. The remaining rural workers and their communities also will be poorer, and those who migrate to the city may be disaffected and a source of social unrest.

Empirical evidence shows that most workers want to stay where they are if they can (Findlay 2011), and, when migration occurs, many migrants move a short rather than a long distance. Indeed, migrants often do not move to the site that would be most economically attractive, but instead select an intermediate site. For example, about half of all migrants are rural-to-rural migrants in Ethiopia (Dorosh et al. 2011). The selection of destinations is influenced by preexisting social and cultural connections, not just immediate financial gain (Brooks and Waters 2010). We will return to this point subsequently, suggesting that governments should assist with the development of rural towns that can attract local migrants from smaller

villages or farms within the same area, while serving as growth poles for the region.

Migration is likely to have two effects on the communities of origin. The poorest members of society are usually the least likely to move. Migrants tend to be the younger and better-educated members of a community, and their departure is likely to reduce the average productivity of the agricultural and rural labor force (Ackah and Medvedev 2010). However, many rural migrants remit income to family members that remain behind, and these remittances can significantly improve household welfare in the community of origin. Policies at origin may also provide financial infrastructure to ease the flow of remittances and to link remittances to financial access at the origin household level (Ratha et al. 2011.)

Migrant households have a higher probability of joining community groups and social networks, increasing the strength of social arrangements such as risk-sharing schemes at origin (Gallego and Mariapia 2010.) Networks help migrants with information, thereby reducing uncertainty and costs, which influences the choice of destination (Chort 2010.) With data from the Mexican Migration Project, Munshi (2003) finds that the size of the destination network increases the probability of gaining employment and expected earnings. Policies in support of migration might include supporting migrant welfare organizations at destination, with particular attention to gender. While male and female migrant networks have the same influence on women's decision to migrate, the destination of female migrants is strongly influenced by the location of female network migrants (Davis and Winters 2001.) Knowledge of these influences can help countries develop more productive and beneficial networks to assist with migration and with the flow of return remittances.

Rural Conflict

Growing water scarcity can become a source of serious conflict within and between rural communities. There is limited evidence this has occurred in the MENA region. For example, fighting has occurred between different tribes in Yemen that appears directly related to conflict over water resources (World Bank 2007). Similarly, there is evidence of a link between violence and environmental degradation in Darfur (Smith and Vivekananda 2007). However, analysis of a broad range of case studies of

environmental degradation has led other scholars like Thomas Homer-Dixon to conclude that it is difficult to identify a direct link between scarcity and violence. Factors like inequality and the degree of social inclusion or exclusion seem to influence the nature and degree of conflict when it appears (Lecoutere et al. 2010).

We conclude that most MENA countries have reached a level of development in which rural communities will not dissolve into desperate poverty and conflict as water becomes increasingly scarce. Affected communities will suffer increasing stress, numerous residents will migrate, and those left behind will be poorer and increasingly marginalized. This fate, however, is severe, and policy makers should be motivated to avoid it, particularly as good alternatives exist. Further, there are MENA countries containing regions that could dissolve into desperate poverty if nothing is done.

Urban Sector

Although our focus is on agriculture and rural communities, the growth of urban population and industrialization is increasing urban water demand and thus will affect the water available for agriculture. Urban areas use less than 10% of the total water available, but their water use is rising rapidly. Potable water and sewerage services must be extended, and doing so will further increase demand on the declining supply of water. A significant number of urban residents in the MENA region still do not have household access to potable water or to sanitation services. The World Bank suggests that significant progress has been made to provide drinking water and sanitation services within the region, including in rural areas, but that important gaps still remain in infrastructure coverage, with roughly 30 million people in the MENA region lacking water services and 69 million lacking basic sanitation. In addition, facilities often function well below design capability or not at all (World Bank 2007).

To provide a simple example, assume a country has 100 units of water, of which 90 units are used by agriculture and 10 units used by the urban sector. Assume that the water available decreases to 90 units as a result of climate change, while the urban sector increases its demand to 20 units. In this case, assuming urban demand is met, agriculture will have only 70 units, a decrease of 22%. However, if conservation can limit water use in the urban sector to 15 instead of 20, or if 5 units of urban wastewater can be

recycled for use in agriculture, water availability in agriculture would be 75 units, or 7% more. Improving the efficiency of water use in the urban sector, whether by reducing leaks in the distribution system, recycling wastewater, or conserving use in the household and industrial sectors, is an important consideration as water scarcity and urban use increase. As we note in the upcoming section on the effect of water pricing, industrial and municipal water use is considerably more sensitive to price than is agricultural water use, so ensuring that urban water prices reflect true water cost is a particularly important tool to achieve water use efficiency (Rosegrant et. al. 2002).

Increasing the Efficiency of Agricultural Water Use

We have argued that water availability will decrease in the MENA region, a higher proportion of water will be used in urban areas, and considerably less water will be available for agricultural use. Developing additional supplies of water will be increasingly costly. MENA countries thus have strong incentive to increase water efficiency in agricultural uses, reducing losses that occur in distribution, increasing the efficiency of water use by plants, and changing the crop mix to ensure higher value produced per unit of water.

In the past, water policy in many MENA countries has emphasized providing inexpensive water to agricultural users. Countries within the MENA region are large food importers. Food security has been a political concern, and providing cheap water has been a means of subsidizing domestic food production. Providing inexpensive water also has been a means to support the incomes of poor farmers, who often produce traditional crops like wheat, and to reward or benefit a smaller number of wealthy farmers who have political influence. However, allocating water at a low price encourages wasteful use of a scarce resource and is not a sensible policy in the long run. Increasing the role of prices in the allocation of water is an important goal to achieving greater water use efficiency.

Economists encourage greater reliance on "market-based" systems, which lets price play a larger role in determining who receives scarce water and what the recipients do with that water. Theoretically, a higher price of water should lead users to seek ways to use less of the more expensive resource, leading to conservation of the scarce resource. Additionally, the higher price rations water among alternative uses, with water "flowing" to

those activities in which it is most productive, e.g., using water to produce crops that produce more value added per unit of water consumes, such as vegetables instead of cereals. However, the introduction of water pricing systems into the MENA countries is controversial. While the higher price should lead to increased efficiency, the higher price also reduces the profits of farmers who must pay for more expensive water, assuming farmers cannot fully pass on the higher costs to consumers. Farmers are thus likely to resist imposition of higher water prices, making the use of water pricing an intensely political issue.

The alternative to a market system is a bureaucratic mechanism wherein authority allocates water based on established criteria. For example, the water authority could dictate that farmers in region A are to receive in a given year (t) a given amount of water liters per are of land cropped (x liters per ha) in year t–1, with no option for trading water. This simple mechanism, however, would lead to problems, two of which can be briefly noted. First, the allocation of water is fixed: farmers who could profitably use more water cannot purchase it, while farmers who receive more than they can use cannot sell it. As a result, less agricultural output will be achieved than would be possible if water could be sold from those who have too much to those that have too little. Second, water authorities are sensitive to political considerations, so that the development of allocative criteria is likely to be influenced by factors other than whether the water is used efficiently in agricultural production, and the criteria may change suddenly if political considerations change. Ultimately, water allocation may have little to do with economic efficiency or social welfare.

In fact, most water systems involve a mix of market and bureaucracy, as the two mechanisms differ in their respective strengths and weaknesses. However, the MENA region has relied heavily on bureaucratic mechanisms, and these are unlikely to perform well in the face of increasing scarcity.

To explore this issue, consider a simple system where a large number of farmers demand water for their farms but the price of water is set at zero. In figure 8-2, the demand curve for water intersects the horizontal axis at Q_D, showing the collective amount of water farmers want to use when the price is zero. The amount of water that is available, Q_S, is well to the left of Q_D. Thus, at a zero price, farmers collectively demand more water than is supplied. The implicit shadow price of the available water is P*, which is much greater than zero. As the scarce water is valuable, everyone wants

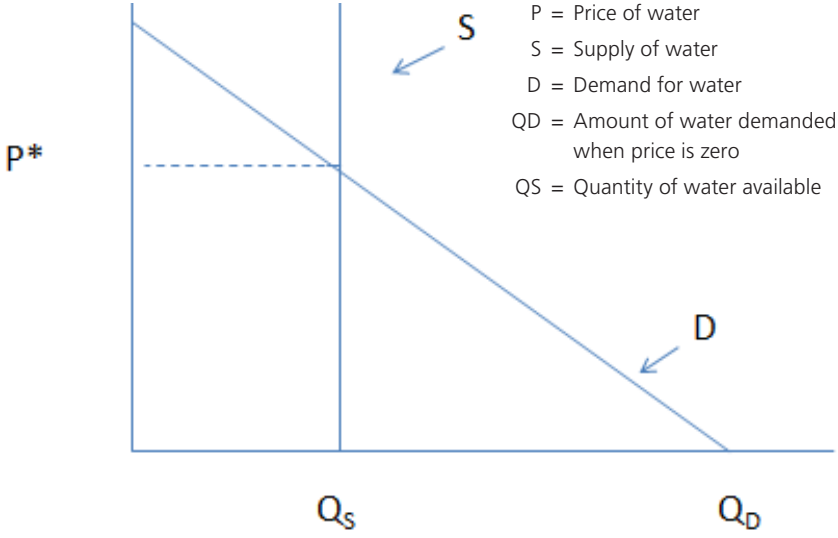

Figure 8-2. A model of a water market with P = 0.

more water when the price is zero. However, if price is playing no role in water allocation, the only mechanism available is bureaucratic authority. The national water agency or some designate must allocate water.

What do we know about allocation by bureaucratic authority? A bureaucracy will establish rules, but these rules will be subject to interpretation and adjustment. Wealthy and poor farmers will compete for the available water using as much influence as they can muster, both individually and in association. Generally speaking, those who are better politically and institutionally connected will get more water. Those who were lucky to receive initial allocations will work consistently to hold on to what they have and, if possible, get more. Further, water holders will do everything possible to frustrate water reforms that would reduce the value of their allocation. As water is worth much more than it costs, water users will be prepared to "pay" a great deal to ensure their allocation is preserved, and this eagerness often leads to bribery and corruption, or simply to wasteful rent seeking. If the water supply declines, decisions have to be made regarding who should be favored and who excluded. Unfortunately, the poor are usually squeezed out.

A market mechanism theoretically allocates water among potential users efficiently, allowing water to move from users whose water use

generates little economic value added to those with higher value added. This mechanism may allow small, relatively poorer farmers to achieve access to water. Poorer farmers would generally prefer to receive water, even if at a cost, rather than to be excluded, directly or indirectly by nonmarket mechanisms (Richards 2002). Nonetheless, increasing water prices can have harsh effect on the profits (incomes) of farmers, including small farmers, and they are unlikely to be happy about being asked to pay for water.

Traditional practice in many MENA countries has been to allocate water to agricultural users in a fixed block at a very low price. The low price, which is well below the "shadow" value of water, is an implicit subsidy to users. Regardless of water's current price, farmers who today receive water will not want the price of water to rise. Those who receive water are clearly better off with the lower price. A number of scholars, e.g., Sowers et al. (2010), suggest that it is "impractical to directly price agricultural water for small-scale users in most countries of the MENA for both political and economic reasons." One argument is political infeasibility, i.e., a belief that users have sufficient political influence to make it infeasible for governments to raise the price. They argue, citing Richards (2002) that when the price of water is low, profits are higher and the higher stream of profits is capitalized in land values. Sowers et al. argue that farmers will fight harder to avoid an increase in water prices because it will reduce the price of the land in addition to reducing their annual profits.

Effects of Higher Water Prices

Will higher prices achieve water savings? How will users respond to higher prices in the short run and in the long run? Rosegrant et al. (2002) present evidence from multiple studies suggesting that the price elasticity of water use in agriculture is about –0.09 in the MENA region, indicating that higher prices will induce water savings. A study by Rosenberg, Howitt, and Lund (2008) found a similar price responsiveness in Jordan, where a 10% increase in the price of water was estimated to reduce water consumption in agriculture by 1% over five years. There may also be thresholds for changes in water prices, with little or no change up to some level and significant changes for price increases above that threshold. Rosenberg et al. show that larger increases in water prices could be fully justified by efficiency concerns and would also produce much larger gains in water conservation

and efficiency. Given that water prices are so low, prices in many countries of the MENA region might double and still remain low relative to their shadow prices. If so, fairly modest absolute increases in water prices might lead to important water savings on a national scale.

If water prices must increase, how can farm income be cushioned, particularly the incomes of poor farmers? One approach that has been suggested is to charge farmers a low price for a volume of water that is somewhat smaller than what they have previously used and then allow farmers to purchase a limited additional amount at a new, higher price. This approach largely protects farmers' incomes, while causing them to face a higher price for water used at the margin. The higher incremental price should encourage them to use the last units of water more efficiently. Further, farmers also might be allowed to "sell" some of their water back to the water authority at the higher price, making any returned water available for reallocation.

Wealthier farmers having larger and more profitable farms might be charged a higher price for the base allocation of water, as there is no income distribution justification for allowing them to pay a low price. Moreover, larger farmers may find it more profitable than poorer farmers to purchase additional water. Thus, if agricultural water is priced and the market is allowed to determine some part of overall water allocation, some water will likely flow from poorer farmers to larger farms—and this is more likely to occur as the price of water decreases. This is a powerful reason for substantially increasing the price of water for larger, wealthier farmers. However, the price of water ought not to exceed its opportunity cost to any farmer.

Even where users do not hold formal water rights, users are likely to view the allocation of a block of water at a low price as the granting of a quasi-property right over the water. Once granted, it can be increasingly difficult to change that allocation in the future. Thus, governments should be clear in their announcements if they plan to continue to change the water allocation and/or the price of the water allocated in the future. Announcing plans makes it easier for opponents of policies to lobby against them, but transparent policies are generally easier to defend and create greater certainty among users.

We have emphasized the importance of introducing a greater role for water prices within systems that are largely bureaucratically determined. It is worth mentioning that some countries have water systems in which

markets play a larger role. For example, in part of the United States, Australia, and Chile, water is partly or largely a private good that can be freely traded in markets. Theoretically, the price of water will adjust to supply and demand, with a higher price simultaneously encouraging water development and conservation, while ensuring that water flows from lower- to higher-value uses. Equally important, a water market allows this process to work through the actions of many individual water sellers and consumers, who, making their own welfare-improving decisions, allow for a more efficient aggregate water allocation, which increases overall welfare.

Water markets have generally produced more efficient water allocations than have bureaucratic systems. Nonetheless, water markets are difficult to implement and do not fully escape the need for regulation (bureaucratic authority). Water use can create strong externalities, which means that one person's use affect's another person's use through non-market channels. When externalities exist, reliance on the private market does not produce fully efficient results. If the externalities are small, the market may still provide a better result than can be achieved by a water users association or government intervention. If the externalities are large, some type of collective action is likely to be better. These externalities include the case where multiple users extract water from a common aquifer and each party has incentive to extract water more rapidly than is collectively efficient. Similarly, because of return flows, changes in water use by some users may significantly affect the water rights owned by others downstream. There is also the difficulty of understanding the effect of groundwater extraction on water availability and water quality, and studies of these effects are unlikely to be carried out by private users who individually extract only a small portion of the water. Finally, environmental water uses are unlikely to receive attention within a market system unless water is specifically set aside by government decision. Thus, even when greater reliance on water markets is sought, regulation and coordination is needed.

Therefore, implementing a comprehensive water market might not be the optimal solution for MENA countries, but allowing price to pay a larger role in water allocation is highly important. Further, it will be useful to increasingly involve farmers in water management as a means of educating them regarding the importance of water management and the collective need to use water more efficiently and to achieve their input, as users, in the design and management of water systems (see Tutwiler 2009).

Agricultural and Economy-Wide Transformation

Wheat has long been the largest crop in terms of area and water use in the MENA region. However, the MENA region has a comparative advantage in higher-value crops such as fruits, vegetables, nuts, and olives, provided these can be produced to meet the high quality standards of European countries. Similarly, horticultural products can and will be produced only if farmers receive high prices for horticultural products and access to modern technology, and if farmers and labor are adequately skilled and motivated. Producing horticultural crops for export will also require development of a much-improved supply chain. This includes postharvest technologies, transportation, and communications, but also marketing, contributing to ensure product condition and its timely arrival to market. While more difficult to produce, horticultural crops would allow farmers to produce substantially higher value added with their resources, which will become increasingly important as the amount of water available is shrinking. Horticultural products use more water per hectare of cultivation than do cereals, but they are also more labor intensive, offering opportunity to employ more labor and generate more income, both on and off the farm, than do current crops. Thus, the switch to horticultural crops is likely to lead to a still further decrease in acreage planted than would be caused by the decrease in water availability, but it should also increase total agricultural output and employment relative to the alternative. Altering the cropping mix and upgrading management and labor skills are important steps if the MENA countries are to maintain agriculture as a competitive and dynamic sector.

The World Bank has recently argued that water reforms and economic reforms must be carried out simultaneously in the MENA region. Economic reforms are fundamental if water reforms are to be effective. The argument is persuasive. Water reform will encourage farmers to use water efficiently from a national perspective only if farmers face appropriate prices for inputs and outputs. Without economic reforms that would remove major existing economic distortions in international trade, energy pricing, real estate, credit, and other areas, farmers will not have the motivation to shift water use from low-value to high-value crops. Cropping choices play a key role in water use, and cropping choice is much more affected by crop prices than by water prices (World Bank 2007). Producer subsidies for wheat, which are closely related to food concerns, ensure that large amounts of

water are used for low-value crops. This limits the water available for other crops that are considerably more valuable.

For example, many countries in the region maintain agricultural policies that encourage the use of water for cereal production. Although these policies were originally designed to promote food security and support the incomes of relatively poor farmers, they also encourage inefficient use of water. The MENA region does not generally have a comparative advantage in extensive cereal production. However, cereal production provides a livelihood today for a large proportion of the agricultural workforce in several countries. Because 70% of the region's poor people live in rural areas, and current unemployment rates in many MENA countries are around 15%, removing price supports for grains and/or increasing the price of agricultural inputs, including water, will be politically difficult. However, direct income transfers or other mechanisms should be more efficient ways to transfer benefits to vulnerable populations than the use of water subsidies. Furthermore, government support for wheat and other crops also encourages farmers to over-irrigate. Subsidized credit for agricultural investment encourages investment in boreholes, which encourages over-drafting of aquifers, while subsidized energy reduces the price of pumping groundwater, making it profitable to pump even from great depth.

Previous studies (World Bank 2001; Shetty 2006.; World Bank 2007; Pishbahar 2001; Muaz 2004) have found that MENA countries have a comparative advantage in a wide range of fruits, nuts, and vegetables, as well as cotton and potatoes. Such advantage occurs partly because their harvest occurs in different months than the countries to which they would export. The World Bank estimates that fruit and vegetables offer higher returns to land and water than do field crops such as cereals. Wheat produces about \$0.05 per m^3, while vegetables produce about \$0.50 per m^3, or 10 times as much. High-value export crops also generate more employment than do traditional crops such as cereals, which have low labor requirements, particularly when modern farming techniques are applied. Figure 8-3 shows that horticulture in Morocco uses nine times more labor than does traditional cereal farming (World Bank 2007).

If the MENA countries are to move into the production of higher-value horticultural products, farmers must have incentives to modernize agriculture, including the financial incentives to carry out such modernization. Purchasers of agricultural output, such as supermarkets, now require

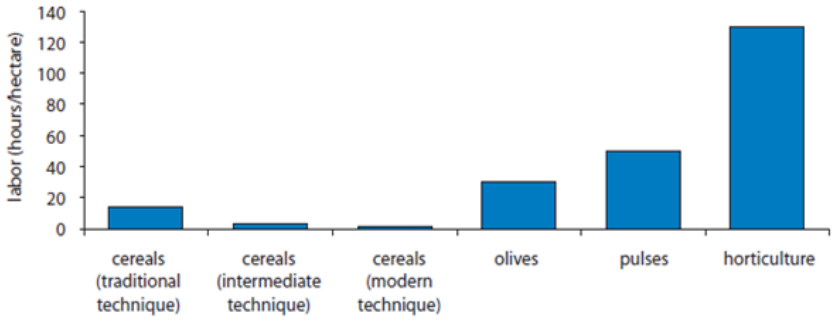

Figure 8-3. Labor requirements of Moroccan agriculture.
Source: World Bank 2007.

consistent, high-quality products and reliable, timely delivery based on longer-term contracts (Shepherd 2005; Codron et al. 2004). It will be difficult for smaller, less-well-capitalized, and less-skilled producers to satisfy these requirements, placing still greater pressure for land and enterprise concentration. These will create difficult dilemmas for governments.

Several economic studies have concluded that progressive trade liberalization should significantly affect agriculture in the MENA region (Lofgren et al. 1997; Radwan and Reiffers 2003; Roe et al. 2005 as cited in World Bank 2007). As indicated above, trade liberalization should raise the domestic prices and exports of fruits and vegetables while lowering cereal prices and increasing cereal imports. However, this process would be politically complicated, as the liberalization process would benefit consumers (who would consume cheaper imported wheat) and larger, more modern, better-capitalized farmers (who would more easily move into fruit and vegetable cultivation), while small farmers might lose, as they currently produce much of the wheat and are expected to have greater difficulty moving into the technologically more complex and more capital-intensive fruit and vegetable cultivation). The impact on farm labor is difficult to determine. As fruit and vegetable cultivation is more labor and skill intensive, one would anticipate that rural employment would increase. However, as fruit and vegetables are also more water intensive, and as water availability will decline sharply, output may sufficiently reduce the area planted to counteract this effect, reducing total labor use.

If employment declines even if economic reform occurs and if total water availability decreases as a result of climate change and the need to reduce

aquifer over-drafting, rural communities could face declining employment opportunities in even the best economic scenarios. Income might increase, but the higher incomes might be earned by larger farmers, more-skilled agricultural workers, and urban entrepreneurs and workers engaged in activities such as input supply, transport, marketing, and finance. Smaller rural communities might contract and wither, with larger towns becoming poles of attraction. In these larger towns and smaller cities, the growing population and rising level of commerce and services might create thriving communities, even as the water availability declines. However, it appears this scenario could materialize only under certain conditions.

If reforms lead to downward pressure on the incomes of poor small farmers and agricultural workers, and if the countervailing growth in urban industrial employment is relatively slow, great pressure will arise to reduce or reverse the reforms. Some will call for the subsidization of water and the reimplementation of protection for production of wheat. If modern, exporting horticultural producers can provide an offsetting influence, the policies may largely survive, but they will be more likely to do so if the government can develop support policies for farmers and workers who suffer. In the longer run, reforms will raise income and employment in the MENA region. Note again, however, that the MENA countries face a growing, severe crisis as a result of declining water availability. Although the reforms we suggest may not fully solve the crisis in rural areas, these areas are likely to be far better off if the reforms are implemented well than if they are not. In the absence of such reforms, economic and social progress will be definitively slower. Nonetheless, the short run costs of reforms appear significant, and careful planning is required if these reforms are to be successful.

Conclusions

This paper analyzes the effects of growing aridity on agriculture, farmers, and rural communities in the MENA region. To do so, we have attempted to place these effects within a broader context. We argue that economic and water reforms will permit more-efficient use of scarce water, shift agriculture toward higher-value crops, increase rural income and employment, and increase the national rate of economic growth. These reforms are especially crucial determinants of rural welfare. However, these sector- and economy-wide policies are insufficient to achieve rural prosperity given

the major impact that the decline in water for agriculture will have. Specific policies to increase human capital in rural areas and increase the socioeconomic viability of selected rural communities will also be crucial elements of a successful policy agenda.

Climate change will contribute to growing aridity in the MENA region. Declining precipitation and rising temperatures will combine with the need to reduce or cease overdrafting of aquifers to significantly reduce water availability in most countries during coming decades. Population growth will further reduce water per capita. The urban industrial sector will grow, and rising incomes will lead to higher water demand. With less water availability and higher urban demand, agriculture—always the residual user—will receive less water.

As water availability declines, agricultural production and employment will also decline, and rural communities that overwhelmingly depend on agriculture as an economic driver and for cultural orientation will suffer greatly unless major reforms are implemented and specific countermeasures are taken. The welfare of rural residents is quite vulnerable. It is essential that water and broader economic reforms be implemented.

Economic reforms must be designed to remove subsidies for low-value crops like wheat and allow higher prices for high-value crops like fruits, vegetables, and nuts. Reforms are also needed to allow farmers access to modern technology at competitive prices. Water reforms must be implemented to induce gradual changes in water use efficiency at the farm level. The water reforms must include some price mechanisms to encourage greater water efficiency by users. These price mechanisms can be tailored, e.g., by providing block water grants that have a low initial prices for a base allocation and higher prices for incremental water use. This approach can ease the income effect on farmers of rising prices, while forcing farmers to face higher prices for incremental water use. It makes sense for water prices to rise over time, allowing for adjustment and also taking account of growing scarcity. However, it would be useful to publicly forecast the rise in prices to the level that the government intends to implement in order to achieve greater certainty in expectations. Thus, future water prices might be specified similarly to the way countries have published future foreign exchange rates, i.e., a crawling peg.

Broader economic reforms will also stimulate more-efficient industrial growth, thus absorbing more people who must migrate from agriculture.

The economic reforms must include adjustment in the exchange rate to an equilibrium level and adjustment in tariffs and quotas to bring input and output price ratios into alignment with border prices. These reforms should increase the rate of economic growth and overall employment, though some studies suggest that they may not increase agricultural employment. Worse, there is the possibility that reforms will reduce the welfare of poor farmers and some agricultural workers as they benefit wealthier farms with greater access to land, capital, technology, and a greater ability to respond effectively to changing market conditions. Thus, while it appears that reforms are a crucial aspect of the region's ability to effectively meet the challenge of declining water availability while still prospering, the reforms will not be easy to implement. To ensure that policies are well designed, it will be useful to involve rural leaders and residents in the planning and implementation of policies. Involving farmers in the implementation of water reforms will also be especially important.

Moreover, still more action will be needed to relieve the expected severe pressure on small farmers and rural communities. Without other policy elements, many people in rural areas will remain impoverished. Given the macro context described, considerable investment will be needed in rural communities to facilitate agricultural development and counterbalance the harsher socioeconomic effects of transition by improving other aspects of rural life. Emphasis is needed on education, health care, finance, communications, transportation, and cultural opportunities that will support thriving rural communities, facilitate agricultural modernization, and allow successful rural-to-urban migration. These investments will improve welfare while also improving labor productivity and rural residents' ability to migrate successfully. Because resources are limited, it will make sense to concentrate investments and services in larger rural towns, where the return to investments will be higher. Such communities can serve as poles of attraction for people migrating from nearby smaller communities. This process, if successful, will allow more migrants to maintain their occupations and their connection with friends, family, and place. Agricultural modernization, when combined with the development of complementary commerce and services, can also contribute to improving the quality of life in these rural communities.

Water is becoming increasingly scarce within the MENA region. Population growth, a need to reduce the use of underground water sources that

Selected Water-Related Statistics for the MENA (FAO-Aquastat 2010, except for AFED predictions)

Table 8-3. Water withdrawal 2008–2012

	National Rainfall Index (NRI) (mm/yr)			Dependency ratio (%)			Fresh groundwater withdrawal (10^9 m^3/yr)			Share of agricultural water from total withdrawal (%)		
Algeria	242	E	1998	4	I	2010				64	L	2000
Bahrain				97		2010	0.24		2003	45		2003
Djibouti	107	E	1999	0	I	2010	0.02	I	2000	16		2000
Egypt	107	E	2002	97		2010	7.04		2000	86		2000
Iran (Islamic Republic of)	207	E	2000	7		2010	53.10		2004	92		2004
Iraq	225	E	1998	53	I	2010				79		2000
Israel	392	E	2001	58	I	2010				58		2004
Jordan	149	E	2001	27	I	2010	0.55		2005	65		2005
Kuwait	67	E	1999	100		2010	0.42		2002	54		2002
Lebanon	558	E	2000	1		2010	0.70		2005	60		2005
Libya	141	E	2000	0	I	2010	4.31		2000	83		2000
Morocco	288	E	2000	0	I	2010	3.17		2000	87		2000
Occupied Palestinian Territory				3	I	2010				45		2005

	National Rainfall Index (NRI) (mm/yr)			Dependency ratio (%)			Fresh groundwater withdrawal (10^9 m^3/yr)		Share of agricultural water from total withdrawal (%)		
Oman	23	E	1998	0	I	2010	1.21	2003	88		2003
Qatar	36	E	1998	3		2010	0.22	2005	59		2005
Saudi Arabia	129	E	2001	0	I	2010	21.37	2006	88	E	2006
Sudan and South Sudan	741	E	2002	77	I	2010			97	L	2000
Syrian Arab Republic	376	E	2000	72		2010			88	I	2005
Tunisia	326	E	1998	9		2010	1.90	2001	76	I	2001
Turkey	615	E	2002	1		2010	11.61	I 2006	74		2003
United Arab Emirates	52	E	2002	0		2010	2.80	2006	83	I	2005
Yemen	233	E	2000	0	I	2010	2.40	2000	91		2005

Note:

E = External data

I = AQUASTAT estimate

L = Modeled data

Table 8-4. Overall statistics 2008–2012

	Total economically active population (1,000 inhab)			Human Development Index (HDI)		
Algeria	14,968	E	2010	0.70	E	2011
Bahrain	627	E	2010	0.81	E	2011
Djibouti	385	E	2010	0.43	E	2011
Egypt	26,383	E	2010	0.64	E	2011
Iran (Islamic Republic of)	30,278	E	2010	0.71	E	2011
Iraq	7,929	E	2010	0.57	E	2011
Israel	2,987	E	2010	0.89	E	2011
Jordan	1,803	E	2010	0.70	E	2011
Kuwait	1,385	E	2010	0.76	E	2011
Lebanon	1,551	E	2010	0.74	E	2011
Libya	2,334	E	2010	0.76	E	2011
Morocco	11,798	E	2010	0.58	E	2011
Occupied Palestinian Territory	1,380	E	2010	0.64	E	2011
Oman	1,100	E	2010	0.71	E	2011
Qatar	1,140	E	2010	0.83	E	2011
Saudi Arabia	10,087	E	2010	0.77	E	2011
Sudan and South Sudan	13,825	E	2010	0.41	E	2011
Syrian Arab Republic	6,689	E	2010	0.63	E	2011
Tunisia	3,917	E	2010	0.70	E	2011
Turkey	24,847	E	2010	0.70	E	2011
United Arab Emirates	4,741	E	2010	0.85	E	2011
Yemen	5,958	E	2010	0.46	E	2011

Note:

E = External data

are already overdrafted, and climate change will combine to dramatically reduce per-capita water availability during this century. This scarcity will eventually have particularly severe impact on agriculture, including rural communities primarily dependent upon it. We encourage MENA countries to consider reforms that can achieve greater efficiency in the use of water, as these reforms should allow more rapid economic growth, higher employment, and reduced poverty over the longer run. In particular, these reforms should contribute to agricultural modernization and rising productivity, employment, and output relative to the situation of no change in policy.

Why are these reforms not being enacted if they have potential for considerable national benefit? Without question, these reforms will be politically difficult to implement in most, if not all, MENA countries. The reforms are likely to cause significant changes in the economic welfare and political influence of different societal groups and thus will encounter considerable resistance. Implementing the reforms could heighten political tension and even threaten the viability of government administrations. We recognize these problems, which will differ from country to country in nature and in magnitude. Nonetheless, water scarcity is going to increase, and countries that do not deal with the problem efficiently will encounter continuing economic, social, and political problems of increasing severity. We argue that it is better to recognize the inevitability of the problem now and begin to craft policies to deal with it in an effective manner.

References

Arab Human Development Report. 2009. Challenges to Human Security in the Arab Countries. New York: UNDP.

Abou Hadid, A. F. 2009. Food Production. In *Impact of Climate Change: Vulnerability and Adaptation.* Beirut: AFED.

Ackah, C., and D. Medvedev. 2010. *Internal Migration in Ghana: Determinants and Welfare Impacts.* World Bank Policy Research Working Paper No. 5273.

Barghouti, S. 2010. Water Sector Overview. In M. Tolba and N. W. Saab, eds., *Arab Environment: Climate Change.* Beirut: AFED.

Bauer, C. J. 2004. *Siren Song: Chilean Water Law as a Model for International Reform*. Washington, D.C.: RFF Press.

Brooks, R., and J. Waters. 2010. Social Networks and Educational Mobility. *Globalization, Societies and Education* 10: 143–157.

Chort, I. 2010). *Migration Networks in Senegal*. Working Paper, Paris School of Economics.

Codron, J. M., Z. Bouhsina, F. Fort, E. Coudel, and A. Puech. 2004. Supermarkets in Low-Income Mediterranean Countries: Impacts on Horticulture Systems. *Development Policy Review* 22(5): 587–602.

Davis, B., and P. Winters. 2001. Gender, Networks and Mexico–US Migration. *Journal of Development Studies* 38(2): 1–26.

Docquier, F., A. Marfouk, S. Salome, and K. Sekkat. 2011. Are Skilled Women more Migratory than Skilled Men? *World Development* 40(2): 251–265.

Dorosh, P., G. Alemu, A. de Brauw, M. Malek, et al. 2011. *The Rural-Urban Transformation in Ethiopia*. Washington, D.C.: Ethiopia Strategy Support Program.

Eid, H., S. M. El-Marsafawy, and S. A. Ouda. 2007. *Assessing the Economic Impacts of Climate Change on Agriculture in Egypt.* Policy Research Working Paper No 4293. Washington, D.C.: World Bank.

Findlay, A. M. 2011. Migrant Destinations in an Era of Environmental Change. *Global Environment Change* 21 (suppl. 21): S50–S58.

Gallego, J. M., and M. Mariapia. 2010. *Labor Migration and Social Networks Participation: Evidence from Southern Mozambique.* Working Papers Series No. 183. Milan: University of Milano-Bicocca.

Gornall, J., R. Betts, E. Burke, et al. 2010. Implications of Climate Change for Agricultural Productivity in the Early Twenty-First Century. *Philosophical Transactions of the Royal Society* B. (365): 2973–2989.

Kasinof, L. 2009. At Heart of Yemen's Conflicts: Water Crisis. *Christian Science Monitor,* November 5, 2009.

Lecoutere, E., B. D'Exelle, and B. Van Campenhout. 2010. *Who Engages in Water Scarcity Conflicts? A Field Experiment with Irrigators in Semi-Arid Africa.* MICROCON Research Working Paper 31.

Lofgren, H., R. Doukkali, H. Serghini, and S. Robinson. 1997. *Rural Development in Morocco: Alternative Scenarios to the Year 2000.* IFPRI Discussion Paper No. 17. Washington, DC: IFPRI.

Molle F., and J. Berkhoff 2006. *Cities Versus Agriculture: Revisiting Intersectoral Water Transfers, Potential Gains and Conflicts.* Comprehensive Assessment Research Report 10. Colombo: Water Management Institute.

Muaz, S. 2004. *The Impact of Euro-Mediterranean Partnership on the Agricultural Sectors of Jordan, Palestine, Syria, Lebanon and Egypt: The Case of Horticultural Exports to EU Markets*. FEMISE Research Report No. FEM21–03. Amman, Jordan: Royal Scientific Society.

Munshi, K. 2003. Networks in the Modern Economy: Mexican Migrants in the U.S. Labor Market. *Quarterly Journal of Economics* 118(2): 549–597.

Oroud, I. M. 2008. The Impacts of Climate Change on Water Resources in Jordan. In F. Zerieni and H. Hotzl, eds., *Climate Changes and Water Resources in the Middle East and North Africa*. Berlin: Springler.

Radwan, S., and J. L. Reiffers. 2003. *The Impact of Agricultural Liberalization in the Context of the Euro-Mediterranean Partnership*. Cairo and Marseilles: FEMISE.

Ratha, D., S. Mohapatra, and E. Scheja. 2011. Impact of Migration on Economic and Social Development. *Migration Policy Practice* 1(1).

Richards, A. 2002. *Coping with Water Scarcity: The Governance Challenge*. Policy Paper, Institute on Global Conflict and Cooperation, University of California, Berkeley.

Roe, T., A. Dinar, Y. Tsur, and X. Diao. 2005. Feedback Links between Economy-Wide and Farm-Level Policies: With Application to Irrigation Water Management in Morocco. *Journal of Policy Modeling* 27(8): 905–928.

Rosegrant, M. W., X. Cai, and S. Cline. 2002. *World Water and Food to 2025: Dealing with Scarcity*. Washington, DC: IFPRI.

Rosenberg, D., R. Howitt, and L. Lund. 2008. Water Management with Water Conservation, Infrastructure Expansions, and Source Variability in Jordan. *Water Resources Research* (44): W11402.

Salami, H., and E. Pishbahar. 2001 Changes in the Pattern of Comparative Advantage of Iranian Agricultural Products: An Empirical Analysis Based on the Revealed Comparative Advantage Indices. *Journal of Agricultural Economics and Development* 34: 67–100. In Farsi.

Shetty, S. 2006. *Water, Food Security and Agricultural Policy in the Middle East and North Africa Region*. World Bank Working Paper Series No. 47.

Shepherd, A. 2005. *The Implications of Supermarket Development for Horticultural Farmers and Traditional Marketing Systems in Asia*. Rome: FAO.

Smith, D. and J. Vivekananda. 2007. A Climate of Conflict: The Links between Climate Change, Peace and War. *International Alert* (Nov.).

Sowers, J., V. Avner, and E. Weinthal. 2011. Climate Change, Water Resources,

and the Politics of Adaptation in the Middle East and North Africa. *Climate Change* (104): 599–627.

Suppan, P., H. Kunstmann, A. Heckl, and A. Rimmer. 2008. Impact of Climate Change on Water Availability in the Near East. In F. Zerieni and H. Hotzl, eds., *Climate Changes and Water Resources in the Middle East and North Africa.* Berlin: Springler.

Tutwiler, R. 2009. *Community-Based Integrated Water Management in Farafra Oasis, Egypt*. Final Technical Report. Cairo: The American University in Cairo Desert Development Center.

UNDP. 2007/8. *Fighting Climate Change: Human Solidarity in a Divided World*. Human Development Report 2007/2008. New York: UNDP.

World Bank. 2001. *Egypt: Toward Agricultural Competitiveness in the 21st Century, an Agricultural Export-Oriented Strategy*. Report No. 23405. Washington, DC: World Bank.

———. 2007. Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa. Washington, DC: World Bank.

Part 3

Panel and Group Discussion

9

Bridging Science and Policy in the Management of Water Resources

Dr. Henry Vaux Jr.

University of California

Daniel Dooley, Esq.

University of California

Introduction

The Rosenberg International Forum on Water Policy is dedicated to fostering policies that reduce conflict in the management of water resources and to developing and executing water policies that are based on science. The focus of this chapter is on the second of these. More specifically, it reports on the content of a series of panel presentations and summarizes the ensuing round-table discussions that were focused on the challenges and means of translating science into policies. The presentations and discussions reported here constituted the final session of the 8th edition of the Rosenberg International Forum on Water Policy. The panel presentations were made by Dr. Moneef Zou'bi, Director General of the Islamic World Academy of Sciences; Professor Sally Fairfax, Professor Emeritus of Political Economy at the University of California, Berkeley; Mr. Ken Matthews, Distinguished Water Resources Professional and member of the Australian Academy of Technological Sciences and Engineering; and Professor Henry Vaux Jr., Professor Emeritus of Resource Economics at the University of California and Chair of the Rosenberg International Forum on Water Policy.

The importance of science in the making of policy generally was recognized in the United States and elsewhere in the first decades of the twentieth century. The contributions of science to the general welfare was underscored by a host of developments in medicine, physics, chemistry, and biology. Early development of the hydrologic sciences contributed in

important ways to improvements in the management of water resources. Science contributed to better understanding of the causes and consequences of droughts and floods, developments in irrigation science contributed to improvements in agricultural productivity, and developments in engineering science aided significantly in the development of water supply and sanitation systems around the world.

For the future, the list of the world's water problems is daunting. Water scarcity will continue to intensify and will likely become most acute in developing countries with high rates of population growth. Water quality will continue to deteriorate, and the loss of quality will contribute importantly to intensifying scarcity. Many of the most important aquifers of the world have been subject to persistent overexploitation, and that will lead inevitably to a loss in the availability of groundwater. The quantities of water available to support increases in global food production will likely decline at precisely the time when food production needs to grow to accommodate the demands for food and fiber of nearly three billion new souls. The specter of global climate change adds greatly to the uncertainty about the timing and availability of water supplies. Thus, for example, snowpacks, which act as water storage bodies, are likely to be smaller and will likely melt earlier and more quickly than has been the case historically. The substantial levels of uncertainty that climate change entails will undoubtedly require adaptive approaches to water management. Such approaches entail learning by doing and adapting to the unforeseen as time progresses. All of these problems can be solved more readily and more effectively by making use of scientific knowledge.

In this chapter the presentations of the four panelists are summarized and the round table discussions are characterized and analyzed.

Panel Presentations

The Importance of Water-Energy-Food Security

Dr. Moneef Zou'bi focused on the Middle East in discussing the components of national security and the importance of the water, energy, and food nexus within the array of those components. Governance in many countries, including those of the Middle East, is vested in several branches, which typically include a legislative branch, an executive branch, and the judiciary. In the Middle East the roles of the branches of government in

setting national priorities and addressing them are not clearly drawn. This means that many activities that should rank highly among national priorities either fail to be identified or fail to be addressed. In the case of water, the problem is further complicated by the presence of numerous and competing political interests attempting to advance self-serving ends and by a failure to articulate a national interest in the effective management of limited water resources. Additionally, there are instances in which confusion between means and ends prevails. In some cases, for example, the means of resolving water scarcity may be politically more important than the actual resolving of water scarcity. These problems are certainly not unique to the Middle East and in fact would generally characterize circumstances anywhere that water is scarce.

Lingering political conflicts in the Middle East and elsewhere in the world create a tendency to define national security in its "hard" (military) form. The evidence of this tendency to allocate resources toward defense and military budgets is particularly striking in the Middle East. The countries with the highest military spending as a percentage of gross domestic product are in the Middle East. On a per-capita, basis the top seven military spenders all come from the Middle East: Iraq, Israel, Jordan, Oman, Qatar, Saudi Arabia, and Yemen. The strong emphasis on funding for military security means that public funds are often allocated away from other programmatic areas that may contribute very importantly to national security. Among these are the interlinked programmatic areas of water, energy, and food. Indeed, among the components of "soft security," water security, energy security, and food security would be high on any list.

The nexus between water resources and energy resources has been subject to intensive examination in the past decade. The complementarity among energy and water runs in both directions. The production of energy requires significant water availability both for hydrolelectric production and for cooling demands from fossil plants. Similarly, it is well documented that irrigated agriculture is significantly more productive than rainfed agriculture in arid and semiarid regions. Thus, a nation's capacity to produce its own food may be importantly determined by the availability of water to support the agricultural sector. This relationship will undoubtedly become more important as the world's population is projected to grow by 3 billion by 2050, and that growth will stimulate a parallel growth in the global demand for food. These components of soft security tend to be neglected

and underfunded in favor of strategies, which support military security. Surely, the development of collective security arrangements for the region and the resolution of political problems would free up public resources that could then be devoted to improvements in the development and management of water and energy resources and increase the production of food.

The long-term security and prosperity for all countries in the region can be achieved only by assuring that food, water, and energy can be sustainably supplied. This imperative will need to be combined with equitable socioeconomic development. If these challenges are to be met successfully, science-based national policies will be needed to address the challenges successfully. Only by taking advantage of available science in the fashioning of policies can the countries of the Mideast and other countries in arid and semiarid regions hope to address their problems effectively and efficiently. Additional science will be needed if these resources are to be managed on a continuing basis. Yet the first imperative will be to take full advantage of existing science.

Future policies will need to be based upon the interdisciplinary sciences, engineering sciences, and the social sciences. Thus, for example chemistry and biochemistry will be crucial underpinnings of policy strategies designed to protect and enhance water quality. Engineering sciences are crucial in guiding the development of water supply infrastructure and sanitation facilities. Social sciences are similarly crucial in designing effective governance and management policies. These include policies governing the management of water resources, implementation of water allocations, and pricing and rationing policies for managing scarcity and cost recovery.

Several conclusions emerge from this presentation.

1. Soft security, such as security of water, energy, and food, is probably more important to a country's development than hard security, which emphasizes the military and defense.
2. Hard security gets the lion's share of resources in the countries of the Middle East and in other arid and semiarid regions. Less reliance on hard security would free some of the resources needed to support the attainment of soft security goals.
3. Science-based policies will be needed to meet the challenges of developing water, energy, and food security simply because they are likely to promote development that is both effective and efficient.

4. While research upon which future policies might depend will be needed, initially it is important to ensure that policy development makes full use of existing science.

The Nexus of Science and Policy.

Professor Sally Fairfax suggested that science and policy are much more aligned than is commonly assumed. Her presentation focused on the roles of science in policy making in the United States. The relationship between science and government had its origins in the early twentieth century when agencies such as the U.S. Forest Service began to rely on science in the making of policy for the management of the National Forest System. The origin of the science-policy nexus coincides with the rise of science as a profession. Training in the science professions became the responsibility of the universities.

During this period science was specifically intended to displace politics. That is, in the United States, the last years of the nineteenth century were characterized by political corruption and class warfare. Toward the end of that period science appeared to offer the possibility that government policies and programs could be based on fact. As it turned out, however, such possibility was never realized and is unlikely to be realized in the future so long as democratic forms of government prevail. Beginning in the early years, science and access to it turned out to be a direct government subsidy to those whose interests were served by government science. Constituency-serving science became the rule, and the primary beneficiaries were the agricultural sector, which benefited from research and education; the irrigated agriculture subsector; and the timber industry and others who benefitted from the management of the National Forest System. The science that the government offered was said to be nonpartisan and to flow from the technical competence of government scientists. It was, however, only nonpartisan in the sense that it was not consistently associated with a political party. Moreover, it was not unbiased, as evidenced by the unwillingness of the Forest Service to accept scientific findings about the natural role of fire in maintaining ecosystems and the influence of forested watersheds on water yields (see, for example, Schiff 1962).

In addition, social scientists have routinely criticized public decision making by scientifically trained experts as standing in opposition to open democratic processes in which public participation plays a major role.

Government and scientific expertise also ignores—purposefully—experiential learning and traditional knowledge, most of which is thought to complement Western science in important ways. Ignoring such knowledge is incompatible with democratic processes. Indeed, scientific agendas and even scientific results have been traditionally tempered by political processes, which have sought to manipulate them for the benefit of those that could capitalize on the findings. All of these observations point to a situation in which science and policy and science and politics have been in close alignment. The bridging, then, of science and policy in a democratic society appears to be less of a problem than the consequences of close alignment. Those consequences include outcomes that primarily serve special interest groups often at the expense of the broader population.

A separate matter of concern is the fact that the relationship between science and public policy appears to be changing. The array of contemporary problems associated with government funding and the related funding of university-based research programs threatens to shift the locus of knowledge generation and sharing. The government funding of research and of many university programs appears to be in the process of collapsing. The result has been a shifting of research support away from public sources to the private sector and, more specifically, to corporations. The result is a further tightening of the relationship between the pursuit of knowledge and profit making and a further loosening of the relationship between the pursuit of knowledge and efforts to advance the general welfare. There are several dimensions to this phenomenon.

The benefits of research supported by corporations and other private entities are likely to be mostly or entirely appropriable by the private sector. Those benefits accrue in a form that enhances the stream of profits to the corporations and returns to its shareholders. The larger public and the larger public interests are not likely to be well served in such a situation. Indeed, the best that they could hope for would be to be ignored. The more likely circumstance is that there will be harm and certainly there will be lost opportunities and high opportunity costs.

Research aimed at endeavors that do not enhance profit making is likely to suffer under such arrangements. Thus, scientific research to improve the understanding of negative externalities, such as those created by pollution, for example, are unlikely to be conducted at optimal scales or in optimal ways. Similarly, research directed at maintaining and protecting public

goods, common property resources, and especially the global commons is likely to suffer from a lack of attention and funding support. The conclusions are clear. To the extent that private entities take over the funding and support of research, the kind of research that is done will lead to benefits that are narrowly appropriable. Further, research that confers benefits across a wide spectrum of the population and are not narrowly appropriable will be relatively worse off and reduced in scope.

A final point concerns the fact that historically much university research has been conducted in facilities that were paid for by the public and by scientists whose salaries were paid for by the public. If the majority of research falls to the province of the private sector, that sector will benefit from facilities that were paid for by the public and for which the public no longer receives appropriate return. In short, then, the changing relationships between science and policy raises important issues about how science is conducted, how scientific research agendas are set, by whom the research is conducted and, most important, the resultant impact on the policy development processes and the allocation of scarce resources.

These are the conclusions from this presentation:

1. In the United States, science and policy have been closely aligned and closely intertwined for more than a century. The resulting science has not been unbiased and has not been immune from politics and the political process.

2. The relationship between science and policy is changing. The public funding support for university-based science and government science has declined significantly. It appears that the private sector is in the process of assuming a support role. One result will be that the private sector will acquire a disproportionately large share of influence over scientific agenda setting, the conduct of science, and the implications of science for policy making and implementation.

Improving the Science/Policy Nexus

Ken Matthews of the Australian Academy of Technological Sciences and Engineering characterized the context of science in water policy making processes, described typical flaws in the water policy-making process; and identified the key attributes of effective and efficient water science arrangements. Matthews argued that good water policy making and good

operational management of water requires a national system that closely links the users and providers of science. There does need to be a close alignment between science and policy making as scientists will need guidance on problems and priorities, while policy makers need inputs from science to identify emerging issues. "Science" as used here includes the social sciences. This is especially important given the growing needs for integrated cross-disciplinary solutions to water problems.

The notion that politics can be taken out of water decision making—that problems can be solved by facts alone—is quite mistaken. Good data and good knowledge are essential for policy making and decision making. Scientists can provide these. However, political processes are essential to articulate and implement society's choices. Such choices are invariably value judgments. Scientists do not have special expertise or qualifications to make value judgments. That is the role of the political process. Thus, it is true that water management decisions should be science rich but they should not be science determined. The choices, judgments, and trade-offs will need to be made by the political process, which can articulate values.

The Australian experience with science and policy is flawed, and some of these flaws are certainly present in other countries:

- Australia has no science strategy. There is no mechanism for systematically linking science and water policy. The priority-setting process to guide the science effort is ineffective.
- Many different institutions are charged with various aspects of water management, and they have developed haphazardly. Lines of communication among them are ad hoc and are frequently ineffective.
- The community that provides science is fragmented, and this often leads to overlap and duplication.
- Science tends to be conducted in a narrow disciplinary way, and there are major difficulties in motivating the conduct of integrated, cross-disciplinary research that is badly needed to help solve modern water problems, which tend to be quite complicated.
- There is a lack of alignment and coordination between provincial levels of government and their water research and management programs.
- Basic research is vulnerable to the loss of funding support, and this is symptomatic of the ever-present risk of loss of science capability.

- The channels through which new and useful science can be put into the policy-making process are unclear.

Given the importance of effective institutional arrangements for managing water and for bringing relevant science to bear on water problems, it makes sense for such arrangements to be regularly reviewed in an effort to minimize or eliminate fragmentation; clarify roles, responsibilities, and lines of communication among water and science agencies; identify instances in which the collaborative machinery between institutions is absent or ineffective and make efforts to reform it; and optimize the expensive research infrastructure by avoiding duplication and facilitating clear communication. Institutional arrangements are critical, and there is no justification for tolerating wasteful and ineffective institutions.

Developments involving the various stakeholders in the Australian urban water sector are instructive of the sorts of approaches needed to improve water institutions, their functioning, and the use of science in making urban water policy. Following a national forum focusing on research to support urban water policy and management, a national working group was established to produce two critical pieces of work. The first of these is a draft statement of Australia's urban water research needs and priorities as well as an enumeration of the research gaps. The idea was to allow all the research users—including policy makers—to signal the set of national urban water research needs as far in advance as possible. In this way providers of funding and support for urban water research will be informed of the critical issues that need to be addressed. Subsequently a number of research funders have said they may be willing to steer their budgets towards shared national water challenges wherever possible.

The second charge to the working group entailed developing recommendations on specific, practical reforms that could be introduced to improve the way scientists, policy makers, and other users of research work together. One such reform under consideration is an occasional national symposium to discuss research needs and capabilities to ensure that the entire research enterprise is as efficient and effective as possible. Another specific reform under consideration would involve developing a repository for all urban water research data sets. A final initiative focuses on building channels for state enterprises to influence the water research agenda and to promote deliberate cross-membership of the management boards of various water institutions. If these reforms can be successfully designed and

implemented by the urban water working group, there is the possibility that the process that led to the reforms, if not the reforms themselves, could be expanded to include all of the water using sectors across Australia.

There are a number of conclusions from this presentation.

1. A clear statement of research needs and priorities is essential. This could take the form of a national water science research strategy with a generous time horizon.
2. An effective working budget process that facilitates the strategic assignment of research support resources to current and emerging research needs.
3. A forum where both policy makers and research providers sit at the same table and interact as equals would be highly desirable.
4. There should be clear—and clearly stated—roles and responsibilities for all stakeholders. There should be clear lines of accountability and communication among them.
5. Finally, it is important that everyone connected with the management and use of water resources understand that developing and maintaining an effective national water science system is a responsibility that must be shared among all sectors. It is not just the responsibility of governments.

Making Science Useful and Effective for Policy Making

For this presentation, Professor Henry Vaux Jr. drew on the findings of a committee of the U.S. National Research Council that he chaired (National Research Council 2004). The work discussed here was part of an effort to define the role of scientific research on water in confronting the water management problems faced by the United States in the early decades of the twenty-first century. At least four attributes of water research and water research agendas are likely to make the outcomes of research efforts in the water resources arena both useful and effective as the basis for enlightened water policy:

- an integrated and interdisciplinary approach to water research.
- casting water and water research problems in a broad systems framework.
- acknowledging uncertainty.

- acknowledging and recognizing the need to be adaptable both in the conduct of water research and in the management of water resources itself.

Research agendas designed to embody these attributes are likely to help to counter some of the current modes and protocols that govern research to the detriment of science-based policy making. For example, research programs conducted by government agencies tend to be focused on agency missions which means that they are frequently narrowly focused and bar efforts to understand large scale problems. Similarly, with individual research investigators, there are strong incentives and tendencies to work strictly within a single discipline and to engage exclusively in reductionist research; this research mode does not work well on complex problems, as it leads to results so narrow that they are ill-suited to undergird the development of enlightened policy. Finally, water resources problems are not always local or regional as is frequently assumed: for national water policy, needed research must be broad in scope and support the use of different solutions, flexibly.

The four attributes that should characterize the modern water research agenda and help to facilitate science based-water policy making are considered below.

Interdisciplinarity

Interdisciplinarity entails the use of expertise from multiple disciplines to solve many contemporary water problems. Achieving it is problematical because the research enterprise is almost always organized along disciplinary lines, and the array of incentives faced by individual researchers emphasize research, which advances the discipline in question rather than multidisciplinary research. Consider several examples where multidisciplinary research is required in the water sector. Numerous factors affect the success of irrigated agriculture in arid and semiarid lands. These include problems related to the inadequacy or deterioration of irrigation infrastructure; climate variability and long-term trends in climate change; and soil variability. Chemistry, physics, biology, ecology, economics, and soil science all play a role. If one considers the societal aspects of irrigation, which one should, additional social science disciplines must contribute. Interdisciplinary research will be very important in devising successful

policies to ensure that irrigated agriculture prospers in an era when population is growing, climate is changing, and the availability of public funds is likely to diminish.

Another example focuses on the control of non–point source pollution. These include fertilizer and pesticide residues and substances found in urban runoff. They pose a threat to the quality of both surface and groundwater and are often larger contributors to overall water pollution than are point source pollutants. More work is needed to understand the fate and transport of non–point source contaminants, including contributions from ecology, soil science, agronomy, hydrology, and economics. The development of effective control policies will also require contributions from the social sciences, education, voluntary action, new legislative authority, and coordination across locales if new and effective policies of non–point source control are to be implemented.

A broad, systems view of context

The linkages among the components of a system, as well as linkages among different systems, are very important and are frequently ignored. For example, it is well known among aquatic biologists that the linkages among elements of aquatic systems are very important. Yet it is apparently true that the linkages between aquatic ecosystems and adjacent terrestrial ecosystems may be even more important in determining the health of these systems. These sorts of linkages tend to be ignored under traditional reductionist research. Many relationships in the physical and biological environment are non-linear and lead to an inability to predict impacts or understand causes and consequences if not viewed in a broad systems context. Issues of river basin management such as allocation of water, protection of water quality, and maintenance of habitat for fish and wildlife require research undertaken in a broad systems context. Understanding the hydrology alone, the timing and magnitude of flows, water temperature, and so forth is not enough.

Similarly, understanding the determinants of water demand in various sectors that use water consumptively requires an understanding of the connection between water and energy in a broad systems context. Thus, for example, in the western United States it turns out that energy is more of a limiting factor on urban water supplies than water is. This knowledge could not have been gleaned in the absence of research in a broad systems context.

The relationship works two ways, as the development of energy resources itself requires water. There is much talk of the fact that widespread development of hydraulic fracturing—fracking—in the United States could make the country energy self sufficient. Yet fracking is a water-intensive activity, and it is unclear to what extent water supplies are available to support it on a large scale. Research in a broad systems context is required to obtain the answers.

Acknowledging uncertainty

Historically, scientists have not normally dealt with uncertainty in a completely straightforward fashion. In recent years the importance of acknowledging uncertainty and treating it analytically has become clearer, as the act of acknowledging uncertainty explicitly contributes to estimating the reliability of research results. Uncertainty arises both from the lack of knowledge and from inherent errors in observing, estimating, and modeling. The need to acknowledge uncertainty in water resources research and accommodate it in water policy is especially compelling in light of evidence indicating that assumptions of hydrologic stationarity are no longer valid.

Beginning early in the twentieth century, some inherent uncertainty in hydrologic estimates could be removed by assuming that past patterns of precipitation, runoff, evapotranspiration, and other hydrologic variables were accurate guides to the future. Failure to account for uncertainty can lead to weak or faulty science. An example comes from a recent report from the U.S. National Academy of Sciences that purports to develop a scientific basis for adoption of a new national risk-based flood management policy. This report includes policy recommendations that are based upon a projected flood that has a probability of occurrence of 1 in 100. Yet it is now understood that hydrology does not exhibit stationarity. That is, past hydrologic records do not provide and accurate guide to future hydrologic behavior (Milly, et. al. 2008). It is unclear how a flood with a probability of 1 in a 100 could even be characterized in a non-stationary in a world. Policy prescriptions that are based on the veracity of assumptions of stationarity are almost bound to be wrong. More science must be done to resolve these issues. There is more science to do to answer that question. The point being that uncertainty looms particularly large in bridging science and policy in the water resources arena and it is important to acknowledge and, where possible, accommodate this uncertainty by being adaptive.

Adapting to change

Modern science and modern policy need to be adaptable. Current and future eras are characterized by change and novelty, which are best managed by being flexible and accommodating to changes in the physical environment rather than by resisting them. Adaptation can have two quite different meanings in the management of water resources. The first accentuates the need to be flexible and nimble. A National Academy Committee defined it as a combination of flexibility in solving problems and shifting norms and standards in response to novel or changing situations. The second meaning is adaptive management, or learning by doing, which, when well designed, can be a significant tool for managing uncertainty. In both instances, science-focused flexibility and adaptation is needed to undergird water policies, which will permit us to address changing and novel circumstances. Adaptive management has the added benefit of generating new knowledge and new understandings as it is practiced.

Conclusions

A number of conclusions can be drawn from this presentation.

1. Reductionist science and science conducted within narrow disciplinary frameworks is less useful as a basis for policy making than science that is conceived in a broad systems context and conducted in an interdisciplinary fashion.
2. The extent of uncertainty associated with scientific findings needs to be acknowledged if findings are to be useful for policy making. Hardly any scientific findings are true all the time, everywhere, and under all circumstances. Scientists need to be quite forthright in acknowledging this and where possible develop estimates of the extent of uncertainty.
3. Future water policies will need to be adaptive so that both predicable and unforeseen change can be accommodated. This means that science must be placed in an adaptive context if it is to be useful for policy making; science itself must facilitate the making of adaptive water policy.

Round-Table Discussion: Issues and Lessons

A number of key questions arose during the discussion that followed the panel presentations. Four areas of focus consumed most of the dialogue.

They were:

- Where will water policy initiatives originate in the future? Will they be driven by regulatory needs or will they emerge from robust scientific engagement?
- Will an increase in available information result in a shift from "top down" water policy development to more "grass roots" pressure to act by policy organizations?
- Is the scientific community positioned to respond to an ever-changing demand for engagement in water policy processes specifically and in public policy processes in general?
- Can the scientific community organize in a more transdisciplinary manner and promote rational water policy development that is responsive to much more complex issues around the world?

As a preliminary matter it should be noted that the discussion revealed a lack of clear-cut answers to these questions. The participants were in agreement that both regulatory and scientific systems are largely based upon disciplines. There was a wide range of opinion about the capability of science to shape more rational and transdisciplinary approaches. Many place blame for the failure to more fully integrate science into water policy processes upon the state of development in particular regions of the world and the relative stability of political structures. There was even a divergence of opinion about the appetite of the scientific communities in the developed world for systematic engagement in water policy making processes.

The discussion revealed widespread viewpoints about where policy initiatives will originate in the future and what the role of science will be. Some believe that policy initiatives will increasingly be driven by science, while others believe that policy initiatives will remain a function of national directives. The explanations of these divergent views were themselves quite different. Some described the current lack of scientific engagement in policy matters as support for the view that little change will occur. Others noted the silo-like structure of both the scientific and water policy communities provide strong support for the status quo.

Among those who believe water policy will emerge from grass roots efforts, two factors were identified that will shape the engagement of science into public policy. First, as socioeconomic conditions improve in the developing countries of the world, the appetite for credible information will rise among the growing middle class. This view, combined with ever-increasing

access to information, will make decision by fiat without corroborating scientific evidence much more difficult. This general view of some discussants was tempered by the acknowledgement that the pace of change will vary in different regions of the world. Further, many noted that uncertainties associated the "Arab Spring" make forecasting change in North Africa and the Middle East very difficult.

Several discussants cautioned that improvement of socioeconomic conditions alone will not create a groundswell for more scientifically based water policy decision making. These discussants noted that in some areas of the world the engagement of the science community with the ruling class has created a distrust of science that cannot be easily overcome.

There was extensive discussion about whether the science community is organized to engage effectively in the public policy arena. Several factors emerged from the conversation. As noted earlier, the disciplinary way the science community is organized does not lend itself to the more complex nature of public policy discussions that exist today and are likely to exist in the future. Second, a number of participants noted the difficulty of translating scientific information into language readily understood in political and policy organizations. The question of how to convey science to nonscientific communities was vigorously debated without clear consensus or resolution. Some discussants noted that water policy makers often totally disregard science in favor of political considerations such as distributive politics.

Most of the discussants agreed that the scientific community must organize itself into more transdisciplinary structures to address effectively emerging water policy questions around the globe. Historical academic organization and relationships, local political conditions, transnational relationships, and geopolitical issues will impact making the necessary cultural shifts to become more transdisciplinary. All agreed that the pace and success of change will vary depending upon the region and local conditions.

In the course of the discussion, a number of local efforts were noted and deserve mention. First, and most relevant to the location of the Forum, the management of the Jordan River in the context of the Israel-Jordan agreements was passionately discussed. Several noted that while the agreements parsed water from the Jordan River, many unresolved issues remain. For example, the impact of oversubscription of the Jordan on the levels of the Dead Sea was noted as one critical and unresolved matter. The lowering of the Dead Sea elevation is adversely affecting groundwater levels in Israel,

the West Bank, and Jordan with resultant escalation of tensions among several countries in the region.

The discussion revealed strong disagreements among the Palestinians and Israelis regarding management of water in the West Bank and Gaza. The Israelis note that the failure to develop internal infrastructure within the West Bank as a constraint to a long-term solution. The Palestinians speak of the difficulty negotiating long-term water agreements when the other party is an "occupier." Both of these examples reveal the difficulties of resolving critical water issues using scientific information in the context of broader regional geopolitical disputes.

Some discussants raised the use of groundwater in India as an area of concern, where there are hundreds of thousands of unregulated groundwater wells. Little data exists about the level of extraction or water quality. It was suggested this is an issue where the scientific community needs to engage in order to understand current conditions as well as to formulate science-based policy options.

There were examples of a high level of coordination among between the scientific and public policy communities. The Danube Basin is managed by a transnational commission that has well-established mechanisms for engaging the scientific community and the broader public. The engagement of the scientific community in the water policy development process in Australia is another positive model. Spurred by extended dry conditions, Australia adopted a National Water Policy that significantly overhauled its legal and administrative structures. Priorities were established and markets created with a high level of stakeholder consensus. The scientific community was very engaged in the process.

The examples emerging from the discussion reflect a broad range of the success and failure of scientific engagement in critical public policy matters. They demonstrate how the political and scientific infrastructure in many parts of the world is not up to the task of addressing critical water-related issues. It was also noted that in North America, the current state of engagement of the scientific community in policy processes is far from ideal.

If the role of science in public policy processes were to be viewed as a continuum with no engagement on one extreme and full engagement at the other extreme, certain conclusions can be drawn from the discussion.

- In virtually all areas of the globe, science has played some role in the formulation of policy. Certainly, the level of influence on policy has

been affected by the security of the government, custom and tradition, geopolitics (regional politics), corruption, and relative power. The level of engagement of science in the formulation of policy is not directly correlated to the level of socioeconomic development of the country or region. There are circumstances where the relationship of science to policy formulation processes is very poor in highly developed countries and regions. Of course, the converse is also true. Further exploration of the reasons why is warranted. It should be noted, however, that science and politics may be closely intertwined in policy-making processes, and it can be difficult to disentangle them.

- There are variations among and between countries and regions that affect where they lie on the continuum noted above, but these variations should not affect the goal, they simply reveal where each country or region is in the process. All countries and regions should organize their scientific endeavors to have the greatest impact on policy formulation given its particular circumstances.
- The transition to more transdisciplinary scientific input to policy processes is far from complete in virtually all areas of the globe. This is as much a function of the failure of science organization as it is of policy frameworks. The scientific community must undertake critical self-evaluation to determine the impediments to organizing its work in ways more suited to major public policy issues.
- It is imperative that the scientific community translate its science into understandable and persuasive language. Too often, policy makers are blamed for the failure to integrate science into policy decisions when, in fact, scientific information has not been transmitted in a way that clearly communicates its relevance to the decisions at hand.
- The weight of science in policy processes is at least indirectly related to the level of engagement of the science community with the affected public and stakeholders. Another way of stating this is that the level of engagement of the scientific community has a direct bearing on the value and relevance of the science and affects its impact on public policy processes.
- The science community must always acknowledge that public policy processes are for the most part a function of the political infrastructure. While science can inform policy, the ultimate responsibility rests with politicians. Policy decisions made by politicians consider

many factors other than science. This is a theme that recurred throughout the session.

The presentations and discussion that occurred at the 8th Rosenberg International Forum on Water Policy session entitled "Bridging Science and Policy in the Management of Water Resources" shed light on the multidimensional complexities of scientific engagement in policy formulation around the world. It revealed that both water policy makers and water resource scientists must recommit to constructive engagement, while recognizing the appropriate role of the other. Much remains to be done.

References

Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, et al. 2008. *Stationarity Is Dead: Whither Water Management?* Science 319: 573–574.

National Research Council. 2004. *Confronting the Nation's Water Problems: The Role of Research*. Washington, DC: The National Academy Press.

Schiff, A. L. 1962. *Fire and Water: Scientific Heresy in the Forest Service*. Cambridge: Harvard University Press.

Part 4

Summary and Conclusions

10

Summary and Conclusions

Dr. Ayman Rabi

Palestinian Hydrology Group

Introduction

There are growing concerns that global changes, including climate change, will have adverse impacts on natural and human systems. These may vary in time and space. More specifically, concerns are increasing about the likely implications of global change for poverty, economic growth, ecosystem services, livelihood opportunities, and overall human development. These impacts are expected to affect significantly the most vulnerable—women, children, the poorest, and the disadvantaged. They are also expected to affect natural systems adversely. At the same time, the water and agricultural sectors, the two main sectors responsible for food production in the MENA region, are expected to be impacted by these changes at the basin, sub-basin, national, and regional levels.

There is widespread agreement that an effective response requires revision of existing policies, laws, and strategies at national and local levels. The revision, which should be based on science, should be accomplished in an integrated and participatory fashion and should reflect the need to adapt flexibly to global change. This will ultimately require the development, strengthening, and coordination of scientific knowledge upon which policies can be based. It will also require improvements in governance systems and the creation of institutional systems that allow more transparent and participatory decision-making processes. Such processes will need to acknowledge the interests of all relevant stakeholders in order to ensure that the adaptive capacity of both social and ecological systems is improved under various change scenarios.

This chapter summarizes the main conclusions drawn from the keynote addresses, thematic presentations, and the roundtable discussions and deliberations of the 8th biennial meeting of the Rosenberg International

Forum on Water Policy held in Aqaba, Jordan, under the theme "Managing Water in the 21st Century: Challenges and Opportunities." The main conclusions drawn under each theme are summarized below.

Managing Water under Global Change

Growing water stress coupled with the current unsustainable human practices including the overuse of natural resources, generation of contaminating substances, alteration of natural systems, and unplanned urban expansion, have resulted in serious social, economic, and environmental threats that lead to multiple global threats such as climate change. One consequence of these changes is that the possibility of predicting the future from past records is now viewed as untenable. This, in turn, undercuts the validity of business-as-usual scenarios. What is needed are effective policy reforms to attenuate or stop unsustainable patterns of human interventions that increase water stress. These trends need to be reversed, not just halted, in order to create an environment in which the rebuilding of ecological, hydrological, and social systems can occur. Moreover, the fashioning of policies to achieve such outcomes must acknowledge and rely upon underlying scientific knowledge. This will require new modes of collaboration and the strengthening of collaborative efforts between scientists and policy makers.

Reversing the situation will also require a new approach in the form of a globally negotiated and considerably strengthened urban eco-hydro-social water contract. The water-energy-food triangle and its various interrelationships should be the focus of the new contract.

There are a number of highly desirable characteristics of an effective urban contract. These include linking water security to public health protection, flood protection, environmental protection, and the creation of social amenities. The contract should also encourage and support sustainable management of limited resources and otherwise promote intergenerational equity.

Many mechanisms can be used in water-related dialogues to bring scientists, politicians, and other stakeholders together. However, such mechanisms are still characterized by conventional ways of framing and managing the problems to which they are addressed. In these instances progress is hard to achieve and, in some cases, result in a worsening of the problem. The challenge of needed reforms is to promote the emergence of

more comprehensive and integrated sets of regional frameworks, such as the European Framework Directive. Such directives should ensure that sustainable and participatory management of resources at the basin level accounts for the interests of all stakeholders, resource scarcity, and the carrying capacity of the environment at hand. It will be important to recognize that institutional fragmentation and asymmetries in governance and in economic and technical capabilities across implementing countries are serious obstacles to successes. Successful creation of adaptive frameworks will require addressing these obstacles. Failure to do so can lead to crises and conflict in water-stressed regions such as the Middle East and North Africa.

The reform of current policies and practices will be especially crucial for countries whose economies are not fully developed. Such countries must still rely on intensive use of natural resources to support economic development and contribute to food security. Many governments still lack the institutional and governmental arrangements needed to undertake the often difficult reforms required to achieve competitive advantage and promote sector survival. These sorts of reforms are also vital in promoting intergenerational equity as well as the social and environmental resilience that will be required to sustain life as the global waterscape responds to the emerging hydroclimatic realities.

Regional Planning and Management

At the water basin level, the success or value of water management strategies and regimes depends on high levels of transparency in governance, the legitimacy and effectiveness of management bodies, and information availability, scientific learning, and knowledge sharing among the various parties involved. Additionally, the level of stakeholder participation in decision making, clarity in defining roles and responsibilities, and the existence of clear conflict-resolution mechanisms are also important determinants of success. Rules and mechanisms that acknowledge uncertainty and possess the flexibility to adapt to changing circumstances are also vital determinants of successful water basin management strategies.

An important conclusion is that there is no "blue print" or "one size fits all" set of institutional arrangements that can be applied everywhere. Institutional design must be compatible with the underlying bio-geophysical

systems in which they are based. The design must also be sensitive to and reflective of the political, economic, and social contexts in which they operate. At the same time, institutional design should account for the history, culture, and sense of place that characterize the region in question. The contextual approach will almost always lead to appropriate accommodations with and adaptation to local and regional variances. This is true of institutional design as well as other factors related to management performance. It is also true that good practices and successful management models and institutional designs that exist in one basin can be customized to account for the social, economic, cultural, political, and environmental conditions that prevail in other basins. In some instances this customization can contribute to the elimination of potential conflicts that might otherwise emerge from the discourse among the concerned parties.

Institutions that facilitate basin-wide negotiations and the reaching of agreements are frequently effective in avoiding or resolving conflict and in optimizing the gains of all parties. This means that parties should enter negotiations in good faith and without unclear or hidden objectives. In addition, when negotiations take place among unequal parties sharing the same resource in a basin, the strong, hegemonic party should not dictate terms to weaker parties in order to maximize its gain or to maintain an unequal status quo. Rather, to ensure that agreements will be lasting and sustainable, the terms should address the interest of all parties in a reasonable and equitable way, and agreements should give every party the sense of ownership and respond to the aspirations of all. Failure to adopt such arrangements means that the resulting agreements, if any, will remain fragile and unlikely to achieve anticipated benefits to any of the engaged parties in the long term. On the contrary, they might even encourage more extreme and unsustainable practices than would otherwise occur.

The Fate of Agriculture under Global Change

The economies of low-income countries are still largely dependent on the economic return from agriculture. This dependency is unlikely to change over the next decade or so. Simultaneously, these economies are likely to become more vulnerable as aridity increases, precipitation declines, and temperatures rise as is expected in the MENA region. Water availability will likely be reduced significantly even while demands for water, fueled by

urban growth, intensify. Increased demand for domestic use will undoubtedly result in further reduction in the quantities of water available for agriculture. The likely outcome is that agricultural production and employment will decline and rural communities that are overwhelmingly dependent on agriculture for both livelihoods and cultural orientation will be adversely affected. The challenge for the countries in question is to redefine their existing agricultural policies and upgrade traditional practices and knowledge to improve their capacity to adapt to changing circumstances. More precisely, for agriculture to continue providing the anticipated support to national economies, to contribute to food security, and to improve farmers' livelihoods in the MENA region, various policy measures and practical actions need to be considered. Among the policy measures deserving of attention are the following.

- **Change the emphasis from land to water.** The traditional strategy of maximizing yield per unit of land may be appropriate when land is the limiting resource for agriculture. Where water is the limiting resources, strategies should focus instead on maximizing water productivity—the return from a cubic meter of water rather than a square meter of land.
- **Change current land use and cropping patterns.** These changes should be focused on growing more water-efficient crops and utilizing more water-efficient cropping systems. Many crops that are grown in water-scarce areas are, in fact, unsuited for arid conditions even while more efficient and better adapted alternatives exist. New cropping patterns should be the subject of enhanced programs of research that can delineate and characterize the comparative advantages of different agroecologies. The result should be to replace inefficient crops, reduce water demand, and increase competitiveness.
- **Change the way water is valued.** Water prices rarely reflect or even approximate the true conditions of scarcity. At the same time, such policies should accommodate the instances in which water is a common or shared resource and acknowledge matters of equity and sustainability.
- **Change trade policies.** Such policies should be designed to encourage the importation of goods that require large quantities of water for production. Trade policies should acknowledge that large amounts of virtual water can be acquired through importation. Such policies can

reduce water demand and at the same time support existing farming systems and their associated social and economic systems.

- **Design economic reforms in a way that removes subsidies.** Production should focus on crops that are relatively high in value, not on low-value crops that are economical to produce only when subsidized. Water management reforms should induce gradual changes in water use efficiency at the farm level. The water reforms must include implementation of price mechanisms to encourage great water use efficiency. These price mechanisms can be tailored through block water grants to ease the income effect on farmers while forcing them to face higher prices for incremental increases in water use. These reforms should increase the rate of economic growth and overall employment even though some studies suggest that they may not increase agricultural employment. Worse, there is a significant possibility that reforms will reduce the welfare of poor farmers and some agricultural workers even as they benefit wealthier growers with greater access to land, capital, and technology plus an enhanced capability to respond to changing market conditions. Thus, while it appears that reforms are a crucial aspect of the MENA region's ability to meet the challenges of declining water availability, such reforms will be difficult to implement because they may undermine prosperity.
- **Invest in rural communities.** Considerable investment will be needed to facilitate agricultural development and counterbalance the harsher socioeconomic effects of transition by improving other aspects of rural life. To facilitate agricultural modernization and boost rural economies, investment should focus on education, health care, finance, communications, transportation, and cultural opportunities. These investments will improve welfare, labor productivity, and the capacities of rural residents to adapt to change. Agricultural modernization, when combined with the development of complementary commerce and services, can be especially effective in improving the quality of life in rural communities.

In addition to the policy measures enumerated above, are a series of practical measures should also be helpful. The most important of these are discussed below.

- **Change attitudes towards basin-level cooperation.** Water use efficiency may be improved at the farm level but cannot be maximized

unless it is also accomplished at the basin level. This requires cooperation, especially among countries that share river basins. Water scarcity and associated problems that impact entire basins must be addressed collectively by neighbors through data exchange, transparency, and collective policies and decision-making.

- **Diversification and intensification of production systems.** Successful adaptation to climate change will require diversification of farm systems to improve ecosystem resilience, reduce risk, and simultaneously create new income opportunities. System diversification includes diversification of crop rotations. One example would be the inclusion of legume crops in cereal systems. Such practices also contribute to the maintenance of soil fertility and support the process of diversifying into higher-value crops such as dry land fruit trees, protected (greenhouse) agriculture, and the cultivation of herbal, medicinal, and aromatic plants.
- **Reduce production and energy costs.** The fundamental driver of agricultural technology adoption by farmers is to obtain an increased return on their investment either by increasing production or reducing costs. Conservation agriculture achieves both. It combines minimum soil disturbance (zero tillage), stubble retention, crop rotations, and early sowing of crops. It offers multiple benefits including savings in time, fuel, and machinery costs for land preparation; improved soil structure with better soil moisture conservation; higher potential yields and reduced soil erosion.
- **Capacity development.** In order to mount research programs to meet the challenges of increasing agricultural production in the face of intensifying aridity a cadre of well-qualified researchers will be needed. Evidence shows that the MENA countries in general are facing a "skills-gap": an acute shortage of qualified agricultural researchers. Greater investments are needed in agricultural research, capacity development, and institutional support. Strengthening the agricultural innovation systems (research, education, and extension) will be essential. Additionally, more investment will be needed to develop a new generation of scientists and technicians who can carry these efforts into the future.
- **Strengthen the agricultural economy.** Better agronomic practices can be encouraged by creating appropriate commercial, technical, and

regulatory environments. Similarly, the agricultural innovation system can be strengthened through research, education, and extension.

- **Employ science and technology fully.** Science and technology have a significant role to play in helping to overcome the challenges faced by the MENA region. An integrated approach will be need, one that addresses the problems of enhancing agricultural productivity and managing natural resources with greater care. Thus, for example, programs of deficit irrigation and the use of saline water hold much promise. The successful development of such programs will require a strong scientific underpinning, and technological innovations as may be necessary to make such practice possible.
- **Crop improvement through conservation and the use of genetic diversity.** The MENA region contains tremendous diversity in cultivated landscapes and wild species. These provide an invaluable resource in the quest to find new methods of coping with changes in temperature, drought frequency, and new diseases and pests. The use of both conventional plant breeding and biotechnology to develop improved germplasm can significantly enhance the prospects for higher crop yields, devising production systems better adapted to climatic change, devising improved crop management systems, and developing better protocols for integrated pest management. All of these will be pivotal in ensuring food security and enhancing the resilience of agroecosystems in the face of climate change.

Bridging the Science and Policy Gap

There was general agreement among the participants that, while additional research is needed, there exists much research and background knowledge on the various dimensions of the intensifying water scarcity that are not actively utilized. Part of the explanation lies with the failure of scientists and policy makers to bridge the gap between them and facilitate the generation of effective, science-based policies. Such policies are vital for the development of water strategies and governance arrangements required to improve adaptive capacity and resilience in ecological and social systems.

This acknowledged gap between scientists and politicians at national or international levels is frequently seen as one of the major causes of the absence of widespread political support for science-based policy. Unless

scientists develop better communication tools and address politicians in understandable ways this gap will continue to widen. Scientist will continue to talk to themselves and politicians will continue to focus on the water issue from narrow political perspectives or short-term actions at the local levels that tend to guarantee reelection at the expense of broader and more far-sighted action.

The relationship between science and policy is changing. The public funding support for university-based science and government science has declined significantly. It appears that the private sector is in the process of assuming a support role. The consequences of this include:

- the private sector will acquire a disproportionately large share of influence over scientific agenda setting with less attention to questions affecting populations broadly rather than private profit-making.
- the way in which science is conducted and the likely neglect of basic science.
- the interpretation of science for public policy-making and implementation.

Given the importance of effective institutional arrangements for managing water and for bringing relevant science to bear on water problems, it makes sense for such arrangements to be regularly reviewed in an effort to minimize or eliminate fragmentation and to clarify roles, responsibilities, and lines of communication among both water and science agencies. It will also be helpful to identify instances in which collaborative machinery between institutions is absent or ineffective and make reform efforts. Effective institutional arrangements will be critical to facilitate clear communication among all of the players.

Finally, it is important that everyone connected with the management and use of water resources understand that developing and maintaining an effective national water science system is a responsibility that must be shared among all sectors. It is not the responsibility of government alone.