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Bridging Science and Policy in the Management of Water Resources

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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.