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Water management: Current and future challenges and research directions

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Abstract Water distinguishes our planet compared to all the others we know about. While the global supply of available freshwater is more than adequate to meet all current and foreseeable water demands, its spatial and temporal distributions are not. There are many regions where our freshwater resources are inadequate to meet domestic, economic development and environmental needs. In such regions, the lack of adequate clean water to meet human drinking water and sanitation needs is indeed a constraint on human health and productivity and hence on economic development as well as on the maintenance of a clean environment and healthy ecosystems. All of us involved in research must find ways to remove these constraints. We face multiple challenges in doing that, especially given a changing and uncertain future climate, and a rapidly growing population that is driving increased social and economic development, globalization, and urbanization. How best to meet these challenges requires research in all aspects of water management. Since 1965, the journal Water Resources Research has played an important role in reporting and disseminating current research related to managing the quantity and quality and cost of this resource. This paper identifies the issues facing water managers today and future research needed to better inform those who strive to create a more sustainable and desirable future.

1. Human Ambitions and Earth's Limits

Throughout the world, demographic, economic, and technological trends have accelerated our ability to knowingly and unknowingly modify the environment we live in and that sustains us. We humans have become the principal driver of environmental change. Our actions are impacting our global environment, including our climate. This in turn impacts the amounts and spatial and temporal distributions of precipitation that falls on watersheds and the timing of its runoff. Coupled with changes in landscapes, due to growth in food and energy production and from the movement of people into urban centers, we are altering the quantity and quality of our freshwater resources on which we depend to survive, both physically and economically. We depend on water not only for life itself, but indeed for our economic wellbeing as well. Water plays a role in the creation of everything we produce. There are no substitutes and while it is renewable there is only a finite amount of it.

In the past, we have made decisions regarding the management of our water resources that have not always helped us become more secure or sustainable. We have disrupted and overallocated river flow regimes—sometimes to the point of drying them up, along with their downstream lakes. We have overdrawn groundwater aquifers; polluted many, if not most of our water bodies including estuaries, coastal zones and even oceans; and degraded ecosystems. We have done this mainly to satisfy short-term economic goals, often goals that may not have included the long-term environmental—or even economic—sustainability of region or basin, and indeed our own health.

Our planet no longer functions in the way it once did. Earth is currently confronted with a relatively new situation, the ability of humans to transform the atmosphere, degrade the biosphere, and alter the lithosphere and hydrosphere. The challenges of our current decade—resource constraints, financial instability, religious conflict, inequalities within and between countries, environmental degradation—all suggest that business-as-usual cannot continue.

These challenges to effective planetary stewardship must be addressed and soon. The various parts of the Earth system – rock, water, and atmosphere – are all involved in interrelated cycles where matter is continually in motion and is used and reused in the various planetary processes. Without interlocked cycles and recycling, the components of our Earth could not function as an integrated system.

In the last 50 years or so we have come to recognize the movements in all Earth's layers, including the plates at the surface, the mantle and the core as well as the atmosphere and ocean. The momentum and acceleration of the impacts of business as usual threaten to tip the complex Earth System out of the environment in which everything living on this Earth has evolved and developed. Some call this new geological period the Anthropocene [*Crutzen*, 2002; *Williams et al.*, 2011]. Water is becoming a central issue in this new period. This applies not only to freshwater systems but also to the oceans, their levels and what lives in them. The interdependency between social or human ambitions on the one hand, and availability and quality of our natural resources and the environment on the other, is obvious; it determines the kind of development that is realistic and stable.

The expansion in the production and supply of goods and services in the recent past has meant more jobs, income, and, generally, greater possibilities for a better life. It has also meant an increase in the use and pollution of natural resources. The adverse effects on water and other vital components of the Earth System are evident. Many river basins in the world are labeled as "closed" or are on the verge of being closed; their flows no longer reach the oceans [*Seckler*, 1996; *Gleick and Palaniappan*, 2010]. An estimated 1.4 billion people live in closed basins [*Smakhtin*, 2008] with more limited development options. The development of potential flood zones along rivers and coastlines has increased the incidence and impact of flood-related damages. According to the *World Health Organization (WHO)* [2007], during the last decade of the last century about two billion people were victims of natural disasters, 85% of which were floods and droughts.

There is no escape from the fact that the need and demand for finite and vulnerable water will continue to expand and so will competition for it. More uncertainty in water availability, higher frequency of extreme weather events, and more rapid return flows of water to the atmosphere are expected in the future. Given the changes in the hydrologic cycle as a result of land use and climate changes and the closed character of many basins, allocations to, and patterns of future water use, will deviate from past trends.

Research is needed to better understand how these complex interactions may develop over the coming decades and the associated social, political, and environmental implications. Clearly, water issues will become even more important in the lives and activities of people [*Cosgrove and Rijsberman*, 2000; *Grayman et al.*, 2012].

1.1. Freshwater Stress

Today everyone is concerned about the potential water scarcity in the face of increasing, mainly population-driven, water demands, and its consequences on our energy and food production. The Global Risk Perception Survey conducted among 900 recognized experts by the World Economic Forum reports that the highest level of societal impact over the next 10 years will be from water crises. http://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf

In recent decades the percentage increase in water use on a global scale has exceeded twice that of population growth. This has led to more, and larger, regions in the world being subject to water stress where the current restricted rates of water use and consumption, let alone the desired rates, are unsustainable. Water demands and supplies are changing. What they will be in the future is uncertain, but it is certain that they will change. Demands are driven in part by population growth and higher per capita water consumption in growing urban, domestic, and industrial water sectors.

By 2050, the world will have to feed and provide energy for an additional 2–2.5 billion people as well as meet the current unsatisfied power needs of a billion. To meet the nutritional needs of this additional population, we should consider the amount of water that is consumed in the production of different goods and, in particular, energy and food. Energy and food security are demands that are particularly critical to water managers. Energy production, water, food security, and climate change are all connected through interactions and feedbacks. For example, the growing, transportation, processing, and trading of food products require large amounts of water and energy. A complete analysis is provided by the Comprehensive Assessment of Water Management in Agriculture [*International Water Management Institute* (*IWMI*), 2007]. This work demonstrates that in a business-as-usual scenario, water consumption in agriculture would almost double.

Per capita water use varies considerably over the globe. In developed regions one can assume an average value of 200 L per person per day. The value adopted internationally for basic human water needs is about 50 L per person per day [*Gleick*, 1996]. The amount of water each person in the USA uses is on average is much higher depending on a number of factors, in particular diet, but also in all the water required to make all the energy and nonagricultural products consumed. A recent report on water consumption in the USA shows reductions in all sectors: including agriculture; municipal and industrial; and thermoelectric power. But the report concludes that while substantial progress has been made, current water use trends are not sustainable in the face of population growth and climate change [*Donnelly and Cooley*, 2015].

Water is increasingly becoming a priority policy issue at the international level. The third United Nations World Water Development Report [*United Nations World Water Assessment Programme (UN WWAP)*, 2009] warns, in an unprecedented fashion, that extremely serious consequences may result from the current inequitable, unsustainable use of water. Both economic development and security are placed at risk by poor water management. That is why the concern about a global energy crisis has recently begun to be accompanied by a concern about a looming global water crisis. The energy and water nexus expressed both by the effects of water use on energy consumption and by the effects of energy production on water consumption, is gaining increasing attention [see e.g., *Hoff*, 2011; *World Economic Forum Water Initiative (WEFWI)*, 2011, *UN WWAP*, 2011, 2012, 2014].

1.2. Globalization

Increasing globalization is motivating the implementation of new rules and procedures for the international trade of goods and services, reflecting the increasing influence of multinational firms engaged indirectly in water use and transfers. This globalization of trade has wide-ranging implications for consumers, governments, and the environment. While bulk water is not commonly traded, except for relatively limited quantities in bottles, the water used to produce the goods that are traded across borders, called virtual water, can have a major impact on water balances in basins and regions. The US is the world's largest exporter of virtual water [*Hoekstra and Chapagain*, 2008].

The impact of globalization on water may be considered from two other perspectives: the negative effects on water of the growing integration of the world economy, in particular concerning water contamination and associated environmental degradation; and water itself as an object of global trade policies.

Some natural resources, such as oil, natural gas, wood, agricultural products, or fish have, for a long time, been traded in international markets without becoming a political issue. Not so with regard to water. Water is different than many other natural resources that are traded because the costs of transport are very significant in comparison to the understated economic value of water and, perhaps more importantly, because of perceptions about the human right to water, and objections to the commodification of the resource [*Gleick et al*., 2002; *Hoekstra and Chapagain*, 2008].

International projects involving water transfer often raise concern and controversy. However, one form of "trade," which is generally accepted without raising special problems, is the natural flow of water among countries sharing a river basin or aquifer. This transaction is normally ruled by political agreements, rather than trade agreements. In practice, only a comparatively small number of agreements for the long distance trade of raw water have been concluded. Water transportation is expensive and usually pursued only in rare cases where other practices, such as desalination, are not possible or economic. Almost all such efforts only provide water for very high-value industrial or domestic needs and not for other important uses, such as for food production.

Trade in high water consumptive goods from water scarce regions may be economically profitable in the short term but it is not viable in the long term and is a threat to meeting other water related goals. Pollution and environmental degradation are not transferred along with the products to the consumer. They are left behind for the producing country to deal with. Countries will need to revise policies to avoid incentivizing high water use for low value purposes and unsustainable export promotion. This is a very complex issue and requires much more research to find real water-trade links and to find possible solutions if trade is causing unsustainable water practices and reducing local availability of adequate water resources.

Trade policies and practices need to be aligned with the goal of sustainable water at global, regional and national levels and to support overall gains in water-use efficiency and providing incentives to countries to produce and trade goods in line with their specific water circumstances, while fully participating in fair, equitable and sustainable trade. Access to water may be a natural advantage (or disadvantage) that should be considered by the World Trade Organization in establishing trade regulations. This could be addressed in the ongoing WTO negotiations and WTO Doha Development Agenda and Hong Kong Ministerial Mandate. As water is an important requirement for the production of most, if not all traded goods, it is an important dimension of trade as it relates to the sustainable development goals (SDGs) and other forums mandated to develop trade-related policies and agreements.

1.3. Nonstationarity in Supply and Demand

Traditionally, water infrastructure and water management systems have been designed and constructed based on historical observations of climate and hydrological data and consumption trends, followed by statistical analysis and interpretations of these data to determine the probability of certain events occurring. For example, infrastructure is often designed to withstand an event that has a certain probability of occurring based on an analysis of the longest time series of historic data available. Infrastructure designed to withstand a 100 year flood is designed for a flood event that has a 1 % chance of occurring in any given year based on historical records. The implicit assumption in such calculations is that climate and hydrological systems behave as stationary systems, meaning that the statistical characteristics of, e.g., rainfall and discharge from a past time period in which data are available, will remain the same into the future. Water engineers and managers generally understand that this is not the case, but can only work with the information they have available, sometimes introducing safety factors in the hopes of covering uncertainty of data and future variability. Climate change now occurring makes it even more difficult to rely on this assumption of stationarity; historically observed data are no longer adequate to meaningfully plan for climate variability and extremes. Managers will need information about how climate change will affect probability in order to carry out risk-cost analyses of alternative investments in infrastructure needed in the future [*Intergovernmental Panel on Climate Change (IPCC)*, 2001, 2007, 2012, 2014].

Natural and human systems have an ability to adapt to change to a certain extent with the existing knowledge and technology. These are called autonomous adaptations. Farmers, e.g., can adjust their crop mix and planting dates over time to allow for changes in quantity and timing of precipitation. Other adaptations require greater investment and institutional changes. Sticking with our example, farmers may need entirely new crop varieties, new irrigation infrastructure, and new education and processing facilities once changes move beyond the ranges that can be handled by autonomous adaptation. At some point, the risk may become unacceptable. In our example, this could be the point where the climate and land in an area are no longer suitable at all for agriculture.

Changes in climate can shift and alter the shape of the entire probability distribution of future hydrologic events and water demand. Both are uncertain. Evidence to date suggests we will be observing more variability, resulting in more frequent floods and droughts of greater intensity and duration. At the same time, demand for water for agriculture and energy production in particular will be influenced by climate change, technological development and urbanization and human responses. More investments will be needed for measures that will enhance adaptation at the regional, watershed and household levels, such as water storage structures, conjunctive use of groundwater and surface water, wastewater capture and reuse, agroforestry, and research that generates more resilient production systems for smallholders. More effort is required to protect and sustain upland areas and mountainous regions where much of the world's water supply originates. Water managers would like to have future supply and demand probability functions so as to provide the reliability, the quality, and the pressure of water supplies people expect.

Climate models are good at modeling the large scale processes for which they were designed, and they do well at showing average changes in temperature. However, precipitation is a more local process, and such models have not yet been able to accurately predict changes in precipitation or its variability at scales useful to water managers. Very little research has been done to date on future demand functions.

Decision makers want to know what options are available to them that will be robust under any scenario of the future. Our improved understanding of physical and social processes and trends, possible future changes, technologies, and management options and our ability to model them as systems can help us find solutions that can be effective now and adaptable across a wide range of feasible future states.

For example, there is a definite need for adaptation to climate change in coastal cities. An eight-step procedure has been in use for New York City's critical infrastructure and climate change evaluation:

1. Identify current and future climate hazards

2. Conduct risk assessment inventory of infrastructure and assets

3. Characterize risk of climate change on infrastructure

4. Develop initial adaptation strategies

5. Identify opportunities for coordination

6. Link strategies to capital and rehabilitation cycles

7. Prepare and implement adaptation plans

8. Monitor and reassess. [*Grayman et al*., 2012]

Research is required to inform this process.

1.4. Water for the Environment

Our built and natural environments can either enhance or degrade the quality of our lives. Nature provides us with multiple benefits, including food and fuel; improved air and water quality; moderation of water flow and temperature regimes; enhanced soil formation and fertility; oxygen production; carbon and nutrient storage; recycling; and cultural, recreational, and spiritual enrichment. Water and sediment regimes within natural ecosystems are major factors in determining their health and sustainability. Well-designed and maintained built environments provide additional essential economic and social benefits. Withdrawals of water to meet urban demands, grow more food, and produce more energy all result in less water for the environment and for maintaining ecosystem health. Our challenge is to identify and then create a sustainable balance among all these demands that are both changing and uncertain.

Inflowing water quality is as important as water quantity. Ecosystem changes may be caused by minor water quality changes. Multiple contaminants often combine synergistically to cause amplified, or different, impacts than the cumulative effects of pollutants considered separately. Continued input of contaminants can ultimately exceed an ecosystem's resilience, leading to dramatic and possibly irreversible losses. Groundwater systems are particularly vulnerable freshwater resources: once contaminated, they are difficult and costly to restore.

Floods and droughts can have a substantial impact on the ecosystems of wetlands and forests. Cycles of droughts and floods are a natural part of ecosystems; they adjust to and are influenced by them. Floods and their associated sediments can recharge natural ecosystems providing more abundant water and fertile soil for plants (including food crops). Urbanization and other land use changes, poor agricultural practices, and industrialization are among those activities that can change water quantity and quality regimes in ecosystems, and hence adversely modify ecosystems [*Palaniappan et al*., 2010].

Today perhaps half of economically available freshwater is used to satisfy human demands—twice what it was only 35 years ago [*Young et al*., 1994]. We are not sure how much water must remain in our natural ecosystems to maintain them; many have already been destroyed by overwithdrawals of water. However, indications are that in many others we are approaching the limits of how much water we can divert from them and still preserve their health, and in turn, ours [*Cosgrove and Rijsberman*, 2000]. Fortunately studies of the role of water in ecosystems are improving our ability to value it and to understand large scale, long-term ecosystem processes and the flows of water they require [*Oki et al*., 2006].

Scientists, engineers, managers, policy makers and stakeholders must work cooperatively together to identify and develop strategies to sustain largely ignored ecosystem values. A fundamental scientific challenge is to be able to specify the spatial and temporal scales needed to understand and manage for ecosystem resilience and sustainability. Focused effort on better articulating the relationships between flow regime, its alteration, and ecosystem dynamics is increasing rapidly [*Arthington and Balcombe*, 2010; *Poff and Zimmerman*, 2010], but identifying the "bounds" on ecosystem sustainability [*Postel and Richter*, 2003; *Richter*, 2009] remains a research goal.

Nearly every hydrologic method introduced prior to 2050 will have been adapted to account for the increased uncertainty and nonstationarity which have become the central challenges of our profession. Regardless of available technology in 2050, water resources planning and managing will continue to take place in a social or political environment, i.e., an environment dominated by humans. Research is needed for an informed debate on the need to pay for the continued existence of something without any need or expectation of using it or seeing it. If this is going to happen, there will have to be a massive shift in the average person's understanding and valuation of the environment, as well as our understanding of national wealth and the cultural values humans place on their water resources.

Water is a natural resource that is embedded in the cultural and religious values of societies. It is what we take pictures or create paintings of. It is why we construct fountains. Cultural differences play a key role in the way we perceive, value and manage water in our different societies. World health and poverty eradication have cultural connotations; culture has positive and negative health impacts on individual well-being—in particular women's health. Research is needed to better understand the cultural dimensions impacting water management practices and how they affect human behavior in different societies. Here the participation of social scientists is particularly critical. Water resources management strategies must take culture fully into account if those strategies are to be sustainable over the long term. Intercultural dialogue should be a guiding principle for raising awareness. Cultural diversity is a source of sustainable practices. Indigenous knowledge holders—i.e., local stakeholders—and scientists should cooperate in finding solutions to water-related problems.

2. Research Needs and Directions

Piecemeal reactions and responses to undesirable disruptions in life support systems are not enough in today's world where humans can control the environment of our planet. Sustainably providing healthy and meaningful livelihoods for all of humanity is our major challenge in this century. Meeting this challenge is going to require changes in the way that the necessary water, food, energy, and other goods and services are provided and beneficially consumed. It is going to require changes in the ways we produce products and in the ways we recycle and dispose of by-products. It is going to require changes in the consumption habits, especially of our most affluent. In short it is going to require all of us as society to identify, through research, develop, through engineering and science, and implement through governance, the technological, economic, political, and social measures that will set a course toward the achievement of a desirable and more sustainable and secure future.

We have the knowledge, the technology, and the economic resources to manage our water resources much more efficiently and effectively than we do today. Scientific research through systematic study of the structure and behavior of the physical and natural world is continuously adding to our knowledge and tools.

Through research we are learning more about how to preserve ecosystems and their need for water. We know that changes in our behavior and our diets can also have a substantial impact on our water consumption. We know we can reduce the waste of water used to produce food that is discarded in various stages within the entire supply chain, from field to fork, before it reaches our dining room tables. We know how to use less energy, and hence less water needed to create that energy. We have options. We need to make choices. Continued research is needed to help us to identify these continually evolving options and to inform us on their effectiveness.

Unlike some other fields such as medicine and physics that devote some portion of their budgets to research that may not have direct benefits for decades into the future, most water resources and environmental research is expected to result in products that will come to the market within a 5–10 year (or less) time frame. In large part, the water resources and environmental fields have not been as supportive of more innovative research aimed at long-range solutions, products or methodologies as we believe they should be (Grayman et al.).

2.1. The Planet Reacts—Will People?

Societies are responding by implementing mitigation and adaptation measures. Some of these are slow, others are fast; some are leading us in one direction whereas others in another. One of the most dramatic changes that has ever affected society—global warming—and the close link to water—has not yet resulted in an adequate concerted effort to cope with the threats. The result, in terms of climate and water changes, is likely to have a degrading or damaging effect on agricultural systems, natural habitats, and economic systems, in addition to the hydrological cycle itself. Scientific arguments about the seriousness of the consequences of our increased greenhouse gas emissions expressed at international climate meetings are only marginally and slowly influencing political decisions and concrete action.

The scientific findings are inconvenient not only for politicians but also for existing economic systems and even parts of the public at large. Opinion surveys indicate a widespread worry in countries, e.g., the member states of the Organization for Economic Co-operation and Development [*Organisation for Economic Co-operation and Development* (*OECD*), 2011], about climate change and its likely effects. But our readiness to modify behavior that is detrimental to our environment remains a big challenge worldwide.

Altering our path to a more desirable future requires new thinking and new social research leading to new water management approaches, and importantly, their political and social acceptance. Society tends to stick to conventional thinking and prevailing practices. Past investments and education tend to perpetuate a way of thinking among people, causing them to formulate and execute policies even if they are inferior to known alternatives. Investments made in water infrastructure (such as dams), storage, and conveyance facilities represent huge stocks of physical capital. The already existing structures and associated institutions and knowledge are, of course, very important for many people. Nevertheless, it makes sense to ask if alternative land and water management strategies might generate desirable livelihoods with less environmental risk for an adequate number of people, given growing water supply and quality constraints.

Path dependence is related to policy formulation. Some practices attain a "privileged" status whereas others are ignored. Projects and ideas in the former category receive strong positive attention and are sometimes tackled with "more motivation than understanding" [*Lundqvist and Falkenmark*, 2010]. It is natural that the public, as well as policy makers, are fascinated by the grand schemes in ancient hydraulic civilizations and similar schemes in the contemporary era—the Hoover, Aswan and the Three Gorges Dam projects, for example. In comparison, rainfed systems are less spectacular and political interest and budget allocations are generally less enthusiastic.

The late John *Briscoe* observed that every country that has successfully lifted its people out of poverty has done so primarily by building its basic productive capacity especially in agriculture, energy, transport and water for economic growth and employment generation. No presently rich country has developed without such investments, which have been the springboard for private sector growth and for job creation. To take but one indicator every presently rich country has developed more than 70 % of its economically viable hydro-electric potential. Africa has developed 3 % of its potential. Not only is this the path that has been followed by all presently rich countries, but it is the path followed by the countries who have, in recent decades, pulled their people out of poverty—like China, India and Brazil [*Briscoe*, 2011]. Water storage is essential and can be accomplished through a range of infrastructure from wetlands through large dams. While errors may have been made in the past, particularly with respect to the environmental and social impacts of large dams, the World Commission on Large Dams [*UNEP*, 2000] has provided a very useful guide to avoid these errors in the future.

2.2. Toward a Water Secure Planet

There is no one optimal path to a one optimal future, say in 2050. There are many paths to many "desirable" futures. But it is hard to imagine any of those futures not having to deal with water scarcity. This will particularly apply in emerging countries, such as China and India that together by 2050 will represent about one third of the world's population.

A feature of any "desirable" future will surely be the existence of healthy ecosystems. Living ecosystems require water. Other demands for water have often been considered to be at odds with the need for water to maintain the life of ecosystems. In addition to the need to allocate water for the maintenance of ecosystems, we will need to eliminate the discharges of human and industrial wastewaters that are being discharged into the environment often without concern for their effects on ecosystems. In short, we will have to determine how to stop depriving ecosystems of water that is essential to life and poisoning them with waste will impinge on human life and development. We do not need more research to tell us this. We can benefit from more research into how this can be accomplished effectively and efficiently.

To ensure that there will be sufficient water to feed a growing and wealthier population, to sustain vital life support systems, and to produce and distribute enough other goods and services, it will be essential to achieve "more crop per drop," "more jobs per drop," "better environment per drop," "improved nutrition per drop," among many such goals. Current trends imply that we could be heading toward using more rather than less drops per job, or per given state of the environment, or per given level of nutrition, unless we work together to reverse this increase. Meeting unmet and growing human needs and escalating wants is a mounting challenge. To consider this and at the same time sustain the functioning of water (fresh and brackish/marine) and terrestrial ecosystems is another major challenge. Identifying and evaluating ways of addressing these challenges is surely a topic for a major collaborative multidisciplinary research effort [*Falkenmark and Rockström,* 2004].

To prevent a severe water management crisis we need to be creative. If we continue to follow a business-as-usual pathway it could lead to a situation in which our current predictive models may not work at all. We need to identify, establish and then set in motion systems of governance and regulation that are capable of forcing us on a path that will lead us toward long-term sustainable development. We will also need research on how best to confront simultaneously financial, social, and environmental challenges. Our main concern must be to create the necessary conditions for human creativity to flourish in the domains of politics, science, culture, and ethics. Local, regional, and world leaders need to put water issues at the top of their agendas before they are forced to by circumstances that they can no longer control. We need to identify and implement creative long-term solutions to the water management problems that could threaten the future of humanity [*Gulbenkian Think Tank on Water and the Future of Humanity* (*GTT)*, 2014].

Gaps between the rich and the poor have been, and remain, wide and are increasing [*International Monetary Fund (IMF)*, 2000; *Shah*, 2010]. Access to safe water and sufficient food is still a dream for almost a billion people. More than 2.5 billion of us lack access to safe sanitation. During the last 15 years or so, food insecurity, in terms of undernourishment, has increased in spite of a continuous increase in aggregate global *per capita* food production and supply [*Lundqvist*, 2010, Figure 2.2]. Increased food insecurity during the last 15 years or so took place despite increases in production and supply being faster than the population increases during the same period. Production, and also supply—what is available in the market after losses and conversions—are at a level that is in excess of what is needed for food security. So why is there food insecurity in our world?

Today overeating is a more widespread phenomenon than undernourishment. An estimated 1.5 billion persons aged 20 years and above overeat [*Beddington et al*., 2012]. Moreover, between one third and one half of the food produced on the farm is lost or wasted before it gets to any plate [*Lundqvist et al*., 2008; *Lundqvist*, 2010; *Gustavsson et al*., 2011]. Increasing resource use efficiency— "more crop per drop"—is important, but if a large fraction of the "crop" is not beneficially used the net result of gains in production are reduced.

These kinds of imperfections not only apply to the use of water and food. Similar observations can be made regarding other resources and commodities. With the strong linkage between food, water, energy, the environment, and human well-being [*Hoff*, 2011] these kinds of imperfections affect all of us as well as the natural resources and Earth's environment. In an era of growing water scarcity we need to identify how to use our technical capacity and human ingenuity to reduce these production and supply chain inefficiencies. Reducing the losses and waste associated with the products we grow or produce from water is important. So far it has not been seriously tried.

2.2.1. Technology

Many believe that technology, the tools and methods used in the production of goods and services, will make it possible to achieve the future we want. Indeed, there is a long list of technological trends and advances that are likely to benefit rapid and effective adaptation of the water sector:

1. Cybernetics, artificial intelligence and instantaneous information technology (smarter internet)
2. Nanotechnology
3. Cost-effective energy technology (solar, space-based energy, algae as fuel)
4. Biotechnology (genetic engineering) to help feed the populace and save endangered species
5. Space-based environmental monitoring systems and instantaneous feedback to predictive models even to remote areas of the globe
6. Geoengineering to reverse global warming (e.g., giant reflectors in orbit; greening deserts; iron fertilization of the sea; aerosols in the stratosphere)
7. Effective, reliable prediction of most weather and climate events

8. Renewable energy replacing fossil fuel entirely – low carbon societies
9. Desalinization (in conjunction with cheap fusion energy) becoming cost-effective and providing water for most large coastal urban areas and megacities
10. Vastly improved sanitation and wastewater treatment technologies and recycling
11. Biotech approaches to pest control for improved agricultural yields
12. Ecological engineering to preserve habitats, reverse species extinctions and combat invasive species
13. Mapping groundwater resources and sustainable extraction levels

Computer-based optimization and simulation models incorporated with interactive graphics, audio-based decision support systems will continue to help us identify those plans, designs and policies that maximize the desired impacts and minimize the undesired ones as well as making clearer the trade-offs between the two. (From *Grayman et al*. [2012].)

Science, technology and innovation strategies are integral parts of sustainable development strategies. Many innovations in sustainable water management are high risk and with uncertain return. Government financing and policies for innovation, supported by public-private partnerships, can be purposely designed and implemented to reduce risks and promote research and development and diffusion and transfer of technologies.

2.2.2. Monitoring

There is a need to develop the global monitoring information system on water to provide the information needed for water management and to monitor progress against targets. This should provide a wide-spectrum of information from the local level and up to national and global levels (e.g., monitoring data, public documents, comprehensive national plans, available and appropriate technologies. Timely, comprehensive, and forward-looking information in accessible formats and the gradual development of the capacity to stream information into the decision making process is a means to allow people and institutions to access new insights and innovations. It could help to build a better connected and empowered society which enables transparency and trust in the pursuit of collective goals.

For example, a network of cell phone-sized, hand-held environmental sensing devices for climatology, soil moisture and chemistry, water quality, streamflow, etc. could continuously transmit data via satellite linkages to data processing and modeling centers. These centers also could monitor evolving storms and continuously update forecasts for communities downwind or downstream. Such an information source could provide every remote village with the much of the information farmers require to take decisions.

Another example of where much better data and monitoring approaches and related capacity is required is for ecosystem management. Ecosystem-related data and monitoring has traditionally tended to focus on the impacts of water use, and interests need to shift more toward monitoring ecosystem services that make more succinct links between ecosystems and human well-being.

But it is more than a matter of better sensors and more satellites. There need to be corresponding improvements in ground-based monitoring networks, and an integration of knowledge from all sources, including complementary airborne monitoring systems in order to improve water resources management.

2.3. The Water—Food—Energy Nexus

2.3.1. Agriculture

FAO and the World Water Council [*FAO and WWC*, 2015] have concluded that, with appropriate investment and policy interventions, food production will be sufficient to support a global population of 9–10 billion in 2050 although food and nutritional insecurity will persist in many regions. Countries in water-scarce regions will increasingly need to devise food security strategies that explicitly consider structural food supply deficit and trade arrangements that will provide protection from food price volatility. Higher pressures on water for food production may be expected to develop because large segments of the populations in the emerging countries will tend to raise their standards of living. Eating more beef than bread, for example, generally requires much more water.

Where water is limited, irrigation typically takes over. In these regions the challenge is to reliably produce more supplies and more varieties of food using less water and other resource inputs in an environmentally friendly manner—and at reasonable and affordable prices for consumers. This challenge must be met as the climate changes, and as almost every input to the food production, processing and consumption chain increases in cost. This can only be done by mobilizing technology and achieving much better coordination, cooperation, and partnerships among the major stakeholders involved: farmers, market operators, regulators, and consumers. Our way of life, well-being, and culture are intimately linked to how and where food is produced, what is produced, how we obtain it, how we prepare it, and how we consume it. Increasing urbanization will impact the volume and quality of water available for agriculture, particularly in peri-urban areas. Increasing demand for water in cities, industries, and for environmental flows, will reduce the volume of water available for agriculture. To compensate for this, we can consider rain water harvesting, aquifer recharge and conjunctive use of ground water, surface water, treated waste water and sea water and farming systems involving halophytes and aquaculture"40. As salt water constitutes 97 percent of all global water resources, methods to use sea water for agriculture, which uses 70% of the world's available freshwater resources, would represent a major technological break—through that would reduce the freshwater burden.

A wide array of "on-farm" agricultural management technologies and practices are available or development that could increase yields and decrease pollution and water use; for example reducing yield gaps (not as high in Asia as in Africa), reducing subsidies, change land use and crop types, improving irrigation efficiency, diversified and intense cropping systems, limiting food waste, water harvesting, supplemental irrigation and precision farming and nutrient management. Innovative technologies and investments for are required for education and training in the management of water for both irrigated and rainfed settings so as to achieve more productive use of water in agriculture. Decision-support tools that inform farmers will be particularly important to smallholders. In the water-scarce Bundelkhand region in India smallholders expressed the need for a Decision Support Tool (DSS) that would tell them or help each of them decide:

1. How much groundwater, pond water and rainwater will be available in different months
2. How water balance will look like in different months (present and future)
3. Whether available water is suitable for different uses
4. How much additional water storage is desired; and at what locations
5. How we as a community, can allocate the available water for different uses
6. Suitability of available land and water for various crops
7. Crop combinations that maximize income and risk involved)
8. Amount of water needed (& at what stages) for particular crop combinations.
9. How soil fertility will change and which fertilizers should be used.
10. What crop/PH processing will add value to products and enhance income
11. Besides agriculture, what other livelihood options will be viable given location, land-holding, income group, etc.
12. What market avenues are available.
13. Which gov't. schemes are available and for what purpose and when
14. Which gov't./local institutions can offer assistance and for what and when
15. Which TK/products can enhance income
16. What infrastructure facilities will be required (seed bank, storage, implements, fertilizers, insecticides, market, insurance, technologies) (V. C. Goyal, personal communication, 2015)

Such a DSS would enhance agricultural risk management, particularly for smallholders, and would be critical in enabling farm households to adopt new technologies, diversify their activities, and sustain food security during periods of high input prices, low crop yields and major weather events. A more systematic use of climatic index-based insurance products and investments in infrastructure that enhance the availability and transport of farm inputs, crop and livestock products, and reduce the transaction costs of marketing farm produce would also provide support; they would increase the value generated by farmers using limited water resources while improving household food and nutritional security. Yet as discussed later in this paper, decision support models are a necessary but insufficient to produce good water management solutions today because the decisions in a democracy are driven by political factors far outside the domain of the decision models.

Smart technologies choices requires comparing between conventional technologies and new ones, balancing traditional infrastructures with green alternatives, mixing local and global knowledge, adapting alternatives from abroad to local conditions, dealing with environmental and social impacts of the alternative technologies, etc. All these decisions will require technology evaluation and assessment tools and good water governance so as to insure transparency and inclusiveness.

2.3.2. Energy

Water management policies must also about ensuring sufficient water to produce the energy demanded by society. Humans and their economies and societies critically depend on reliable supplies of energy. Energy, as electricity and liquid and gaseous fuels, available when and where needed, requires water to produce, such as for cooling and refining.

Water, of sufficient quality and pressure, available when and where needed, requires energy to produce. In short, energy is needed to provide much of the water we need and use, and water is needed to provide most of the energy we need and use. How can we ensure enough of both to meet all future water and energy demands? Limitations of either can constrain future economic and social development as well as adversely impact human and environmental health.

The global population in 2050 is expected to be two billion more than it is today. Greater wealth in many emerging markets is resulting in new and growing cities and increased energy and water consumption. The inhabitants of the new cities will likely consume more water than their forebears and to do this they will need more electricity. This of course could increase global carbon emissions. The impact on our ecosystems and our health is currently unpredictable. If we are to be dependent on hydrocarbons for a large share of our energy for the next several decades, we need clean fossil fuel technologies and effective carbon capture and storage mechanisms. But current technological solutions for both are water intensive, and water may not always be available where and when it is needed. Projected water demands for primary fuel extraction, carbon sequestration, and alternative transportation fuels derived from biofuels, shale gas, oil sands, coal, hydrogen, and the development of natural gas supplies from shale gas are significant.

At the same time efforts to improve water security through construction of desalination and/or wastewater treatment infrastructure and/or large interbasin transfer projects have significant energy implications. Shifts toward cleaner energy—such as the increased use of biofuels and coal with carbon sequestration—can significantly increase freshwater demands. Existing hydrocarbon and alternative energy production, including biofuels, is water intensive. However algae might become the surprising choice for future biofuel production. Not only can it provide a surprisingly high concentration of lipids, but it can fix a great deal of carbon dioxide. Furthermore, algae can be used to treat wastewater, while producing biofuels such as biodiesel, ethanol, biogas, and hydrogen. This can lead to shortages in water supplies that in turn can lead to shortages in energy production.

Despite these interdependencies, water and energy policies are rarely integrated. "The disconnect between water and energy policies is driven in large part by the failure of water and energy practitioners to engage with and fully understand one another" [*Cooley et al.*, 2011]. Part of the reason for this is the geographic scales of concern to energy and water utility managers are usually quite different. Energy providers are rarely focused on regions as small as a city, or town, or county that water utility managers are responsible for. And water utility managers of local municipalities are not likely to feel they need to take into account the production of electricity or gasoline hundreds of kilometers away that they may eventually use [*van der Veer*, 2010].

Sustainable energy and water development and production in the future will require an understanding of the interdependencies of both components of such systems. A balance among the needs of all users of energy and water and an appreciation of the impacts on climate, the environment, and the economy will also be necessary. This will likely require some changes in human behavior.

In a world of limited energy and water resources and where more people want and can afford more of them, should not we examine our current management policies and uses? In particular, how can we produce more energy with less water? The science is available, but too often the incentives for water use favor increased use and do not foster change. Can we reduce fossil or nuclear energy production or avoid cultivation of biomass crops for energy purposes? Cooling systems of thermal power plants can be made more water efficient. Is clean coal really a good solution? Could not we stop using drinking quality water for fighting fires or for flushing toilets and transporting wastewaters in urban areas? Addressing these and similar questions can help us in our attempts to achieve a more energy and water sustainable future.

Technologies could make discussions of these possibilities more innovative and productive. Web-based meetings are now commonplace in businesses and among private citizens and it is only a matter of time until online computer support of these virtual meetings becomes commonplace. Preprogrammed responses to anticipated issues could play off within computers before people get involved and emotions sidetrack negotiations. Personal and group preferences could attach values to alternatives developed in computers independently from the stakeholders and the power utilities. Software could bring up likely acceptable compromises for consideration by the stakeholders.

2.4. Urban and Industrial Water Demands

Today half of the world population lives in urban areas. UN Habitat predicts that virtually the entire demographic growth of the world over the next 30 years will be concentrated in urban areas, mostly in low-income countries. By 2050 urban dwellers will account for about 85 % of the population of the more developed world and some 65 % in the less developed regions—seven out of ten people will live in urban settlements [*UN Habitat*, 2012]. With this migration comes a complex trade-off between environmental risks in rural and urban settings. Migrants from rural areas often leave behind unsafe water supplies that put them at risk of waterborne infectious diseases, but they are exposed to new risks, such as urban air pollution, exclusion from health care and poor housing conditions and associated communicable diseases.

The U.S. Environmental Protection Agency (EPA) is implementing an Urban Waters Initiative by investing in water infrastructure, stepping-up enforcement and prevention of harmful stormwater runoff. It focuses on reconnecting communities to urban waterways and creating programs relevant to under-served communities in urban areas. The web page (http://www.uswateralliance.org/tag/urban-waters-initiative/) shows an example of its implementation. Other initiatives for energy and water savings are green roofs and decentralized wastewater treatment systems where economical. See, for example: http://www.habitattuolumne.org/build-your-first-house-for-your-dog/ http://www.treehugger.com/cars/bus-roots-public-bus-doubles-as-mobile-green-roof.html and http://www.iees.ch/cms/index.php?option=com_content&task=view&id=74&Itemid=9.

Urban centers depend on water and energy inputs to function properly. The treatment and final disposal of liquid and solid wastes are still challenging the public health and public works agencies of the majority of urban centers, primarily in the developing world. Water supply, sanitation, wastewater treatment, storm water drainage, and solid waste management have been planned and delivered largely as isolated services. Commonly a range of authorities, each guided by distinct policies and pieces of legislation, continue to oversee these water subsectors at the city level.

Because the traditional urban water management model has failed to distinguish between different water qualities and identify uses for them, high-quality water has been diverted to indiscriminate urban water needs. Even basin-level management often neglects to acknowledge the cross-scale interdependencies in freshwater, wastewater, flood control, and storm water. Thus, there is a need to identify, and then implement, ways to rehabilitate urban ecosystems. This will require innovative institutional mechanisms, and a balance between autonomy and cooperation. Urban water planning, development, and management need new strategies because water is just one component, albeit an important one, of an increasingly complex interlinked system that includes urban supply of energy, food, employment, transportation, and job creation.

Agriculture can support larger numbers of urban residents, but farmers must be able to retain access to sufficient water to support crop and livestock production. The interaction between cities and the countryside will become increasingly intertwined. If well managed, it could offer new opportunities for mutual benefit, including recycling and reuse of water and nutrients held in municipal waste products.

Integrated urban water management in the future will reframe a city's relationships to water and other resources. It will require improving environmental monitoring and information by expanding the scope and factual basis of comprehensive urban water management models. In addition, it will require a framework for negotiations that includes all of the stakeholders and stresses the importance of gradual but comprehensive institutional formats and clarity in local, regional and national decision-making processes.

Decentralized systems are sometimes proposed, as opposed to the centralized ones adopted by most cities in developed nations. But it is not an either/or option. Local systems are, and must be, part of larger physical and institutional contexts. The choice should be based on economic analysis, but also consider other aspects, such as institutional issues around responsibility for operation and maintenance and flexibility in system development.

Thanks to superior productivity, urban-based enterprises contribute large shares of gross domestic product (GDP). While in the past, industrial development has used as much water as might be available, today it is increasingly recognized through market signals that water has a value and that there is an opportunity cost associated with most uses of finite resources. The trend is clear. Less is withdrawn and more wastewater is treated, so that both the water and some of the elements that accumulate in the production process can be reused. Industries in many countries are now consuming less water per unit output and reducing pollution loads in their waste. 21st Century approaches to urban water management will incorporate (1) increased water conservation and efficiency, (2) distributed stormwater management which captures and uses rainfall, (3) source separation, (4) water reclamation and reuse, (5) distributed water treatment, (6) heat recovery, (7) organic management for energy production, and (8) nutrient recovery.

Given the challenges in urban water management, urban water resources research will be an increasingly prominent component of the entire water resources research effort in the foreseeable future.

2.5. Addressing Water Management Constraints to Achieve Prosperity

Within a couple decades, water scarcity may affect about two thirds of the world's population. In many countries there is still a tendency to deal with water scarcity problems by augmenting the *water supply*, e.g., by increasing surface and groundwater storage and allocation through the creation of new infrastructure, desalination of saltwater or brackish water, reuse of wastewater, or recharging aquifers. This tendency has prevailed over focusing on reducing *water demand*, e.g., by stemming the losses in transport and distribution systems, implementing adequate tariff systems, which seek to encourage lower water demand levels, changing water use technologies, and, generally, increasing the efficiency of water use in domestic, industrial, and irrigation systems; in other words, seeking to increase overall water productivity.

Reducing water demand can also be achieved by controlling other aspects that are not directly related to water, but which are equally important. This can be achieved, for example, by controlling demographic growth, increasing the efficiency of the use of goods that consume water (in particular food products) in their production processes and supply chains, promoting appropriate land use planning, or attenuating the effects of climate change on water through adequate mitigation and adaptation measures.

Water managers today and those in the future will have to be familiar with a wide range of applicable disciplines and be able to interact with a variety of professionals, stakeholders and users. These managers and their agencies should have sufficient technical, economic, social, financial, and environmental skills to be able to engage in dialogue with the professionals and affected stakeholders in the regions where improved water management is needed. They should have the capacity to interact with politicians and inform them of the science behind any impact predictions. They need to understand policy makers' short-term political commitments, and be able to facilitate the conciliation of politicians' initiatives with long-term sustainable water resource policies.

The ability to fully represent the real world in analysis and simulation tools will undergo a change that revolutionizes engineering practice in this area by enabling fine-grained representation of the real world, perhaps limited only by the rate of increase in scientific knowledge as opposed to engineering capability. We will therefore experience changes in practice not just in speed and scale, but in kind. The human skill sets required to manage and work effectively in this changing environment will evolve; syntax, sources and organizational models will change, but the ability to apply intellect and propositional logic will not. Systems analysis will be a principal tool of the future.

Prosperity is understood to be a state in which people are living and doing well. People are happy and healthy [*Jackson*, 2011]. The goal of our society should be to create the conditions under which it is possible to increase prosperity, within the ecological and natural resource limits of our finite world. Determining just how best to do this involves understanding the complexity of the system of drivers and impacts that affect human well-being through water security and the risks or benefits to society of alternative policy and management decisions [*Cosgrove and Cosgrove*, 2013]. By using a range of models for analyzing the consequences of different possible future scenarios, one can identify robust adaptable policies that work across sectors and scales. Thus these model-based analyses could avoid the present quandary of implementing new policies only to find out that they aggravate a problem rather than curing it because of forgotten factors in the system.

2.6. Governance

Given today's accelerated pace of technological development and the slow pace of social developments, it seems likely that the biggest issue or constraint in the future will remain what it is today: namely the human component of water management, not the technical one. Improving our governance policies and procedures takes even more time than obtaining the funding needed to improve our infrastructure systems. This time lag is especially troubling given the consequences of not meeting the world's demands for water [*International Food Policy Research Institute (IFPRI)*, 2009, 2010, 2012].

Achieving effective water governance involves a wide range of issues that have been studied by many investigators. One proposed way of achieving improved water management is the implementation of *integrated water resources management* (IWRM). This has been defined as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems" [*Global Water Partnership (GWP)*, 2000, p. 22]. As is the concept of sustainability, IWRM is more of a goal, than of the achievement of a given set of criteria.

Information on IWRM is limited and it is even less accessible to partners in the developing world. Obtaining new skills requires improved access to information, sharing capacity (e.g., as when trainees become trainers) and its application. Information materials, training materials, knowledgeable capacity builders and experts are part of the inputs to a capacity-building program, and online platforms of open content education and training materials can help facilitate these processes. This is particularly the case with IWRM, which requires a cycle of responsiveness to capacity development needs coming from different target groups around the world, along with and adaptive knowledge management systems. *OECD* [2011] recognized that integrated water resources management as adopted by many countries cannot be properly implemented without considering a broader governance framework. This would include not only sustainable water policies but also measures governing scientific, educational, and technological issues, as well as communication and participation [*Carr et al.,* 2012; *Delli Priscoli,* 2004].

Humans have difficulty dealing with future water problems, particularly at a global level. This is illustrated by the slow evolution of the positions adopted by international organizations at an international level. Two decades ago, water was not even an issue discussed in the final declaration of the UN Conference on Environment and Development held in Rio de Janeiro in 1992 [*United Nations (UN)*, 1992]. Water only started to be considered as a crucial element of sustainable development since 1998, when the UN Commission on Sustainable Development adopted the text "Strategic Approaches to Freshwater Management" [*UN*, 1998, p. 2]. Recently, the concept of effective water governance has grown in importance and has led to the widening of the water agenda, so as to include the consideration of social and political institutions and processes, corruption, and power imbalances between poor and rich countries and between rich and poor peoples [*Rogers and Hall*, 2003].

A change in paradigm occurred with the publication of the 3rd World Water Development Report [*UN WWAP*, 2009]. Most paths to sustainable development are linked to water, but the decisions that determine how water resources are used or abused are not made by water managers alone. That is the central theme as described in *The United Nations World Water Development Report 3* "begins with political-process actors – *in government, civil society and business* – deciding on socio-economic development objectives and *formulating policy* and *operational decisions* to achieve them. Their decisions, which respond to *life and livelihoods* requirements, are implemented in a context of externalities – often beyond their direct control – that interact with and modify *drivers of change*, creating *pressures* on land and water resources (among others). *Water resources* managers address the demands of *water uses* to meet the *life*-sustaining requirements of people and other species and to create and support *livelihoods*. In doing so, they may add to – or reduce – the *pressures* caused by these drivers. However, their actions may fall short of their objectives because of constraints related to inadequate water, financial or human resources or because the external forces are behaving in unforeseen ways. Making progress thus requires returning to the original political actors in the decision-making process for responses that take these constraints into account."

The challenge to water managers is even greater when dealing with transboundary water bodies, especially international ones. Transboundary rivers and aquifers are common features of today's hydrologic and political landscape. Within different countries and groups of countries that share an aquifer or river it is vastly beneficial to come to an agreement on how to share the water in times of stress before that stress occurs rather than to work out such agreements during times of stress. The water in transboundary rivers and aquifers is resource whose management requires institutions that cross traditional political borders.

A decision-making process is needed in which water managers inform the initial decision making and participate in planning the appropriate responses, interacting with the principal actors and with the managers of other sectors. Thus increasingly, collective governance "beyond governments" is seen as part of the solution, with state and nonstate actors (civil society, companies and governments) working together. In this rapidly changing world, it is best to adapt in time to prevent crises rather than adapting in response to them. In the end achieving the goal is a political challenge. It involves determining the distribution of power and resources within a given community (a usually hierarchically organized population) as well as the interrelationship(s) between communities. Much more research and systematic study is required of successes and failures of legal frameworks and institutional efforts to link water management to management of the economic and social development sectors.

2.7. In Support of the Sustainable Development Goals

The Millennium Development Goals (MDGs) which expire at the end of 2015 were the first attempt of the international community to set goals with time-limited targets for development. A large number of people on the planet have achieved the targets of the eight MDGs and some have surpassed them, albeit in some cases in an unsustainable manner. Consider the progress that can be made if there is agreement on goals, as with the MDGs, specifically the MDG to halve the number of people without access to safe drinking water by 2015 [*World Health Organization (WHO)*, 2014]. Because defining "safe drinking water" and monitoring it would be difficult, a target was built on "access to an improved source of drinking water." In the 25 years from 1990, 2.5 billion people will have been provided with such improved access. Thus, an agreed, well-defined goal will have been achieved with the will, the effort, the technical capacity, and the funds.

The MDGs did not cover all the challenge areas; e.g., there were no targets covering the need for access to neither energy nor the threats of climate change. They did not take account of the important role of water in achieving most of the targets of the MDGs. Nor did the targets recognize the difference in national implementation capacity or priorities.

The Sustainable Development Goals (SDGs), to be finalized and adopted by the UN General Assembly in September 2015, will follow up on the MDGs and take account of lessons learned during the implementation of the MDGs. The 17 goals and over 160 targets in the draft document are based on a common definition of "the future we want" that comes from open consultation that attracted tens of thousands of stakeholders individually or through membership organizations. The overall objective is human well-being. Individual nations, while agreeing to the common goals, will have the flexibility in setting targets to achieve them according to their own capacity and priority needs.

3. Conclusion

Piecemeal reactions and responses to undesirable disruptions in life support systems are not enough in today's world where humans can control the environment of our planet. In this Anthropocene epoch, we are the only species with the capacity to reflect on our behavior and change it as needed to secure our health and economic and social well-being. Providing healthy and meaningful livelihoods for all of humanity is our major challenge in this century. It is going to require all of us as a society to identify, through research, develop, through engineering and science, and implement, through governance, the technological, economic, political, and social measures that will set a course toward the achievement of a desirable and more sustainable and secure future.

Research will always be needed to identify and evaluate the impacts of alternative paths toward this future, and the tradeoffs that will be inevitable given our multiple, and not always compatible, dreams or goals. But clearly translating research results in ways that make them policy relevant is also needed. Research results presented in WRR papers, for example, need to be "translated" into language that shows their relevance to policy makers, and indeed the public. It has to be written in a way that motivates, entertains and informs in a manner that they can understand.

Researchers from many disciplines will work together in the future. They would do well to be inspired by the Vision of the American Society of Civil Engineers whose members see themselves as:

"Entrusted by society to create a sustainable world and enhance the global quality of life, civil engineers serve competently, collaboratively, and ethically as

1. master planners, designers, constructors, and operators of society's economic and social engine—the built environment;
2. stewards of the natural environment and its resources;
3. innovators and integrators of ideas and technology across the public, private, and academic sectors;
4. managers of risk and uncertainty caused by natural events, accidents, and other threats; and
5. leaders in discussions and decisions shaping public environmental and infrastructure policy."

The fundamental issue facing everyone is how to reconcile our desires for all of us on this globe to have a good life with the constraints imposed by the availability of a renewable, but limited, water resource. It can be done. Let our optimism be a torch to light the way forward!

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