Climate Change Resilience and Adaptation

Perspectives from a Century of Water Resources Development

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ABSTRACT: The Fourth Assessment Report of the Intergovernmental Panel on Climate Change and the influential Stern Report both reinforce the warming of the earth's climate system. The alarming environmental, social, and economic consequences of this trend call for immediate action from individuals, institutions, and governments. This article identifies parallels between the problem of adaptive management presented by climate change and an earlier 'global water crisis'. It explores how adaptive strategies have successively emphasized three different principles, based on science, economics, and politics/institutions. The article contends that the close association between climate change and water resources development enables a comparative analysis to be made between the strategies that have been adopted for the latter over the last 100 years. It argues that the experience of water resources development suggests a strong interdependence between the three principles and concludes that conceptualizing them as different dimensions of a single governance framework is necessary to meet the challenge of climate change adaptation.

KEYWORDS: climate change, governance, ecological principle, institutional principle, instrument principle, resilience, water resources

The IPCC has produced four key reports (IPCC 1990, 1995, 2001, 2007b), providing increasing evidence that twentieth-century changes in the earth's climate are unprecedented in historical times. In this body of work, physical models and empirical evidence have in recent decades established links between the atmospheric concentration of greenhouse gases and temperature rises, and the IPCC (2007b: 30) has argued strongly that "[w]arming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level." Although this represents a broad scientific consensus, skeptics remain, and Hulme (2009: 1) notes that, in the UK, "only 41% believed humans are causing climate change, 32% remained unsure and 15% were convinced we aren't." This explains the recent vigorous defense of the science of global warming that has been conducted, both online and in academic publications, by institutions such as the UK Meteorological Office[1] and the Royal Society (2008). The science forms the basis

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of startling predictions of social and economic consequences, such as those in the influential analysis by Stern (2006) (hereafter, the Stern Report), which assumed a 2 °C rise in global temperature. Yet Anderson and Bows (2008) argue that this understates the likely scale of impacts because past accumulation of greenhouse gases has already reached levels that will see temperatures rising inexorably past the 2 °C 'tipping point', beyond which many believe that warming will result in serious disruptions to human activities and natural ecosystems. They also argue that warming will most likely exceed a 4 °C rise during the twenty-first century.

Predicted consequences are so great that most political leaders support the need for action to curb future emissions. However, the system of financial incentives agreed upon in the 1997 Kyoto Protocol and at conferences thereafter is widely regarded as being ineffective, and agreement on coordinated action to replace it appears elusive, as exemplified by widespread disappointment with the 2009 climate conference in Copenhagen (Vidal and Watts 2009). Dimitrov (2010: 796) describes the Copenhagen conference as "a failure whose magnitude exceeded our worst fears, and the resulting Copenhagen Accord was a desperate attempt to mask this failure." This depressing analysis and a renewal of public doubt about the IPCC's scientific methodology form the backdrop against which individuals, institutions, and governments must act to respond to the threats posed by anticipated future global warming.

Two broad strategies that have emerged from UN deliberations and have been promoted by the IPCC to tackle global warming are 'mitigation' and 'adaptation'. Mitigation seeks to reduce atmospheric greenhouse gas emissions through emissions control and technological changes (e.g., by achieving greater environmental absorption and storage), whereas adaptation is seen to involve changing human behavior in response to predicted threats. Mitigation strategies are not without criticism, but there is strong support for the economic measures associated with them, such as carbon trading and carbon offsets, if only because poorer nations hope that this will provide much needed financial support, while governments of richer countries hope that it will minimize the economic (and political) cost of reducing emissions. Adaptation has been promoted as necessary to increase the ability of people and ecosystems to survive the 'shocks' associated with climate change. However, there is also some confusion, not least because mitigation includes elements of adaptation, such as changes in energy consumption, waste reduction, and the like, alongside economic incentives for investment in technological change. Similarly, adaptation strategies also utilize technical solutions that have to be funded; hence, economic tools are part of the adaptation debate.

In discussions on mitigation and adaptation, it is clear that favored strategies are concerned both with technological change and with influencing human behavior through a variety of instruments that include both financial and regulatory measures. In this article, we argue that similar conclusions can be drawn from an examination of water resources development, which, during the twentieth century, sought to manage the hydrological cycle through solutions based initially on science and engineering. More recently, and into the twenty-first century, the effort to maintain this cycle has been made through (re)designing systems of water governance (Plummer and Slaymaker 2007). The aim of this article is to assess, from a variety of perspectives, the experiences that have been gained during the last 100 years in the process of tackling water resources problems and to apply and contrast these to concerns about the impacts of global warming that have been emerging over recent decades. Water resources and climate are obviously linked through hydrological cycles and energy exchanges between the earth and the atmosphere, but more than this, we argue, they share common management approaches based around the notions of resilience and governance of ecosystem resources that can help us gain critical insights into strategies to combat climate change.

The article initially reviews predicted impacts of climate change on water resources in order to explore the continuum between the atmosphere and hydrology and to demonstrate why strategies developed to tackle flood risk and water scarcity may be relevant to current attempts to respond to global warming. We then turn to a discussion of resilience and governance, which is used to present three principles of environmental management: science, embracing an 'ecological principle'; economics, embracing an 'instrument principle'; and politics/institutions, embracing an 'institutional principle'. We use these three principles to structure the rest of the article, which systematically considers first the lessons learned from water resources development and then contrasts these with current approaches to climate change adaptation.

Climate Change and Water Resources

The IPCC has concluded in both its Third Assessment Report (IPCC 2001) and its Fourth Assessment Report (IPCC 2007b) that freshwater resources are being affected by climate change. Future predictions include a decline in glacier storage and increases in the occurrence of precipitation extremes, leading to more droughts and floods. Increased runoff of 10–40 percent is predicted in higher latitudes and wet tropics, with a 10–30 percent increase in dry tropics. The greatest regional changes are likely to occur in Africa, where water stress is expected to rise, and in Australia, which is likely to experience water security problems through reduced precipitation. In Asia, decreased meltwater flows are likely to offset climate conditions that would be otherwise favorable to increased crop yields. The three key manifestations of climate change in relation to freshwater resources are rising sea levels, increased flood hazards, and more frequent incidence of drought.

Sea Level Rise

Freshwater resources are threatened by sea level rises, including both surface flooding in coastal areas and saline intrusion into groundwater. Gregory and Lowe (2000) forecast a rise of around 40 centimeters from 1990 to 2100, with 15 centimeters already observed during the twentieth century (Dessler and Parson 2006). More controversially, Meir et al. (2007) suggest that previously unaccounted for contributions through glacial melting will add a further 10 to 25 centimeters of sea level rise by 2100, or 50 percent more than the IPCC's (2007b) overall projections of 20 to 50 centimeters (see also Oppenheimer et al. 2007; Solomon et al. 2008). As 100 million people live less than 1 meter above sea level and 40 percent of the world's population lives within 60 miles of the coast, this is a serious threat, especially in areas of Southeast Asia (Dow and Downing 2006). For this hazard, as for those arising from increased water stress, the actual impact will depend upon the human capacity to respond and adapt to these changing threats.

Flood Hazard

According to the IPCC's (2007b) Fourth Assessment Report, it is likely that up to 20 percent of the world's population will inhabit areas where flood risk has risen due to climate change. There is evidence that precipitation has increased in eastern areas of the Americas, in Northern Europe, and in Central Asia, and that it has decreased in Southern Asia, Southern Africa, and the Mediterranean. It is also highly likely that for glacier- and snow-fed areas, runoff has increased, while rivers have warmed. In general, higher storm flows can be expected to result from global warming, as explained by Arnell (2002, 2003) and Kerr (2007). However, even where increased precipitation causes higher runoff, this water resource benefit is likely to be moderated by increasing variability and seasonal changes. Considerable uncertainty is attached to predictions of river flow, since the conversion of precipitation changes into river flood regimes involves extremes of two variables: intensity and duration (Bell et al. 2007; Prudhomme et al. 2002). There are also spatial differences: in the UK, for example, upland catchments have proved easier to model than lowland catchments, where groundwater input is more significant. Similarly, rural and urban climates may be distinct (Arnfield 2003; Roth 2007). Impacts in urban areas are a significant challenge because of the complex nature of the urban hydrological system (Marsalek et al. 2006), with combined threats of fluvial flooding from river channels and pluvial floods due to higher rainfall intensity and poor urban drainage infrastructure.

Drought

The Fourth Assessment Report (IPCC 2007b) has identified the risk of drought as rising during the twenty-first century, principally in tropical regions. However, with more extremes in precipitation and drier summers predicted for the northern hemisphere, the incidence of droughts is likely to increase across the globe (Lloyd-Hughes and Saunders 2002). Drought needs to be differentiated from desiccation. The former is a short-term and abnormal water shortage due to an imbalance between water supply and demand (Agnew 2002; Wilhite 2000). It can result from a reduction in precipitation but can also arise from changes in human activity that raise demand for water above the available supply. Desiccation refers to increasing aridity as determined through 30-year climate averages. Climate change threatens both increased drought and desiccation. However, adaptation strategies will differ according to whether one is dealing with drought, which needs an immediate response, or desiccation, which requires longer-term strategies.

The regions predicted by the IPCC (2007b) to be most threatened by increasing drought and aridity are areas of high precipitation variability where agriculture is the dominant land use, in particular, sub-Saharan Africa. Southern Africa could lose almost a third of maize production, while losses of rice and millet could be over 10 percent in South Asia. Impacts and possible responses are not straightforward, however, and Challinor et al. (2009) and Soussana et al. (2010) both argue the need for improvements in agro-climate modeling. Drought effects on crop growth may be tackled through irrigation and other technologies, if they can be afforded (Parry et al. 2005). However, crop choice has a significant effect on drought hazard, and a warming world with higher carbon dioxide levels also heralds other changes. For example, crops such as wheat, soybean, and rice (known as 'C_3 plants' because CO_2 is fixed by a 3-carbon compound, phosphoglyceric acid) are well placed to respond positively, because they have lower water use efficiencies compared to typical dryland crops such as millet or sorghum. Thus, a CO_2 richer world means greater growth potential for some plants in temperate areas, but only if there is sufficient water to offset the impacts of higher temperatures. A further factor is that the vulnerability of poorer areas of sub-Saharan Africa to water scarcity may be increased where production systems are geared to global economic linkages rather than to local risk factors (Franke and Chasin 1980; Glantz 1994). The interaction of socio-economic and biophysical factors in determining overall vulnerability prompted Thornton et al. (2006) to argue for a move beyond considering only water supply when deciding upon drought management strategies. Similarly, the Energy and Resources Institute (TERI 2003) suggests three forms of drought vulnerability: biophysical, social, and technological.

These concerns about climate change intersect with perceptions of a 'global water crisis' (UNESCO 2009) that is identified both with the failure to meet the demand for water in a more populated and urbanized world (WWC 2010) and the commitment included in the UN Millennium Development Goals (MDGs)[2] to reduce by half the proportion of the global population lacking access to clean water and adequate sanitation, numbering some 1.1 billion and 2.6 billion people, respectively (UNDP 2006). This 'crisis' narrative is problematic, however, for two reasons.

First, the focus on domestic water needs, as in the MDGs, raises questions of what standard to use. In a report for the World Health Organization (WHO), Howard and Bartram (2003) state that a water supply of 20 lcd (liters per capita per day) will provide water sufficient only for drinking and basic hygiene, whereas a supply of at least 50 lcd, from a source no more than 1 kilometer away, is required to meet most essential water needs. In practice, measured water consumption values are greater, typically around 100 lcd from urban street standpipes (Twort et al. 2000), rising to 300–500 lcd for developed countries and even up to 800 lcd (in the US). The range of values poses questions about how those who are already facing water scarcity can possibly adapt to a warmer, drier world, and how the higher levels of demand that are typical of urban households can be met. The latter is significant because most of the future global population growth is expected to take place in cities, and there are already 21 'megacities' with populations that exceed 10 million. Against this, Potts's (2009) work concludes that urbanization trends in Africa are not as pronounced as they are commonly represented, especially in medium-sized towns where most of the observed increases are due primarily to local population growth and not to in-migration.

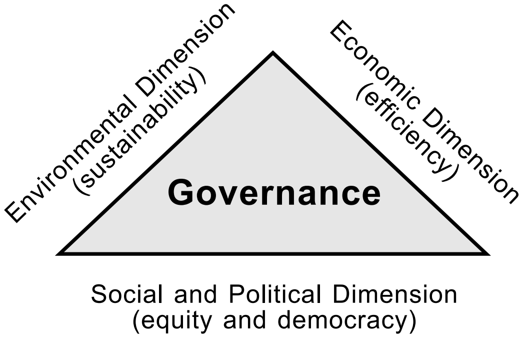
A second problem with the water crisis narrative expressed in terms of domestic use, as in the MDGs, is that, in terms of total water withdrawal, agriculture dominates: 70 percent of global extraction is for that purpose in rural areas, compared to 22 percent for industry and 8 percent for domestic household use. Moreover, the pattern of rising withdrawals is not reproduced everywhere. For example, in the US, total water withdrawals reached a plateau in the 1980s,[3] while household water consumption in the UK has remained around 150 lcd since the mid-1990s (Ofwat 2007).

Nonetheless, since the eighteenth century, global demand for water has grown 35 fold, whereas population has increased 8 fold (Altinbilek 2002).There are undoubtedly problems of water scarcity in some parts of the world, most obviously in arid regions. Twenty-nine countries are classified as being 'water stressed' in terms of the amount of water that is annually available for all economic activity (less than 1,700 m^3 c^{-1} y^{-1}). This list includes India and Denmark but also many of the poorest developing countries. A further 17 countries, mainly from the Middle East and North Africa, are classified as facing 'water scarcity' (less than 1,000 m^3 c^{-1} y^{-1}), based on data from the World Resources Institute.[4] As a consequence, a major concern emanating from future climate scenarios is that changes to the global water supply, along with increases in demand for food production and a growing urban population, will be among the biggest challenges. While concern over global warming is relatively recent, the need to manage and adapt to water resources constraints is not new, and this presents an opportunity to learn from past methods of adaptation to different environmental conditions. In the next section, we outline a framework to identify different dimensions of adaptation.

Governance, Resilience, and Water Development Principles

Governance is a key concept in adaptation strategies: essentially, it is about how decisions are made. Reed and Bruyneel (2010: 647) observe that the meaning of governance varies between, on the one hand, an emphasis upon government as a centralized authority that deploys financial and regulatory instruments and, on the other hand, concepts of devolved decision making by people and communities. They further note a distinction between governance and management, which are presented as operational procedures. Figure 1 depicts three elements of water governance as presented in the UN's Second World Water Development Report (UNESCO 2006). Recent reports on water resources development have stressed the importance of effective governance, as exemplified in the EU Water Framework Directive of 2000[5] and repeated in the UN's Third World Water Development Report (UNESCO 2009). It should be noted that figure 1 presents a normative view of environmental management, whereas in practice markets are not perfect, environments degrade, and equity is rarely achieved. Nevertheless, it illustrates an integrated approach that combines environmental, economic, and socio-political dimensions. To the extent that these dimensions are combined successfully, we might draw the same diagram with 'sustainability' in the center, or even 'resilience'. This is to not say that governance is the same as sustainability or resilience; rather, good and effective governance is a requisite for those features.

Figure 1: Dimensions of Water Governance



Source: UNESCO (2006).

The need to integrate these dimensions for effective environmental management has formed the basis for thinking about water development since a recasting of water development priorities emerged from the International Conference on Water and the Environment (ICWE), held in Dublin in 1992. These key issues were subsequently incorporated into the Earth Summit held in Rio de Janeiro in the same year (Lundqvist 2000; UNCED 1992). The three principles emerging from the ICWE have been reworked, notably through the incorporation of gender issues into the third principle (WWC 2000). They typically include the following:

1. *Ecological principle*—recognizes the need for holistic management of the water resources, usually interpreted as managing water in an 'integrated' way, according to its hydrological units, such as river basins or subterranean aquifers. Here scientific management and expert decision making are the norm, generally invoking the agency of a Weberian state model to ensure that individual, smaller-scale actions are subordinated to a 'greater good', defined variously in environmental, political/security, or economic terms.
2. *Instrument principle*—recognizes water as an economic good whose efficient use and conservation should be promoted through charges payable by users. Here neoliberal ideas, whose resurgence in the 1980s coincided with the concept of 'sustainable development', are embraced, notably through the use of water pricing as a means of determining allocation priorities and the valuation of ecological services.
3. *Institutional principle*—calls for decision making on water resources to be decentralized to the smallest scale feasible, following the criterion of subsidiarity, and to be representative

of all water users. Here importance is attributed to decentralized and participatory decision-making processes.

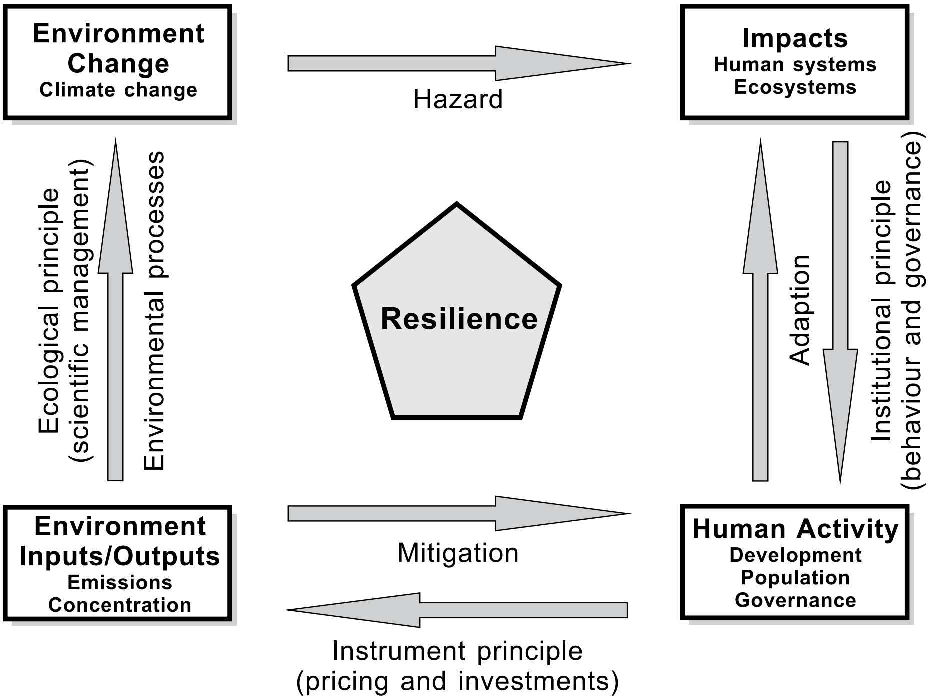
It is possible to map these principles onto the development of water resources. Within the environmental or biophysical dimension (ecological principle), we can locate the engineering approaches that dominated water resources development, from early water treatment some 4,000 years ago (Symons 2006) to the first municipal water treatment plant in Scotland in the early nineteenth century. Walski (2006) charts this technological development of water supply, noting that 2,000 years ago cities in Asia had functioning water systems long before the development of modern hydraulic engineering in the nineteenth century. Today, a plethora of water control technologies are available to tackle environmental constraints, including mega-dams (Altinbilek 2002), desalination (Burbano et al. 2007), and even cloud seeding (Silverman 2003). However, this emphasis upon hydrology and engineering has become substantially counterbalanced, if not replaced, by the economic dimension (instrument principle) and the socio-political dimension (institutional principle). This has shifted the focus to water allocation through both pricing mechanisms and 'deliberative' decision making in which all water users or 'stakeholders' are represented. The category of stakeholders is typically drawn widely to include all those whose interests, such as amenity value, may be affected by the water use of others. Women have been explicitly identified as needing stronger representation in water management, in recognition of the gendered nature of the labor that provides household water supplies in many societies (Peter 2006). Together, the instrument and institutional principles have shifted attention from technology to governance. This shift, which Renzetti (2002) traces to the middle of the twentieth century, is evident in the historical development of water supply as identified by Swyngedouw (2006):

- Pre-1850s: Small-scale supply enhancement through private investors for profit in Western countries
- 1850s–1920s: Large-scale municipal sanitation and potable supply development
- 1920s–1970s: National-scale public provision of basic needs and economic development
- Post-1970s: Privatization, with water viewed as an economic good

For the first three of these stages, the financing and organization of water resources development was driven primarily by the increasing scale of engineering works needed to meet growing urban demand during the nineteenth and early twentieth centuries. Only since the last quarter of the twentieth century has investment in water become guided by neoliberal ideas of pricing and cost recovery, indicated as the final stage in the above chronology. Over the past two decades, this primacy of neoliberal models of market-based management has, in turn, become increasingly contested on the ground that it does not satisfy social goals for universal access to adequate water, as reviewed by Agnew and Woodhouse (2011).

We argue that there are strong parallels between water resources development and responses to climate change: both were initially focused upon scientific evidence leading to technological solutions, followed by economic instruments to provide incentives for change via 'commodification', with finally a move to embrace political mechanisms based on considerations of social inclusion and equity. In figure 2, we have presented these three principles as key instruments for maintaining resilience in the face of climate change impacts. In contrast to figure 1, we have introduced a fourth element, 'hazards', in figure 2 to acknowledge that not all environmental or climate change necessarily has a destructive nature. Environmental change is thus not synonymous with impacts that require an adaptive response.

Figure 2: Framework for understanding responses to climate change using ecological, instrument, and institutional principles



Resilience

The concept of resilience—the ability to respond to environmental shocks—is attributed to the ecologist C. S. Holling (1973). It is defined by the IPCC (2007a: 880) as "[t]he ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change." It has been found useful in work on climate change because it recognizes that the same climate change might produce different impacts due to variations in the stability and vulnerability of different social or ecological systems. Resilience has, for example, been incorporated into work by the International Livestock Research Institute on mapping climate vulnerability and poverty in Africa (Thornton et al. 2006).

Pelling's (2011: 42) recent review notes that resilience "is not simply synonymous with adaptation." This is illustrated by an example where (short-term) risk management can lead to (longer-term) institutional inertia, which highlights the need to understand the "social processes shaping resilience" (ibid.: 43). Figure 2 has the merit of illustrating that adaptation and mitigation measures are part of a continuum linking human impacts and actions to resilience. Perhaps more controversial is our use of three water development principles (ecological, instrument, and institutional) to label particular types of engagement. While oversimplified, as discussed below, this framework provides an opportunity to identify key management dimensions underpinning resilience in the face of climate change and to show how different climate change responses can be mapped onto different paradigms for natural resources management. The article now deals with the three principles in turn, each section commencing with a discussion of the lessons learned from water resources development before turning to consider the possible implications for climate change adaptation.

Ecological Principle—Scientific Management

Some have challenged the 'global' nature of the water crisis (Agnew and Woodhouse 2011; Rogers et al. 2006). They suggest that this focus ignores the successful application of science and technology in many places, which has resulted in water being brought to areas of potable need, allowing for massive increases in food supply through irrigation, as well as health improvements through improved sanitation and water treatment. This progress has been underpinned by advances in hydrological science, moving from understanding channel flow characteristics to catchment-wide linkages between land surfaces and the atmosphere (Ward and Robinson 1999) and predictive modeling of hydrological variables, most recently based upon artificial neural networks (Maier et al. 2010). Developments in the science of water treatment and sanitation, using filtration and chlorination from its early origins in nineteenth-century Scotland (McGuire 2006; Symons 2006; Twort et al. 2000), have been credited with a 50 percent increase in life expectancy in the US during the twentieth century (Christman 1998). Perhaps most emblematic of these engineering achievements is the construction of large dams, which has allowed for a fivefold increase in irrigated area during the twentieth century (presently covering about 300 million hectares),[6] a growing supply of drinking water for expanding urban centers, and the generation of 19 percent of the world's electric power (Altinbilek 2002; World Bank 2009). This remains an important development model,[7] and although three countries (China, the US, and India) dominate, by 2000 some 45,000 large dams had been constructed in over 150 countries. As a result, in less industrialized economies, irrigation is often the largest use of water, typically 80 percent or more (Anand 2007). However, in the face of increasingly uncertain rainfall, access to irrigation technology, along with fertilizers and new seed varieties, is an important asset in adaptive strategies (Parry et al. 2005).

The success of scientific and engineering-led water development initiatives has provided a model that has been promoted by international development agencies, such UNESCO's International Hydrological Decade (1965–1974) and the UN International Drinking Water Supply and Sanitation Decade (1981–1990). There has nonetheless been increasing acknowledgment of failures and of the unpredictability of outcomes from water development projects in which a top-down management style has given priority to scientific and engineering considerations. Adverse impacts of large-scale water developments—dams in particular—have been documented in detailed case studies (Goldsmith and Hildyard 1984; WCD 2000) that identified many dam projects as failing to reach their goals of hydroelectric power production (HEP). Altinbilek (2002) and others[8] have also warned of hazards associated with dams and their potential failure, while Ortolano and Cushing's (2002) study of one of the first mega-dams, the Grand Coulee in the US, concludes that the adverse impact upon the indigenous population continues some 70 years later. Questions about the sustainability of irrigation have also been raised, particularly with regard to problems of soil salinization and groundwater contamination, leading to a decline in irrigated area per capita of population (Postel 1992). Even California, one of the richest regions on the earth, has struggled to meet its insatiable appetite for water through technology. In February 2009, Governor Arnold Schwarzenegger proclaimed a state of emergency as California entered a third consecutive year of low rainfall, with consequent reductions of up to 50 percent in deliveries of water to irrigated agriculture, notably in the San Joaquin Valley, resulting in losses in agricultural production estimated at almost $1 billion (CDWR 2009). Local water shortages are compounded by widespread deterioration in water quality, with only modest improvements achieved between 1993 and 2003 in the most heavily affected streams in the US (Sprague et al. 2009).

Evidence that irrigation did not necessarily benefit all of those involved resulted in a shift in focus of irrigation design, particularly in South Asia, from technical considerations of water storage, transmission, and application to issues of poverty, social organization, and participation in decision making (Chambers 1994). More generally, declining confidence in the ability of engineering design to deliver predictable economic benefits led to growing political opposition to large-scale water projects and a decline in investment. Bank support for development dropped from $4.4 billion per annum in the 1980s to $2.6 billion per annum by the late 1990s (Bird 2002). Moreover, despite a renewal of World Bank interest in investment in dams—notably in Africa since 2000 (Pearce 2006)—loans for irrigation and drainage in Africa were lower in 2002–2005 than they had been in 1978–1981 (CAWMA 2007: 73).

Large-scale engineering remains an important element of water resources development, especially when HEP is central to cheaper energy production (cf. the Three Gorges Dam in China and the Grand Anatolia Project in Turkey). More broadly, science and engineering play a central role in programs to 're-engineer' rivers in industrialized countries in order to improve their ecological or flood management functions. However, engineering has come to be seen as part of a continuum in which human organization and behavior play a much larger role. This is exemplified in proposals for flood responses in the Netherlands (de Graaf et al. 2007) that list four types of adaptive capacity:

1. *threshold capacity*—engineering to prevent damage, which requires a high degree of social organization;
2. *coping capacity*—reducing immediate impacts with a focus upon relief, requiring good communication and clear responsibilities;
3. *recovery capacity*—short-term return to previous state, requiring insurance and disaster funds); and
4. *adaptive capacity*—the ability of a community to cope and adjust in the future, which may require significant changes in lifestyle and land use.

A further key function of science and engineering is evident here: the provision of information relevant to environmental decision making. As we shall discuss below, 'asymmetries of information' (i.e., situations in which one party in a transaction has more—or possibly more reliable—information than the other) have a major impact on political and institutional processes. Thus, environmental 'threats' can become 'institutional facts' that are propagated to support specific land use policies. Lemos (2003), for example, describes how the threat of drought in Brazil is used to 'insulate' policy makers from public accountability for the policy choices that they have made. For our purposes here, we need to note that the levels of uncertainty attached to many types of environmental data have a major influence on such decision-making processes. This has been found to be true of water resources management (e.g., with respect to the availability of records of river flows), and it is of primary significance when we turn to the science of predicting climate change and designing responses to it.

Scientific Uncertainties and Adaptation to Climate Change

Successful adaptation requires stakeholder engagement to have access to the necessary resources, including adequate information to support the mobilization of investment by those developing and implementing climate change policy. Much of this depends upon an understanding that climate change is a threat that will materialize during the twenty-first century. It is therefore important to understand the remaining scientific uncertainties and the impact that they may have on stakeholder engagement. The areas of uncertainty can be exemplified by considering the predictions of the impacts of climate change on water resources. These may be categorized as (1) a lack of agreement over how best (which measurements, which variables) to measure and predict climate change; (2) a more specific problem associated with 'downscaling', that is, forecasting change at the scale of a region or sub-region; and (3) an unstable database that is inadequate and deteriorating in certain critical respects. We shall review each of these briefly in turn.

1. *Measuring and predicting climate change*. Although it has long been recognized that the earth's climate has undergone major changes over geological timescales, current concern centers on the observation that mean global temperatures have risen at 0.13 °C per decade from 1956 to 2005, or nearly twice the rate observed (0.74 °C rise in 10 decades) for the twentieth century as a whole. The interpretation of this fact as a sign of accelerating global warming is disputed, and it is worth recalling that only three decades ago climatologists were writing about global cooling (Ponte 1976). Skeptics' objections (Oldfield 2005; Schiermeier 2010) include challenges to historical interpretations of temperature records and claims that warming trends are much smaller than normal inter-annual temperature variations; that existing climate models are too limited and fail to take feedback mechanisms sufficiently into account; that observed temperature trends are due to natural causes, such as solar changes; and that the climate system will be resilient to any changes being observed. Conversely, Oppenheimer et al. (2007) caution that the climate change consensus may hide important feedbacks that could exacerbate warming effects, such as increased contribution from melting glaciers on sea level rise, the amplification of feedbacks between climate and carbon cycles (e.g., the release of carbon from thawing permafrost), and possible interactions between sea surface temperatures and tropical circulation. Taken together, these arguments define a 'chain of uncertainty' that starts with predictions of future human activities, including energy scenarios and greenhouse gas emissions, to which are added variations in impacts on atmospheric composition before introducing questions of scale, both temporal and spatial, over climate and hydrological responses.

Much of the climate change literature focuses on where there is the greatest consensus, that is, on temperature and precipitation. However, predicting flood and drought hazards requires data not only on rainfall frequency and intensity but also on variables such as evaporation, soil moisture, and groundwater, which are much less commonly measured. This deficiency is particularly marked for evaporation—a key meteorological variable because it reflects the distribution of energy between sensible and latent heat fluxes, is required for predictions of soil moisture deficits that have implications for groundwater recharge and surface runoff, and is the basis for agro-climatological forecasts of food production. However, measuring evaporation is complex (Allen et al. 1998), and recent reviews of methods for calculating potential evaporation for climate change studies note that it may be an important source of uncertainty (Kay and Davies 2008; Kingston et al. 2009).

2. *The problem of downscaling*. The IPCC's (2007b) Fourth Assessment Report contains broad generalizations about future conditions, but the literature identifies severe limitations for predicting localized and short-term patterns of change. Some predictions—for example, forecasts of future European summers that are drier and winters that are wetter—are fairly consistent. In contrast, predictions for South Africa diverge, ranging from more days with heavy rain, to changes in the number of consecutive rain days, to no trend at all for annual total rainfall (Hulme 1996; Kruger 2006). Others predict local spatial variations, with increased summer rainfall over central and

eastern plateaus in the Drakensberg mountain range and little change in the Western Cape (Hewitson and Crane 2006). This illustrates the uncertainty involved in interpreting results of regional GCM (global circulation model) forecasts (for scale units of 100 kilometers or more) in order to create local and catchment-scale hydrological forecasts. This was termed 'climate inversion' by Kim et al. (1984) and recognized by the IPCC (2001) as 'downscaling'. Of the two downscaling methods commonly used, the statistical approach is faster but produces uncertain predictions for extremes of both precipitation and temperature than the more computationally demanding dynamic (synoptic) approach (Hundecha and Bardossy 2008). Prudhomme et al. (2002) believe that at present there is little confidence in precipitation predictions at timescales of less than a month. They state that "there exists no universal downscaling method for all situations" (ibid.: 1139), a view that is supported by Hewitson and Crane (2006). The problem is not merely one of choosing an appropriate method, as the statistical approach is dependent upon having a reliable database to capture conditions. This presents problems for assessing the impacts of climate change upon water resources, above all, at a local level where they are 'visible' to the majority of people.

3. *An unstable database*. A further complication for climate analysis is that the actual networks of stations have changed during the observation period, creating the possibility of an added artifact in the climate signal (Chappell and Agnew 2008). In West Africa, for example, the number of stations decreased in the wetter coastal area and increased in the drier continental area, while the total number of stations with complete records decreased dramatically after the late 1970s. The same observation was recently made for Africa as a whole, and Kenya in particular, at the Second Africa Water Week in Johannesburg: "You can only get reliable rainfall data in Kenya up to 1980 as the existing infrastructure, like rain gauges and stream gauges, are no longer working" (Ogodo 2009). There are, then, a number of uncertainties from the basic observational networks through to predictions of global economic activity that need to be understood when giving advice about adaptation strategies. Taking these uncertainties into account, it can be understood why resilience—the ability to withstand (unspecified) shocks—and adaptive capacity have become such important concepts.

Technology and Adaptation to Climate Change

As with water resources management, many of the initial steps in climate change adaptation have centered on technological change. Adaptation to water scarcity has focused on infrastructure to secure supplies (Parry et al. 2009). As Page (2005: 302) notes: "It is imperative that more capital should be fixed in the form of pipes, taps and reservoirs in the developing world." The wide range of available technologies (Agnew and Woodhouse 2011) also addresses the priority of conserving water through more efficient use, including reducing pipe leakage that causes a 'normal' loss of 10–20 percent (Lahlou 2001) or that averages 36 percent (within a range of 8 to 62 percent) in Asia. While the problem of such water loss is mainly associated with urban areas, many rural irrigation systems have efficiencies well below 50 percent. Heavily promoted water conservation measures include rainwater storage, water audits, and water-efficient household appliances (Sharp 2006), many of which may be 'retrofitted'. Deoreo et al. (2001) noted that such measures in the US enabled household consumption to be significantly reduced to around 150 lcd. Similarly, Kolokytha and Mylopoulos (2004) estimated a 20 percent decrease in consumption through residential retrofitting and calculated that using gray water (e.g., rainwater) saved up to 39 percent. The reuse of waste water is well established (Symons 2006), with techniques that are suitable for water-scarce regions and developing countries (Al Baz et al. 2008; Sánchez et al. 2006), including the treatment of contaminated water through desalination (Burbano et al. 2007).

More strategic technological adaptation to climate change is evident in the concept of the 'absorbent city' (White 2008), according to which the design of urban areas can be used to adapt and even mitigate the expected increase in floods, while retaining water in the city can reduce scarcity. Similar goals inform 'green landscapes', in which water is conserved and temperatures are mitigated (Gill et al. 2007). Comparable holistic approaches are evident in the use of rainfall water harvesting to improve resilience to water scarcity in Africa (Rockstrom 2003). There are, then, many promising attempts to use technology to adapt to future climate extremes, but it is a challenge to introduce these ideas in congested and impoverished areas of cities in the South. Therkildsen (1988) noted failed attempts in Africa to supply water in the 1960s and 1970s, and Thompson et al. (2001) found in East Africa that mean water use had actually declined between the 1960s and 1990s, due to the reduced reliability of the piped water supply, as municipal water services could not maintain the infrastructure.

As with our review of water resource infrastructure at the beginning of this section, these failures mark the limits of engineering approaches, and responses have invariably highlighted a need for greater emphasis on economic, social, and political aspects, such as the need for greater partnership with communities (Rietveld et al. 2008), management at the lowest appropriate level, community ownership of schemes, full cost recovery for operation and maintenance, recognizing key roles of women, and inclusion of the poor (Gine and Perez-Foguet 2008). These conclusions are consistent with the lessons learned by the UK's Department for International Development regarding water provision: recognize water as an economic good, respond to demand, and put people at the center (DFID 2001). However, there is also evidence that such formulations may fall short of what is required. Examining failures in the supply of water in Mumbai, for example, Gandy (2008: 122) observes that an "array of technological, scientific and architectural innovations … enable wealthy households to insulate themselves from the environmental conditions of the poor." He concludes: "The recent history of Mumbai has militated against the kind of progressive political movements that galvanized processes of sanitary reform in, for example, European cities during the second half of the nineteenth century and the early decades of the twentieth century" (ibid.).

We suggest, therefore, that while science and engineering lie at the heart of the ecological principle and offer the potential to deliver fresh impetus in adaptive behavior at a range of scales, the environmental dimension is unlikely to be successful in isolation from the economic and socio-political dimensions. This is illustrated by integrated water resources management (IWRM), a key application of the ecological principle. IWRM has been promoted widely (UNESCO 2006) as it enables different water users and different types of water to be managed within a single unit—normally, the watershed defined by topography and surface hydrology (Lenton and Muller 2009). Mollinga et al. (2007) argue that this hydrological catchment may impose a false boundary and that 'problemsheds', which are socio-political constructs, are more appropriate as a unit of management and hence regulatory organization. The ecological principle, then, as with engineering-led adaptive strategies, may be imposing false boundaries, which require people to 'fit' the data, and institutional arrangements that are likely to be problematic. We now turn to the economic dimension and institutional dimensions of governance.

Instrument Principle—Economic Strategies

We noted above that, over the last 100 years, the financing of water management has changed in industrialized societies from the municipal to the national scale and has increasingly been linked to strategic economic planning (Swyngedouw 2006). The broader scale has required more extensive investment and greater emphasis upon cost recovery, associated with intensifying contestation of how costs should be distributed. The need to raise investment from private sources and the adoption of the instrument principle for water services and supply have moved the debate to address whether water is a basic right or can be privately owned. The Organisation for Economic Co-operation and Development (OECD 2003), for example, notes that water can be regarded as a 'public good', to which everyone has a right in a non-competitive manner; as a 'private good', which is owned and to which there are access restrictions; and as a 'common good', to which there is non-competitive access only until the resource becomes scarce. It is argued that, for adaptation to be successful, local resources will have to be harnessed alongside external injections of capital. The MDGs also recognize the need for adaptation to be based around economic and behavioral changes (Moriarty and Butterworth 2003).

The Fourth World Water Forum of the World Water Council (WWC), held in Mexico City in 2006, noted the necessity to develop local financing capacity and markets. The forum concluded: "This necessity is founded on the recognition that users and taxpayers are in the end the main financiers, and on the associated shift from full cost recovery to a solidarity system of fair tariffs combined with targeted subsidies" (WWC 2006: 108). This is echoed in UNESCO's Third World Water Development Report, published at the Fifth World Water Forum in Istanbul, which states, in relation to financing: "While there may appear to be many financing options for water resources development, governments still have only three basic means of financing them: tariffs, taxes and transfers through external aid and philanthropy" (UNESCO 2009: xxi). This makes clear that the cost of borrowed capital, if it is not written off through international aid, must be paid by users or by taxes. Here is a perspective in which the instrument principle remains since access to water is defined as having a cost, but the distribution of that cost is governed by the social criteria of need and the ability to pay. The same debate will need to take place over interventions concerning climate change adaptation.

One of the key financial mechanisms to raise revenues has been water pricing. However, pricing is also proposed as a means of adapting to greater scarcity through its inclusion in water demand management (WDM), which has become a key strategy across the world, including Europe (Sharp 2006), the Middle East (Magiera et al. 2006), and China (Chen et al. 2005). WDM contains three elements that are reflected in adaptation strategies to climate change: economic (water pricing); technical (infrastructure, including metering, recycling, and retrofitting); and social (education, legislation, and regulation). Most attention has focused on a range of socio-economic strategies that seek to influence water demand (Babel et al. 2007). Kolokytha and Mylopoulos (2004: 263) are emphatic about the need for a change in direction, asserting that "demand management is considered to be the best potential solution to meet future [water] needs" because, they argue, supply enhancement does not effectively deal with growing competition between consumers. Treating water as a commodity rather than a basic human right is not without criticism, and many factors can influence responses to water prices (Jeffrey and Geary 2005; Kenney et al. 2008; Martinez-Espineira 2002). Renzetti (2002: 157, 158) concludes: "In general, the demand for water is a function of its price, the prices for other goods, the scale of activity … and the nature of the preferences or technology of the decision maker … [E]xcept in very unusual circumstances, the value of water is neither zero nor infinite." However, he notes that economic theory does not provide guidance on the actual decision making by the consumer. Sharp (2006) echoes this perspective, criticizing previous studies of demand management for their aggregation of data while failing to understand household decisions sufficiently. Jansen and Schulz (2006) note a lack of micro-level studies and cite a household study from Sri Lanka, which showed that demand was actually price-inelastic and income-inelastic, so that price increases may not conserve water. Their study of demand in South Africa similarly found that water use among low-income groups showed only modest responses to pricing changes, while cheap water for poorer groups did not lead to greater wastage.

The South Africa case is of particular interest because the 1997 Water Services Act explicitly recognized a "right of access to basic water supply and basic sanitation,"[9] to be funded in a variety of ways. In urban municipalities with substantial income from metered water users, a rising block tariff recouped the cost of the initial 'free' water, while rural water supply was capped at a 'free basic' level by 'appropriate service levels' provided through standpipes with restricted flow rates. It is relevant that there is a history of non-payment for services in South Africa, although J. Brown's (2005) study in Nelspruit (renamed Mbombela in 2009) led her to argue that a culture of non-payment is not simply a legacy of the historical boycotting of rates, although this is still within living memory. Rather, it is made up of many contributing factors that have resulted in an environment where it is the norm not to pay service bills, regardless of the ability to pay. This highlights the importance of legitimacy in determining the viability of pricing policy. The association of pricing policies with a transfer of ownership (privatization) has significantly undermined legitimacy in some cases. However, less than 5 percent of the world's population are supplied water by the private sector (Anand 2007: 78), and it is important to note that privatization is not necessary for the operation of a pricing system for water. Anand finds that the notion of fairness is paramount in attitudes toward privatization and whether water should be treated as a public good (ibid.: 9). The degree to which people trust the government to ensure that everyone is treated in a similar manner may explain why privatization in England and Wales was accepted, while in India, Tanzania, and Ghana it produced protests (ibid.: 252).

Turning from investing in water to funding responses to climate change adaptation and mitigation, we find that the sums required are staggering. Drought is often cited as the world's costliest natural disaster, causing annual damage of US$6 to $8 billion (Wilhite 2000). During the UN Drinking Water Supply and Sanitation Decade (1981–1990), a total of US$13.5 billion was invested in water supply and sanitation (Tebbutt 1998: 259), and at that time it was estimated that future investment would have to increase fivefold to US$5 billion a year. All this is dwarfed, however, by the sums required to tackle climate change. The Stern Report (2006) predicted climate change impacts would cost 5 to 20 percent of global GDP, whereas mitigation costs would be less than 1 percent of GDP if acted upon now. At the 2008 World Water Congress of the International Water Association (IWA) in Vienna, it was reported that World Bank investment to combat climate change would need to more than double the current annual rate of $80 billion, just to cope with the present situation through mitigation and adaptation (Jowit 2008). Parry et al. (2009: 9) have noted a convergence of predictions of the expected costs of adaptation for developing countries, with figures falling between US$10 to $100 billion per annum: "The UNFCCC report concluded that total funding need for adaptation by 2030 could amount to $49–171 billion per annum globally, of which $27–66 billion would accrue [mostly for infrastructure] in developing countries." Unfortunately, Parry et al. (ibid.: 41) also conclude that the UNFCCC forecasts may be an underestimate. Dimitrov (2010: 815) reports that the 2009 Copenhagen Accord contains a commitment to additional funding for mitigation and adaptation of US$30 billion for 2010–2012, rising to US$100 billion by 2020, from public and private sources, but notes that the accord is non-binding and does not provide details on institutional arrangements.

This is not just a problem of funding adaptation for the rural poor. Since 2008, some 3.3 billion people are estimated to be living in urban areas, and this number is expected to rise to 5 billion by 2030. Much of this growth is taking place in Africa and Asia, so that by 2030, 81 percent of the urban population will reside in developing countries. We mention here the caveat that such approximations may overestimate urban growth rates (Potts 2009), but existing numbers of urban poor mean that many now live in squalor with limited ability to respond to climate change

(Bicknell et al. 2009; Moser and Satterthwaite 2008). De Bruijne et al. (2007) note that in many respects the situation facing urban areas in the South is far worse than that of Europe 150 years ago. Poverty is deeper, there are fewer opportunities to access land and water resources, and existing resources are being degraded through pollution and over-abstraction.

Responding to climate change includes a combination of market-based mechanisms, technology transfers, and human lifestyle changes (Dessler and Parson 2006). Investment is required, and the question of who should pay for it is key. We have already presented a growing emphasis on cost recovery with regard to water resources investment, moving from state intervention to private capital. Swyngedouw (2006) notes that much of the investment required to meet the water MDGs is expected from the private sector, and this is reinforced in a recent UN analysis (Griffith-Jones et al. 2009). Discussions of climate change mitigation focus upon the need to recognize the responsibility (both current and historical) of the industrialized nations of the North for high greenhouse gas emissions, while the costs of impacts fall upon the most vulnerable and poorest communities of the South. The Stern Report (2006) was a major contribution to the argument that the global cost of immediate action to mitigate climate change outweighed the eventual cost of dealing with climate change impacts. However, the size of the costs involved have arguably only served to intensify the argument over who should pay. There is also controversy over the effectiveness of the economic tools available for mitigation and the potential conflict between mitigation and economic growth (Cosbey 2009), but the major problem is the expected cost of sharing the burden. Ahmad and Opschoor (2009: 1) note that there is presently limited funding, especially for current adaptation measures, never mind those extending well into the future: “Given the nature of adaptive capacity and its linkage with development in general, strategizing development planning and raising development finance is essential in meeting adaptation requirements.”

We are, then, at an interesting turning point in the management of climate change impacts, where the need to raise capital for investment and the adoption of economic principles for management have promoted private, non-state engagement. Similar moves in the management of water resources two decades ago have been followed by promotion of greater public engagement, for example, in the EU’s 2009 Water Framework Directive (Carter 2007). Dungumaro (2007) cites public participation as a core of integrated water resources management. Hence, questions of governance and stakeholder involvement have come to the fore, as illustrated in figure 1. We will expand upon these next, not least because it has become clear that economic tools need to be informed by a detailed political understanding of how behavior can and will be changed.

Institutional Principle—Politics and Participatory Decision Making

By the 1970s, the effectiveness of state-led top-down development was being questioned, and two alternatives were proposed. One, which we discussed above, sought to make resource allocation decisions subject to the ‘discipline’ of markets, as understood in classical economics. The second, associated with Jürgen Habermas, promoted ideas of a more active, ‘participatory’ citizenship, with decisions being subjected to ‘deliberative democracy’ in which technical experts would engage in discussion with ‘ordinary’ citizens to examine the rationale behind and consequences of new developments. In this section we consider increased participation in adaptation strategies, which can broadly be seen in ‘upscaling’, dissemination, and efforts to raise awareness and strengthen stakeholder engagement.

The goal of involving citizens as stakeholders in planning activities has been fostered by many reforms to water management institutions and by efforts to use spatial planning (Howe and White

2004) to contribute to sustainable development. Carter (2007) argues that spatial planning has become key to promoting participatory measures: increasing democratic legitimacy, building consensus, and strengthening decision making are some of the derived benefits. Equally, some countries, such as South Africa (J. Brown 2007), and the EU (Carter 2007) have incorporated stakeholder participation in water development policy. Gaining experience in implementing such initiatives has seen the concept of 'social learning'—described by van Slobbe et al. (2008) as a move away from linear planning and the reliance on expert knowledge—come to the fore. Blackmore et al. (2004: 6) explain social learning as "a process of knowing based upon experience and practice that is developed collectively and interactively among multiple interdependent stakeholders."

Increased participation needs to recognize the importance of gender, which was included in the institutional principle and incorporated into Goal 3 of the MDGs.[10] On the UNDP's Web site for women's empowerment, UNDP administrator Helen Clark states: "Development cannot be achieved if fifty percent of the population is excluded from the opportunities it brings."[11] In the past, water resources development assumed that households would alter their practices in a predictable manner to take advantage of improvements in water supply. Such assumptions have been criticized for failing to take adequately into account intra-household decision making and the gendered outcomes of changing natural resources management (Hunter 2006; Nyong and Kanaroglou 2001), including cultural restrictions placed on women who attempt to move from private (household) spaces into the public realm (Sultana 2009). In urban areas, constraints still exist, although space may be constructed differently and women in urban households may have greater access to assets (Moser and Dani 2008). Efforts to overcome gendered limitations to participation are reinforced by research that aims to identify positive instances involving women in water management (Fonjong 2008; Were et al. 2008; Wirfa et al. 2008).

An appreciation of the importance of stakeholder participation has been associated with a reinterpretation of the reasons for the failure of water pricing to deliver expected changes. In particular, a reappraisal of the role of 'communication', sometimes referred to as 'education', has identified the danger that this becomes top-down, reinforcing the position of the 'expert'. As Page (2005: 298) observes: "The engineers and politicians who now manage water supplies in Cameroon claim that most consumers are reluctant to pay for their water because they are ignorant; their attitudes need to be modified." The messages from water companies through Web sites and leaflets, plus occasional media campaigns (e.g., during droughts), are criticized as being ineffective in changing behavior (Kenny et al. 2008; Sharp 2006). Conversely, Fenemor et al. (2008) studied community resilience in New Zealand that developed through active partnerships involving the knowledge base of resource users and stakeholder participation in management. It appears to be important that conversations are initiated as early as possible so that both agendas and language are shared. Lundqvist (2000: 264) also notes the significance of water user engagement, as well as the need for better training and capacity building: "Education, training and research must transcend borders, between disciplines and between sectors and between cultures and countries."

Blackmore et al. (2004) conclude that obstacles to stakeholder participation in water resources development include overly complex institutional contexts and lack of experience with this strategy. Van Slobbe et al. (2008) note that in Sri Lanka there has been frustration over 'too much' participatory engagement: participatory practices require an investment in time and social spaces in order for interactions and negotiations to take place. Also needed are patience and tolerance, since results are not instantaneous. J. Brown (2007) has cautioned about the limitations that participatory approaches may offer in practice and the frequent absence of evaluation of the outcomes of stakeholder involvement. Her study in South Africa suggests that, where stakeholders have strongly competing interests in water use and where there are major asymmetries of information, it is unlikely that consensus will be reached through consultation among local stakeholders. Another South Africa study (H. Brown 2009) broadly supports this conclusion but also wonders whether social learning raises too many expectations, for example, that stakeholders' collective interest in collaborative management would be greater than their individual (and potentially competing) benefits from non-collective water use.

In seeking to develop more effective stakeholder engagement in adaptive water resources management, a persistent challenge is the upscaling of participation by single individuals to the level of communities. A similar step may be needed to enable collective management of the impacts of climate change. Ryan (2004) notes that adaptation is constrained by poverty due to limited resources (funds, human capital, institutional capacity), lack of knowledge or shared understanding, and resistance to change. Community-driven approaches, such as community-led total sanitation (CLTS),[12] offer some promise of improvements (Deak 2008), but there is no consensus over the best approach to scaling up adaptive action of individuals and households, either spatially or vertically (social hierarchy). Ryan's (2004) review of the literature on upscaling underlines a lack of rigor in defining project objectives and an overemphasis upon anecdotal reporting of project achievements. The review describes the following key roles for different stakeholders:

- Local community: managing the process and being in control
- Central government: institutional support through financial and legal provisions
- NGOs: facilitation, support, and training
- INGOs: advocacy and support
- Private sector: supply chain development
- International community: long-term commitment without intervention

Large disparities in socio-economic conditions present problems for the consistent engagement of stakeholders across a water catchment. In South Africa, stakeholder preferences varied so widely within studied catchments that consensus and effective decision making were blocked (J. Brown 2007). In Bangladesh, there have been positive experiences involving CLTS projects, and Deak (2008) notes here the importance of 'self-spread', with enthusiastic supporters helping to promote programs. Other critical factors that have been identified include (1) planning that assesses coverage (spatial) together with sustainability (timescale); (2) institutions, partnerships, and policy support for community engagement; (3) capacity building and financial stability; and (4) a shift from 'project implementation' to 'service delivery'. We have, then, identified from the water development literature a number of obstacles to greater subsidiarity and devolved decision making, ranging from questions of scale to the need for social learning and capacity building. There is strong evidence that, for technical and scientific support to be fully effective, engagement with stakeholders should be undertaken at the earliest opportunity, while consultation must be more than simply seeking responses to written reports.

Strategies of greater engagement with stakeholders have also gained strong support in discussions of climate change adaptation, promoted by the IPCC (2001) through the notion of a community's adaptive capacity. Similar ideas at the household scale have sought to estimate vulnerability in terms of household assets and capital, which are identified as key components of an individual's ability to make environmental responses to climate change (de Graaf et al. 2007; Nicol 2000). This emphasis upon household adaptive capacity is also found in Wamsler's (2007) analysis of disaster risk reduction in El Salvador. She lists three types of coping strategies: (1) reducing risks through technical measures (e.g., construction), environmental controls (e.g., runoff reduction), economic measures (e.g., diversifying income), and organizational change (e.g., social networks, community engagement); (2) ensuring against risks through self-insurance (e.g., education, ownership, family or institutional insurance); and (3) recovering from risks (e.g., through loss financing and community action). A similar approach is evident in a recent change in attitude to flood risk management in the UK (Johnson et al. 2007), moving from a purely engineering approach of flood defense measures to management of risks in much the same way as noted by Pereira (2007) for drought management. Rather than seeing nature as something to be controlled and dominated, the new attitude ('living with floods') places more emphasis upon adaptation that ensures ecological integrity.

In his review of adaptive management, Pelling (2011) argues that the concept emerged three decades ago to support decision making under conditions of uncertainty with an emphasis upon social learning. He goes on to argue that adaptive management has a role to play in adaptation to climate change, where there is much uncertainty and a need for multi-stakeholder engagement for social learning. However, Pelling cautions that, to be effective, institutions and organizations need to be receptive to local viewpoints, that sustaining local engagement is a challenge, and that, for community-led efforts to be credible, they need to secure technical and scientific support (ibid.: 32). This last point brings us full circle to the first principle, while reinforcing that all three (science/ecological, economics/instrument, and politics/institutional) are not meant to be implemented in isolation; rather, it is a matter of emphasis.

Conclusions

In this article we have explored the growing consensus on water development strategies in terms of three principles—ecological, instrument, and institutional—and we have argued that the same consensus is required for responses to climate change. In particular, we advocate the need to embrace the institutional principle, with an emphasis upon governance and stakeholder engagement, while noting the significance of the instrument principle, that is, that investments need to be financed in an equitable and legitimate manner. However, recent efforts to implement the institutional principle, which fosters subsidiarity and the engagement of citizens and local communities in water governance, have not been without difficulties. This principle does not offer a panacea, and we have reached the same conclusion for strategies that focus on science or economics.

Tackling environmental constraints through science and technology (e.g., by increasing the supply of water or by conservation measures to maintain ecosystem functions) can have major impacts, for instance, when large dams are involved. In addition, problems frequently arise over the distribution of benefits and the subordination of individual or local community interests to a 'greater common good'. We have argued that science and technology are necessary but that they are insufficient, on their own, to foster adaptive capacity, since they do not provide the means with which to manage the uncertainty that is inherent in scientific measurement and that arises from economic and social factors. If science therefore does not hold all of the answers, the (Weberian) scientific arguments, based on a greater common (public) good, may not find acceptance.

Two alternative and opposing views have gained importance as the efficacy of science has been questioned:

1. *Neoliberal*—pricing to ensure efficient resource use. Understanding the costs associated with resource use is a necessary dimension of adaptive capacity, but considerations of economic efficiency will be conditioned by questions of equity (distribution of costs and

benefits) and, linked to this, political perceptions of fairness (e.g., whether some people have unmet needs that may be regarded as ‘human rights’) and legitimacy.

2. *Institutional*—deliberative and accountable democracy to decide who gets allocated what. This view rests on a belief in the power of rational argument to ensure that adaptive behavior is equitable and politically legitimate, but it is undermined by asymmetric power relations, through which more powerful stakeholders prevail over others, irrespective of questions of equitable resource use. A related key factor involves asymmetries of information, particularly with regard to scientific information and an understanding of environmental processes and change.

These viewpoints suggest the need to re-evaluate the role of the state and the political processes through which development goals and priorities are determined and implemented.

A number of parallel but more recent discussions have developed concerning adaptation to climate change. Science has arguably led the dialogue and dominated policy formulation, yet it is beset with uncertainty, especially at the local scale where adaptation will have to take place. Technology will be important for various forms of adaptation, from water conservation measures to flood storage engineering and water supply enhancement—but it has to be paid for. The sums involved globally are staggering, and this has moved us increasingly toward discussions of investment in mitigation and financial support to developing countries for adaptation measures. The experience of carbon trading, tradable emissions quotas, and so forth suggests, however, that wider issues of ownership and equity need to be addressed, alongside the capacity for private investment. In practice, the lack of binding commitments resulting from the 2009 Copenhagen conference has highlighted the problems of adopting the instrument principle to combat climate change. As with water resources, the lack of funds in many parts of the world that are most at need means that adaptation will have to rely heavily upon social and political organization. In addition, one lesson learned from nearly half a decade of water pricing and demand management is that people do not always respond in a predictable manner to economic measures.

This has contributed to more a recent emphasis upon governance, including community-based actions and social learning, in order to meet the challenges presented by climate change. The experiences of water development, however, are not entirely promising. They have exposed the limitations of local participation in bringing about change, particularly in circumstances when asymmetries of power and conflicts of interest translate into competition to control scientific information and its interpretation. Reliance on local decision making has proved difficult, not only because of these asymmetries of power, but also due to the need for upscaling. We will thus find all three principles advocated, with different degrees of emphasis, in support of adaptation measures. Assessing which measure is most appropriate becomes a question of the purpose of the adaptation: is it a short-term response to an immediate threat, or is it intended to support the community in the long term through fundamental changes in lifestyle and land use? As with the adaptive management of water resources, the question essentially requires that the development goals of climate change adaptation be determined and agreed upon, for it is only against these objectives that measures to adapt to climate change can be effectively evaluated.

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NOTES

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8. "A Scramble for Africa: Large Dams Benefit Contractors and Corrupt Governments More Than They Aid the African People," *Nature* 440 (2006): 383–384; "China's Dams in the Danger Zone," *New Scientist* 196 (2008): 5.
9. See the 1997 Water Services Act at http://www.dwaf.gov.za/Documents/Legislature/a108-97.pdf (accessed January 2011).
10. For more on Goal 3 of the MDGs, see http://www.undp.org/mdg/goal3.shtml (accessed January 2011).
11. The UNDP addresses women's empowerment and gender equality in its main areas of work. See http://www.undp.org/women/ (accessed January 2011).
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