Putting Climate Change into Water Resource Management: Adaptation Efforts in the U.S., U.K., Canada, Australia, and the Netherlands

Heejun Chang* · Jon Franczyk** · Deg-Hyo Bae***

국문요약

기후변화가 지역의 수자원에 영향을 미칠 것으로 예상됨에 따라 수자원 관리자들은 이에 대응한 적응전략을 수립하는 것이 필요하다. 이에 본고에서는 미국, 영국, 캐나다, 오스트렐리아, 네덜란드의 적응관리의 실태를 검토하였다. 이들 나라들은 현재의 수자원 관리관행, 제도적 장치, 기후변화의 잠재적 수자원 영향에 따라 매우 상이한 적응관리를 하고 있다. 이들 나라들의 비교연구를 통하여 기후변화에 따른 한국에서의 지속가능한 수자원 관리를 위한 정책적 관련성을 도출하였다.

주제어 : 기후변화, 수자원 정책, 적응, 지속가능성, 지역

ABSTRACT

As global climate change is expected to influence regional water resources, water resource managers need to establish adaptive management to cope with climate change. We examined adaptive management efforts in the US, UK, Canada, Australia, and the Netherlands. Each country is implementing different levels of adaptation efforts based on current water management practices, institutional arrangements, as well as the varying degree of water availability, current climate effects and expected climate change effects. Based on the comparison of these countries, we suggest policy implications for the sustainable water resource management of Korea under climate changes.

Keywords : climate change, water resource policy, adaptation, institution, sustainability, region

* Assistant Professor, Department of Geography, Portland State University (changh@pdx.edu)

** Graduate Student, Department of Geography, Portland State University (franczyk@pdx.edu)

*** Associate Professor, Department of Civil and Environmental Engineering, Sejong University (dhbae@sejong.ac.kr)

I. Introduction

As the result of numerous scientific studies throughout the past several decades, the scientific and political communities, as well as the public at large, are rapidly accepting the phenomenon of global climate change. The effect of climate changes on regional temperature and precipitation will have far reaching consequences on many aspects of nature and society, at global, regional, and local scales (IPCC 2001, Crane et al. 2005, Giorgi 2005). Uncertainty in the timing and magnitude of these future changes further complicates the development of sound responses by governments and private sectors to minimize their consequences (Webster 2003, Krahe et al. 2005).

Water is one of the primary natural resources that will be influenced by these predicted climate variations and climate changes. Shifts in seasonal precipitation and increases in storm intensity, flooding and drought are expected to occur within the 21^{st} century and will influence the timing and distribution of regional water supplies (Ivey et al. 2005, Huntington 2006). Higher temperatures will increase water demands in many areas of the globe, which will introduce further stress on supply infrastructure (USEPA 2000, Gutzler and Nims 2005). These changes in precipitation and temperature patterns may have enormous regional economic impacts on sectors associated with water resource systems (e.g., drinking water supply, cooling, navigation, recreation, agriculture). Recent studies on the predicted effects of global climate change on water resource have focused on the importance of research at the river basin scale in order to best serve regional water managers (Loe et al. 2001).

According to the Government of Canada's Climate Change Impacts and Adaptation Program, "As the adaptive capacity of a country, a community or company increases, its vulnerability to climate change decreases," (CCIAP 2003). Krahe et al. (2005) states that there are three challenges to sustainable water resource development: meeting societies' growing demands, maintaining water quality, and maintaining the health of the regional water and land resources. Addressing the impacts of climate change on water resource requires that local and regional stakeholders not only be aware of the current predictions but also act upon this information. In order to use the results of climate change research studies with confidence, current water managers need explanation and clarification of predictions and the inherent uncertainties involved, as well as, the benefits it will have to their water management policies (Power et al. 2005).

In response to climate change predictions, finding the solutions to these challenges will require a holistic approach, combining the efforts of diverse disciplines and levels of expertise (Holman et al. 2005). One method that is currently receiving considerable attention is known as Participatory Integrated Assessment (PIA). PIA uses a combination of scientific and non-scientific individuals and groups to develop management responses and policies that best suit the resource availability characteristics of a specific region. This is accomplished through stakeholder focus groups, workshops, participatory planning and/or modeling, and policy exercises (Kloprogge and Van Der Sluijs 2006).

There have been varied responses to climate change predictions by the management of water resources in different countries around the world. These responses are shaped by both the degree of climate change impacts anticipated for that region and the economic resources and determination of each county (Arnell and Delaney 2005). In Korea, regional climate models downscaled from global circulation models projected surface warming and increasing variability of seasonal and regional precipitation patterns, with more frequent extreme events in the 21st century (Boo et al. 2006, Im et al. 2006). As part of the Sustainable Water Resources Research Center of the 21st Century Frontier Research Program in Korea, there have been scientific studies examining regional climate change and its potential impacts on runoff in Korea river basins (Kim et al. 2005, Bae et al. in review). However, adaptation to this projected climate change in the water resource sector is currently missing. Hence, there is a need to examine what other countries have incorporated climate change information into their water resource management and policy.

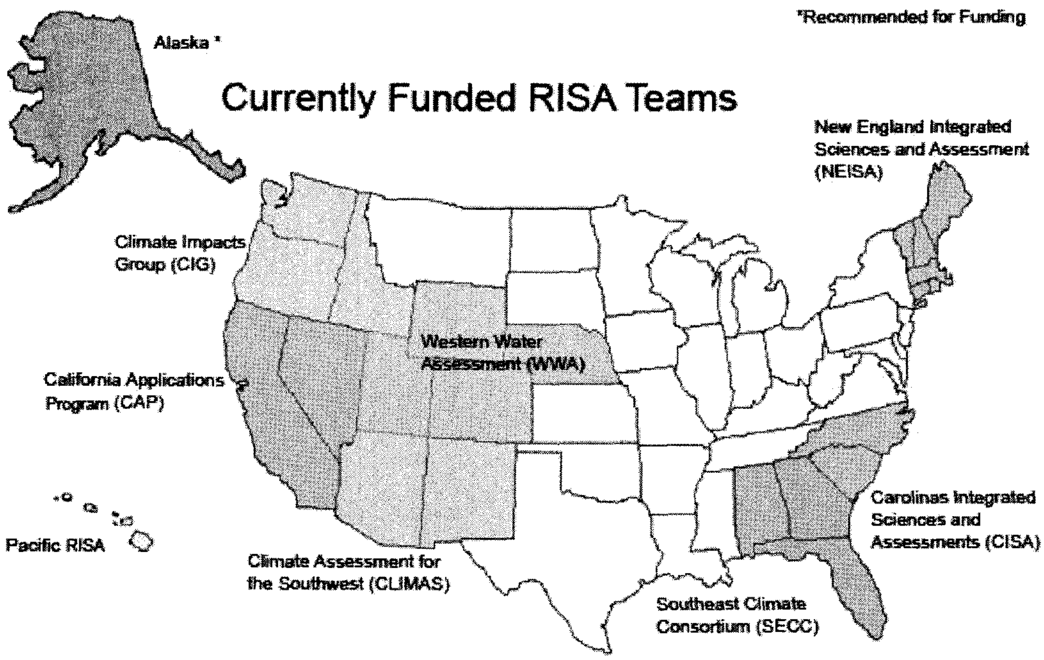
This study will discuss the governmental, scientific, and stakeholder integration for addressing global climate change and its effect on water resource management in the United States, the U.K., Canada, Australia and the Netherlands. These countries were chosen because of their unique water resource characteristics (hydrology and management policies) and challenges (water demand and climate), and the difference in climate change impacts predicted for their regions of the world. This provides examples of research and methods for climate change adaptation by the water management industry in response to various regional conditions around the world. Based on the comparison of these countries, we seek to draw some policy implications for sustainable water resource management of Korea under projected climate change.

II. Case studies

1. Climate Change Adaptation in the United States

The United States contains a diverse range of climate regimes, particularly in the western region of the country. Because of the semi-arid climate of most of the Western United States, the reduced runoff predicted by climate change models could drastically impede development, particularly in the agricultural sector. In the Eastern United States, water availability is much higher; therefore, the effects of climate change on water resources will be less detrimental to this region (Hurd et al. 1999) even though pollutant loads might increase by increasing runoff (Chang et al. 2001). For this reason, this study will focus on the integration methods taking place in the Western United States.

In order to provide climate variability and change information to various decision and policy-makers around the county, the National Oceanic and Atmospheric Association (NOAA) developed the Regional Integrated Science Assessment program (RISA). The RISA program (http://www.climate.noaa.gov/cpo_pa/risa/) was started in 1995 and uses primarily university-based climate research, but also employs studies from government and private sources. It is currently comprised of eight teams, or RISAs, that are located in different regions of the country and address climate change issues that are unique to those areas (Figure 1).



<Figure 1> Map showing the eight RISAs in the United States (Source: RISA http://www.climate.noaa.gov/cpo_pa/risa/).

The RISAs focus on regional and local-scale research and integration, linking "climate observations and predictions with vulnerability, institutional, and economic assessments," (RISA 2006, p.2). Their primary goal is to make climate change research useful and useable to the public so as to better serve society. Besides addressing climate change impacts on water resources, RISAs also provide information and decision support on how climate change will impact wildfire risk, crop management, air quality, forest management, as well as other potentially vulnerable areas of society (RISA 2006).

The first integration team created by RISA was the Climate Impacts Group (CIG), in the Pacific Northwest (Hill 2006). Based out of the University of Washington, CIG addresses the impact of climate changes on the water resources in the Pacific Northwest, as well as, develops methods to integrate this knowledge to the water managers of the region. In one of the first studies completed by scientists affiliated with CIG, Callahan et al. (1999) stated that in 1996, the majority of PNW water managers almost never used climate forecasts as the basis for their decisions. Through interviews with twenty-eight water resource manager organizations in the region, they found that this was because of high levels of uncertainly, low confidence in the forecast outcomes, lack of verification statistics, and forecasts that conflicted with each other. They also found that at that time, water managers had almost no communication with climate scientists (Callahan et al. 1999).

Since conducting its first workshop in 1998, CIG has made a positive impact on the attitudes of water managers in the region towards climate change predictions. A study by Whitely-Binder (In Press) revealed that by 2002, the discussion and integration of climate change information in water management policy had dramatically increased, primarily through individual water manager interest, mainly due to CIG workshops. Suggestions by stakeholders as to other forms of information and support that would help the integration process included more detailed and locally scaled climate scenarios, case studies, and technical support for modeling and projections. PNW water management organizations that are now integrating climate change projections into their policies include the Idaho Department of Water Resources, members of the Washington Watershed Planning Program, the Columbia River Intertribal Fisheries Commission, and the Northwest Power Planning Council (Whitely-Binder, in press), covering the majority of the Columbia River basin.

Integration methods that focus on the local scale, urbanized areas in Central Arizona are being developed by the Decision Center for a Desert City (DCDC). The DCDC is based at Arizona State University (ASU) in Tempe, Arizona and is funded by the U.S. National Science Foundation. It provided organizational and planning support to the 2005 Arizona Water Summit, in conjunction with the RISA group Climate Assessment for the Southwest (CLIMAS) and another ASU organization, the Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) (DCDCa 2005). The DCDC conducts monthly water/climate meetings with local stakeholders.

The DCDC is currently involved in two innovative projects that can be used to integrate climate change information with water resource management. First, it is in collaboration with SAHRA to develop an interactive water management system, called the Southwest Water Information Project (SWIP). Scheduled for release in 2006, SWIP will provide climate forecasting data, visualization and modeling tools, and city-wide demographics information that can be used to make more informed policy decisions. Water stakeholders will also be able to create dynamic climate simulations and display temporal changes in localized, geographic patterns. Initially, the project will focus on the Arizona cities of Phoenix and Tucson, but is planned to expand to similar Southwestern cities (DCDCb 2005).

Second, DCDC is on the advisory council for the development of a unique and innovative 3-D decision-making support service called the Decision Theater. The Decision Theater is designed to display policy-relevant simulations and models on a 260 degree, faceted screen, which will allow collaborative groups to visualize spatial and temporal changes in physical and behavioral trends at different scales and resolutions. Its founder, Dr. Michael Crow, expects to create a means to facilitate university-based research that is more relevant to the community. The primary goal of the Decision Theater is to bring together information from many different disciplines and present it visually in order to promote understanding and collaboration between stakeholders, researchers, and the public. Since its inception in 2005, the theater has been useful in forecasting and developing regional water supplies for urbanized counties in the Phoenix, Arizona region (Decision Theater 2005).

2. Climate Change Adaptation in the U.K.

When accounting for the influence climate change will have on the U.K., there are several factors that provide its water industry with an advantage over many other regions of the world. Most importantly, the current predictions indicate that the effect of global warming in this region, as well as, population growth will be well below the world norms (Jones & Petts 2006). However, forecasts of drier summers and increased rainfall intensity (Subak 2000) have prompted the U.K. to implement several national efforts to prepare for these occurrences. Because of a drought in the mid 1990s, during which there were water delivery problems from eight out of ten of the country's major water suppliers (Figure 2), an action plan was developed in 1996 that required all water companies to produce estimates for future water supplies over 25 years. This plan, called the Water Resources and Supply: Agenda for Action, was designed in collaboration with the UK Climate Impacts Programme (UKCIP) and the Environment Agency, and employed climate change scenarios from the UK Hadley Center. These plans are reviewed annually and kept up-to-date with improved climate change forecasting and methods for assessing the impacts on regional water supply and demand (Subak 2000). This has helped create a foundation for assisting water resource stakeholders in acquiring knowledge about climate change, as well as, implementing an ongoing adaptation process.

<Figure 2> Delivery areas for the major water supply companies in the U.K.
(Source: Water U.K. (2006).

The UKCIP is the primary organization working to educate and partner with local stakeholders in the U.K. Started in 1997 and based out of the University of Oxford, the UKCIP is funded by the Department for Environment, Food & Rural Affairs (DEFRA) and is responsible for coordinating climate change research and working with stakeholders, including those involved in water resources (UKCIP 2006). Holman et al. (2005) describes the UKCIP organization as "providing a bridge between the researchers and the decision-makers in government organizations and business." It has accomplished this through promoting stakeholder-led research for nine regions of the county, organizing and hosting events that bring stakeholders and the science community together, and providing frameworks for assessing uncertainty, decision-making and risk. The UKCIP also has created a comprehensive 'toolkit' that organizations can utilize for developing various adaptation options and evaluating regional climate change impacts. Finally, the UKCIP is in the process of creating a case-study database that would offer examples of how climate change adaptations have been constructed in other areas around the country (DEFRA 2005).

The first major program that focused on the regional impact of climate change on water resources in the U.K was developed in 1998. The Regional Climate Change Impact and Response Studies in East Anglia and North West England (RegIS) was funded by DEFRA and was overseen by UKCIP. It integrated research from Cranfield University, the Silsoe Research Institute, the University of Manchester, and the University of Oxford. The water resource sector was represented by the United Kingdom Water Industries Research (UKWIR), which also provided a portion of the project funding (Holman et al. 2005). Some of the project's primary objectives were to produce reliable climate change scenarios and assess impacts using "regional experts, decision-makers, and other 'stakeholders'" (The RegIS Project 2006, 'Objectives'). It would also develop a methodology that could be used by stakeholders and interest groups from other areas in the U.K. The program's key areas of research regarding water resources were focused on the region's demand and supply (surface and groundwater), quality, and coastal flooding (The RegIS Project 2006). It used a combination of hydrologic and socio-economic modeling, as well as, climate change scenarios from the Hadley Center to assess the climate change impacts for the region (Holman et al. 2005). RegIS became an important example for similar studies in the U.K.

Research concerning water resource stakeholder perceptions on the effect of climate change on regional supply has been conducted by the Centre of Social and Economic Research on the global Environment (CSERGE). CSERGE is a prominent research center in the U.K., focusing on interdisciplinary studies in environmental and sustainable development (CSERGE 2006). In a study by Subak (2000), water managers from each of the ten major water/sewerage companies and several smaller companies were interviewed. Subak (2000) developed questions to determine their observed weather changes and responses to those changes, their views on climate change impacts on the region' s water supply, and the relevance of climate impact programs in their water supply planning. The mild influence of climate change forecasted for the U.K., as well as almost a decade of adaptations under the U.K. government' s 'Agenda for Action,' influenced the various responses from England' s major water resource companies. The majority of the companies admitted that they had no significant supply forecast or planning programs in place before the 1990s droughts. Even though two-thirds of the managers observed changes in rainfall patterns in their regions as of 2000, the majority did not perceive global warming to have an important impact on the water resource industry in the U.K. and saw the implications of changes in demographics and population movements as having a greater significance (Subak 2000, Arnell and Delaney 2005). However, some companies used weather and climate information to estimate peak water demand (Downing et al. 2003).

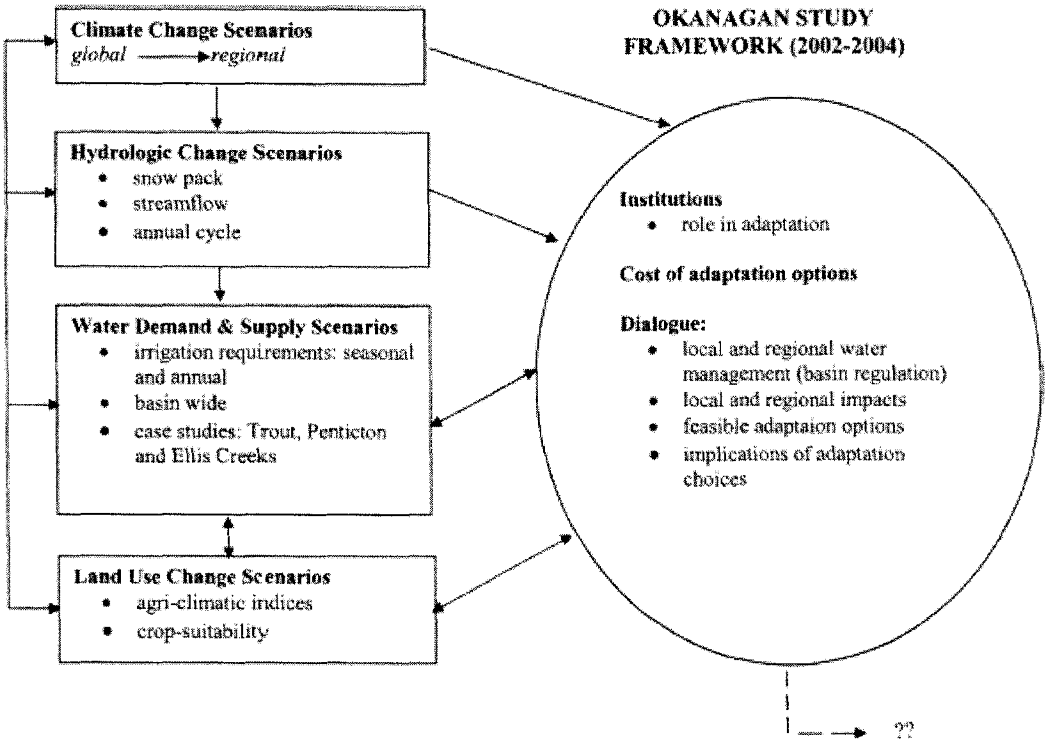
3. Climate Change Adaptation in Canada

Unlike the U.K., climate change predictions for Canada suggest that global warming will have more of an impact on this region. This includes reduced snow pack, earlier snow melts, and reduced summer stream flows for many parts of the country (Loe et al. 2001; Cohen et al. 2006). This prompted the Canadian government, through Natural Resources Canada, to develop the Climate Change Impacts and Adaptation Program (CCIAP) in 1998. This program provides funding to research concerned with predicting climate change impacts throughout Canada and developing adaptation methods designed for each region. Its main purpose is to reduce Canada' s vulnerability to climate change in all sectors of its economy. In 2004 CCIAP completed "Climate Chang Impacts and Adaptation: A Canadian Perspective," a major report that outlines climate change concerns for the country' s major sectors, including water resources. The contents of the report are based on published studies from the previous five years and include methods to encourage increasing the public awareness of adaptation options for the use of water resource, such as focus groups (CCIAP 2004)

In order to promote linkages between stakeholders and researchers, CCIAP has formed the Canadian Climate Impacts and Adaptation Research Network (C-CIARN) in 1998 (CCIAP 2006). C-CIARN's water sector office was started in 2002 at the McGill University, Montreal. Its goals are to facilitate interaction between regional stakeholders and scientists and to help determine research priorities. One of the primary ways C-CIARN accomplishes this interaction is to organize workshops, conferences, and training sessions that are designed to educate and inform attendees, as well as, to provide a forum through which connections can be made (C-CIARN 2005).

For six years, Canadian scientists, in collaboration with government agencies, and local water managers and user groups, have been participating in an ongoing study of the Okanagan River basin in the Canadian province of British Columbia (BC). This research team is led by Stewart Cohen from the University of British Columbia and Denise Neilsen and Scott Smith, both from the Pacific Agricultural Research Centre, BC, Canada. The team has produced numerous reports and presented their findings to several regional organizations, such as the Canadian Water Resources association, the British Columbia Water supply Association, and the Okanagan Basin Water Board. The study's purpose is twofold: (1) to provide climate change impact research that would be useful to the water resource stakeholders in the region and (2) to promote increased stakeholder communication about water management adaptation. It is also meant to promote integration between scientists and knowledgeable stakeholders throughout the research process, a practice of 'shared learning' called Participatory Integrated Assessment (PIA). The different stakeholders included members of watershed and regional planning authorities and local watershed stewardship groups, professional water managers, local government agencies, and irrigators (Cohen et al. 2006).

The framework developed by Cohen et al. (2006) started by producing an 'adaptation portfolio' that regional stakeholders can use to base their future water management decisions (Figure 3). This portfolio included the outcomes of climate change, hydrological and land use change, and water supply and demand scenarios in order to provide a holistic picture of possible climate change impacts on the river basin. The research team then organized three workshops that would explore the various adaptation options the water industry had available to minimize climate change impacts in their area. According to Cohen et al. the purpose of this dialogue was to "engage local decision-makers



<Figure 3> Example of the Okanagan Study Framework (Source: Cohen et al. 2006)

who have practical knowledge of the social and institutional context within which any future anticipatory adaptation interventions would occur," (Cohen et al. 2006, p. 351). The Okanagan research group continues the development of their PIA methods in the region. Using knowledge from their study results, they plan to create a decision support 'tool' that will generate water management scenarios under different climate change predictions (Cohen et al. 2006).

4. Climate Change Adaptation in Australia

Because Australia is the world' s driest continent, its water resources are extremely vulnerable to climate change, especially in the southern region of the county (Greenhouse 2006). Observed historic trends indicate that there has been a reduction in precipitation and river flows since the 1970s, primarily during the winter seasons (Grigorkina 2003). Power et al. (2005) explains that these flow reductions have had water managers in many parts of Australia express increasing concern about climate impacts on water resources. Climate change projections indicate that Australia is expected to experience intensification in the variability of droughts and rainfall deficits, which will affect water availability for all sectors of society (Greenhouse 2006).

The Australian government is addressing climate change adaptation for the water resource industry through its national science agency, the Commonwealth Scientific and Industrial Research Organization (CSIRO). CSIRO first initiated the use of climate forecasts for the Western Australian water industry in 1985 because of prolonged droughts, and continued addressing the impact of climate change in the region throughout the 1990s. In 1998 it developed the Indian Ocean Climate Initiative (IOCI), which partners water managers with governmental agencies and university research scientists, and promotes the integration of climate research with water management policies. The IOCI completed its five-year climate change impact research phase of its climate change initiative program in 2002 and has made the results available for regional stakeholders, the focus of the program' s second phase. Its communication program for phase 2 develops seminars and workshops, the most recent in 2005, in order to maintain community and research relationships and address practical issues and priorities associated with climate change (Power et al. 2005).

A study by Power et al. (2005) indicated that the perception by the Western

Australian government is that IOCI has increased awareness of climate change issues and has had a substantial influence on the decision-making process of regional water managers. The success of the IOCI program has led to continued governmental funding for the second five-year phase. A larger-scale program model is also being proposed for the Murray-Darling basin, the most populated basin located in eastern Australia (Power et al. 2005). With ongoing climate change and population and industrial growth, the Murray-Daring basin provides a unique opportunity to examine how society could adapt to expected climate change. A new integrated science will focus on adaptive irrigation management under global climate change scenarios and on better understanding of the long-term climate risk to water resources.

5. Climate Change Adaptation in the Netherlands

The Netherlands is a highly populated country (400 person/km^2) where approximately a quarter of its land is below the sea level, and is home to 75% of its population. Because of rising sea levels during the 20th century (20cm per century) and the expected acceleration of the sea level rise in the 21st century, there has been an increasing concern for the impact of climate change on water resources and related ecosystem (Kabat et al. 2005). The expected climate change in the Netherlands for the 21st century includes a continuous rise in temperature with more frequent mild winters and hot summers and increasing intensity of extreme summer and winter rainfall (Royal Netherlands Meteorological Institute 2006).

One adaptive effort to projected climate change is "the Leven met water" (Living with Water) programme sponsored by the consortium of Dutch government, private agencies, universities, and research institutes. Spurred by the 1993 and 1995 floods and the summer 2003 drought, there has been a movement toward a new paradigm of water management. This new paradigm, so called "make space for water", attempts to intergrate social processes, climate change, and spatial planning for adaptive water management in response to expected extreme hydroclimatic events. As a result of these paradigm changes, the government initiated several different methods for handing water at the national, provincial, and municipal levels. The adaptive measures not only include technological innovation (e.g., broadening river bed and waterproof construction such as amphibian homes and floating greenhouses), but also incorporate water management as an integral part of social processes and spatial planning (van Walsum et al. 2005). Operating on the interface between science and public policy, the Living with Water program will continue through 2009 with funding of 45.7 million Euro (Leven met water 2006).

Another broader adaptive effort is the "Climate Changes Spatial Planning Foundation" , a research program housed in Vrije Universiteit Amsterdam and Wageningen University (Climate Changes Spatial Planning. 2006). Climate change is gaining its importance in spatial planning in the Netherlands, and through smart spatial planning, the adverse effects of climate change could be minimized. Freshwater management is one of the main sectors in the program. With inputs from public and private sectors, university researchers are investigating alternative land management and innovative technologies. Many geographers and regional planners as well as engineers are currently participating in the program.

In addition to this ongoing Dutch Climate Changes Spatial Planning Research foundation programme, the government recently launched a new initiative called ARK (Adaptation Programme for Spatial Planning and Climate). ARK will be several times larger than Climate Changes Spatial Planning, in both size and scope. Through partnership between policy makers, researchers and other stakeholders, it will develop a comprehensive agenda that deals with climate change across several sectors of the society and economy.

III. Discussion

1. Comparison of five countries

Although there have been extensive studies concerning the impacts of climate change at multiple scales, research has yet to develop generalized conditions or procedures under which the integration of this knowledge with water management policies can be successful (Lemos and Morehouse 2005). In fact, several studies have concluded that the adaptation and integration programs that have been adopted in the countries discussed are regionally specific, and that no one generalized integration model is possible (Ivey et al. 2005, Lemos and Morehouse 2005, Arnell and Delaney 2006). Such differences stem from different water management practices and institutional arrangements as well as from the varying degree of water availability, current climate effects and expected climate change effects.

1) Climate variability and change and water availability

When considering adaptation within the water sector, it is important to remember that climate change will not impact all countries and regions to the same degree, which has implications for resource allocation for adaptation (Levina and Adams 2006). The five countries examined here have different degrees of vulnerability to climate variability and change. The extreme hydroclimatologic events (i.e., flood and drought) that occurred in Europe in the 1990s and the early 2000s prompted country-wide efforts toward adaptive management both in the UK and the Netherlands. Under climate change scenarios, both countries will experience increased winter flooding and summer droughts. To cope with this increasing trend, for example, some of the most innovative adaptive measures have been initiated in the Netherlands. Because 70 % of their gross national product is earned within flood-prone areas, it is natural that such adaptive measures are politically more acceptable than in other countries. In the UK, climate change impacts will be most severe in south and east where population is growing in major urban areas. The American southwest (i.e., Southern California and Arizona) is facing a similar situation, and climate change is becoming a part of regional planning. For example, the governor Schwarzenegger of California established the Climate Change Team and asked the Secretary to report the potential impacts of climate change on California and to prepare for mitigation and adaptation plans, including water resources. In Canada, while climate change will likely increase annual precipitation, seasonal changes in flows (higher winter flows and lower summer flows) will increase discrepancies between supply and demand. Such impacts will be pronounced in populated provinces such as Ontario and British Columbia (Lemmen and Warren 2004). Australia' s focus on the Murray-Darling basin has been initiated from the notion that the ongoing drought would continue under climate change scenarios.

2) Institutional arrangements

The five countries examined here have different administrative systems. The US, Canada, Australia have decentralized structures with numerous regional (state and provincial) governments and independent water management agencies. In contrast, the UK and the Netherlands have government central structure. Table 1 summarizes some major features of centralized and decentralized structures that could facilitate or impede adaptations to climate change.

The U.K. and the Netherlands have accomplished the greatest development of their integration program out of the five countries examined in this study. This may be related to relatively small size of these countries compared to other three countries. It may be more efficient for a central government to implement some standardized policies in a country with a small sovereign area. The US, Canada, and Australia contain geographically diverse areas that are administrated by numerous regional and provincial governments. Because environmental matters are generally better managed on a regional scale, these countries also have a decentralized water management system. With limited guidance from the federal government, coordinating stakeholders with different interests could impede adaptive management to climate change.

Table 1. Major features of centralized and decentralized structures that could facilitate or impede adaptations.

	Centralized (UK, the Netherlands)	Decentralized (USA, Canada, Australia)
Policy approach	Consistent approach to adaptation	Varied approach to adaptation
Long-term planning	A top-down strategy allows looking far ahead into the future	A bottom-up approach may focus on short-term planning
Number of Players	Limited number of players in the water resource sector	Multiple number of national, regional, and local institutions and stakeholders
Decision-making process	Bureaucratic top-down decision making process may limit local adaptation effort	Flexible bottom-up decision making process encourage local adaptation effort
Links between national and local priorities	Challenge to incorporate local interests into a national agenda	Challenge to incorporate national or other regional interests into a local agenda
Flow of information	Central government has access to all information	Local government's access to information may be limited

In addition, when information and data sharing does not occur cross the boundaries of regional and local government, adaptive efforts could be further delayed. For example, Australia' s integration efforts are much further behind the other countries. This is surprising considering the continent' s water resource availability constraints and the resource' s vulnerability to expected changes in climate. However, the water resource stakeholders' increased awareness and concern about the impacts of climate change on the region will provide a great deal of motivation to continue with the governmental program' s development and expansion.

Canada' s C-CIARN project illustrates a different story. It is an inventive approach to facilitating the sharing of relevant information and data between researchers and stakeholders among the six regions and seven national sectors across the country. This nation-wide network makes it easier for regional groups to hear about new programs or research results from other parts of the country. This is done through websites, public education and outreach centers, workshops, and training (C-CIARN 2005).

The DCDC, through information and data sharing via the Decision Theater and the SWIP project, is developing one of the most innovative approaches to climate change integration. The ongoing development of the SWIP project will not only promote specific research into how climate change will impact large urbanized areas, it will also provide a new modeling tool that can be used for other cities and large towns. The Decision Theater, should it be developed to its full potential, could be an invaluable tool in assisting water resource stakeholder groups to envision and develop collaborative solutions to adapting to climate change.

3) Water management practices

Each country and region' s current water management practices also affect adaptation efforts. Key tasks in water management include developing long-term water resource management strategies, regulating water abstraction, supply and demand, and minimizing flood and drought risks (Levina and Adams 2006).

While climate change is not directly taken into account in long-term water resource management in most countries, there are some examples that indirectly facilitate adaptation and improve the resilience of water resource systems. In US, the Environmental Protection Agency strategically plans to increase wetlands (400, 000 acres) for flood protection, and the Bureau of Reclamation is advancing a framework that copes with water supply challenges in the West by 2025. This framework is designed to help proactively manage scarce water resources by using tools such as conservation, efficiency and markets, collaboration between stakeholders and policy makers, innovative technology, and the removal of institutional barriers. Other countries have adopted similar strategies to managing scarce water resources.

Levina and Adams (2006) pointed out four main reasons why climate change is not directly addressed in water management strategies. First, water managers and policy makers overlook available climate information when climate change is not a priority political agenda. Second, water resource managers are reluctant to use the uncertain projections of different climate models and associated with runoff projections. Third, the reactive nature of water management inhibits the proactive long-term planning that takes into account climate change. Fourth, there are few standards for incorporating climate change into water resource decision making.

Despite these reasons, some countries and regions are making efforts to active adaptive management strategies. The California Water Plan in the US examines potential strategies for adapting climate changes. The Thames Estuary 2100 in the UK develops a Thames Estuary Flood Risk Management strategy for the next 100 years using different scenarios of climate change. The Kiwa Water Research in the Netherlands is developing adaptive strategy tools to secure production and distribution of drinking water under climate change scenarios. These adaptive management strategies recognize that climate change will pose additional stress on regional water resources and the government needs to take actions to prepare for climate change.

The degree of regulation of water abstraction determines how much water can be taken from surface and ground water and how it is allocated for different sectors of society and environment. This has implications for addressing potential situations of water shortages as a result of climate change. Each country and region adopts different legal frameworks to regulate water abstractions. While water abstraction requires a permit by regional environmental departments in the UK and the Netherlands, it is not always mandatory in some parts of US. Abstraction licensing might provide regulatory agency flexibility to manage water for a specific location and sector. For example, where aquifers are under stress, withdrawals could stop until the ground water levels recover. Because most abstraction permits occur at the local level, it is pivotal that local authorities receive up to date comprehensive information on possible water stresses as a result of climate change (Levina and Adams 2006)

Water supply structures, including dams, reservoirs, and canals can serve adaptation technologies to manage water resources to expected climate change. While there have been debates regarding the construction of major dams or reservoirs, a small-scale water infrastructures at the community scale might provide useful adaptation tools by redistributing water temporally. Some regional governments attempt to store water through underground recharge projects. Demand-side management, such as water metering, market-adjusted water pricing, water recycling, replacing old leaking pipes, and encouraging the use of water efficient home appliances, also facilitates adaptive management. Water metering has proven to reduce consumer water use by 37% in Ontario, Canada.

Flood management practices will also have significant implications for designing adaptation strategies, as floods may become more frequent under a warming world (Huntington 2006). In the USA, long-term flood mitigation programs are funded by the federal government (i.e, the National Flood Insurance Program and Flood Hazard mapping program) in cooperation with state agencies. Such federally-funded programs make up to date floodplain maps available for people and developers, providing opportunities for preparing for potential damage.

4) Some similarities in adaptation efforts

There are important similarities in the programs that are being developed in the five countries examined. The majority of these programs have initially used the interview process to determine the types of knowledge and tools that would best assist stakeholders, as well as the negative factors that are currently inhibiting their use. Follow-up interviews are often used to gauge the success of new developments within the program and how it could be improved. Each country has also been successful in the use of workshops and focus groups to increase climate change awareness and promote collaboration among the various stakeholders, government agencies, and research organizations. This has contributed to sustained interaction and continued relationships between the groups, both considered vital factors to ongoing cooperation (Lemos and Morehouse 2005). Another similarity among each country' s integration programs is that they are all directly affiliated with a major university or multiple universities. Lemos and Morehouse (2005) explain that instead of keeping the research community separate from the problems that water management faces, this promotes a 'culture of research' that produces knowledge and addresses water resource questions collectively.

5) The role of academic community

The academic community has a high profile in each climate change integration programs discussed in this study and is usually the driving force behind organizing events and developing new approaches. The majority of the program main offices are based out of one of the primary universities involved, such as the University of Oxford, U.K. (UKCIP), McGill University, Canada (C-CIARN, water resources), University of Washington, U.S. (CIG), Arizona State University, U.S. (DCDC) and Vrije Universiteit Amsterdam and Wageningen University (the Netherlands). Professors also serve as program panel members, such as the executive chair of the IOCI, B. Sadler from the University of Notre Dame, Australia (IOCI 2003). However, the largest contributions that universities provide to these climate change integration programs are the climate change research and case studies that are carried out by their professors and students. University members have completed numerous climate change impact studies and integration assessments in the Pacific Northwest, U.S. (Callahan et al. 1999, Whitley-Binder [in press]), the Okanagan Basin, Canada (Cohen et al. 2006), and the U.K. (Subak 2000, Holman et al. 2005, Arnell & Delaney 2006). The academic community will continue to play a vital role in the ongoing development and expansion of each of the climate change integration programs discussed.

2. Implications for Korean water resource management and policy

Which aspects of each country' s policy could be considered for integrated water resource management of Korea under expected climate change? We draw five implications below.

First, adaptation strategies need to consider specific regional and sectoral characteristics. As examined in this study, climate change impacts will vary over space and time. According to recent modeling efforts, the spatial and temporal variability of Korean water resources will also increase under climate change scenarios (Bae et al. 2006) and combined population and industrial growth scenarios (Chang et al. 2006). Particular attention needs to be paid on sectors and areas vulnerable to climate change. A regional approach, such as integrated regional assessment at the river basin scale, would provide a useful framework to address such concerns (Yarnal 1998; Chang and Knight 1999).

Second, adaptation strategies need to be integrated with other land use planning strategies. As demonstrated in the case of the Netherlands, spatial planning could be a useful strategy, not only to reduce greenhouse gas emissions from lands, but also to effectively mitigate potential negative effects of climate change on water resources (e.g., flood hazards). Other land management practices, such as wetland protection, could also help reduce flood vulnerability. Sustainable rural planning through best agricultural management practices may help reduce soil erosion during wet periods and decrease water demand during dry periods by capturing water in the soil for a prolonged time.

Third, effective adaptation strategies require coordination among stakeholders at different levels of the administrative hierarchy. Unwillingness to integrate climate information into decision-making often results from institutional barriers as well as current management practices. In addition, when there are multiple players with conflicting interests, it is difficult to make efficient adaptive strategies. Hence, there is need to establish standards for incorporating climate change into long-term water resource decision making at the national level. Such national guidance will facilitate short or mid-term water resource decision- making at the regional and local level.

Fourth, innovative technology could be a useful tool for establishing adaptive management strategies. For example, 3-dimensional geovisualization used in decision theatre at DCDC facilitated adaptive water management in Arizona by reducing uncertainty and communicating scientific processes in a transparent way. In addition, websites containing up to date climate and water information would be useful for mitigating potential climate hazards. Various stakeholders will be able to not only use such information but also provide feedbacks for better risk communication. Similar tools could be introduced for adaptive water management in Korea.

Fifth, university could play a central role for facilitating adaptive management at a regional and a local level. As was the case in all countries examined in the current study, university is a useful channel for communicating scientific results. Many universities create new scientific information related to climate change and adaptation and provide such information for stakeholders in an understandable format. A continuous dialog between academia and stakeholders is necessary to ensure transparent communication. Hosting conference workshops for incorporating the various needs of stakeholders and on site visits from university researchers will enhance mutual understanding of pressing issues, as was clearly demonstrated by C-CIARN. We suggest establishing university research centers geared to participatory integrated assessment of climate and water in Korea. University researchers' willingness to share data and information must be the prerequisite step to this.

IV. Conclusions

As global warming and climate change has gained acceptance throughout the world, governments, scientific communities, and water resource stakeholders have explored ways to develop and disseminate regional adaptation measures. Although much research on climate change and its implications regarding water availability at the global and local scale has been completed, methods of communicating this knowledge to decision-makers are still being developed. It can be concluded from the efforts of each of the countries included in the study, that water resource stakeholders are receptive to addressing climate change impacts once they have been exposed to the study and research results. The United States, England, Canada, the Netherlands, and to a lesser extent, Australia, have numerous adaptation programs in place and have used workshops, focus groups, and websites to increase the availability of this information and, subsequently, the water resource stakeholder awareness of how it can be beneficial to their management policies. Together with the Netherlands' Living With Water program, the ongoing Canadian study by Cohen et al. (2006) is the strongest example of how the academic community, governmental agencies, and local stakeholders can work together to develop sound methods for adapting to climate changes in the Okanagan Basin and establish a methodology for adaptation throughout the county.

Even though global climate change was not the primary impetus behind their water industry's adaptation measures in the 1990s, England and the Netherlands have progresses the farthest of the countries in this study, in terms of climate change preparedness. Of course, when compared to the relative size of the United States and Canada, and the water resource challenges of Australia, England and the Netherland have been at an advantage. However, their progressive adaptation programs have been very beneficial to the water industry's awareness of regional climate change impacts.

The continuance of climate change research will increase the accuracy of climate modeling and the reliability of climate projections. These advances, coupled with a greater efficiency in the dissemination of climate change information and the development of adaptation methods, will help better prepare the water resource industries in the United States, England, Canada, Australia, and the Netherlands to be able to cope with future climate uncertainty. Climate change will become one of the major factors that affect the availability and quality of water resource in Korea. It is about time to learn lessons from other countries' experiences to facilitate proactive water resource management under a warming world.

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