The Water-Energy Nexus: A Challenge for Knowledge and Policy

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

Chris Davis
Chair, Urban Water Security Research Alliance

CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

Integrated Water Resource Management is a risk based approach advocating the co-ordinated development and management of land and water resources in order to ensure sustainable development. As finite freshwater supplies become strained as a result of population growth and climate change, energy is becoming increasing pivotal in the provision of water. Conversely, water is central in the production of most forms of energy. However, policy-making and decision-making *between* these closely linked systems remain largely disconnected. This has been a policy blind-spot in many countries, thus posing a problem for the ongoing sustainable management of water resources. This paper highlights emerging issues created by the intersection of water, energy and climate in the light of recent experience in the USA and Australia up to 2010. It notes the emergence of the issue in recent work of the National Water Commission (NWC) and the Prime Minister's Science Engineering and Innovation Council (PMSEIC). The paper recommends a reliance on the key principles of Integrated Water Resource Management as a structured framework for assessing and responding to the nexus between water, energy and climate change. In doing so, this paper provides suggestions for identifying, mitigating and adapting to the various risks arising from this contemporary challenge, and suggests the need for systematic review of current regimes for development approvals.

1. INTRODUCTION – WATER, ENERGY, CLIMATE

Following the global endorsement of 'sustainable development', there is now a general acceptance that the sectoral and fragmented approaches which have traditionally underpinned the work of the research, business and government sectors cannot adequately advance the goals of an ecologically sustainable, socially desirable and economically viable future (United Nations Environmental Programme (UNEP), 2007; World Commission on Environment and Development (WCED), 2007). Consequently, there is a discernible shift toward more holistic or 'integrated' models that recognise a wide array of stakeholders and address the increasing complexity of environmental issues across political, organisational and natural boundaries (Margerum and Born, 1995; Ewert *et al.*, 2004). In the context of water management, this push for holism found expression in the concept of Integrated Water Resource Management (IWRM), which has been defined by the Global Water Partnership (GWP) as "a process which promotes the co-ordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000, p.22).

Reliable water and energy supplies are fundamental to modern industrial societies and are inter-dependent. Without energy, we cannot run IT and communication systems; power our homes, schools and offices; or manufacture and distribute our products (United Nations Industrial Development Organisation (UNIDO), 2003; DHI Group, 2007; Pacific Institute, 2009). On the one hand, energy is required to extract or manufacture water (for example, desalinated water or recycled water), to move it from source, treat it, convey to businesses and households, and then treat again before it is disposed of or recirculated into the water cycle (Cohen *et al.*, 2004). Conversely, water is vital for the extraction, refining and transportation of raw energy materials, and for the power stations that generate electricity, whether directly in hydropower or for the cooling and emission-scrubbing processes in thermoelectric generation (US Department of Energy, 2006). Some of these inter-relationships are outlined in Figure 1.

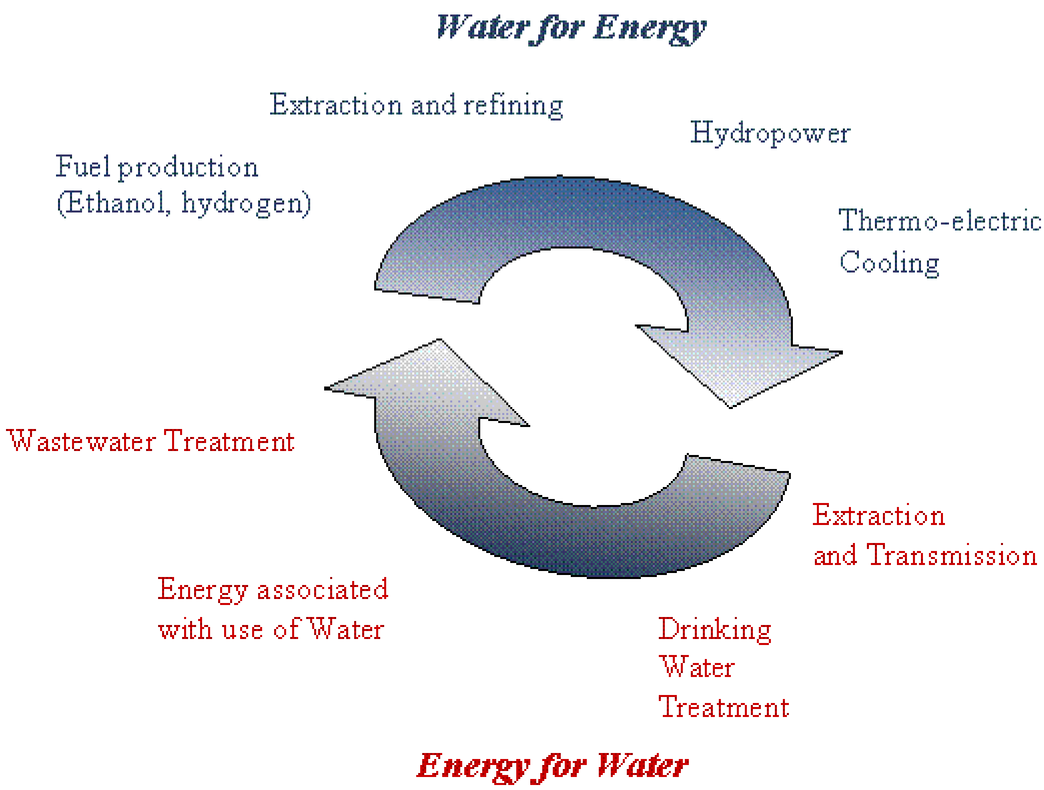

Figure 1: Links between water and energy (WBCSD, 2009).

Population growth and higher real incomes will increase the demand for water and energy. Higher demand for energy will drive a corresponding demand for more water, and vice versa (World Business Council on Sustainable Development (WBCSD), 2009). These complex and co-dependent relationships will be exacerbated by climate variability, which is predicted to decrease surface water availability in many parts of the world and to further increase energy demand (IPCC, 2007a). As well as the creation of feedback loops between these systems, interactions between the sectors of water, energy and climate may also have the potential to cause 'emergent' effects in other systems owing to unplanned or unintended interactions (Novotny, 2005). Furthermore, within each domain there exist multiple knowledge systems linked to research, business, government and civil society institutions. These interact with each other in a variety of ways but may also retain a degree of separation. This paper defines this system of interconnections as the 'Water, Energy, Climate Change (WECC) nexus'.

Whilst there is a pressing need to understand the interactions that constitute this nexus, existing policy frameworks for water, energy and climate response have generally been developed in isolation (Proust *et al.*, 2007). Furthermore, very little research has been undertaken into how the links between water, energy and climate can be accounted for and incorporated into international, national and regional policy development (European Cooperation in Science and Technology (COST), 2009). In order to demonstrate the contemporary challenges posed by the WECC nexus, this paper briefly considers recent experiences of two countries: the United States of America (USA) and Australia, before returning to considering a conceptual framework to take these issues forward.

2. RECENT USA EXPERIENCE

In the USA, power generators account for forty per cent of all freshwater withdrawals, but only three per cent of freshwater consumption, the remainder being returned to the environment (Electric Power Research Institute (EPRI), 2007). However, competition for water resources as a result of population growth coupled with a prolonged drought in some regions has meant that this apparently low proportion of consumptive use has proved to be problematic. In areas that are water-stressed, the operations of many power generation facilities were curtailed as a result of water shortages (US Department of Energy, 2006). Goldstein *et al.* (2008) report that the Southwest of the USA has been particularly vulnerable to this escalating issue:

> *If...scarce water resources continue to be utilised beyond their natural recharge rates, and innovative approaches for the integrated use of water and energy are not implemented, the semi-arid regions of the USA may be economically constrained and environmentally degraded, with potentially severe impacts to the social fabric* (Goldstein *et a.l*, 2008, p.7).

Similarly, the Southeast region of the USA, whose existing nuclear and coal-fired power plants account for sixty-five per cent of all water withdrawn (equivalent in volume to the total national daily freshwater withdrawal for public consumption), has been facing a situation where the onset of drought coupled with increasing demand for water and energy has caused price volatility as well as conflict over resources (World Resources Institute (WRI), 2009). Weiss (2008), reports that the prolonged shutdown of a nuclear plant in the Southeastern region of the USA as a result of water shortages could lead to a tenfold increase in local electricity costs. Furthermore, heated discharges from power plants, which are considered harmful for water quality and local ecosystems, are likely to exacerbate environmental damage as water is returned into a diminished system (Pacific Institute, 2009).

The US administration has taken steps to address the critical nature of the co-dependency between water and energy through the initiation of a nationwide 'Water-Energy Roadmap' process (US Department of Energy, 2006). The roadmap has identified a large number of problem areas associated with the energy and water relationship. These include the lack of long term planning in effectively addressing energy-water interactions at a State, catchment or regional level; the lack of data or models that can be applied to the energy-water relationships; the impact of climate change and its impacts on water supplies and energy production; concerns with respect to the carrying capacity of electricity transmission and distribution systems; general concern about infrastructure decay and degradation; the lack of fundamental understanding of the quantity, quality and conjunction between the nation's surface and groundwater resources; and the need for improved energy and water conservation and efficiency (Hightower, 2007). The need for better information sharing across and within sectors has also been reported as an important issue (Goldstein *et al.*, 2008). Subsequent to the roadmap process, in 2009 two US Senators introduced a draft "Energy and Water Integration Act of 2009 (EWIA)". Their Bill was intended to allow the Department of Energy, in collaboration with the National Academy of Sciences, to conduct an in-depth analysis of the impact of energy development and production on US water resources (EWIA, 2009).

3. RECENT AUSTRALIAN EXPERIENCE

Australia, the driest inhabited continent, is marked by variable rainfall patterns, extended droughts, and scarcity of water in many areas. Larger cities have been entirely reliant on surface water supplies (NWC, 2005; PMSEIC, 2007). Australia's population has trebled in the last 80 years and is likely to increase from 21 million in 2008 to 35 million by mid-century (DIC, 2008), considerably increasing the demand for water and energy. This projected increase in demand is set in the context of changing patterns of rainfall, with a surplus in some tropical areas and deficits in others (IPCC, 2007a). Nearly eighty-five per cent of electricity in Australia is generated from coal-fired power stations (Knights *et al.*, 2007), which themselves are large users of water. Under current technology and regulatory systems, as more electricity is produced to cope with rising demand, greenhouse gas emissions continue to increase. Rising ambient air temperatures are also predicted to impede the reliability and capacity of the energy generation and distribution infrastructure systems (Australian Academy of Technological Sciences and Engineering (ATSE), 2008). The Intergovernmental Panel on Climate Change (IPCC) noted that Australia will have to address the implications of change in climate extremes on water use and on energy demand (IPCC, 2007a). However, the development of co-ordinated mechanisms within Australian Federal and State governments to address these interlinked issues has not been forthcoming (Proust *et al.*, 2007; Marsh, 2008).

Australia's electricity sector accounts for 1.4 per cent of Australia's total water consumption (NWC, 2009). This does not include water withdrawn and returned to the system. The recent vulnerability of Australia to the WECC nexus is described in the following report by the Australian Energy Regulator (2008):

> *Wholesale electricity prices began to rise from around March 2007, when the drought constrained hydroelectric generation capacity in New South Wales, Tasmania and Victoria, and limited the availability of water for cooling in some coal-fired generators. These conditions were exacerbated in winter 2007 by strategic bidding by some New South Wales generators, which led to record prices. The drought continued to affect wholesale electricity prices in New South Wales, Victoria, Queensland and Tasmania during the September quarter of 2007.* (AER, 2008, p.4)

The Australian Energy Regulator (2008) also reported that South Australia, due to drought conditions, experienced record high prices averaging $243 per megawatt hour of electricity over the March 2008 quarter compared to an average cost of $59 per megawatt hour for the 2006 to 2007 period. Across the national electricity market as a whole, negotiated contracts for wholesale electricity supply for industrial users jumped from $35 per megawatt hour in 2006 to $95 per megawatt hour in 2007 (Wilson, 2007).

Australia's reliance on centralised surface water storage has meant that it is highly susceptible to climatic change. Recent episodes of drought, with decreased run-off into dams, resulted in crisis responses including high level restrictions in many of the country's cities and regional centres (PMSEIC, 2007). As such, the need to rely on alternative water resources became an imperative for many regions in order to avoid major water restrictions and service interruptions to domestic and industrial water supply (Saliby *et al.*, 2009).

From the viewpoint of long-term urban water planning, some analysts have urged the implementation of a 'total water cycle' approach involving water conservation measures, and a range of supply options of different quality including rainwater, sewage, stormwater, and seawater (Brown *et al.*, 2009). These supply sources can be matched to appropriate uses including potable and industrial uses, and managed appropriately to minimise nutrient discharge to waterways (Wong and Brown, 2008; Brown *et al.*, 2009). However, the political responses to water shortages across most regions of Australia in recent years have generally rejected the broad sustainability perspective, instead opting for large energy-intensive water supply infrastructure, including desalination and purified recycled water (the latter being viewed more favourably by sustainability advocates: Keath and Brown, 2009).

Saliby *et al*. (2009) comment that, given its reputation as climate-independent, 'desalination is becoming a highly realistic solution that can ameliorate, if not eliminate the current water crisis'. It was recently estimated there are 294 desalination plants (mainly small-to-medium scale) operating in Australia, with a further 976 under construction, and a further 925 under consideration (Hoang *et al*., 2009) attracting investment of some $40 billion (Chong, 2009). It was estimated that 460 GL per annum, or 15 per cent of Australia's urban water supply, could come from desalination by 2013 (Water Services Association of Australia (WSAA), 2009), with cities such as Melbourne anticipated to have a potential future reliance of up to 33 per cent (Department of Sustainability and the Environment (DSE), 2008). By comparison, stormwater, which in Melbourne equates in volume to the entire annual water demand of the city, and which in Brisbane exceeds total demand by 50 per cent (PMSEIC, 2007), is vastly under-utilised (Brown *et al*., 2009).

After initial capital costs, energy is the single largest variable operational cost for a desalination plant, amounting on average to sixty per cent of annual operating expenditure (NWC, 2008) and requiring a significant amount of peak and base load demand from the National Electricity Market (Knights *et al*., 2007). The NWC (2008) reported that a 25 per cent increase in electricity price would increase the overall operational cost of a water desalination plant by 12.5 to 18.75 per cent. Given that electricity prices are heavily influenced by rainfall, or lack thereof, it can be seen in the context of the WECC nexus that desalination is not as climate-independent as sometimes claimed. Furthermore, there are also considerations of increased greenhouse gas emissions from coal-fired power stations that supply the national electricity grid. Whilst some desalination facilities are planning to 'offset' their potential emissions, the Australian Government's long-term goal of reducing carbon emissions by 60 per cent below 2000 levels by 2050 (Carbon Pollution Reduction Scheme (CPRS), 2008) is likely to be made more difficult as a result of the significant increase in electricity demand required by mass adoption of desalination as a means to augment water supply (Knights *et al*., 2007).

4. A FRAMEWORK FOR MANAGING THE WECC NEXUS RISK

The above consideration of the recent experiences of two countries, illustrates the challenges posed by various aspects of the WECC nexus. These are 'wicked' challenges that are complex, multijurisdictional, open-ended and intractable (Head, 2008). The climate is unpredictable, knowledge of various links between water, energy and climate change is incomplete, and nested within these sectors are multiple knowledge frames, within which there are different views about how to manage or understand these various systems and their interactions (NeWater, 2009). As such, the WECC nexus further compounds the already high degree of uncertainty prevalent in the management of water resources. In this report, it is submitted that Integrated Water Resource Management (IWRM) offers a viable approach to managing the WECC nexus risks into the future.

IWRM is concerned with the avoidance of water system failure through the implementation of sustainable water policy. Essentially, it is a risk management framework (Rees, 2002). IWRM is underpinned by a set of four principles agreed on by governments at the 1992 Dublin and Rio de Janeiro conferences (Global Water Partnership (GWP), 2000):

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- Women play a central part in the provision, management and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognised as an economic good.

In addition to the guiding principles, the IWRM framework also provides a set of three overriding criteria which should be recognised in the pursuit of IWRM, accounting for social, economic and natural conditions (GWP, 2000):

- Economic efficiency in water use.
- Equity: The basic right for all people to have access to water of adequate quantity and quality.
- Environmental and ecological sustainability.

The IWRM framework further argues that the effective implementation and management of water resources requires three important elements which need to be developed and strengthened concurrently: the enabling environment, institutional roles, and management instruments (GWP, 2000: Figure 2). These three elements will be elaborated below in the context of assessing and responding to the WECC nexus. There are strong overlaps between the three elements and it is the sub-elements which are the important ingredients for successfully managing the WECC nexus.

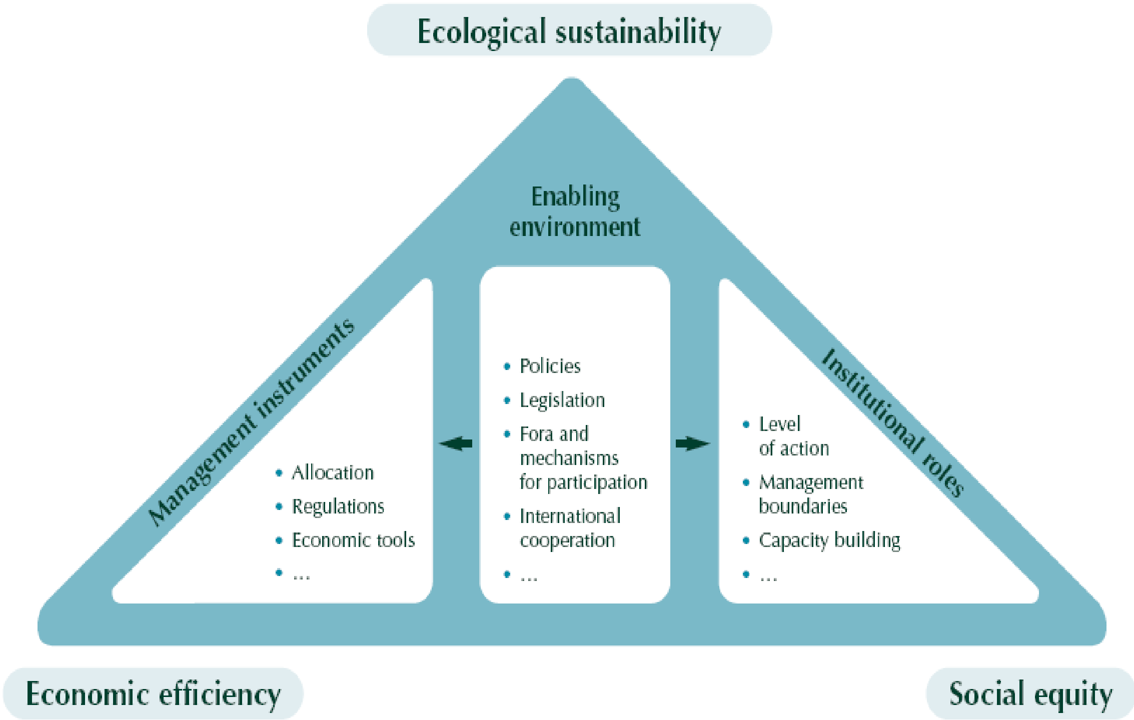

Figure 2: Framework for integrated water resource management (GWP, 2000, p 31).

4.1. Institutional Roles

Institutional roles and development include a wide range of formal and informal rules and regulations, customs, practices, ideas and information and interest groups that provide the context within which decisions can be made (GWP, 2000).

4.1.1. Holistic Governance

Fresh water is a limited and precious resource, which needs to be holistically managed to ensure necessary water services for different purposes, functions and services (International Conference on Water and the Environment (ICWE), 1992). From a political science perspective, holistic governance requires 'mutually reinforcing sets of objectives framed in terms of outcomes and then working back from there to identifying a set of instruments which have the same happy relationship in order to achieve these outcomes' (Perri, 2005). However, the research literature indicates that the sectors of water and energy have been largely disconnected in policy and program terms.

Co-ordination is a key element in the GWP (2000) framework for IWRM. Perri (2005) describes co-ordination as involving 'the development of ideas about joint and holistic working, joint information systems, dialogue between agencies, processes of planning and making decisions'. This is distinguished from full 'integration' which is in essence the 'actual execution or implementation of the products of co-ordination through the development of common organisational structures and merged professional practices and interventions' (Perri, 2005). The underpinning ethos of a co-ordinated approach is to address public sector fragmentation or 'departmentalism'. The challenge is to overcome the legacy of tunnel vision, mutual export of problems and preoccupation with defending institutional turf in 'vertical silos' where organisations work in isolation, programs are contradictory, redundant or both (Hood, 2005; Peters, 1998; Rees, 2002). This is particularly relevant to the WECC nexus where existing disconnections could intensify temporal, spatial and institutional risks and cost shifting (Rees, 2002). Therefore, co-ordinating and integrative mechanisms are required so that holistic assessment can be facilitated, the various economic, environmental and social risks can be identified, and appropriate risk-sharing strategies can be implemented.

In order to achieve this, the International Water Association (2008) suggests that both water and energy should be jointly optimised and synergised as critical resources in a manner that takes account of competing interests for the two resources. Optimisation should seek to ensure preferential access of water and energy sources of low cost and minimal environmental risk, ahead of options with higher cost and environmental risk (Wong and Brown, 2009).

In designing institutions (level and type of government) capable of taking a more holistic and stakeholder preference based approach to managing water related risks, Rees (2002) argues that the most important characteristic of risk to be analysed to inform the design is the degree to which risks are subject to displacement (shifting) and spread. The following key questions, adapted from the four elements identified by Rees (2002, pp.28-9) as being involved in risk displacement and spread, are vital for developing more rigorous and holistic institutional and policy settings and decision making associated with managing potential WECC nexus risks:

- What is the extent to which risk mitigation measures in area A or time A will increase the probability of risk in area B or time B?
- To what extent might risk mitigation in a sector associated with water, energy or climate produce new forms of 'emergent' risk in other sectors, including broader environmental risks?
- What are the critical interactions identified by research concerning the linkages between water, energy and climate change?
- In particular, what are the key biophysical, political, technological, regulatory, socio-economic and institutional factors that influence the WECC nexus? (Where, when, and at what scale?)

4.1.2. Integration

Problems characterised by complexity and uncertainty require integrated approaches to problem-solving (Head, 2008; Hooper, 1995). Organisational integration, e.g. through amalgamating relevant line agencies as a way of addressing WECC nexus issues, may not be necessary, because the transaction cost of this type of integration could be very high. Practical integrative mechanisms may include:

- technical integration where scientific descriptions of the environment being studied are reported in a consistent manner;
- procedural integration where an agreed set of protocols is used for all aspects of IWRM to make all the information accessible in a standard or known format;
- imposed integration where one or a few leading agencies drive the process and define the scope, methods, format and reporting of the various aspects of a particular study; and
- reporting integration where the various aspects are summarised, analysed and reported by an appointed group or unit which integrates the various aspects. (UN 2008, cited in Collins and Ison, 2010, pp.671-2).

One of the major areas of difficulty in the implementation of an IWRM approach is flawed allocation or poor demarcation of responsibilities between actors, inadequate co-ordination mechanisms, jurisdictional gaps or overlaps, and the failure to match responsibility, authority, performance and capacities for action (GWP, 2000) In the context of the WECC nexus, which is likely to involve a significant number of actors, important consideration needs to be given to which elements should be integrated, who should collaborate with whom, and how such networks should be formed (Oliver *et al.*, 2007). Klein and Plowden (2005) comment that the design of integrated approaches should start from the assumption that cross-cutting work is not 'natural' and that integrative or collaborative efforts should therefore be 'incentivised'. Key questions may include:

- What levels of government should be involved in order to increase coherence between decision making at different political scales in relation to the WECC nexus?
- What strategies should be employed to encourage co-ordination and collaboration in research and policy efforts associated with the WECC nexus?

- What organisational innovations are required, including new roles and functions?
- Are there any gaps or overlaps in responsibility impeding the implementation of WECC- nexus responses?
- What new knowledge and skills are needed amongst public administrators in order to manage these issues?

4.2. Enabling Environment

The enabling environment encompasses the policies and legislation that form systems of governance. It includes the various rules, platforms and mechanisms, including information and capacity building, by which various policies, legislative and regulatory instruments are created, influenced and designed (GWP, 2000).

4.2.1. Mechanisms for Participation

The second and third Dublin principles are associated with participation and equity, emphasising the need for stakeholder participation in the development and management of water resources. However, there are great difficulties in reaching a common understanding across the different domains in the WECC nexus, where both the nature of the problem and the solution can be questioned, where different values, vocabularies, assumptions and perceptions exist, and where there is a lack of trust (Gooch, 2006; Harris, 2007; Hooper, 1997; Head 2007, 2008). Discussion and collaboration across different government departments, or between different stakeholders associated with the WECC nexus, are likely to involve translation across a number of philosophical, disciplinary, institutional, jurisdictional and organisational boundaries. Self-interest, maintaining jobs, budgets, income, research grants or prestige will all affect decision-making (Rees, 2002).

This is compounded by the reality that contemporary environmental management now faces particular challenges where 'facts are uncertain, values are in dispute, stakes are high and decisions are urgent' (Funtowicz and Ravetz, 2001, p.18). It has been strongly claimed that in such situations, expert opinion is no longer sufficient to make decisions or inform policy, and that relevant evidence must come through an 'extended peer community' where experiential knowledge is valued alongside orthodox scientific knowledge (Funtowicz and Ravetz, 2001). This message has been reiterated by an independent report commissioned for the Australian Prime Minister's Science, Engineering and Innovation Council (PMSEIC, 2007) which identifies the importance of social research and the involvement of the community in order to improve understanding, acceptance and design in regard to different water supply options.

Whilst some recognition of this broader approach is beginning to slowly emerge in the water sector, the energy sector appears to be almost devoid of participatory processes and community debate regarding energy policy and regulation, nationally and internationally. This may be partly attributed to the gradual deregulation of the electricity sector, and the economic power of large energy corporations, which are private businesses in the USA and increasingly so in Australia, with a mandate to maximise their revenue through the increased sale of electricity.

Rees (2002) argues that the adoption of participatory processes enables key questions associated with IWRM to be addressed and answered. The same risk-based inquiry should apply across the sectors of water, energy and climate and their intersection in order to aid strategic consideration of the management and adaptation challenges arising from the broader WECC nexus. Relevant assessment questions include:

- Which levels of expenditure on risk mitigation can be justified in user preference terms?
- Under capital constraints and human capacity constraints, which risks are the least acceptable, and thus the key priorities for action?
- Who will bear the remaining risk costs and to whom should the costs and benefits of risk mitigation be allocated?
- Which risk mitigation methods are most acceptable in economic, social and political terms?

- How will the affected public respond to different risk reduction measures?
- To what extent can risk mitigation be regarded as a private rather than a public good, and thus subject to private choices?
- Which risk reduction measures does the community have the will or the capacity to introduce and maintain? (Rees, 2002, p.16)

4.2.2. Co-ordination Mechanisms

A key tenet for establishing a strong and effective enabling environment is co-ordination at the highest level. Invariably, this requires political will (Hooper, 1995). An example might be the proposed Energy and Water Integration Bill in the USA, which was premised on both political support and funding to initiate improved knowledge and reporting concerning the interactions between these systems. In Australia, some useful initial data collection and investigation has occurred through the National Water Commission (NWC) regarding the interplay between water, energy and climate change (NWC, 2009), and PMSEIC (2010) has drawn attention to the need for further research. However, an agreed strategic framework for coordinated action is still lacking.

As well as co-ordination mechanisms and targeted legislation, other important facets of the enabling environment identified by the GWP (2000) include cross-sectoral and upstream-downstream dialogue, co-operation and appropriate financing structures and investment allocations (including conditions for private sector involvement and performance). Although this framework was initially geared toward the water sector, it can be readily adapted to broader water, energy and climate change analyses along with the risk based inquiries outlined in the previous sections. Other key questions include:

- Who are the key stakeholders involved?
- What mechanisms are in place for sharing knowledge?
- How aware are the public sector, business sector and the broader community of the WECC nexus? What evidence supports this?
- What evaluation studies have been undertaken concerning the effectiveness of proposed measures?

4.3. Management Instruments

Management instruments are the tools and methods which assist the decision making process, enabling decision makers to make rational and informed choices between alternative actions (GWP 2000). For example, in relation to water planning there are several key issues concerning water entitlements and the extent of available water resources. This has been acknowledged by both the USA and Australian governments. As noted above, the USA has established a ‘roadmap process’ and subsequent discussions have occurred in relation to the proposed ‘Energy and Water Integration Bill’. Similarly, the NWC, through the inter-governmental agreement on the National Water Initiative in 2004, has been trying to investigate ‘how much water do we have, where is it, where is it going, what is it being used for and who is entitled to it?’ (NWC, 2005). Given that the effects of predicted climate change will be amplified in the water sector (GWP, 2008), answering these questions regarding allocation is critical to the protection of each region’s future security. As the impacts of the WECC nexus intensify, crucial issues will arise in times of water scarcity as to: who and what should get priority; what conflict resolution mechanisms are in place to deal with such an eventuality; and who ultimately would decide? Difficulties in answering such questions are likely to be of serious concern across jurisdictional and stakeholder boundaries.

It is a basic human right for all people to have access to clean water and sanitation services (e.g. the UN Millennium Goals). Similarly, the World Energy Assessment report (UNDP, 2004) states the importance of energy services for satisfying basic human needs, improving social welfare, and achieving economic development. The principle of water as an economic good contributes to achieving societal objectives such as effective and equitable water use and to incentivise water conservation (Dukhovny, 2009). With reference to this principle, the Global Water Partnership (GWP, 2000) distinguishes between value and charging. The value of water for alternative uses is seen as a way of making rational allocation choices for water, which can be implemented either by economic or regulatory means. On the other hand charging for water is the application of an economic instrument intended to reduce demand (e.g. price signals which encourage conservation), to ensure cost recovery, or to signal willingness to pay for additional services.

Such systems for water allocation and water markets have developed rapidly in Australia since the 1990s, but the situation is arguably different within the electricity sector which has remained a market system heavily focused on charging rather than debating value. Given that both water and energy are fundamental resources linked to civilised life and social equity, there is a strong presumption in favour of greater alignment between the ways we value, allocate and charge for water, energy and climate goals and measures. It was noted in the Australian example above that the value of water to the electricity industry during times of drought had a direct impact on the price of electricity. With the gradual introduction of a carbon market in Australia, the market landscape could be further complicated. How will these various water, energy and carbon markets interact? The National Water Commission suggests that the interaction between these different markets will increase (NWC, 2009). However, this interaction and inter-dependence will require reconsidering the viability of maintaining their different structures, different regulatory arrangements, different operating philosophies, and different risk profiles into the future.

In addition to allocation mechanisms, management instruments also include regulations and economic tools. A report to the Australian PMSEIC noted that large increases in water efficiency and saving processes are possible through more efficient tariff structures, along with incentives for implementing water sensitive design (PMSEIC, 2007). There is no reason why similar measures could not be designed to reward energy-efficient technologies and systems. Another area for development is information standards and regulatory guidelines concerning the consumption of water in the production of energy and for the consumption of energy in the production and distribution of water (NWC, 2009). It is likely that an integrated assessment regime will be required in future to understand and plan for the management of risks arising from the water, energy and climate nexus. Thus, some key issues may include:

- What are the likely impacts of new regulations, standards and incentives related to the WECC nexus?
- How do existing policies impact on a range of WECC nexus issues? Positively or negatively?
- Are the necessary quantitative data available to understand and account for these interactions? And, if not, how might we go about obtaining these?
- What qualitative data are available and what further qualitative data are necessary to understand how and why these interactions occur in specific ways?
- What risk assessment methods should be employed?

5. CONCLUSION

This paper has highlighted and described some of the complex links between water, energy and climate. Recent experience in the USA and Australia demonstrates that, in considering future options for water security, the energy requirements and climatic impacts of each solution-option must be taken into account. Similarly, approaches that consider energy security but which do not simultaneously account for water or climate variability are not likely to be sustainable. However, by and large, policy and decision-making has not been actively scrutinising the key connections between these linked systems. There are signs this is gradually changing. A report on urban water futures (PMSEIC, 2007) urged that the energy requirements of water supply options be better assessed to ensure optimal outcomes. A recent report for PMSEIC (2010) highlights the complex 'intersections' between water, energy and carbon processes, and calls for greater attention to promoting 'resilience', i.e. practices that emphasise adaptation and learning. These approaches will need to draw not only on market mechanisms, including appropriate pricing, but also on non-market measures such as standards, regulation, consultation, education and R&D programs.

There is widespread and increasing recognition that a more holistic integrated approach is required to address the complex sustainability issues faced by modern societies. A host of new concepts and phrases embodying 'integrated' approaches to sustainable development have been widely circulated. However, in the context of water management, Integrated Water Resource Management (IWRM) appears to have a special standing as a globally endorsed, well structured, mutually reinforcing framework. The challenge is not so much to coin new conceptual language but to implement the insights from recent integrated frameworks. As Henrik Larsen recently stated at a European workshop focused on managing the links between water, energy and climate:

> *'the solutions are not to be found in new strategies but in getting the old ones [such as IWRM] right'* (COST, 2009).

This paper has demonstrated that the IWRM framework can be utilised in practical ways to form a risk-based management approach capable of incorporating the contemporary challenges of the water, energy and climate change nexus. Whilst raising more questions and challenges than answers, this paper demonstrates that the IWRM approach, underpinned by the Dublin Principles, and structured in the three domains of the enabling environment, institutional roles and management instruments, can provide a useful and comprehensive framework for addressing these questions. In doing so, the IWRM approach provides a way forward for the identification, mitigation, management and adaptation challenges in relation to the various risks and opportunities that may be posed by the WECC nexus. These issues can be applied immediately to analysing the adequacy of current assessment and approval regimes for resource development projects, for urban expansion, for urban renewal projects, and for major infrastructure planning.

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