Integrated water resource planning in the context of climate uncertainty
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ABSTRACT

In many locations, climate change may significantly reduce urban water supplies and could also affect water demand. With uncertainty around future climate, supply-demand planning needs to adapt. This paper addresses the question: How does climate change alter Integrated Resource Planning (IRP) for urban water? The paper covers the setting of planning objectives in the face of climate change, assessing the impacts of climate change on urban water supply and water demand, and considers the available responses. While climate change represents a major challenge for urban water planning it also reinforces key principles of IRP such as adaptive management, the central role of water conservation and need for public engagement in water planning.

Key words | climate change, integrated resources planning, urban water supply, water demand

INTRODUCTION

Climate is a major factor in determining available water supply in most towns and cities and can also have a strong impact on water demand in urban areas. Human-induced climate change is projected to increase global average temperatures and alter critical climate variables including rainfall and evaporation over the coming decades (IPCC 2007). In addition increased variability in climate is expected in the form of more severe droughts and flooding events.

Significant changes in climate are predicted to occur by 2050 with further changes likely after that (IPCC 2007). Urban water supply-demand plans commonly consider timeframes of 25 to 50 years. Climate change and uncertainty around future climate must therefore be considered as part of urban water supply-demand planning.

Integrated resource planning

Integrated Resource Planning (IRP) is a supply-demand planning process which involves forecasting future demand and estimating the available supply to determine the supply-demand gap. It involves considering a range of options to reduce demand or increase supply in order to balance supply and demand. A fundamental part of the process is the need to assess water conservation and supply options together on an equal basis. Initially developed by the electricity industry in the United States in the 1980s, IRP has been an important component of urban water supply-demand planning in Australia and elsewhere since the mid 1990s (White & Fane 2002). IRP has been described as a planning process that aims to integrate: centralised and distributed sources of supply, demand-side and supply-side options, and often conflicting economic, social and environmental objectives (Swisher et al. 1997). It is an open, participatory, strategic planning process, emphasising least-cost analysis of water conservation and supply as a means of meeting service needs (Vickers 2001).

In considering the implications of climate change for urban water supply-demand planning this paper takes as it’s starting point the Australian IRP framework as described in Turner et al. (2008). The IRP framework is based on over 10 years experience in the urban water sector and sets out a process that can be used to develop a long-term urban water
supply-demand plan. A summary of the IRP framework is shown in Figure 1 below.

Step 1 of the IRP framework includes considering the planning objectives for the urban water system. Step 2 covers demand forecasting and estimating available supplies. Step 3 involves developing a range of water conservation and supply options and determining how to meet planning objectives at least-cost while accounting for sustainability impacts and uncertainties. Steps 4 and 5 follow and describe implementation of the selected responses and on-going monitoring of the outcomes.

Adapting urban water IRP to account for climate change will mean incorporating predicted climate change impacts and increased uncertainty about future climates as well as the implication of potential increases in the climate variability. What shifts are needed and how IRP can be modified while maintaining its key principles is the topic of this paper.

Planning for droughts

Particularly in Australia planning for droughts has always been an important aspect of urban water planning and management. As well as a long-term plan to balance supply and demand, water utilities should have a drought response plan and contingency or emergency plan (Erlanger & Neal 2005). When droughts occur, the drought response plan traditionally provides a short-term response in terms of water restrictions. In case of an extreme drought, a contingency or emergency plan is also needed to ensure that basic water needs for a community can be met during an emergency through the provision of a ‘minimum level of supply’ at all times (Erlanger & Neal 2005).

To date the connections between drought response plans, contingency plans and long-term supply-demand planning have been viewed predominantly from the supply-side. The expected increases in climate variability are likely to mean a heightened role for drought response and contingency measures within supply-demand planning.

In the context of climate change, ideally the drought, contingency, and long-term components will be brought together as part of IRP.

THE IMPACTS OF CLIMATE CHANGE: AUSTRALIAN EXAMPLES

Human-induced climate change is projected to have impacts on both the average patterns of rainfall and evaporation as well as on climate extremes such as droughts and floods. Due to the sheer size of Australia and diversity of climate zones the impacts of climate change represented through these changes will differ significantly between regions. Hence the impacts of climate change on urban water systems will be significantly different from location to location.

There is substantial uncertainty around climate change impacts at a global level and also for many regions. These uncertainties can be magnified when considering how changes in climate will affect patterns of rainfall and runoff. From an urban water planning perspective it will be both the projected impacts of a changing climate and the associated uncertainty that will need to be managed.

Projected climate change impacts

Climate change can be expected to affect both geographic and seasonal patterns of rainfall as well as the intensity and frequency of rainfall events.

The impacts of climate change will differ across regions. In Australia, for example, regions such as south-west Western Australia and southern Victoria are projected to experience a significant decline in winter and spring rainfall and there is a likely drying trend on the eastern coast of Queensland (BoM 2007). In contrast the eastern seaboard of New South Wales is projected to experience only a
slight rainfall reduction or no change (DWE 2008). Drought occurrence is projected to increase in south-western and south-eastern Australia (BoM 2007) while for the tropical north, extreme daily rainfall events are projected to increase in frequency.

**Uncertainties about climate change impacts**

There are a level of uncertainty about the impacts of climate change at a global level. Firstly the future greenhouse gas (GHG) emissions trajectory that the world will take is unknown. There is also some uncertainty around the sensitivity to GHG that the climate will exhibit over time.

Uncertainties exist in translating global change to impacts at a regional level. Climate change impacts will vary spatially and impact different regions to varying extents. Significant uncertainties exist in each of the linkages from a change in regional climate, to changes in rainfall and evaporation, and then to changes in run-off and available supply. For example, it is not clear how an average increased evaporation due to rising temperatures and the phenomenon of ‘catchment drying’ will impact on run-off. Likewise in some locations an increase in extreme storm intensities might contribute to greater volumes of runoff without changes in average rainfall.

Further, due to the complex nature of the climate system, climate change has the potential to cause structural shifts in the climate. In water planning terms such a shift would be seen as a sudden rather than gradual change in climate variables, particularly rainfall and run-off. In some regions of Australia observed decreases in run-off in recent years and decades have been interpreted as a ‘step change’ resulting from a structural shift in the climate.

Perhaps the most well-known example is the case of Perth. In the period from 1997 to 2005 the inflows into storages were about 30% lower than the post-1974 average (Water Corporation 2008). The inflows in the post-1974 period are themselves approximately 50% lower than average across the historical record. This sequence is interpreted by water planning authorities as a ‘step change’ in run-off for Perth and the city is currently building a second desalination plant in response. In Melbourne average inflows to storages have been observed to have decreased by 35% over the last decade and this trend is also being treated as a ‘step-change’ by urban water planners (DSE 2007). There is however a level of uncertainty as to whether these observed ‘step changes’ in runoff are in fact the result of a shift in climate or part of a drought event outside the historical record but within the range of natural variability for the region.

In the same way that the projected impacts of climate change are location-dependent, different regions will have differing levels of uncertainty around future climate including different vulnerabilities to a ‘step change’ in rainfall or runoff.

**SETTING PLANNING OBJECTIVES IN THE CONTEXT OF CLIMATE CHANGE**

Step one of the IRP framework includes establishing the significant issues for a region and considering how these relate to the planning objectives for urban water. For many urban regions assuring water supply in the face of climate change will be a critical issue. For some regions providing additional water services to a growing population will also be an issue.

Before considering the implications of climate change, the objectives of urban water IRP for supply demand planning would include:

i) filling any projected long-term supply-demand gap,
ii) providing water services cost-effectively, and
iii) meeting sustainability goals.

Climate change and uncertainty around future climates will have a bearing on how each of these objectives is met.

The implications will not solely be in relation to the adaptation of urban water systems to climate change but also the need to mitigate the impacts of climate change through reducing GHG emissions. In the context of climate change two additional objectives for supply-demand planning can be defined in terms of:

iv) the adaptation of urban systems to the impacts of climate change and climate uncertainty, and
v) mitigating the impacts of climate change through reducing the GHG intensity of water service provision.

The adaptation of urban systems to climate change will have a number of implication for IRP. As a start it
will require accounting for predicted climate change impacts in projections of the long-term supply-demand gap (see following section). More critically it will mean actively increasing the resilience of our urban water systems. This can be assessed as having the potential to accommodate and/or adapt to a wider range of possible future climate scenarios including increased variability and climate extremes.

An objective of climate change mitigation implies a need to account for the GHG emission impacts of water conservation and supply options and to manage urban water so that the GHG intensity of water service provision is minimised. In the past urban water systems have not been major energy users. However, will the droughts experienced over the last decade and concerns over ‘step-changes’ in climate change, several cities have more than doubled the energy intensity of their water supply systems due to the incorporation of desalination plants and inter-catchment transfers (i.e. Sydney, Perth and Adelaide). The energy intensity of water service provision is expected to increase further in many of these cities with further large scale augmentation associated with desalination, inter-basin transfers and major recycling plants already under construction (Kenway et al. 2008). As examples from cities in Australia have shown, climate uncertainty can become a driver for decisions to install energy intensive supply options. These examples highlight a need for better integration of adaptation and mitigation objectives.

### ESTIMATING CLIMATE CHANGE IMPACTS ON WATER SUPPLY AND DEMAND

When applied to supply-demand planning, step 2 of the IRP framework involves assessing the available water supply and forecasting future water demand. The outcome of this step is to make an estimate of the long-term supply-demand gap for the town, city, or region in question.

The methods of analyses used for estimating both available water supply, or system yield, and water demand are dependent on what is assumed about future climate. This is particularly the case where water supplies are drawn from surface water storages. Climate change scenarios should therefore be incorporated into the ‘base-case’ estimates of supply and demand developed during step 2. These scenarios however need to be based on reasonably established projections of the expected climate change impacts in a region.

### Generating climate change scenarios

A range of methods have been (and continue to be) developed to create climate change scenarios that can be incorporated into urban water planning. Ashbolt & Maheepala (2008) identified the three main approaches. These are:

- using General Circulation Models (GCM) and regional ‘downscaling’ of GCM to develop climate change scenarios;
- developing climate change scenarios based on hypothetical changes in specific climate or hydrological variables (such as rainfall or runoff); and
- using an analogue climate scenario based on a selected period of the historical climate record or based on a climate record from another location.

### Incorporation in supply estimates

The impact of climate change on available water supplies could be dramatic in some regions. Projected changes in rainfall and runoff could have substantial implications for existing surface water-based supply systems and for urban water supply-demand planning. In most cases the assessment of the potential impact will involve the development and selection of what can be considered a reasonable climate change scenario for that region. In many regions the level of uncertainty that exists around future climate will be an issue. An approach to managing this uncertainty is to develop a range of climate change scenarios. While the ‘most likely’ scenario or scenarios can be used for estimating the supply-demand gap a larger range of scenarios can be used to test the supply-demand plan and particularly contingency planning.

In many regions climate change scenarios can be based on regionally down-scaling of GCMs which model global climate. Through representing the physical processes in the atmosphere GCMs project climate change effects on temperature and other climate variables at a scale of several
hundred square kilometres. These models also translate temperature and other changes into rainfall predictions. Various techniques can be used to ‘downscale’ the data from a GCM to a regional level with a resolution of around 10–20 km. At this resolution the projections can then be used in urban water planning.

A climate modeling approach based on GCMs provides the most comprehensive and physically-based approach to understanding the impacts of climate change on water supply and water demand. However such an approach is also data and time-intensive.

Further, a variety of GCMs and downscaling techniques exist and there are therefore questions around which models and combinations of models are best to use in any region. Due to this uncertainty it is common to use a number of models in order to provide a range of projections in terms of rainfall and temperature changes. However, in some regions these ranges diverge between increasing and decreasing runoff. In others the models converge on a prediction of a decrease or increase in runoff.

In some regions water planners may judge that hypothetical or analogue models are considered a better fit for the recently observed climate record. Such scenarios need to represent plausible trajectories of future climate or hydrological variables. In Australia for example water utilities in Perth, Melbourne and Adelaide have incorporated climate change impacts directly as hypothetical scenarios into their supply estimates. These have substantially reduced or de-rated system yields. These hypothetical scenarios are based on the judgment by water planners that a ‘step change’ in the climate has occurred.

Finally, in some regions the projected changes in rainfall will be minor or potentially result in an increase. In these cases the historical record may well be the most reasonable future climate scenario.

**Incorporation in demand forecasts**

Climate change can be expected to affect demand for water in urban areas. The magnitude of this impact is however unlikely to be as significant as the impact on available supply. This is because water demand is affected by a range of factors including average end-use efficiency of appliances and fixtures, average lot sizes and changing demographics. These factors can be expected to have a larger impact than climate on demand.

The seasonality of water demand is a good indicator of how sensitive future demand will be to climate change in a particular location. This is because increasing temperatures particularly in summer will increase outdoor irrigation demand as well as the use of evaporative air conditioners and cooling towers. As only particular end-uses will be affected, an end-use based demand forecast will be of value in assessing the potential impact of climate change on demand. End-use based demand forecasting is one of the key features of IRP (Turner et al. 2008).

The impact of climate change on demand will vary between locations and depend on a combination of climate variables including humidity, rainfall and evaporation. In some locations, particularly on the coast, an increase in temperature can be expected to be accompanied by an increase in humidity. This will dampen the expected increase in demand. Hence, in Australia inland centers are more likely to need to account for the impact of climate change scenarios on demand forecasts.

**AVAILABLE RESPONSES**

Step 3 of the IRP framework ‘Develop the response’ involves designing a range of water conservation and supply options and then determining how to meet the planning objectives.

In the context of climate change the responses need to be expanded beyond demand and supply-side options that can meet the objective of ‘closing any projected long-term supply-demand gap’ to account for the objectives of climate change adaptation and mitigation. Some key responses are discussed below.

**Tapping a diversity of sources of supply**

It is generally recognized that adaptation to climate change will require sourcing water from an increased diversity of water supplies. This is particularly the case for urban regions dependent on one or more climate dependent surface water source(s). Diversifying supplies may include tapping groundwater, recycled water, or
desalinated seawater. Such sources have the advantage of being totally or partially climate independent. Having sources in different catchments, particularly if these catchments are subject to varying climate influences, can also provide source diversity.

A diversity of scales of supply could also be advantageous. This can be achieved by water conservation measures that harvest water from within urban areas. Such distributed sources of supply include rainwater tanks, stormwater harvesting schemes and small-scale wastewater reuse. With enough localised sources of supply, this would increase the resilience of urban water systems to challenges such as climate change, and create water sensitive cities (Wong et al. 2008).

Increasing end-use efficiency

As well as playing a role in closing any projected supply-demand gap, increasing water use efficiency will help meet the objectives of climate change adaptation and mitigation.

From an adaptation perspective water efficiency has benefits for the supply-demand balance as it reduces total demand. More critically end use efficiency can be expected to reduce ‘minimum levels of supply’ that a community requires to be provided within an extreme supply shortage. This is particularly the case for increased efficiencies of plumbing products like showerheads and toilets. Demand management programs that increase water use efficiency can also be a drought response measure and rolled out during a drought. In Australia, South East Queensland has recently demonstrated the use of rapid large-scale accelerated demand management programs.

From a climate change mitigation perspective, water efficiency can substantially reduce energy use and GHG emissions. For example, electricity and gas saved from avoided water and wastewater service provision, and avoided water heating by customers. Of these two areas of energy demand, water heating is substantially greater than water and wastewater service provision (kenway et al. 2008). Therefore water efficiency measures that reduce heated water consumption provide a greater mitigation of GHG emissions.

Readiness options

Readiness options are drought response or contingency measures that can be mobilized on a relatively short lead-time. They provide a capacity to respond to water shortages however the options themselves are not implemented until required. In a similar way to water restrictions in a traditional drought response plan, readiness options are characterized by trigger points based on the available supply in the existing system and the lead-time for bringing on-line a particular water source. The design, approvals, and other relatively low cost elements of option implementation are progressed to prepare the options for implementation. However, they are not actually implemented until specified trigger levels are met.

Potential readiness options can include: inter-catchment transfers, developing or augmenting a desalination plant, tapping new groundwater sources or indirect potable wastewater reuse. Readiness options can be designed to provide flexibility in terms of both timing and also scale. As mentioned above large-scale accelerated demand management programs are also a potential drought response measure. These types of measures can ‘buy time’ during drought by slowing the rate of the depletion for storages and ultimately delaying the triggers for readiness options.

The use of drought response measures including readiness options reflects a desire to avoid unnecessary large capital investments where future climate remains uncertain while also recognizing that the risk of total water supply system failure is catastrophic and must be avoided.

Adaptive management

To meet objectives of climate change adaptation and mitigation as well as the existing urban water planning objectives will require a level of flexibility and an adaptive management approach.

An adaptive approach aims to provide a flexible response to a range of possible future scenarios. As well as being responsive it enables new understandings of uncertainty to feed back and improve the future planning responses. An adaptive management approach also facilitates incremental responses to emerging uncertainties. This is important for
reducing the risk of large scale infrastructure investments associated with anticipated future climate scenarios being made now when the need may not actually eventuate.

Adaptive management also provides an approach by which the drought response, the contingency and the long-term components of supply-demand planning can be better integrated. For example, in some situations it may be that the ‘readiness option’ that was developed as a drought response or contingency measure once implemented will become the new long-term supply for a given urban area.

**Accounting for greenhouse gas emissions**

In order to meet the objective of climate change mitigation GHG emissions from supply-demand planning responses need to be accounted for.

Some new supply, particularly desalination or those requiring pumping to transport water a significant distance, will be energy intensive. This can be expected to lead to an increase in GHG emissions or if renewable energy is purchased for them an increase in costs. In comparison, readiness options have only a likelihood of being built and adding to GHG emissions. Demand-side measures can typically be expected to reduce energy consumption and GHG.

Options comparisons should account for these differences and give an equivalent measure of GHG emissions across all options. For example, if it is assumed that renewables are purchased for a new supply option, then it can be argued that this places a value on GHG emissions that can be applied across all demand and supply-side options.

**Engaging the public**

Urban water systems will be better able to adapt to climate change if the public are highly engaged with the supply-demand planning issues in their region.

Water customers and the public need to be part of planning process: to be informed about planned responses, to know what to expect, and what might be expected of them under particular conditions. An engaged public that has been part of and trusts in the planning process in their region is critical for an adaptive management approach to work. Without public engagement a climate change response based on ‘readiness options’ and adaptive management is unlikely to succeed.

An engaged public that understands the issues and uncertainties associated with climate change could also potentially tolerate more regular drought response measures as they will more clearly identify with the need for their response and the effects of their action.

Significantly, if the recent drought in Australia is an example of what can be expected in other countries, then climate change is an opportunity for the general public to become much more engaged with urban water issues. The perceived threat of climate change to urban water supplies has resulted in a high public awareness around water conservation with shifts in public attitudes to water use. It has also seen a high uptake of measures such as rain tanks and greywater reuse systems.

**CONCLUSIONS**

In the context of climate change, the key question that IRP asks ‘how can we meet long-term water supply-demand objectives by fully accounting for the potential of water conservation as well as supply augmentation?’ remains valid.

However, climate uncertainty and particularly the increasing potential for extreme drought events mean that there is a need to reconsider the IRP process. This includes the objectives that are set, the methods for estimating available water supply and water demand, and the available responses.

Predicted climate change impacts will need to be included in the analysis of the current supply and demand situation. Adaptive responses to manage increased uncertainty about future climates as well as the implication of increases in climate extremes will be necessary. In addition there will be a heightened requirement for drought response and contingency measures including readiness options within urban water supply-demand planning. Also there will need to be a greater tolerance from the public for more regular low level water restrictions as a drought response. Ideally the drought, the contingency, and the long-term
components of supply-demand planning will be integrated as part of IRP.

While adapting IRP for urban water in the face of climate change will require significant adjustments, climate change also reinforces key IRP principles. Public engagement in water planning will remain important and increased use of efficiency and other water conservation measures will have central roles to play in creating urban water systems that are less vulnerable to climate change.

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