Risk-based assessment of water availability in a changing climate

ATEF KASSEM, TAMAS HAMORY, IVANA VOUK & DAVID HARVEY

Environment Canada, Sustainable Water Management Division, Environmental Stewardship Branch, Ottawa K1A 0H3, Canada

atef.kassem@ec.gc.ca

Abstract Water availability assessment is a complex undertaking and is becoming more challenging given the uncertainty associated with climate change. It requires the evaluation of not only water supplies, but also of the competing water demands for socio-economic development and maintaining a healthy ecosystem. Both water supplies and water demands are subject to significant seasonal and annual variation, which is expected to be exacerbated by climate change. By analysing the time varying water supplies and water demands, water availability can be presented in terms of probability or in a risk-management context. The large uncertainty surrounding climate change, as well as future socio-economic and other developments can be dealt with by using scenario analysis that incorporates a wide range of future socio-economic and climate scenarios or possibilities. Such analysis allows the establishment of the relative change in risk to the water resources system (e.g. frequency of occurrence of shortages) as a result of climate change (scenarios) and the analysis of the impacts of adaptation measures on reducing such risk.

Key words water availability; climate variability; climate change; risk; climate adaptation

INTRODUCTION

There is mounting evidence that water resources and supply security are becoming increasingly vulnerable to climate change. The potential for changes brought about by climate change, such as shifts in the intensity and seasonal distribution of precipitation, warmer temperatures with increased evapotranspiration and an increase in the frequencies of extreme events, including droughts, can have significant implications to the economic and social systems, which depend on water resources. Such changes can further exacerbate water-use conflicts and pose unprecedented challenges to the hydrological, climatic and atmospheric sciences; to water management in both public and private sectors, and to policy makers at all levels of government.

The growing amount of literature describing the threats to water availability and the ecosystem due to climate change and variability is largely qualitative and speculative. Despite the considerable advances in global climate models, their predictions are still far from certain and there is a great deal of ambiguity as to the nature, magnitude and rate of climate change, as well as the potential impacts on the socio-economic system and the environment.

Given this uncertainty, there is a need for a new approach to water availability assessment which takes into consideration the impact of the climate on water supplies and water demands in order to improve our knowledge of vulnerability to climate change. This should enable assessment of the risks (and benefits) posed by a changing climate and the ways that existing policies, programmes and socio-economic circumstances serve to reduce (or exacerbate) vulnerability to climate change; and, ultimately, to build the foundation upon which appropriate decisions about adaptation can be made.

This paper presents a methodology for the assessment of the risks to water availability and demonstrates its application using data from a watershed in the semi-arid region of western Canada. The methodology is based on integrating water supplies and water demands at the basin level with due consideration of their annual and seasonal variability, using data from historical records as well as from global climate models. From such analysis it is possible to present water availability in terms of probability or risk and analyse the possible impact of climate change on increasing (or reducing) the risks to the water resource system.

GUIDING PRINCIPLES FOR WATER AVAILABILITY ASSESSMENT

Water availability can be viewed as the amount of water available at a particular location and particular time to satisfy the demands on the water resource. In other words, water availability can be viewed as the product of water balance between the available supply and the demands. A positive water balance implies adequate supply to satisfy the demands. A negative water balance means shortages and the need to ration water use with social, environmental and economic consequences. Water demands can be broadly categorized as withdrawal or consumptive demands and non-withdrawal, environmental or instream flow demands. Withdrawal demands involve the removal of water from its source for such uses as municipal supplies, industrial and agricultural activities. A portion of this water is consumed and lost from the water supply system. Many of the water demands such as irrigation and other outdoor water uses are highly sensitive to the prevailing climatic conditions. Non-withdrawal demands refer to instream flow needs such as ecological demands and navigation. They constitute an important component of water availability since they impose a constraint on the amount of water that can be withdrawn. For international and inter-jurisdictional basins, constraints on water withdrawal can also be imposed by water sharing agreements which must be part of a basin water availability assessment.

Water availability assessment therefore requires knowledge of water supply as well as water demands, and is best carried out at the basin or sub-basin level. Both water supplies and water demands change seasonally as well as annually, due primarily to the prevailing climatic conditions, and as a result water availability can change from year-to-year in a rather random fashion corresponding to the random nature of climate variability.

As a prerequisite to dealing with the impact of climate change on water availability, it is imperative to first analyse the impact of climatic variability on water availability using historical climatic data. Such analysis which implies a "stationary climate", i.e. assuming that past climate will (statistically) be repeated in the future, provides a baseline upon which impacts of future climatic changes can be assessed.

Projections of future climatic changes introduce an element of uncertainty and complexity to the water availability question. The predicted changes in precipitation and temperature patterns are expected to result in alteration of the seasonal and annual water supplies as well as water demands as compared to historical trends. Also, since climate change is expected to materialize in the future, any water availability assessment under climate change must include projections of future water demands. Obviously, there are a large number of variables involved and a great deal of uncertainty about the future. Under these circumstances, a scenario-based approach should be adopted, which covers a wide range of future possibilities *vis-à-vis* socio-economic development, climatic conditions as well as other factors that affect water supplies and water demands. The assessment of the risks to water availability and the vulnerability of the socio economic system to climate change can be achieved through integrated assessment of the impacts of climate change scenarios on future water supplies and water demands using the base case of a "stationary climate" as a reference point.

WATER AVAILABILITY IN A CHANGING CLIMATE

Climate variability

The only certainty about historical climate is its variability, both seasonally and annually, which is random in nature. As a result, both water supplies and water demands, and thus water availability, vary from year-to-year, also in a random fashion. An assessment of the impact of climate variability on water availability can be made using historical water supplies and estimating the corresponding water demands from historical climatic data. Historical water supplies can be estimated by naturalising the recorded streamflow by removing the effects of historical abstractions or from a hydrological model for the basin. Most water uses are sensitive to the climate and this sensitivity must be a part of the water availability assessment. This is particularly important for uses such as irrigation and other outdoor water uses (e.g. lawn watering, parks, golf courses, etc.). Water availability assessment under historical climatic conditions can lead to an appreciation of the vulnerability of a watershed to climate variability before any climate change induced stresses on the water resource system. Its results can be treated with confidence since it is based on actual data and it also provides a baseline upon which climate change impacts on increasing (or reducing) the risks to water availability can be assessed.

An illustration of the impact of climate variability on water availability is shown in Fig. 1. It was developed using data from a major river basin in the semi-arid region of western Canada. The figure presents 92 years of historical surface water supply, represented by naturalized streamflow, and the corresponding water demands derived using historical climatic data for the same time period. Water demands were estimated using a simulation model calibrated for the basin (Kassem, 1992; Kassem *et al*., 2005).

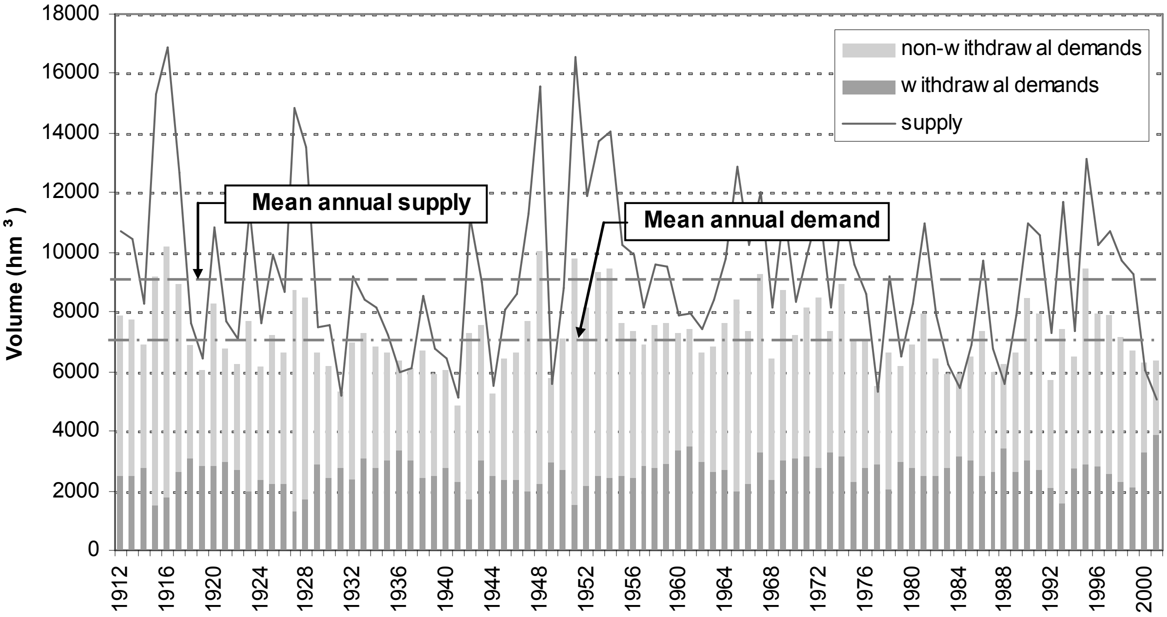

Fig. 1 Example of variability of water supply and water demand due to climate variability.

The figure clearly shows the significant variability in both water supply and water demand from year to year as a result of natural climatic variability and the random nature of this variability. While average supply and demand values may indicate ample water availability, a year-to-year analysis shows many occurrences of water shortages or critical water availability. This observation highlights the importance of incorporating climate variability when assessing water availability since critical water availability would generally coincide with dry periods when water demands are highest and supplies are lowest. From such analysis, it is possible to present water availability for the basin in terms of probability or risk, as illustrated below.

Climate change

The above analysis is based on the assumption of a "stationary climate", i.e. assuming that past climate is (statistically) repeated in the future. With climate change, this assumption may no longer be valid and adjustments to both future supplies and future demands due to climatic changes are needed. In the absence of firm predictions of future direction of climatic changes, it is extremely difficult to determine their impacts on water supplies, water demands and, hence, water availability with confidence. However, it is possible to examine the sensitivity of a basin to a range of climate change possibilities. The procedure for water availability assessment under climate change is similar to the assessment using historical climatic data. For a given climate change scenario, the resulting water supplies are first determined using a hydrologic model for the basin. Water demands are then estimated by employing the same climatic data. Water availability is thus obtained from the resulting water balance. If one can cover the spectrum of future climatic and socio-economic possibilities, then a picture can emerge about the range of availability issues to deal with.

RISK-BASED ASSESSMENT OF WATER AVAILABILITY

The above analysis shows the random nature of past climate variability and the resulting water supplies, water demands and overall water availability. It is practically impossible to predict the future climate at any particular point in time. However, by analysing the time varying water supplies and water demands, it is possible to represent water availability in terms of probability or risk. Such analysis should be carried out first using historical climatic data to establish a base case or reference point. Given the uncertainty associated with future climatic changes, a scenario-based approach can be used to evaluate the impacts of alternate futures on the relationship, as illustrated in Fig. 2. The results presented in the figure correspond to conditions resulting from a number of climate change scenarios using data derived from selected global climate models (Toth, 2005). In these analyses, climatic data produced from each of the climate models were used to estimate the resulting impacts on both water supply and water demand, and hence on water availability. Water supply predictions were obtained from a hydrological model calibrated for the basin (Pietroniro *et al.*, 2005).

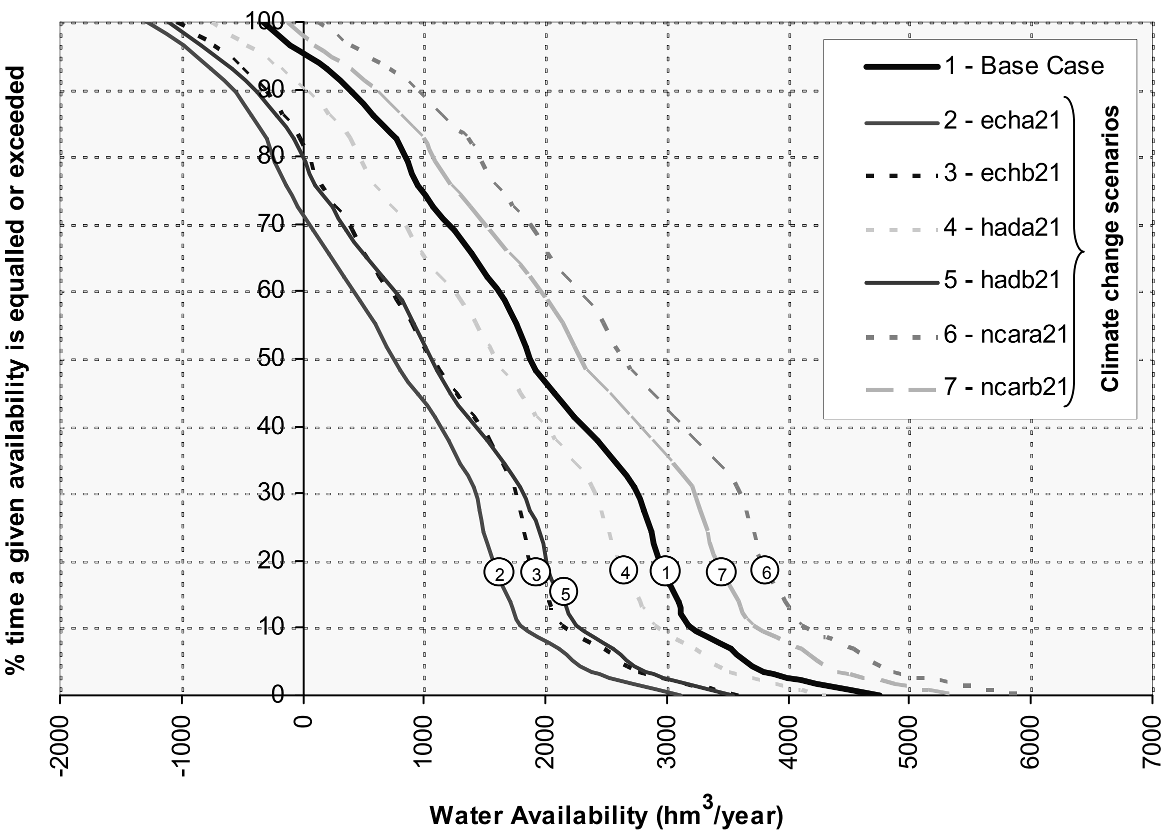

Fig. 2 Water availability in terms of probability or risk. [a21 and b21 climate change scenarios data were produced by the ECHAM4 model developed by the Max Planck Institute for Meteorology (GER), the HadCM3 model developed by the Hadley Centre for Climate Prediction and Research (UK), and the NCAR-PCM model developed by the National Center for Atmospheric Research (USA)].

The figure shows the percentage of the time a given volume of water is available under the base case of a stationary climate and for each of the climate scenarios. It also shows the volume of deficit or surplus water in terms of probability. For example, the analysis shows that under the stationary climate assumption, there is about a 5% (that is, one in 20 years) chance or risk of water shortage. This shortage can be as high as 400 hm^3. About 75% of the time (i.e. 3 in 4 years), a surplus volume of 1000 hm^3 will be available for additional uses, etc. Similar information can be obtained for the analysis under each of the climate change scenarios. The divergence of the results of the various global climate models presented in Fig. 2 highlight the uncertainty associated with climate change predictions. Predictions from the NCAR-PCM model would result in improvement in water availability, while the other two models' predictions would result in reduced water availability. Nonetheless, this kind of analysis, if carried out in conjunction with a range of climate change scenarios representing the spectrum of future possibilities, can be valuable for water management decision-making. It provides information on the range of possible future risks to water availability and can also guide the development of adaptation measures.

Climate adaptation

The above analysis can provide valuable information regarding the vulnerability of the socio-economic system to climate variability and climate change and the associated risks of water shortages or deficits. Such analysis can be expanded to include various adaptation measures in order to quantify the impacts of such measures on reducing the risks to the water resource system.

Seasonal variability

The risk-based water availability assessment example presented is based on an annual water balance which implies that all available annual supplies can be utilized, i.e. the basin is fully regulated, which is seldom the case. Annual assessment, while useful, does not provide a complete picture of water availability and does not mean that shortages would not occur seasonally. The above assessment can be repeated using shorter time steps (e.g. monthly or even weekly) to account for seasonal variability of supplies and demands. It is also important that such assessment accounts for the water resources infrastructure, such as storage and flow regulation, interbasin and intrabasin water diversions.

CONCLUSIONS

Water availability assessment for a watershed must take into consideration the temporal fluctuation in water supplies and water demands due to natural climate variability. This allows viewing the subject in terms of probability or risk rather than in absolute terms, which is not very useful to policy-makers dealing with water availability, climate change and climate adaptation. The large uncertainty surrounding the predictability of future climatic conditions, as well as future socio-economic and other developments, can be dealt with by using scenario analysis that incorporates a wide range of future "possibilities". Comparative analysis of water availability under the "stationary climate" and "altered climate" conditions allows the establishment of relative change in risks to water availability due to climate change. This provides policy makers with valuable information upon which to base management decisions in an environment of uncertainty.

Adaptation to future climatic changes will be similar to adaptation to past climate variability, except that there could be a wider range of variations. Water availability assessment with due consideration of climate variability and change could be extended to include the impact of various adaptation options on reducing the risks to the water resource system. Experience gained from adaptation to past climate variability should give us valuable lessons for adaptation to climate change.

REFERENCES

Kassem, A. (1992) *The Water Use Analysis Model (WUAM), Program Documentation and Reference Manual*. Environment Canada, Ottawa, Ontario, Canada.

Kassem, A., McRae, T. & Sydor, M. (2005) Integrated water resources management – using an integrated water use and supply planning model to inform decision-makers on the impacts of climate change and variability on irrigated agriculture in Canada's South Saskatchewan River Basin. In: *OECD Workshop on Agriculture and Water: Sustainability, Markets and Policies* (Adelaide, Australia).

Pietroniro, A., Toth, B. & Toyra, J. (2005) Climate change impacts on water availability in the South Saskatchewan River Basin – physical modelling. In: *58th CWRA Conference: Reflections on Our Future: a New Century of Water Stewardship* (Banff, Alberta, Canada).

Toth, B. (2005) Environment Canada, National Water Research Institute, Saskatoon, Saskatchewan, Canada (personal communication).