Case Study C

DROUGHT INDEX FOR RAROTONGA (COOK ISLANDS)

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INTRODUCTION

Rarotonga, the largest island and the economic centre of the Cook Islands, has over 50% of the country's total population (estimated at 13,700 in December 2000). The island's water supply is sourced from 12 stream filter-bed intake systems that feed a double ring-main distribution network. The total demand includes domestic and commercial water requirements, agricultural applications (including irrigation of market gardening) and significant wastage through a leak-prone distribution network. During drought periods demand increases while the supply falls and it becomes difficult or impossible for the system to satisfy all existing uses (Ricci and Scott, 1998).

The topography of Rarotonga has a significant effect on rainfall distribution over the island. Thompson (1986) notes that mean annual rainfall is highest in the centre of the island (over 4000mm) whereas on the coastal margins conditions are driest in the north west (2000mm) and wettest in the south (3000mm). Long-term rainfall records for the Rarotonga Airfield (in the north-west of the island) illustrate the temporal variability of rainfall (Figure 1). There is a distinct dry season, however very low rainfalls can occur in any month. This variability creates a significant risk for a water supply system with limited storage capacity.

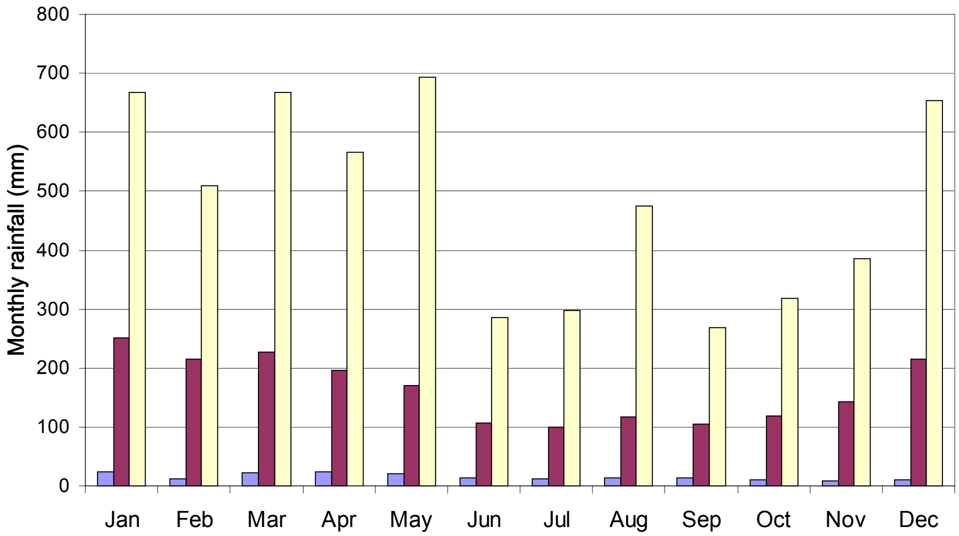

Figure 1: Minimum, average and maximum monthly rainfall recorded at Rarotonga Airfield over the period 1929 to 2002.

Despite the relatively long record of rainfall on the island there is very limited hydrological information available. Prior to 1999 monitoring of water supply pressures provided an indication of flow conditions. More recently, assistance from NZODA has allowed the development of a hydrological monitoring network with the construction of three flow-monitoring sites and four automatic rainfall monitoring sites (Mason, 2001). This network is being operated with technical direction from the New Zealand National Institute of Water and Atmospheric Research Ltd (NIWA) and will, in the future, provide a better understanding of Rarotonga's water resources.

The Department of Water Works of the Ministry of Works (MOW) is responsible for water supply on Rarotonga. They face problems resulting from a deteriorating distribution network (estimated water losses between 50 and 70%), relatively high consumption (260 litres per capita per day) and limited storage capacity in the water supply system and the water supply catchments. These factors result in low pressures and limited water availability in some areas during droughts. A number of actions have been proposed to address this situation including:

- Construction of surface water storage capacity,
- Development of further surface water catchments,
- Upgrading of the reticulation network through a programme of leak detection and control,
- Introduction of demand management programme through metering and charging for use, and
- Development of groundwater as a supplement to the reticulated supply.

A distribution network upgrade project is currently underway. Nevertheless, there may be potential for adaptive management of the system during drought periods. Drought monitoring and prediction would be particularly useful to support such management efforts.

DROUGHT INDEX

A drought index can provide a measure of the severity of a drought and be used as the basis for specific management measures. However, drought is a difficult phenomenon to measure since it has a range of impacts at different time and spatial scales. Drought can be defined in terms of plant water requirements, fire hazard, catchment yield, groundwater resources etc., and each requires a different basis on which to calculate a drought index. For the situation in Rarotonga where catchment storage is limited and there is very little hydrological data it is appropriate to use a meteorological definition of drought. Three alternative rainfall based drought indices evaluated by White et al. (1999) for Tarawa, Kiribati were:

- Standardised Precipitation Index (SPI)
- Rainfall deciles
- Rainfall depreciation

These methods have been tested to evaluate their appropriateness to the Rarotonga water supply management situation.

Standardised Precipitation Index

The Standardised Precipitation Index (SPI) has been developed by McKee et al. (1993) to quantify precipitation deficits for different time scales. These time scales reflect the impact of drought on the availability of different water resources; soil moisture conditions could be expected to relate to an SPI calculated on a relatively short scale, whereas streamflow and groundwater conditions reflect longer time scales. As defined by McKee et al. (1993) the SPI is normalized so that wetter and drier climate can be represented in the same way. The classification of drought provided by McKee et al. (1993) is shown in Table 1.

Table 1. Standardized Precipitation Index categories.

SPI Range	Climate Classification	Theoretical Occurrence (%)
+2.0 and above	Extreme wet	2.3
+1.5 to +1.99	Severe wet	4.4
+1.0 to +1.49	Moderate wet	9.1
0 to +0.99	Mild wet	33.9
0 to -0.99	Mild drought	33.9
-1.0 to –1.49	Moderate drought	9.1
-1.5 t0 –1.99	Severe drought	4.4
-2.00 and below	Extreme drought	2.3

Rainfall Decile Method

The rainfall decile method, as described by White et al. (1999), is based on a ranking of the rainfall over the period of interest in terms of the relative quantity of rain that fell in that period compared with the total distribution of all recorded rainfalls over the same period. Like the SPI, it requires the specification of an appropriate time period, however rainfall deciles are a non-parametric measure of drought since they involve no assumption about how rainfall is distributed. Rainfall deciles can be conveniently calculated using the PERCENTRANK function in EXCEL spreadsheets (White et al., 1999). The classification of rainfall decile used in the Australian Drought Watch System is listed in Table 2.

Table 2. Classification system for the decile method as used in Australia.

Decile	Percentile Range (%)	Climate Classification
	100	Highest of record
10	90 to <100	Very much above average
8-9	>70 to <90	Above average
4-7	>30 to <70	Average
2-3	>10 to <30	Below average
1	>0 to <10	Very much below average
	0	Lowest on record

Rainfall Depreciation Method

The rainfall depreciation method is similar to the concept of a catchment wetness index where a weighted sum of previous months' rainfall is used as a measure of the water in storage. White et al. (1999) describe it as being essentially a pseudo water balance method and offer two alternative definitions: one based on compound depreciation and the other on simple arithmetic depreciation. For the Rarotonga application a simpler definition was adopted on the basis of trial-and-error calculations to produce a weighted sum index as follows:

$$DI_i = P_{i-1} + 0.9*P_{i-2} + 0.8*P_{i-3} + \ldots\ldots\ldots + 0.1*P_{i-10}$$

where
DI_i = Weighted Sum Drought Index for month i
P_{i-1} = Precipitation in month (i –1) etc.

White et al. (1999) correctly point out that this method has a number of limitations: it is not strictly an index, it can not be directly compared with values from another site and is physically unrealistic since it effectively assumes that rainfall losses are a fixed fraction of monthly rainfall. Nevertheless, the simplicity of the method (it is very simply calculated in EXCEL) and the intuitive connection with the concept of 'catchment memory' offers some advantages for use by non-specialists.

ANALYSIS OF PRECIPITATION RECORDS FROM RAROTONGA

These three alternative methods of calculating a drought index for Rarotonga have been compared using the Rarotonga Airfield monthly rainfall record for the period from January 1929 to March 2002. The choice of an appropriate time scale over which to calculate the SPI and decile methods was determined by calculating the SPI with time scales ranging from 1 month to 24 months and, in the absence of long-term hydrological data, using a qualitative appreciation of the nature of water supply catchment response to choose the 6 month time scale as being the most useful. Rainfall deciles were calculated using that same time scale. In the case of the weighted sum index the earlier trial-and-error approach (Ricci and Scott, 1998) had already established a 10 month 'catchment memory' however, considering the reducing weight given to less recent months' rainfall, this method is sensitive to the more recent rainfall.

Standardised Precipitation Index

Figure 2 shows the SPI calculated for three particular time scales: 3, 6 and 12 months. The index shows negative anomalies below the x-axis and positive anomalies above. The three plots illustrate the way in which time scale plays a role in drought severity – at the 3 month time scale (uppermost plot) some drought episodes are rated as extreme (SPI < -2.0) though they barely register at the 12 month time scale (e.g. the short term drought in mid-1935). Conversely extended drought periods may result in extreme conditions at longer time scales even though conditions have returned to normal at shorter time scales (e.g. the 3 month SPI for June 1999 had become positive even though drought classification remained severe at the 12 month time scale).

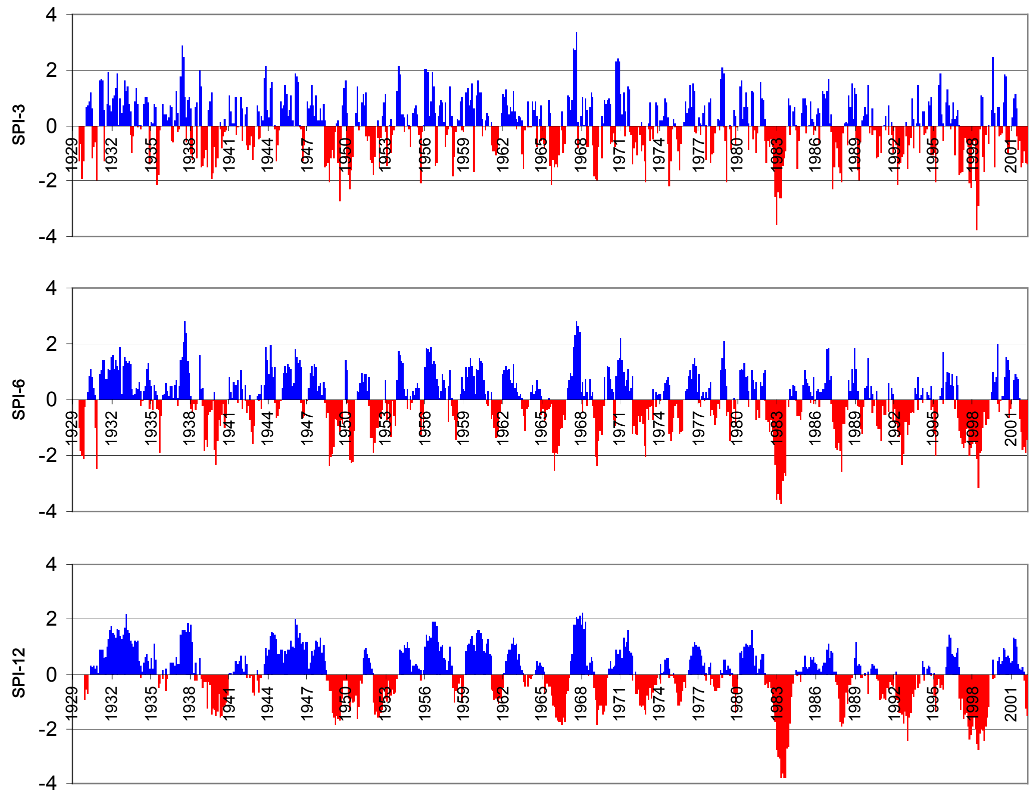

Figure 2. Standardised Precipitation Index for three alternative time scales (3 month upper plot, 6 month middle, 12 month lower).

Rainfall deciles

The 6-month rainfall deciles are shown in Figure 3 for the full length of record (1929 to 2002) with instances highlighted where the percentile value is less than 10% (classified as very much below average in the Australian Drought Watch System). The 6-month rainfall deciles and 6-month SPI are compared for part of the available record (1980 to 2002) in Figure 4. A zero SPI corresponds to a 50% percentile. In broad terms the two indices provide similar descriptions of the nature of rainfall anomalies over the period. However, there are clear differences the significance of which could be usefully investigated if adequate hydrological data was available to support the necessary analysis.

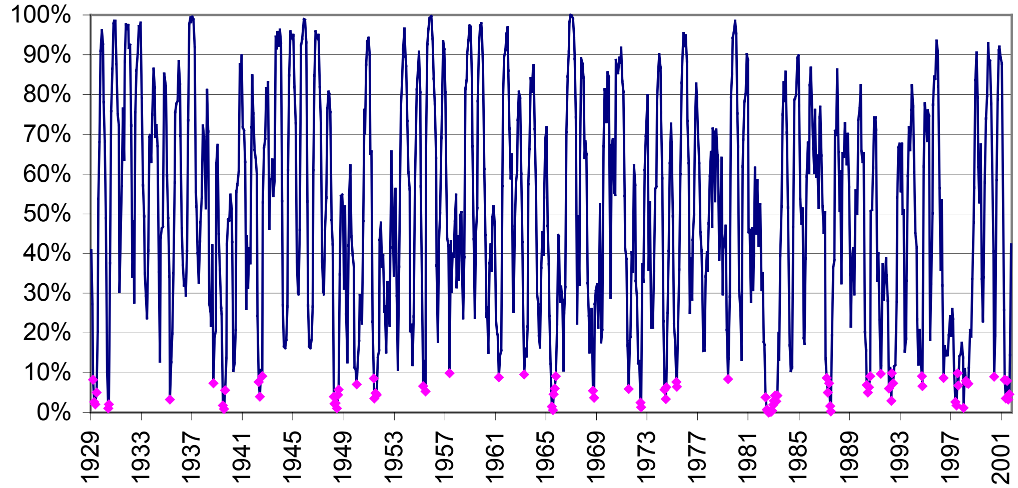

Figure 3. Six-month rainfall deciles for Rarotonga Airfield. Instances where the percentile is < 10% are highlighted.

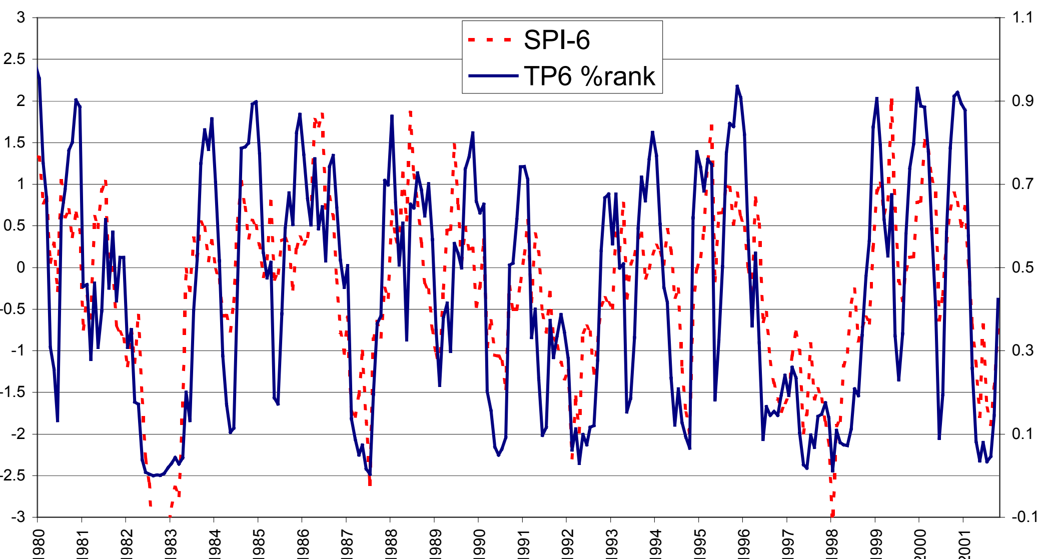

Figure 4. Six-month rainfall deciles (TP6) and six-month SPI (SPI-6) compared.

Weighted Sum Index

The weighted sum index is plotted in Figure 5 for the entire record – periods when the index fell below 600 are highlighted. The weighted sum index is compared with the 6-month rainfall deciles in Figure 6 and with 6-month SPI in Figure 7.

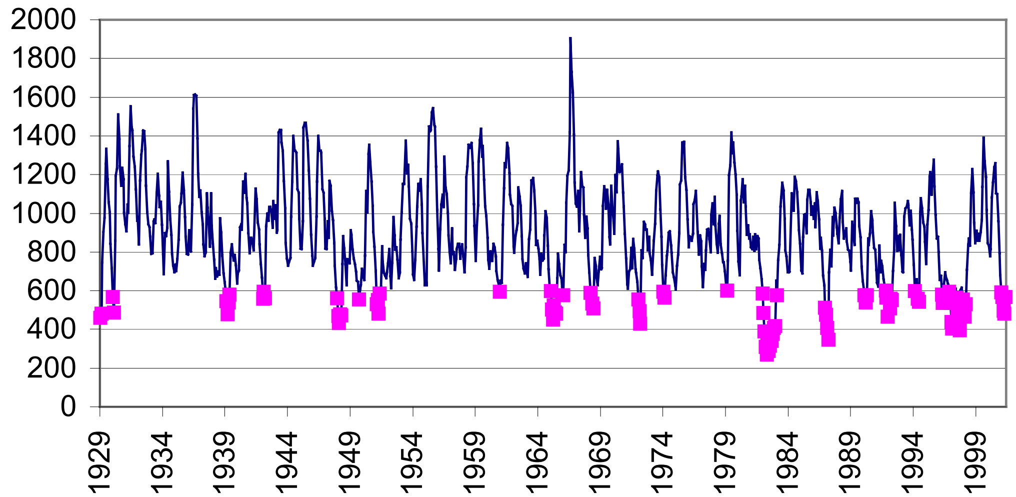

Figure 5. Weighted Sum drought index for 1929 to 2002.

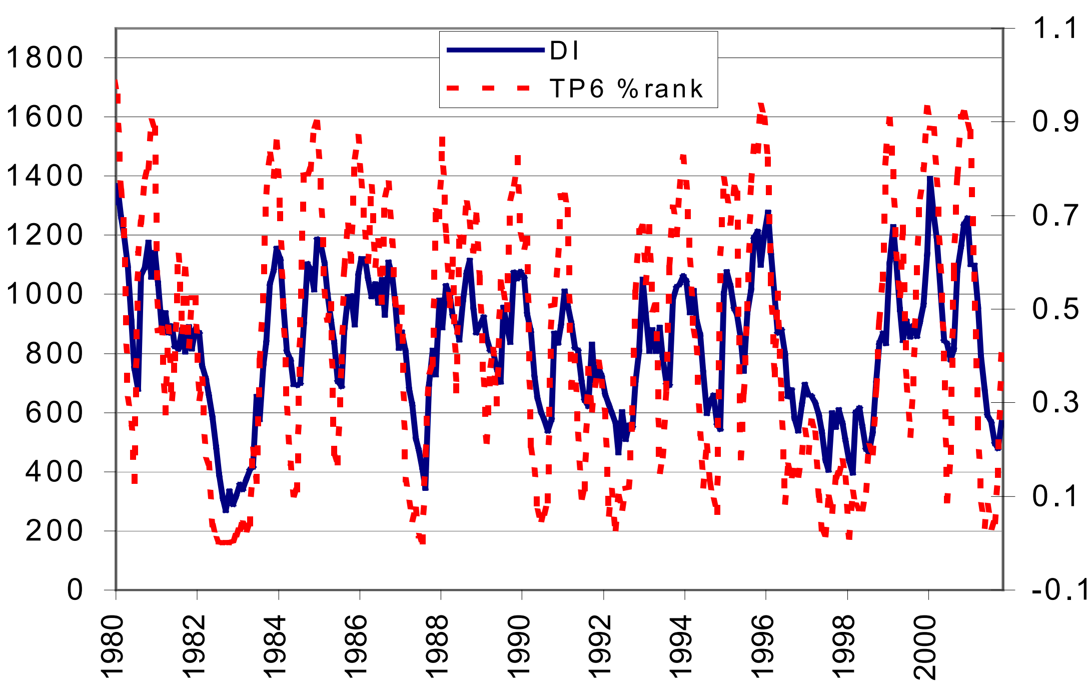

Figure 6. Weighted Sum drought index (DI) and 6-month rainfall deciles (TP6) compared for period from 1980 to 2002.

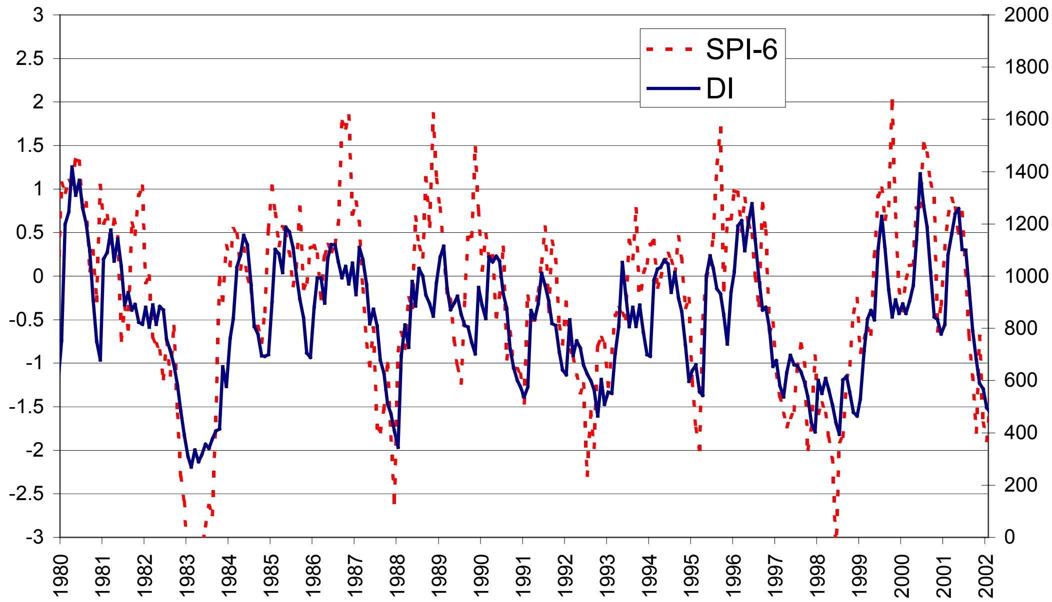

Figure 7. Weighted Sum drought index (DI) and 6-month (SPI-6) compared for period from 1980 to 2002.

The Weighted Sum Drought Index as currently defined fails to distinguish the severe rainfall anomalies indicated by both the SPI and rainfall deciles. It will be possible to determine the significance of these discrepancies once adequate hydrological data becomes available. It may be necessary to adopt an alternative specification of the Weighted Sum (possibly using one of the rainfall depreciation definitions) or to abandon the simple method in favour of a more complex alternative.

At present the current formulation of the Weighted Sum drought index is preferred on the basis of its simplicity and ease of calculation. It provides a useful qualitative measure that can be used to provide a ranking of different drought events and can be easily adapted as more information and understanding develops.

USES OF A DROUGHT INDEX

The current water resources management allows only a limited range of responses to drought conditions including:

- Measures to trap more water by installing stream by-passes upstream of the water intake,
- Short-term emphasis on leak detection and control,
- Water restrictions limiting use in specified zones of the supply network and
- Restriction of non-essential uses and bans on daytime use for some uses.

An ability to monitor, and in the future predict, evolving drought conditions should make possible earlier application of these methods and should also assist efforts to develop an adaptive capacity to respond to drought episodes. Public consultation and education through improved water use monitoring and provision of information about drought may promote alternative responses such as:

- Development of roof catchment systems,
- Water conservation measures (e.g. dual flush cisterns, use of grey water for garden watering, and
- Pre-emptive leak detection program.

Once sufficient experience is gained with the method the drought index could be used as a basis for public information and the Department of Water Works could issue monthly reports which advise the public about the state of the water supply system and place the current situation in context with previous droughts. This could be a useful aid in promoting water conservation efforts and raising the level of understanding about the nature of Rarotonga's water resources.

DISCUSSION

A drought index can provide a useful basis for management decisions. The simple Weighted Sum drought index is a first step in measuring drought and can be adapted as experience and further data become available. In the future seasonal precipitation forecasting may provide early warning of developing drought conditions. Reliable drought forecasts will make possible earlier and more effective drought responses. However, a strong commitment to ongoing monitoring of the water supply system and the associated hydrological network will be required to take full advantage of climate forecasts.

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