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Desalination 188 (2006) 61–67

DESALINATION

www.elsevier.com/locate/desal

Assessing supply risks of recycled water allocation strategies

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Received 15 November 2004; accepted 29 April 2005

Abstract

A tool to assess the supply risks associated with water allocation strategies employed at effluent reuse facilities is described. The tool is a monthly water balance model and sensitivity analysis. Through analysis of climate records at the Hawkesbury water reuse scheme site (the location of a combined effluent and storm water reuse facility), it was found that an estimate of irrigation demand followed standard statistical distributions. The estimated distribution of irrigation demand was used in conjunction with a water balance model to estimate future storage distributions and hence risks of future over- or under-supply scenarios. The tool is suitable for use in an operational environment to evaluate the influence of demand management strategies.

Keywords: Effluent; Recycling; Modelling; Demand management

1. Introduction

The use of recycled waters in Australia is increasing. In 2001/2002 an estimated 166.5 gal/y of effluent (approximately 10% of available supply) was used [1]. The reason for recycling effluent (and/or storm water) may be both a convenient method of disposal and as a valuable, reliable resource. Schemes such as the Hawkesbury water reuse scheme (HWRS) [2] view effluent as a valuable resource and have a number of water clients with varying demand patterns.

During scheme operation, the water distributor attempts to match the demand with continuously renewed resources and stored resources. Supply problems may emerge when not enough storage has been reserved to meet future demand or when not enough storage capacity (air space) has been reserved to store resources during low demand periods. While it is recognised that 100% reuse may be difficult to achieve, management should seek to maximise beneficial use of available resources.

Presented at the International Conference on Integrated Concepts on Water Recycling, Wollongong, NSW, Australia, 14–17 February 2005.

When designing a scheme, a planning model such as MEDLI [3] or the NSW EPA [4] viability check model may be used to simulate a number of years of theoretical operation to assess scheme design reliability. Planning models, however, are limited in that they simulate past data sets and evaluate average risks rather than assess future risks based on current operational status and water client flexibility.

A tool has been developed to assist irrigators and scheme managers to assess current and future water allocation decisions in the operational phase of a project. The tool combines a sensitivity analysis with a monthly time-step water balance model. The tool was developed from experience with the HWRS, a combined effluent and storm water facility located at the University of Western Sydney Hawkesbury Campus [5]. A spreadsheet water balance model running "off-the-shelf" add-in software is used with variables (such as irrigation demand) subject to random fluctuations according to the required statistical distribution. This approach allows for a quick, risk-based approach to evaluate future water allocation decisions. Managers and irrigators may take model output to represent the supply risks of demand management practice associated with water allocation strategies and make plans to alleviate potential problems.

2. Context

Planning models for the use of recycled waters such as MEDLI [3] may simulate up to (or above) 100 years of daily climate data to assess storage/irrigation area requirements for effluent reuse systems. Models used to simulate the reuse of effluents may assume that irrigation areas available to be used will be used and that pump breakdown and shutdown of infrastructure for maintenance may not occur in the simulation period. Such problems are common occurrences with the operation of irrigation enterprise and result in the imperfect application of irrigation waters, the over- or under-use of storage space and the inevitable problems of not enough or too much water to meet future demand.

Many options may be open to the irrigator or operator to reduce or increase demand for irrigation water. A water market may be used to allocate irrigation waters with total use being influenced by water price. Areas under irrigation may also be varied from season to season, and pastures may be brought on and off line depending on water availability. These demand management options are available to irrigators and water distribution managers; however, the effect of one particular strategy over another may be difficult to judge. Simple tools are needed to gauge the effects of these short-term operational adjustments rather than returning to design-oriented, long-term series models.

3. Methodology

A water balance can be undertaken to estimate the month-by-month volume of water that can be used through effluent irrigation (e.g., NSW EPA [4]). Generally, the ability to use or store water by a scheme is influenced by climatic factors such as evaporation and rainfall, the area under irrigation, the supply of new resources and the available storage capacity.

For this application a water balance over the water storage has been constructed for the HWRS using 3-month time steps. The terms of the water balance are: Inflow (E), irrigation (I), rainfall (P), evaporation (T) and storage (S). The water balance is shown in Eq. (1).

$$\mathrm{d}S = E - I + (P + T)\,A \tag{1}$$

where dS is the change in volume of water stored and A is the area of storages.

Each of the terms in Eq. (1) can be described at different levels of detail. The following sections outline how each term is derived for the HWRS supply risk model.

3.1. Effluent inflow

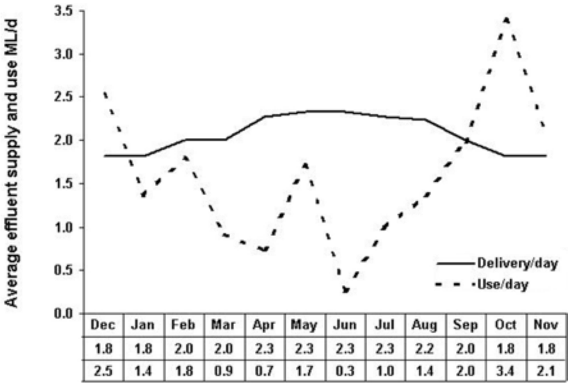
Effluent inflow to the HWRS is not constant throughout the year, predominantly due to extractions from the effluent stream before the water reaches the HWRS. Fig. 1 shows 2001–2002 data collected for the HWRS showing average daily effluent delivery and water use at the HWRS. To balance supply and use the reuse of effluent for irrigation often will require a large storage volume to counter the variability in use and climate [6].

3.2. Irrigation

The amount of effluent able to be irrigated (sustainably) may depend on soil and crop type, as well as climatic factors. Soil moisture accounting can be used to estimate the influence of climate on specific soils and crop types. However, on a simplified level there may be a general relationship between rainfall, evaporation and crop type for specific locations without resorting to more complex soil moisture accounting. Data collected from the HWRS in 2002 show that a relationship exists between the monthly rainfall and monthly evaporation to the volume of irrigation used (Fig. 2).

Deviations from the trend line in Fig. 2 may indicate factors such as change in total area under irrigation, availability of supply, capacity to deliver required moisture (i.e., infrastructure capacity), changes in plant requirements and variability in the application method/process. Nevertheless, the trend does indicate that over a month irrigation use may be approximated by the difference between rainfall and evaporation.

The range of climatic conditions captured in a long-term series of data can be used to test the robustness of short-term operational and demand management strategies. The data contained in long climate time series can be expressed in more compressed form using statistical analysis. Climate data, in particular rainfall data — have been analysed statistically to enable design rainfall estimations across Australia [7] and the synthesis of extended series at sub-daily time scales [8].



	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	1.8	1.8	2.0	2.0	2.3	2.3	2.3	2.3	2.2	2.0	1.8	1.8
	2.5	1.4	1.8	0.9	0.7	1.7	0.3	1.0	1.4	2.0	3.4	2.1

Fig. 1. HWRS effluent supply and use 2001–2002.

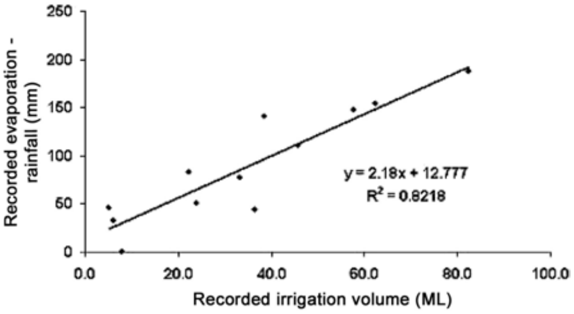


Fig. 2. Evaporation – rainfall and irrigation use at the HWRS.

Climate data have been obtained for the HWRS site which contain a 67-year daily rainfall time series and a 17-year daily evaporation series. Evaporation for the HWRS site follows a relatively similar pattern from year to year. Therefore, average monthly evaporation and recorded total monthly rainfall were computed from the available record. Average monthly evaporation multiplied by a crop factor (0.9) was used to compute monthly values of evaporation–rainfall. The monthly crop-adjusted evaporation–rainfall represents the first approximation of an irrigation requirement. Irrigation run-off and percolation may also be considered in the irrigation demand function.

Run-off from irrigation areas is assumed to be zero as allowing run-off of irrigation waters is generally discouraged [4,6]. Percolation may be needed to leach the salt from the root zone. It can be estimated as a fraction of the irrigation water by looking at the tolerance of the plants being irrigated [4]. The irrigation water for the HWRS is typically 900 μS/cm [5]. Therefore, a percolation fraction of about 10% of the applied effluent is allowed for.

NSW EPA [4] recommends minimising the percolation and run-off. Eq. (2) gives the estimated total monthly irrigation depth for the HWRS. The calculated 3-month irrigation depth can be less than zero. In this case it is given the value of zero.

$$I = 1.1 \times (P - 0.9 \times T) \qquad (2)$$

where I is the irrigation depth (mm), P the rainfall depth (mm) and T the evaporation depth (mm).

The 3-month irrigation depth shows normal distribution characteristics. The irrigation depth results for each month can be ranked and presented in a normal scores plot [9]. The normal score plots for the 3-month HWRS site irrigation depth data show that it is usually distributed as shown in Fig. 3(a) and (b).

The mean and standard deviation of each 3-month irrigation requirement (mm) (given by the slope of the line and the x-axis zero intercept) is used in a sensitivity analysis with the water balance model to determine storage probabilities.

3.3. Rainfall and evaporation on storages

The water surface storage area multiplied by a fraction (say 70%) of irrigation requirement (determined above) gives this relatively minor term in the water balance [Eq. (1)]. For the HWRS the surface area of storage is approximately 10 ha.

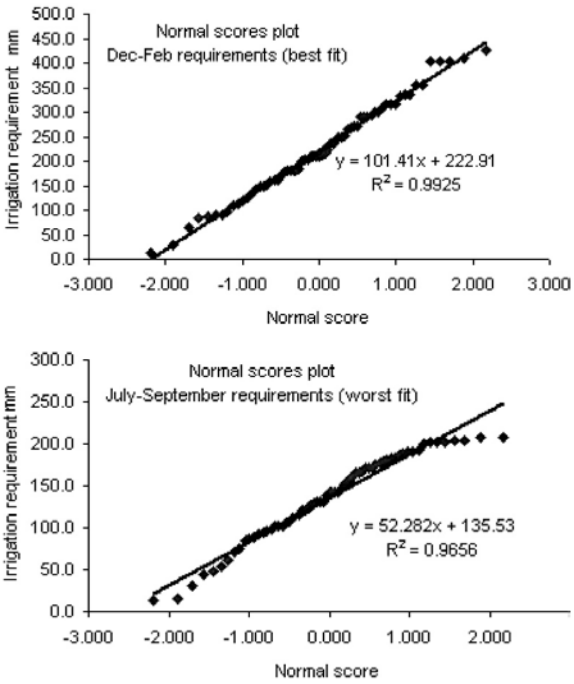


Fig. 3. Irrigation requirement (in mm) for HWRS appears normally distributed for (a) December through February and (b) July through September.

4. Results

The statistical parameters required for each 3-month period are the median irrigation requirement and the standard deviation. Through the use of a computerised random number generator or sensitivity analysis software, a number of simulations of the Eq. (1) water balance may be performed to obtain a distribution of the likely storage situations in the near future. Table 1 shows the derived 3-month mean and standard deviation irrigation requirement values for the HWRS site.

It was found (through analysis of 6-month irrigation requirement distributions) that undertaking two successive predictions using the 3-

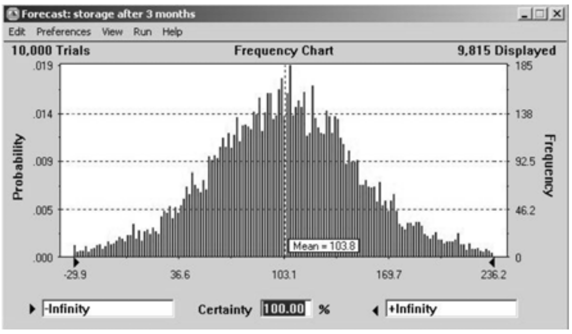
Table 1
Three-month irrigation requirement data

Month	Median (mm)	Standard deviation	R^2 correlation
January	155.1	82.64	0.9797
February	132.7	62.94	0.9839
March	100.9	48.17	0.9743
April	72.9	38.74	0.9811
May	95.9	43.05	0.9899
June	135.5	52.28	0.9656
July	188.6	69.02	0.9804
August	210.6	84.20	0.9736
September	249.6	88.21	0.9802
October	245.2	95.61	0.9847
November	222.9	101.41	0.9925
December	175.9	95.51	0.9850

month values was sufficient to predict the system storage distribution 6 months in advance. The statistical properties of the distributions for each time period (3 months for this example) can be used with the water balance model and Crystal Ball sensitivity analysis software (Decisioneering 2000) enacted in Microsoft Excel. An example of how to use the supply risk assessment tool is presented below.

The supply risk assessment tool was applied to the HWRS configuration. For this example assumptions regarding water use at the HWRS are as follows:

- The area under irrigation for the simulation periods is 105 ha.
- The maximum operational storage available is 230 ML.
- The November, February and May data from Table 1 (simulating December–August requirements) is used to describe the distribution of irrigation requirements.
- The delivery of effluent is in accordance with the data in Fig. 1.
- The initial volume of storage is 180 ML at the end of November, i.e., just before the summer irrigation period.



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Certainty 100.00 %
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Fig. 4. Predicted storage volume distribution after 3 months from the end of November.

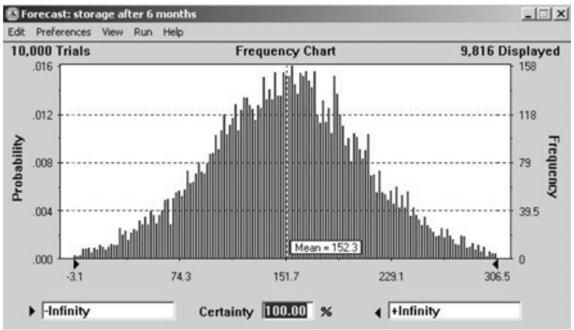

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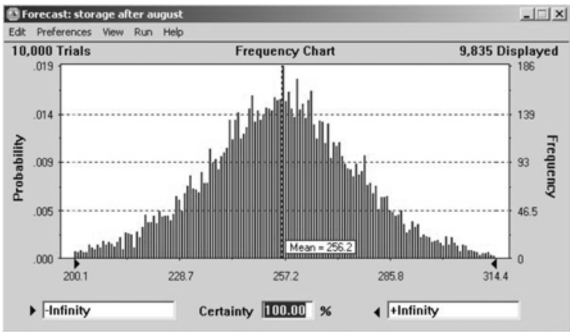
Fig. 5. Predicted storage volume distribution after 6 months from the end of November.

- The number of model trials selected is 10,000.

Figs. 4 and 5 show the predicted storage volume distribution after 3 and 6 months from the end of November with initial storage volume set to 180 ML and irrigated area of 105 ha. The mean storage after 3 months from November is approximately 104 ML, and there is a very low probability of either falling shot of water (below zero storage) or exceeding maximum storage levels (set at 230 ML) during this period. At 6 months after November the mean of the storage distribution is 152 ML; however, there is a chance (approximately 10%) that maximum storage will be exceeded by the end of May given the initial parameter set. This level of risk of overflow may, however, be acceptable.

The median storage volume after 6 months of 152 ML has also been used as the input figure to



-Infinity Certainty 100.00 % +Infinity

Fig. 6. Predicted storage volume distribution after 3 months from the end of May with an initial volume of 152 ML storage.

a 3-month supply risk assessment for the winter period of June–August with 105 ha of irrigated land. Fig. 6 indicates that starting at 152 ML of initial storage at this time there is a 90% chance that supply will exceed storage capabilities. Options may need to be explored regarding the safe disposal or increased use of effluent during this time to control and minimise any potential discharge. These new options need not be last-minute decisions; steps could be taken during the lead-up to the winter period to encourage additional sustainable use.

5. Discussion and conclusions

The supply risk decision support tool can be used at the HWRS at any time to support water allocation decision making. It allows for the evaluation of risk associated with water supply scenarios, particularly the risk of under- and over-supply for the HWRS. Similar tools, however, can be constructed for other schemes.

The developed tool does not rely on long-term series evaluation and is able to deliver quick advice in the decision making environment. With further data collection the water balance model underpinning the risk model can be fine tuned to better represent specific seasons, irrigator types or crops specific to the HWRS site and hence deliver an even better appraisal of water allocation strategies.

The model is intended for use in an operational environment, rather than the design and evaluation phases of scheme development. The modelling example above indicates that water use strategies enacted in the present can be used to manage supply problems in the future. Rather than providing the "average" value of what the storage situation may look like in the future under a particular scenario, the model produces a distribution to accompany the average and hence give operators an evaluation of the supply risk applicable to the chosen scenario.

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