10th WEDC Conference

Water and sanitation in Asia and the Pacific : Singapore : 1984

The reliability of using rainwater tank supply

Dr K C Tai and T D B Pearce

INTRODUCTION

The use of rainwater tank supply is now a matter of public policy in South Australia. It is now recognised as an allied strategy in water conservation in the driest State of the driest continent. With about 83 percent of the State receiving an average annual rainfall of less than 250mm, Adelaide's limited surface water supplies are being supplemented by additional water pumped through pipelines from the River Murray. However, water from the River Murray is very hard and since rainwater is not, its uses are favoured for drinking, washing and cooking purposes. This preference for rainwater use is significant in South Australia as consumers' utilities play a big part.

In 1982, statistics collected by the Australian Bureau of Statistics in Adelaide have revealed about 213 000 households out of a state total of about 456 000 households were using both mains and rainwater supplies (Ref 1). Of the 213 000 households, 120 350 households (56.3 percent) use only tank water for food preparation or drinking, while 73 900 (34.6 percent) use raintank water for some or all of their clothes washing.

The preference for rainwater is greater in areas outside of the Adelaide Statistical Division, where 70 150 households (80 percent) out of 87 950 households use rainwater for food preparation or drinking, as compared with 50 200 households (40 percent) out of a total of 125 000 households in the Adelaide Statistical Division.

The State Government of South Australia is encouraging the use of rainwater tanks as such a use could make a worthwhile contribution to the State's limited water resources. It has brought out a booklet prepared by the Engineering and Water Supply Department in conjunction with the Department for the Environment and Planning (Ref 2). That booklet, "Rainwater Tanks - their Selection, Use and Maintenance", provides information in situations where rainwater supply is to be used in conjunction with mains water. Recently, there has been a surge of interest for rainwater to be used as a sole source of domestic supply, because of increasing housing development beyond reticulated areas. This paper is concerned with the latter objective.

ANALYSIS

The simulation analysis uses historical rainfall data to evaluate changes in storage of a rainwater tank, using the mass storage equation (Ref 3).

The simulation evaluates an upper bound situation when demand is assumed constant and a lower bound when demand is made variable according to a self-imposed water rationing rule. This rule is arbitrary since there is no standard rule for human behaviour. Variable demand can be used to demonstrate the likely effects of human response, especially when water level in the raintank decreases and when ultimately, the supply could be used solely for cooking and drinking purposes. Hence self-imposed water rationing could occur during extended dry periods (droughts), as non-essential rainwater uses are curtailed.

The values of demand selected are 60, 100, 200, 400 and 600L/day/household. The lowest value is for a single low consumer, while the highest value is for a four person in-house consumption.

The mass storage equation is given by:

$$Z_{t+1} = Z_t - D_t + Q_t$$

subject to $0 \leq Z_t + 1 \leq S$, and

$$Z_t - D_t \geq 0, \text{ and}$$

$$Q_t = C\,(P_t - E_t),$$

where

$Z_t + 1$ is storage at the end of the t^{th} time period;

Z_t is storage at the beginning of the t^{th} time period;

D_t is release during the t^{th} time period;

Q_t is the inflow during the t^{th} time period;

S	is the maximum storage capacity;
C=0.8	is the catchment coefficient for roof and gutter to account for roof and gutter spillage;
P_t	is the rainfall during the t^{th} time period;
and	
E_t	is the evaporation loss from the raintank during the t^{th} time period (2mm/month)

The release rule for the constant demand D_t, is to supply all the water demanded, and if there is insufficient water in the rainwater tank to meet the required draft, the tank storage empties. The release rule for the case of variable demand is based on knowledge of current storage (assumed at the end of the month), and an appropriate release based on restriction is worked out for the next month. Hence, as the storage volume decreases, self-restrictions are imposed so that demand is adjusted to monthly fluctuations in supply. There is no universal release rule to follow. The one adopted in this study follows a step function for the variable demand and is expressed as follows:

STORAGE VOLUME (% of storage capacity)	RELEASE (percentage of constant demand)
$0 \leq Z_{t+1} < 50\%$	25%
$50\% \leq Z_{t+1} < 66\%$	50%
$66\% \leq Z_{t+1} < 83\%$	75%
$83\% \leq Z_{t+1} \leq 100\%$	100%

RESULTS

Performance Characteristics

With space restriction as the constraint, the case of Adelaide is taken as an example, with constant and variable demands displayed in figures 1 and 2 respectively. The reliability chosen is 80 percent, which is seen to be non-conservative in regard to sole supply, although reliabilities of 85, 90, 95 and 99 percent have been investigated. The curves display the relationship between the required raintank storage volume against the required roof area for a given demand and reliability.

The reliability used here is the reliability over time, Re(t), which is defined as the proportion of months in any year during which the rainwater tank is not empty (ref 3). It is not volumetric reliability, defined as the total volume of water supplied to the total volume of water demanded.

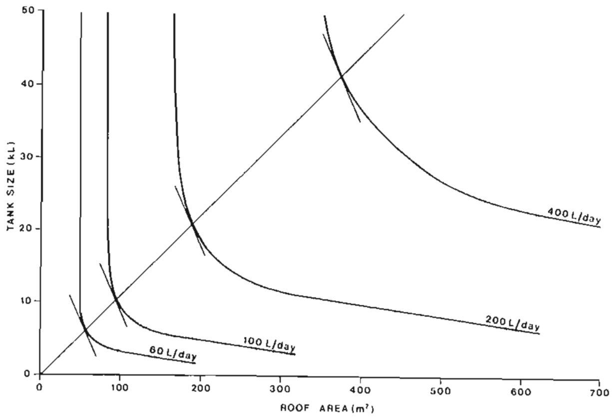

FIGURE 1 – RELIABILITY 80% – ADELAIDE CONSTANT DEMAND

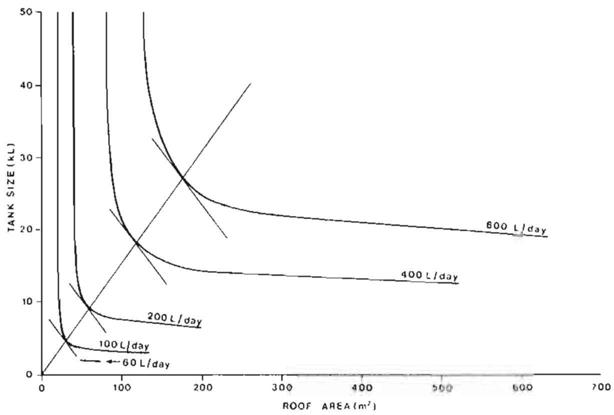

FIGURE 2 – RELIABILITY 80% – ADELAIDE VARIABLE DEMAND

The performance curves of raintank storage/roof area show three areas of interest:

a) the vertical section of the curve, showing a minimum feasible roof area, when any increase in tank size will merely add on empty storage space:

b) the almost horizontal section of the curve, showing a minimum feasible tank size, when any increase in roof area will merely add to greater tank spillage, and

c) the bend region of the curve, where there is limited substitutability of roof area or storage tank volume or vice versa.

In the bend region of the curve, the ratio of optimal tank size V_T, to the optimal roof area A_R is obtained by equating the marginal rate of substitution MRS (roof area A_R for storage volume V_T) to the slope of the budget line P_r/P_t, where P_r and P_t are the unit costs of roof area and storage volume.

$$\text{MRS } (A_R \text{ for } V_T) = \frac{\partial V_t}{\partial A_R} = \frac{P_r}{P_t}$$

The optimum point is given by the tangent of the budget line against the bend of the curve. At this optimum point, a ray drawn through the origin at a constant slope of V^*_T/A^*_R will exhibit constant returns to scale, which are evident in both cases of demand. The significance of this is apparent, for if and when demand is increased by a certain ratio, the optimal tank size and roof area need to be increased by that same ratio, given that unit costs of both tank and roof area remain constant.

The criterion for constant returns to scale is when demand $D_t = f(V_T, A_R)$ is increased by a scale factor m, such that $mD_t = f(mV_T, mA_R) = mf(V_T, A_R)$ for $m > o$ (see ref 4).

Hence if demand in any row in Tables 1 and 2 is expressed as a ratio of demand in the previous row, the value of that ratio applies also to the ratio of tank sizes and roof areas.

TABLE 1: Constant Returns to Scale under Constant Demand

Demand D_t L/day/ household	Vol of Tanks V_t litres	Roof Area A_R sq.m.	Reliab. Re (T)
60	5900	57	0.795
100	9800	96	0.798
200	20300	188	0.795
400	41000	375	0.796

TABLE 2: Constant Returns to Scale under Variable Demand

100	4760	32	0.845
200	9100	60	0.810
400	18000	118	0.801
600	27000	176	0.796

Severity Characteristics

Under condition of optimal selection with constant returns to scale, there appears to be a close similarity of severity characteristics deducible by run-analysis of empty and non-empty storage states.

For the case of constant demand, the frequency distributions of monthly failure are similar, with March, April and May (the autumn season) as the critical period of likely failures. For the case of variable demand, the distributions are not exactly similar, but the critical period has advanced by a month, is, February, March and April.

Although the total number of monthly failures X(t) is large, many of the monthly failures are found to be in sequence so that the number of sequential failures N(t) is less than X(t). The process X(t) is a compound Poisson process with,

$$E[X(t)] = E[N(t)].\ E[Y]$$

where E is the expectation notation and E[Y] is the expected or average length of monthly failures in any year.

If the time t represents the failure time domain and if the recurrence interval of sequential failures follows an exponential decay function, $f(t) = \lambda e^{-\lambda t}$, it could be shown that the expected recurrence interval is given by $E[T] = \frac{1}{\lambda}$

The encounter probability E_c of sequential failures could be estimated for the design life L of the rainwater tank, where (ref 5),

$$E_c = 1 - e^{-\frac{L}{E[T]}} = 1 - e^{-\lambda L}$$

But in any given year L = 1, $E_c = 1 - e^{-\lambda}$

The severity charactistics are summarised in tables 3 and 4.

TABLE 3: Severity Parameters under Constant Demand

D_t (L/day)	60	100	200	400
X(t)	345	340	344	342
N(t)	138	137	139	136
E[Y](months)	2.50	2.48	2.47	2.51
E[T](years)	0.89	0.90	0.87	0.89
E_c	67%	67%	68%	67%

TABLE 4: Severity Parameters under Variable Demand

D_t (l/day)	100	200	400	600
X(t)	260	320	355	343
N(t)	108	121	137	134
E[Y](months)	2.41	2.64	2.59	2.56
E[T](years)	1.18	0.99	0.90	0.89
E_c	57%	64%	67%	67%

Hence for a time reliability of 80 percent of success or 20% of failure, the encounter probability of a sequential failure event is about 67% for constant demand and slightly less for variable demand.

While there is an option in the variable demand to choose an optimum tank size/roof area smaller than the optimum combination given by the constant demand at the same reliability, there is a trade-off penalty involved between cost saving and a drop in volumetric reliability R_v.

TABLE 5: Trade-off between reduction in optimal tank sizes and roof area with volumetric reliability R_v.

D_t (L/day/H)	% Reduction in tank sizes & roof area V_t	A_R	% Reduction in volumetric reliability R_v
100	49%	33%	61%
200	45%	32%	63%
400	44%	31%	63%

The potential saving in capital cost has to be weighed against the self-sacrifice of water rationing, which could be very inconvenient.

Apart from the consideration of trade-off, there is a potential range in the hazards of supply failures which could occur from time to time given the variability of Adelaide's rainfall regime.

The simulation analysis indicates three categories of prospective failure: mild, moderate and severe (fig 3). An estimate of encounter probability E_c for the estimated life time of the rainwater tank (25 years) suggests that the method of selection is appropriate (fig 4).

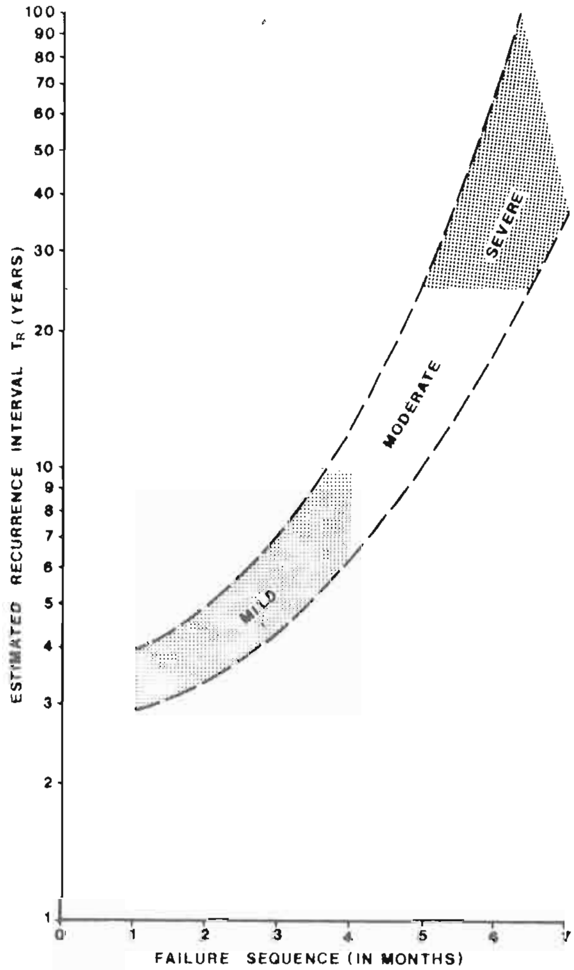

FIGURE 3 - ESTIMATED RECURRENCE INTERVAL AND FAILURE SEQUENCE

TABLE 6: Severity of Supply Failures

Severity of Supply Failures	Extimated Recurrence Interval	Failure sequence in months
Mild	Less than 10 yrs	4 or less
Moderate	10 to 25 yrs	5
Severe	Greater than 25 yrs	6 or greater

TABLE 7: Estimated Encounter Probability for the estimated life time of the tank (25 yrs)

Severity of supply Failure	Const. demand E_c	Variable Demand E_c	Recomm. Range E_c	Failure sequence in mths
Mild	85-95%	88-100%	greater than 85%	Less than 4
Moderate	66-82%	64-86%	65-84%	5
Severe	40-67%	30-56%	30-65%	6 or greater

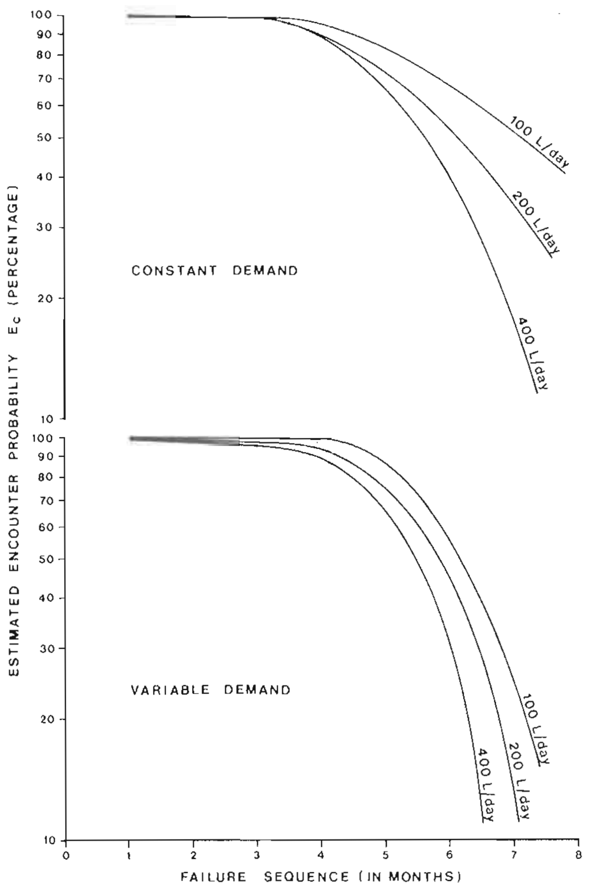

FIGURE 4 - ESTIMATED ENCOUNTER PROBABILITY IN 25 YEARS

CONCLUSIONS

Although the use of rainwater tank supply is now a matter of public policy in South Australia, more pertinent information should be made available to the potential consumer, especially in the case of sole supply. Not only performance characteristics but also severity characteristics should be evaluated. Potential consumers of rainwater tank supply will then have a sound appreciation of the hazards and risks involved in terms of supply fluctuations caused by variation of rainfall inputs. They would be able to select tank sizes for their requirements and use the water more efficiently i.e. maximize supply from their tanks.

The performance curves and the severity characteristics deduced from a given rainfall sequence are site-specific. Where there is significant variation of rainfall regime in space and in time, caution should be exercised in using such performance curves to size up appropriate combination of rainwater tank and roof area.

ACKNOWLEDGEMENT

The authors are grateful to the Director-General and Engineer-in-Chief of the Engineering and Water Supply Department, South Australia, for his permission to publish this paper. The opinions expressed by the authors are not necessarily those of the Department.

REFERENCES

1. SIMS, G.C: Use of water applicances by households, South Australia. Australian Bureau of Statistics (Adelaide) November, 1982. Catalogue No. 8709.4, 11 August 1983.

2. THE GOVERNMENT OF SOUTH AUSTRALIA: Rainwater tanks ..... their selection, use and maintenance. The Engineering and Water Supply Department and the Department of Environment and Planning. D J Woolman, Government Printer, Oct 1983.

3. McMAHON, T.A. and MEIN, R.G: Reservoir Capacity and yield. Elsevier Publishing Company, NY 1978.

4. NICHOLSON, Walter: Micro-economic theory. Basic principles and extension. 2nd Ed. the Dryden Press, Illinois, 1978.

5. SHANE, Richard M and LYNN, Walter R: Mathematical model for flood risk evaluation. Journal of the Hydraulics Division, Proceedings ASCE, No. 4119, HY 6, Nov 1964, pp 1 - 17.