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Australian Climate Change Adaptation Network for Settlements and Infrastructure

Node 4: Infrastructure

Increasing the adaptive capacity of water storage systems by reducing evaporation

In many arid countries, the annual evaporation rate is capable of exceeding the annual average rainfall. This means that water storage is not sustainable, having the potential to severely impact communities and industries who suffer from water scarcity. Future impacts of climate change, including intensification of rainfall events and increasingly prolonged periods of drought, are likely to exacerbate these issues. With rainfall patterns becoming less predictable, it is important to build the adaptive capacity of water storage systems. One means of improving adaptive capacity is to reduce evaporative losses.

Conventional open water reservoirs are highly vulnerable to evaporative loss. In Africa,

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Fill in the Dams?

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Abstract: Small dams in inland Australia are key farm infrastructure and are essential for the economic survival of rural business during sustained drought. However, harsh arid climatic conditions result in annual evaporation losses greater than annual water usage. The purpose of this study is to investigate the feasibility of replacing small farm dams with groundwater dams, constructed by filling the farm dams with gravel or sand. Water is then stored in the soil pore space, where evaporation decreases as a function of water depth below the surface of the soil, until at a depth of 0.9m, evaporation is negligible. Although storage volume is reduced, this method may be an efficient alternative to the current unavoidable evaporation losses from open surface waters. Daily evaporation data, and storage efficiency of representative farm dams has been compared to the computed evaporation and storage efficiency from equivalent dams filled with coarse material. Data has been taken for a number of sites in western New South Wales from 1966 to 2006. Results have shown that when the water level is below the surface, evaporation is significantly reduced and water saved, particularly from larger dams in arid regions rather than semi-arid regions. For the case of the largest farm dam considered at Mildura, the average annual volume of water Australia.

Keywords: Groundwater dams, evaporation loss, small farm dams, Australia, arid, semi-arid.

1. INTRODUCTION

Unpredictable and low rainfall brings great risk of economic survival to farmers in arid and semi-arid areas of Australia who depend on crop and cattle production as a primary source of income. Traditional water storage dams experience sizeable evaporation losses. Prolonged periods of drought in arid and semi-arid regions are severely affecting communities who regularly suf.7( )6.(25l(es catt)--6.4(eo)7.3(a)-119rly)-9(ect(d)-5(1r)-6.4(ee)5.9(xei-5.7(n)-5r(d)1-0.3(f)6) intense drought.

This contribution considers whether groundwater dams may be a practical and efficient way of storing water in arid and semi-arid climates of inland Australia. As a preliminary investigation of potential Australian application, the concept of filling in existing farm dams with coarse granular sediments is considered. Such a change will inevitably incur greater initial set up costs which may be offset by economic benefit of the amount of water saved from evaporation. A primary cost will be filling in the dam with an appropriate material with high specific yield.

Multitudes of small farm dams exist in arid inland Australia and Manning (1987) states that "small reservoirs have proportionately higher evaporation losses" [than large reservoirs]. Research by the National Program for Sustainable Irrigation shows that depending on surface area and depth, "40 percent of stored water in farm dams can be lost through evaporation". Any alternative storage scheme must be more reliable in terms of both the net supply volume of the supply and suitable quality (White, 1960; Van Haveren, 2004, Nissen-Petersen, 2006). Alternative preventative measures to reduce evaporation losses in Australia involve the use of chemical films, covers, sun shades and tree barriers (NPSI, 2005; Manning, 1987) and there are significant and multiple difficulties in their application to small farm dams in arid and semi-arid Australia.

2. GROUNDWATER DAMS

A conventional groundwater dam "obstructs the flow of groundwater and stores water below the ground surface" (Nilsson, 1988; VSF-Belgium 2006). This term refers to both sand storage dams and subsurface dams. A subsurface dam "is constructed below ground level and arrests the flow in a natural aquifer, whereas a sand storage dam

3. MODELLING OF CONVENTIONAL AND GROUNDWATER DAM PERFORMANCE

During this investigation, the performance of conventional and groundwater farm dams was investigated for six sites in western New South Wales using available data in conjunction with a simple rainfall-runoff model of storage.

Rainfall runoff from the upstream catchment (V_{runoff}) is assumed to be the sole inflow to the storages. Outflows are farm demand (D), evaporation (E), seepage losses and any dam overflow of excess capacity ($V_{overflow}$). It has been assumed that any losses due to seepage are negligible. As daily records were the most suitable data, a daily time step has been used in the model. The equation for the volume of stored water V on day i is:

$$V_{(i)} = V_{(i-1)} + V_{runoff\,(i)} - D - E_{(i)} - V_{overflow(i)} \tag{1}$$

It should be noted that the surface area of each farm dam is on average 0.5 percent of the area of the catchment and so the direct rainfall onto the storage was considered negligible. If the direct rainfall on the storage was included the effect would be as if the annual evaporation has reduced by the annual rainfall. A spreadsheet model was created for the purpose of comparing the available volume of water in the farm dam and the same sized groundwater dam on a daily time step over the period of available rainfall and evaporation data.

3.1 Rainfall and Evaporation Data

Approximately forty years of daily rainfall and pan evaporation data was available at the six sites selected. The sites and the duration of their recorded observations are summarised in Table 1 and mean values are summarised in Figure 2. In the context of much longer climatic records in eastern Australia, it is to be noted that the period 1967 to date is regarded as a period of above average rainfall (Rančić and Acworth, 2008).

Table 1. Site Details

Site	**Record Length (years)**	**From**	**To**
Mildura	39	01/01/1967	31/12/2006

Detailed analysis of household size and stock populations were impossible during this investigation. Consequently, it was assumed that the daily demand from the farm dams were constant flows of $2.7m^3$/day, $8.6m^3$/day and $18.6m^3$/day based on information from Neal *et al.* (2001) according to the reservoir capacity.

We are assuming that small farm dams are not used for crop irrigation. Therefore demand has been assumed to be approximately constant all year round, however a sensitivity analysis of the model with respect to the demands and runoff is recommended for incorporation in any future investigation.

4. RESULTS

For each model scenario, inflow and outflow volumes and mean storage water levels were calculated on a daily basis

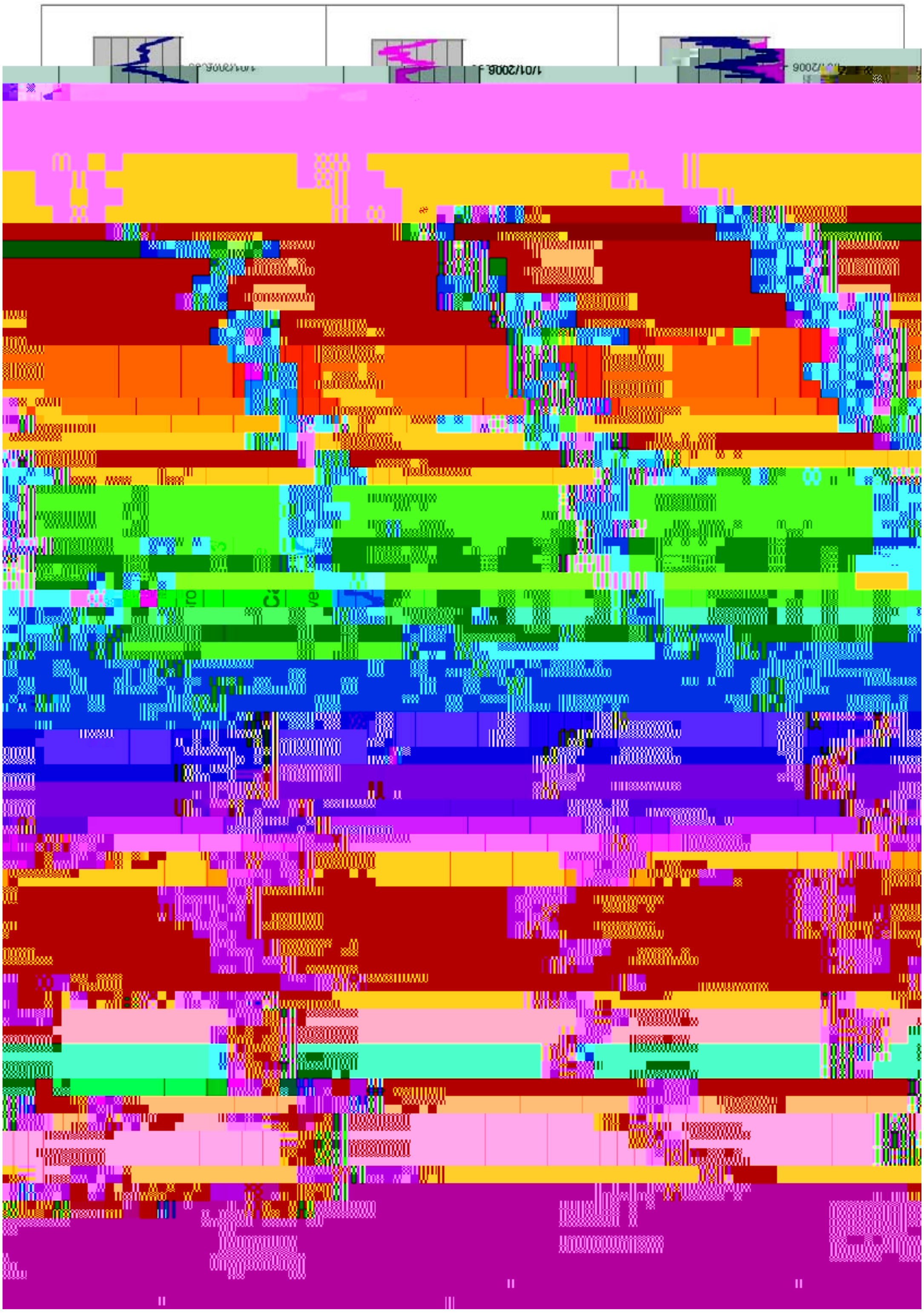

Figure 4 - Results for Case 3 at Mildura (Bennett, 2007)

4.1 Construction and Economic Feasibility

From a construction feasibility point of view, if all basic requirements such as appropriate material and required plant are available locally, then construction is believed to be straightforward. Construction time will be largely based on the time required for bulk earthworks, which depends on the volume of the dam and the haulage distance of materials. If constructed on an appropriate site, and built properly, it is generally concluded that groundwater dams will be successful as they have been in other parts of the world (Nilsson, 1988). The addition of sediment to the dam storage may compromise geotechnical considerations which may require additional earth mass.

Regarding economic feasibility, if material is readily available at little or no cost, then the main cost of this exercise is attributed to the hire of construction equipment as well as well and pump purchase and installation costs, or the costs of a gravity draining pipe from which water can freely flow. Economic feasibility will also be relative to the available storage volume and water saved from evaporation.

5. CONCLUSIONS AND RECOMMENDATIONS

Whilst these results must be regarded as preliminary, the use of groundwater dams has significant potential to substantially reduce evaporation from farm dams in arid and semi-arid Australia. This has the potential to produce two desirable outcomes for agricultural management in inland Australia:

1. provide more reliable water supplies; and,
2. reduce runoff diversion from downstream catchments.

However, this investigation has used literature data values to assess the effectiveness of groundwater dams including sediment specific yield, catchment runoff coefficients and evaporation rates in shallow groundwaters. Further desktop investigation of groundwater dam potential using more sophisticated seasonal demand models may be justified. Nonetheless, field trials will be necessary to demonstrate the potential of these structures under Australian conditions.

A further possibility is to consider the use of groundwater dams underlying more conventional storages. This may have the desirable characteristic of maintaining a large active storage volume yet also providing water supply protection during times of extreme drought.

The study concludes that the application of groundwater dams would be beneficial in arid areas of Australia for

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Evaporation mitigation by storage in rock and sand

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Abstract. For many countries in the world, the annual evaporation rate may exceed the annual average rainfall by an order of magnitude. Economic mitigation methods are presently of keen interest to drought-affected countries subject to climate changes. Sand filled dams have been used to reduce evaporation by storing water within the soil pores. However, the effective water

1. Introduction

For many countries in the world, development is limited by available water resources. In

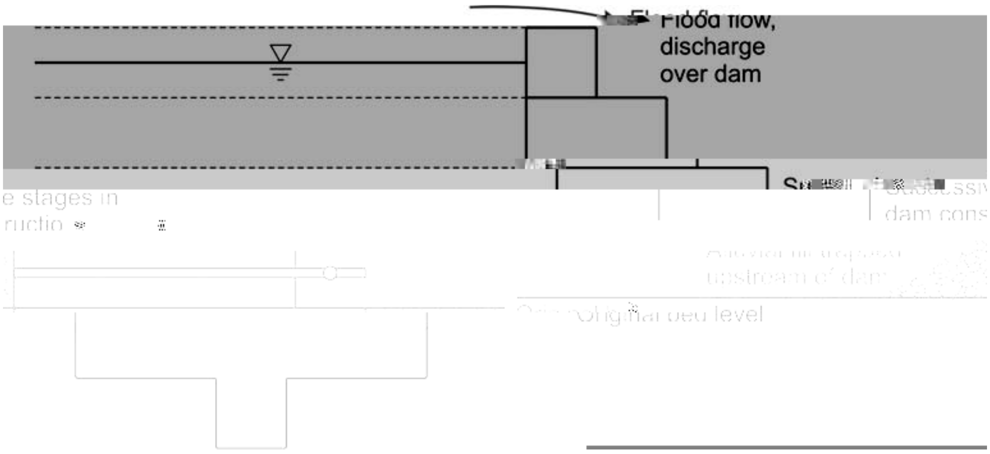


Figure 1. Conceptual diagram of a sand storage dam.

Hellwig (1973) showed that by using coarser sand mixtures the rate of evaporation was reduced relative to fine sand. It is also well established that specific yield (the volume of water that can be extracted from a saturated soil/water matrix) increases with grain size. In spite of Hellwig's work showing that grain size plays an important role in mitigating evaporation from groundwater dams, to our knowledge there has been no systematic investigation of performance of larger grain sizes.

The texture of the surface has a significant effect on the surface evaporation rate. Wipplinger (1958) reported that water at the sand surface evaporated very rapidly. Pavia (2008) monitored evaporation rate by the change in weight of a 20mm layer of saturated sand and found that the evaporation was approximately 15% faster than that from the surface of an open body of water.

In Australia, conventional open water reservoirs in arid or semi-arid zones are formed by constructing earthen embankments across ephemeral waterways (Nelson, 1985). These storages are highly vulnerable to evaporative loss and may significantly reduce flows in rivers and to l6n rive54114 T465.0002 T

2. Method

2.1 Test facility

Table 1. Summary of the physical properties of the test materials and test conditions

Material	$_{50}$ and range (mm)	Mean porosity (%)	Mean specific yield (%)	Mean saturation loss (%)	Temp. (ºC)	Relative Humidity (%)
Empty tank	-	100	100	0	10.3-31.5	18-89
Sydney Sand	0.40 (0.075 to 2.0)	46	17	29	13.5-23.6	35-93
10mm Basalt	10± 0.6	46	41	6	9.7-21.7	28-96
80mm Basalt	80± 10	50	47	3	9.3-32.0	14-99
80mm Sandstone	80±10	57	46	11	16.1-27.6	44-96

The high mean porosities associated with the 80mm rock are associated with their relative large size in comparison with the tank width as well as rock porosity. The mean specific yields highlight the superior performance of larger materials in terms of recovery of water by drainage from the matrix. The distribution of mean saturation losses are as anticipated. It is interesting to note the very similar mean specific yields of the 80mm materials, perhaps indicating that the volume contribution of the sandstone pores amount to ~7% of the total volume.

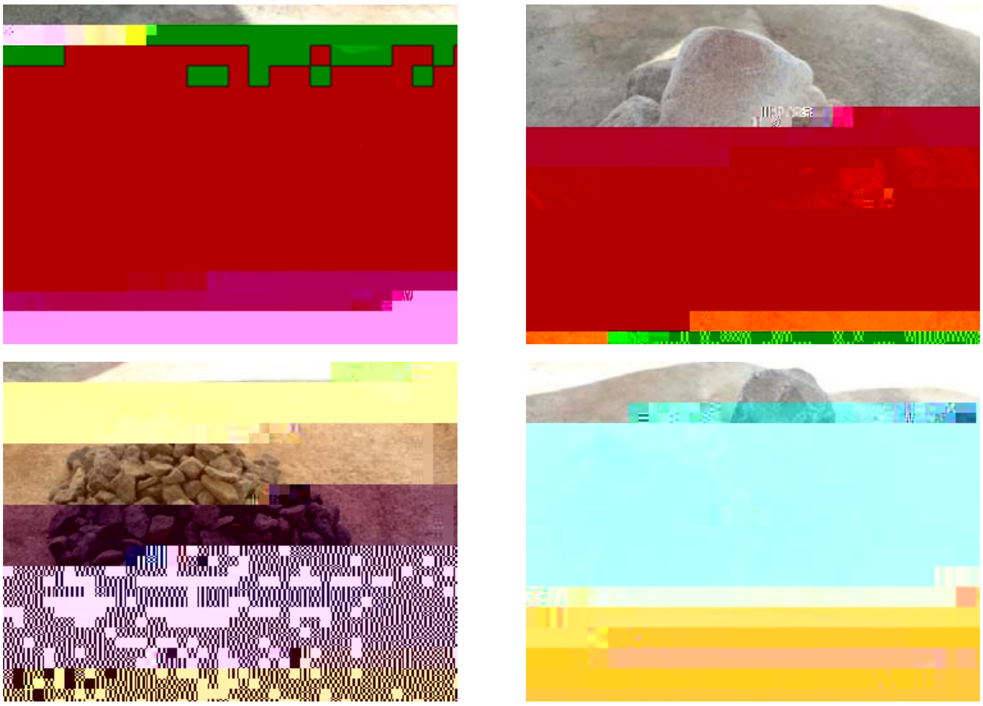


Figure 3. Test material used during this investigation. Upper left: sand; lower left: 10mm basalt; upper left: 80mm sandstone; lower right: 80mm basalt.

Australian Bureau of Meteorology weather station at Observatory Hill, approximately 5km away. These measured temperature and relative humidity data were subsequently used to compute the psychrometric coefficient, the slope of the saturation water vapour pressure curve, the surface saturation vapour pressure and the vapour pressure in the air. The raw data obtained from all tests is presented in Figure 4.

3. Results and Discussion

3.1 Preliminary observations

The test programme associated with this investigation was very demanding in terms of the time required to complete each test. As shown in Figure 4, capture of adequate representative data could take up to one month. Although repeat testing is desirable, to date there has not been sufficient opportunity to run a complete set of duplicate measurements. However, the suite of observations for the different test conditions is self-consistent yielding the following observations with regard to the data shown in Figure 4:

1. The evaporation rate systematically decreases with increasing grain size.
2. The evaporation rate systematically decreases with increasing depth beneath the surface.
3. The more porous sandstone shows a systematically higher evaporation rate than the low porosity basalt.
4. As would be anticipated, the evaporation rates above the 80mm rock matrix are very similar to those of open water. Near the surface, but just inside the granular matrix, the rate of depth increases by a factor of approximately 2 becau

3.3 Evaporation from granular materials

With the facility filled with sand or gravel, evaporation will cause the level to fall in proportion with the specific yield ( ) of the material. Greater sheltering from wind would be anticipated to decrease the volumetric evaporation rate (=   ) in finer grainer materials. However, increased capillarity-related effects in finer grained materials would be expected to increase . At present, any means of distinguishing sheltering processes from those that are capillarity-related is unknown. Consequently, we are forced to use a bulk function   which quantifies the effect of the granular material on the evaporation rate. We rewrite equation (1) as:

$$= \frac{\gamma}{\Delta + \gamma} \, \overline{(\ )\ \ (\ )\left(\quad - \quad\right)} \qquad (2)$$

where is the depth below the surface. Clearly, without any granular medium in place, ( )=1 and =100%.

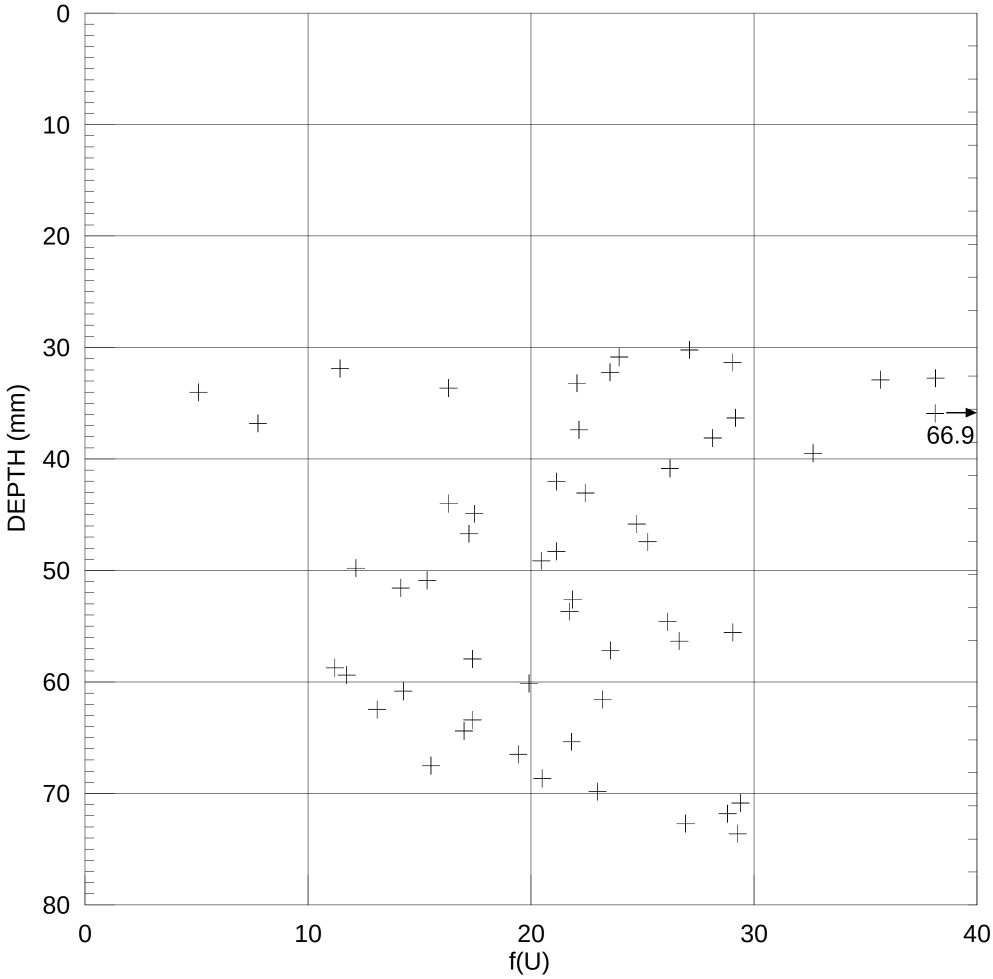
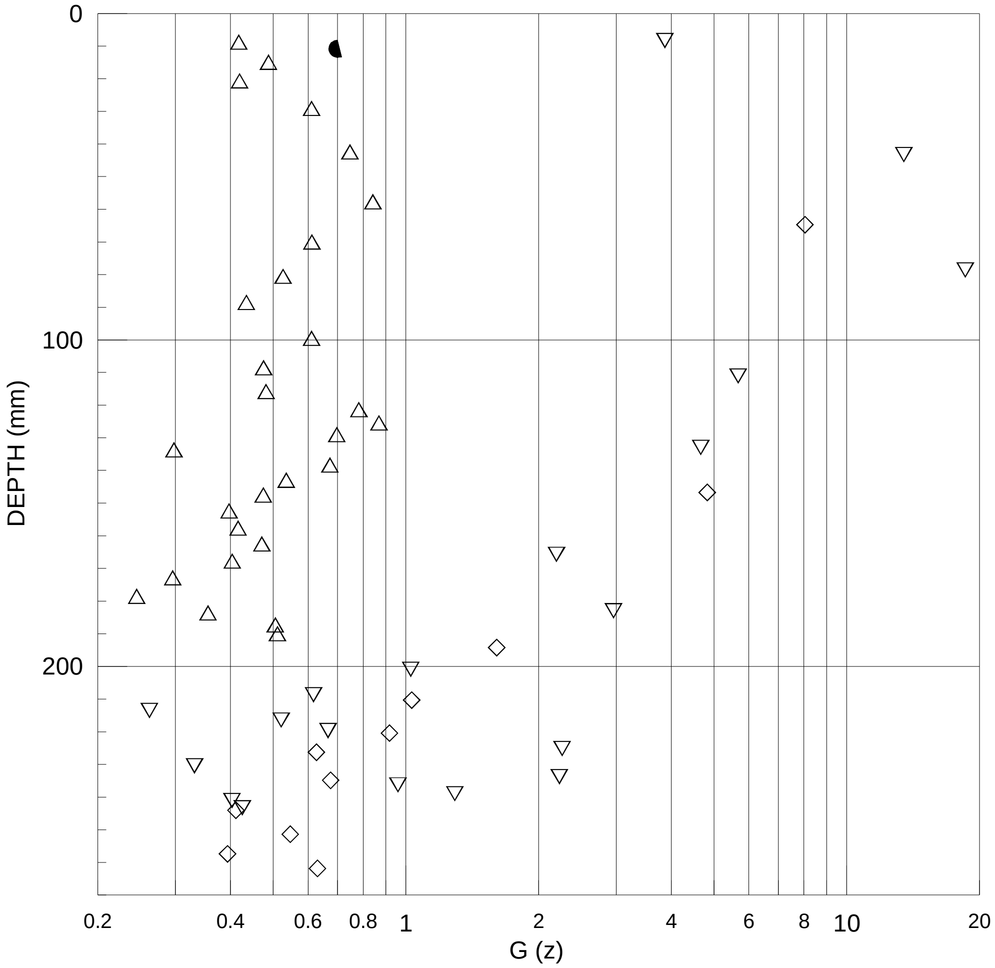


Figure 5. Variation of the function ( ) determined from the evaporation measurements in an empty tank.

Using the data shown in Figure 4 with appropriate temperature and humidity-dependent corrections and a constant value of ( ) = 22.3, we have determined ( ) for the different granular materials tested. The results of this analysis are shown in Figure 6. The following observations can be made:

1. Noting the inherently noisy nature of differentiating discrete data, all materials show a systematic decrease in the evaporation rate with depth. This is in agreement with Figure 4.
2. The 80mm basalt is the only material that yields an equivalent evaporation rate systematically less than that of open water.



3. A depth of approximately 200mm marks a transition in the behaviour of all other materials.

Neglecting the potential radiation-related component and assuming stationary environmental conditions for the Wipplinger and Hellwig experiments, the model forms of because of changed rock permeability and surface properties.

This study is able to extend the conclusions of Hellwig (1974) to larger materials and corroborate his finding that as the grain size increases, the near surface evaporation decreases. This is presumably due to reductions in capillarity and adhesion.

Modifications to Penman's equation for groundwater systems have been developed that perform adequately in terms of the captured data. This study has shown that both linear and exponential parameterisations provide similarly acceptable characterisations of the data. However, the exponential forms do better represent the behaviour of evaporation from sand captured during this study.

There are clear differences in the depth scales required to characterize the variation of evaporation with depth between this present study and those of Wipplinger (1958) and Hellwig (1974). Future work should be able to distinguish more carefully between the radiative and wind-induced components of the total evaporation budget. Present evidence is that radiative processes are able to penetrate deeper into the surface.

These findings are fundamental to further economic assessment and development of hydraulic structures in arid Australia as an adaption approach to changing rainfall and evaporation rates. They may also help provide more robust criteria for design and selection of materials to those countries where sand storage dams are currently implemented.

5. Acknowledgements

Laboratory assessment of the performance of porous coverings in evaporation mitigation

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Abstract: *Loss of water resources due to evaporation is an issue of ongoing concern in Australia with*

An alternative and potentially economically feasible method of evaporation reduction is the reduction in surface area of water by the addition of floating modular devices to the surface of reservoirs. In recent years, many modular devices have been developed commercially to reduce the evaporation from an open water body by reducing the surface area of water exposed to the atmosphere. Floating modular devices may also potentially reduce evaporation by modifying the air velocity and humidity immediately above the water surface (e.g. NPSI, 2006).

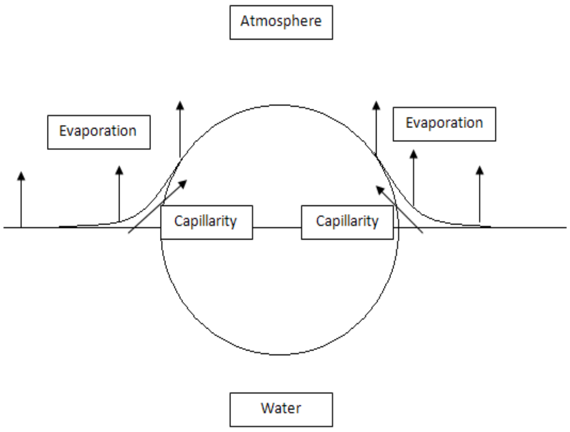


Figure 1. Conceptual diagram showing adhesion and capillary processes on an isolated floating modular device

However, there is also the possibility that adhesion and other capillarity-related processes may significantly enhance wetting of the skin of the devices thereby reducing the efficiency and effectiveness of these devices. Specifically, as depicted in Figure 1 below, if the surface of the floating modular device is hydrophilic, the water will be drawn across the skin of the modular device expanding the surface area of water exposed to evaporative processes.

Hellwig (1973), Pavia (2008) and Peirson *et al*. (2010) have all noted significantly enhanced evaporation rates for near-saturated granular materials, presumably due to adhesive processes drawing water to and across the surfaces of the grains (Figure 1).

Evaporation may also be enhanced following rain or dew deposition, or by wetting or spray generation by wind-induced rolling of a surface piercing modular device.

This present contribution is a preliminary laboratory assessment of the potential for adhesive processes to reduce the effectiveness of floating devices in reducing evaporation from open water bodies. In the following sections we describe the techniques used during the investigation, summarize the results obtained and make recommendations for future investigations. (See Busuttil, 2010.)

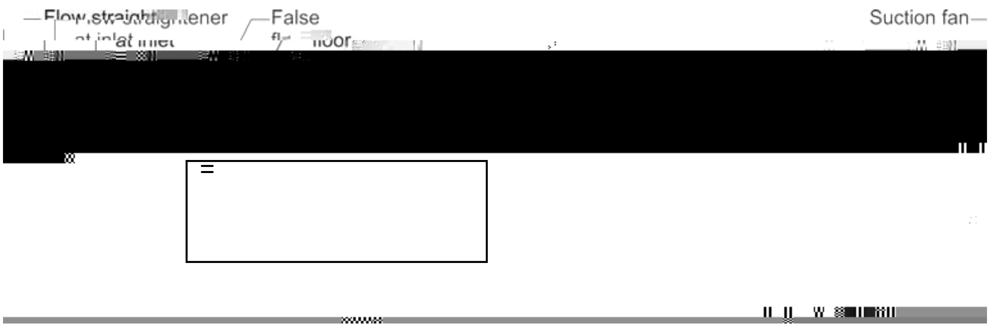
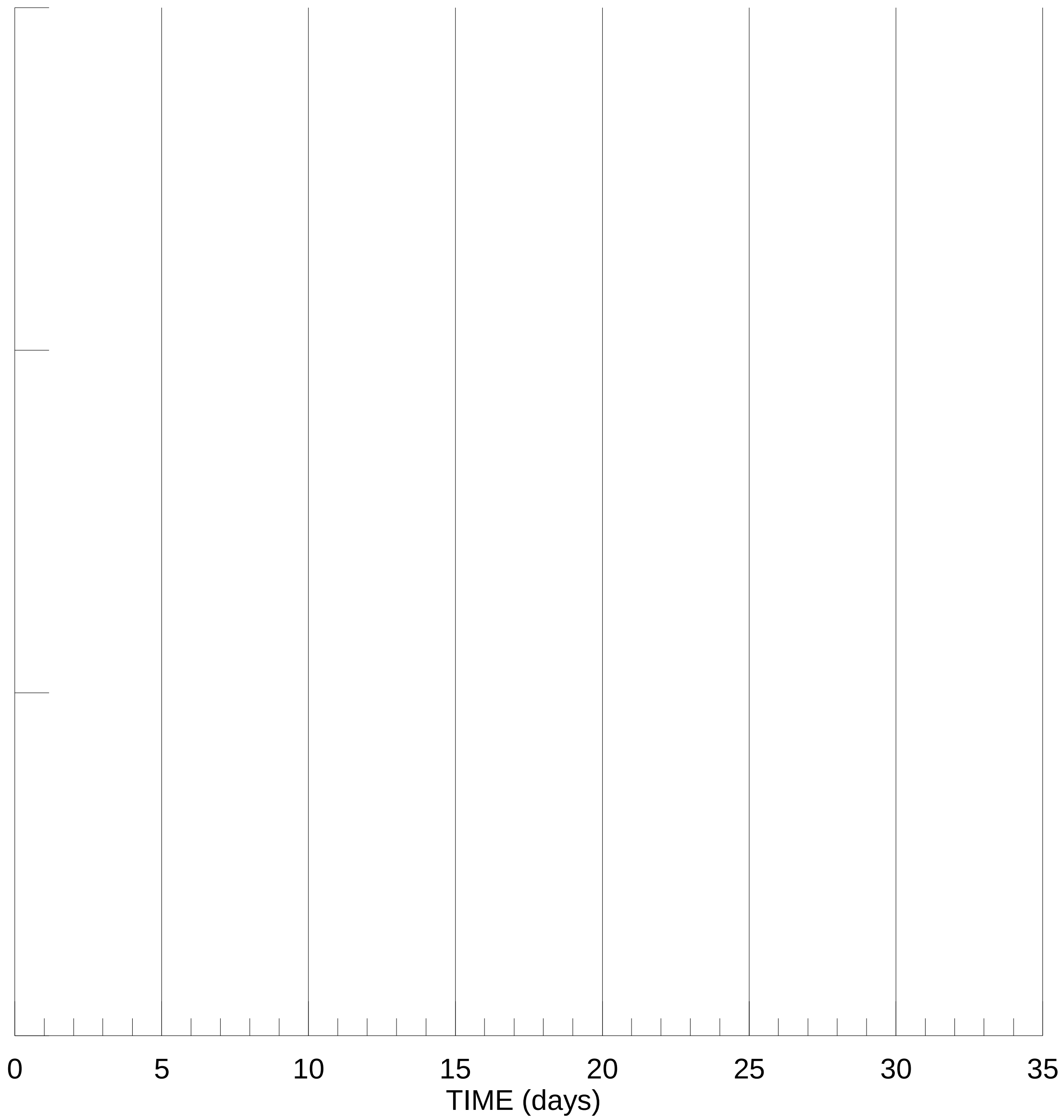


Figure 2. Side view of the test facility

2. METHODOLOGY

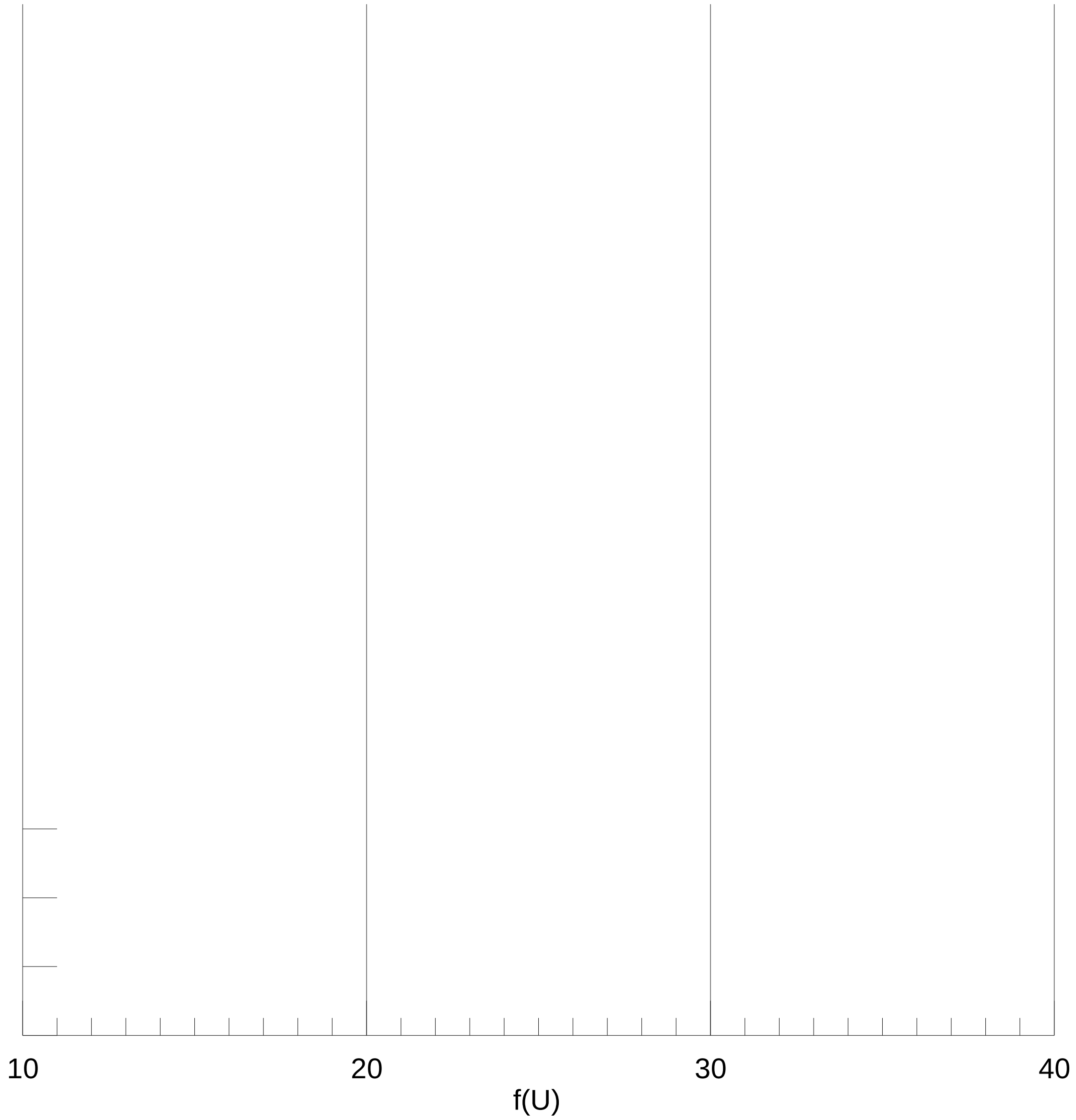
2.1. Test facility

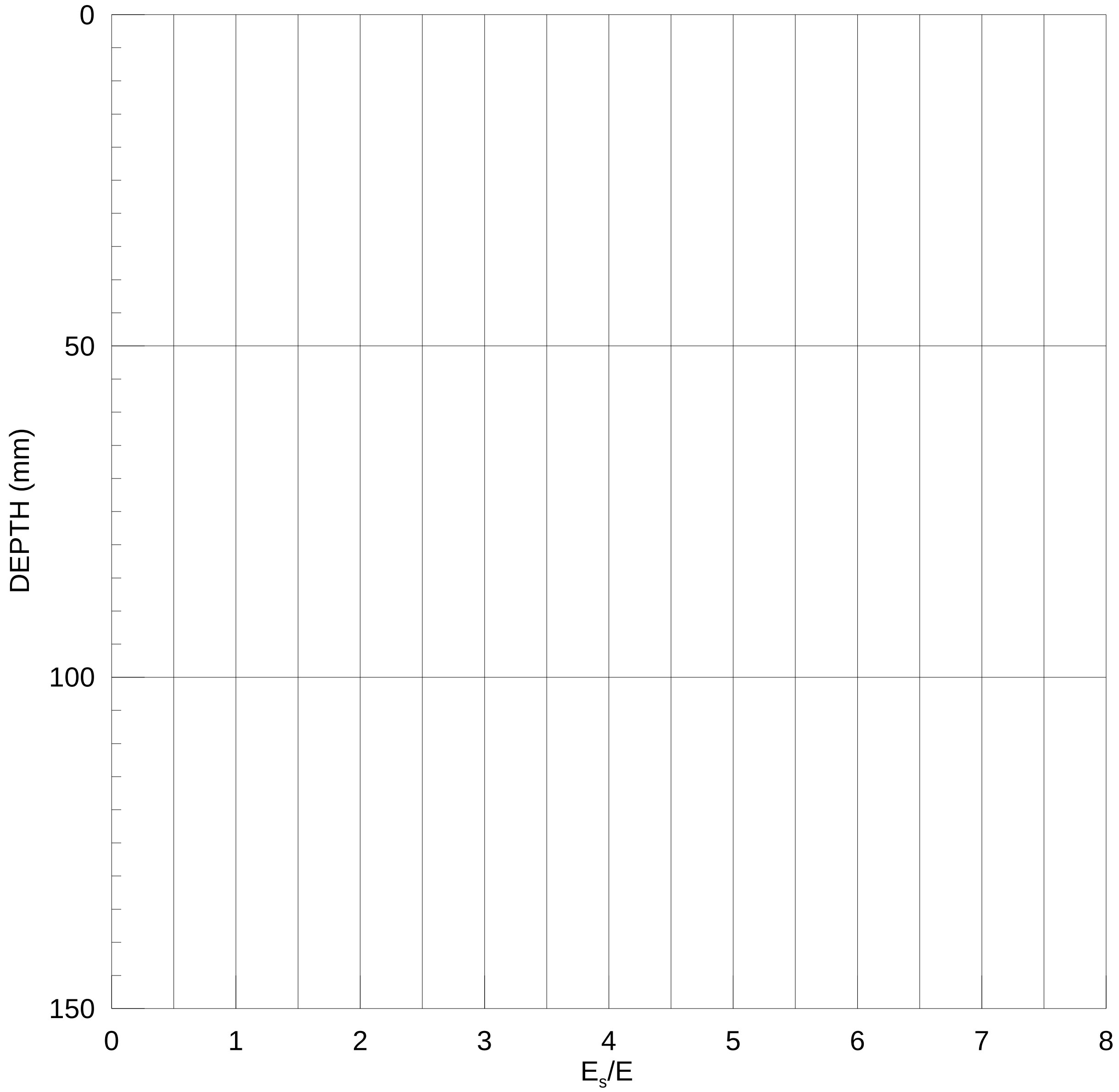
The test facility is identical to that used by Peirson *et al.* (2011) to quantify wind-forced evaporation from groundwater dams and is shown diagrammatically in Figure 2. It is located within the 1.0m by 0.6m wind tunnel at the Water Research Laboratory and consists of a Perspex tank 1.2m by 0.3m and 0.4m deep encased in the floor of the tunnel. A suction fan draws air at a constant velocity of 6.9±0.2m/s through the tunnel. Flow straighteners at the tunnel inlet ensure that the air flow transitions smoothly into the tunnel.



3. RESULTS AND DISCUSSION

The physical configuration of each test, its ambient conditions and key results are summarised in Table 1. Figure 3 shows the raw water level time series records obtained for each test. Figure 3 shows that in each test case, the evaporation rate remains approximately constant but with some weak modulations, due to changes in the ambient temperature and humidity.





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surface-sheltering devices has been completed. Good repeatability using this experimental approach has been obtained.

The testing of devices with porous surfaces has shown that the actual evaporation rate with the devices installed can be higher than that which occurs at the surfaces of open water. Consequently, surface texture is important in detercc.0872 .tf ded