What is a representative pan factor value for the eastern Pilbara?

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Abstract

The size and cost of an evaporation pond are sensitive to the pan factor, which is required to estimate pond evaporation. The pan factor Map14 in Luke et al. (1987) suggests a value of 0.62 around Newman in the eastern Pilbara Region of Western Australia.

A pan factor for Ophthalmia Dam near Newman was estimated based on energy and water balance modelling. Even though the lake water is fresh, with salinity ranging from 24mg/L to 381mg/L, the pan factor was found to be 0.54. This lower than expected value suggests that previous estimates should be revised.

Introduction

The Bureau of Meteorology (BOM) measures pan evaporation from Class A pans with bird guard in Australia. Pan evaporation data is used in the design of evaporation ponds, infiltration sumps, mine void water balance and other rainfall-runoff related assessments. Pan evaporation is multiplied by a pan factor to estimate expected evaporation from surface of a lake, pond or reservoir. Evaporation ponds are readily used in mining projects throughout the Pilbara to manage contaminated water generated by mining operations. These ponds are typically lined to minimise groundwater seepage and sized not to release stored water to the environment. Evaporation is the typical means of removing water from these ponds. To design the surface area of the pond, a water balance approach is typically used. Water balance based designs aim at removing all inflows to the pond by evaporation, and minimise the footprint area and depth of water storage.

Luke et al. (1987) provides the most relevant estimates of the pan factor for Western Australia in the public domain to date. Map14 (Figure 1) in Luke et al. (1987) suggests that in the vicinity of Newman, where many iron ore mines operated by BHP Billiton, RioTinto and Fortescue Metals Group are located, the pan factor ranges from 0.60 (roughly 200km east of Newman) to 0.65 (225km west of Newman). The pan factor increases to 0.7 towards the western coast near Port Hedland, Onslow and Carnarvon. Note that the definition of the Pilbara boundary shown in Figure 1 is approximately the same as the definition of the Pilbara in Pilgrim (1997).

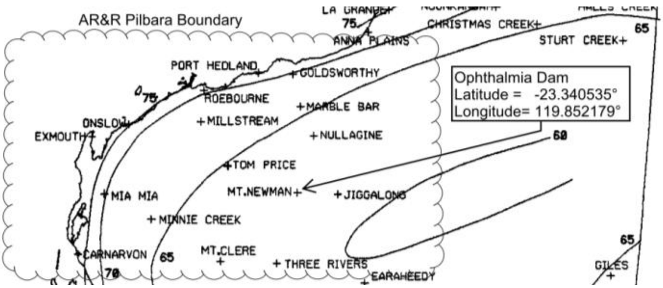

Figure 1 *Distribution of the pan factor for the Pilbara Region (reproduced from Luke et al 1987, Map14)*

The required surface area for an evaporation pond for a water depth is sensitive to the pan factor. This is illustrated by an example calculation of required surface area for a trapezoidal pond using the rainfall and pan evaporation data discussed in this paper. An evaporation pond receiving a discharge of 70m^3/day with salinity in the range of 4000mg/L would require a surface area of 2.3ha, 2.7ha or 3.2ha depending on whether the pan factor is 0.70, 0.62 or 0.54. These results were obtained for a peak water depth of 1m during the simulated period from 1980 to 2010. In this calculation the pan factor was adjusted for the effect of salinity. This example illustrates that for a pan factor reduction of 0.08, the required surface area increases by roughly 18%.

This paper presents an estimate of the pan factor for Ophthalmia Dam, which is located 12.5km east of the township of Newman in the eastern Pilbara Region of Western Australia. The estimated pan factor was found to be 0.54, even though the reservoir water is fresh. The lower than expected pan factor for Ophthalmia Dam leads to the question of what the representative pan factor for the eastern Pilbara is.

Ophthalmia Dam

Ophthalmia Dam was established in 1981 to capture surface water runoff for subsequent slow release to replenish the downstream alluvial and calcrete aquifers, which support the Ophthalmia Wellfield that supplies drinking water for Newman. The aquifer recharge system downstream of Ophthalmia Dam is comprised of four excavated recharge ponds, two river basins and an open-earth canal, which can be flooded as required with releases from Ophthalmia Dam (Department of Water (DoW) 2009).

Before 1981 groundwater levels were falling as a result of water withdrawal from the aquifer. Since the construction of Ophthalmia Dam, groundwater levels have stabilised. Leakage through the floor of the dam (seepage) has been sufficient to maintain aquifer levels; therefore, regulated releases from the dam outlet for the purpose of aquifer recharge have not been required (DoW 2009).

The dam receives stream flows from the Fortescue River (gauged catchment area= 2822.1km^2 at the DoW gauging station 708011), Warrawanda Creek (ungauged catchment area= 1248.7km^2) and Whaleback Creek (ungauged catchment area=

235.9km^2) (Figure 2). The water level in Ophthalmia Dam is recorded at the DoW gauge (station 708012, Latitude= -23.340535^o and Longitude= 119.852179^o) installed at the dam. Note that DoW708011 is located adjacent to DoW507005 (Figure 2).

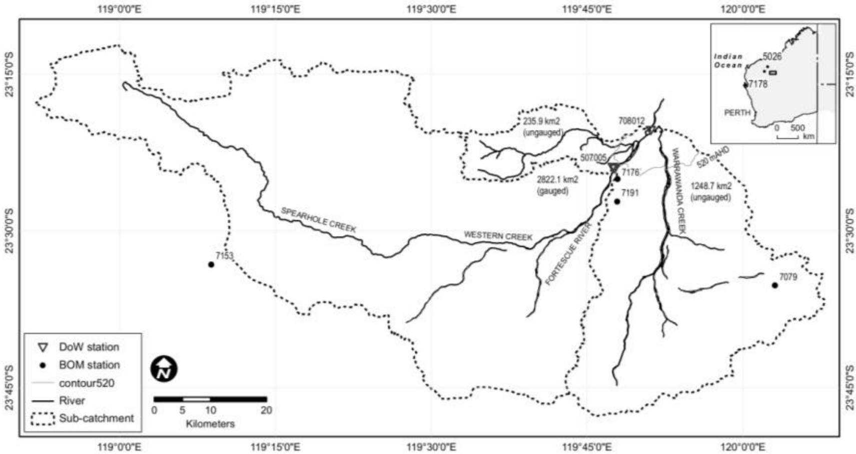

Figure 2 *Meteorological and hydrological stations within the catchment of Ophthalmia Dam*

The dam has a storage of 21.6x10^{6}m^3 at the Service Spillway at RL513.5m and is essentially empty at RL509m, giving an effective water storage depth of 4.5m (Figure 3). The dam typically empties from RL513.5m within a year if no significant rainfalls occur (Figure 4). The gauged data suggest that Ophthalmia Dam has typically overflowed every 1 to 3 years since 1994. Although the dam did not overflow for 8 consecutive years from 1987 and 1995, it was 75% full for four years. Although 34% of the total catchment is ungauged, the measured water levels of the dam can be simulated from the gauged flow and the bathymetric data. This suggests that the flow pattern of the ungauged catchment could be similar to the gauged catchment, i.e. higher flows occur during overflow events, which contribute to dam overflows, and lower flows are typically generated from a very small fraction of the catchment in close proximity to the reservoir. The gauged stream flows ranged from 3.6x10^{6}m^3 in 1983 to 391.3x10^{6}m^3 in 2000.

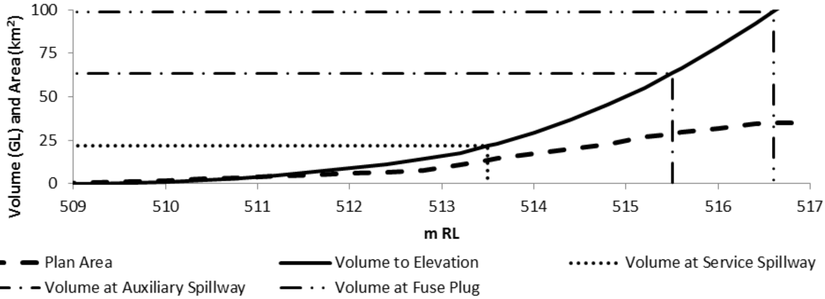

Figure 3 *Bathymetric data of Ophthalmia Dam*

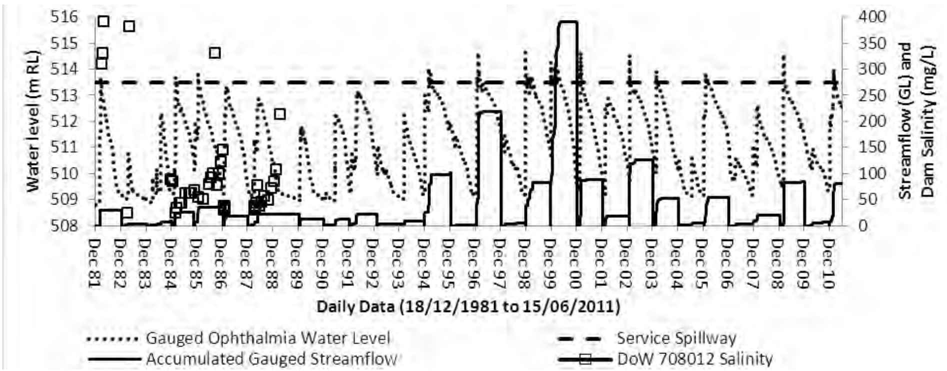

Figure 4 *Gauged Ophthalmia water level, salinity and Fortescue River stream flow*

Salinity at the dam was measured at DoW708012 from 1982 to 1987 three to four times a year. After the first year of operation, the salinity in the dam was greater than 125mg/L for 4 out of 46 measurements. On two occasions the salinity exceeded 300mg/L. The peak salinity was 381mg/L when the dam level was 510.5mRL (12% full). Stream flow salinities were also measured upstream of the reservoir from 1980 to 2001 at DoW708011(located adjacent to DoW507005 inFigure 2), which ranged from 13mg/L to 550mg/L with only 7 out of 49 measurements greater than 100mg/L.

Method

Two separate models were applied in estimating the pan factor for Ophthalmia Dam: 1) an energy and water balance model to estimate reservoir evaporation and water levels; and 2) a hydrologic water balance model that utilises pan evaporation and the calibrated pan factor to reproduce the same lake evaporation and water levels obtained from the energy and water balance. The DYnamic REServoir simulation Model (DYRESM) from the University of Western Australia was used to model the energy and water balance. The Ophthalmia Water Balance Model (OWBM) was developed in GoldSim (refer to www.goldsim.com for details) for pan evaporation based hydrologic water balance.

DYRESM is a one-dimensional hydrodynamics model for predicting the vertical distribution of temperature, salinity and density in lakes and reservoirs. DYRESM estimates evaporation from the surface of a modelled reservoir by accounting for heating due to long wave radiation, short wave radiation penetration into the reservoir and sensible heat (surface heat convection to the atmosphere and vice-versa). Surface heat, mass, and wind and stream flow driven momentum exchanges comprise the primary driving mechanisms for DYRESM (Imberger and Patterson 1981). DYRESM is free from calibration and its governing equations are presented in Hamilton and Schladow (1997).

The conservation of mass principle is applied in both models for water balance, i.e. sum of stream flow and rainfall volumes minus sum of evaporation, seepage and overflow volumes equals change in reservoir storage for each simulation time step. Simulated volumes are represented as water levels based on a relationship between reservoir storages and corresponding water elevations. DYRESM and OWBM differ in estimation approach for evaporation from the reservoir surface. OWBM estimates evaporation volumes by multiplying a pan factor to pan evaporation depths and reservoir surface areas. DYRESM considers the latent heat of vaporisation for evaporation estimation. Since the Ophthalmia reservoir also loses water from seepage, it was set to zero in both models to isolate this unknown. Both models were initialised with a known water level corresponding to 20 November 1994 and daily simulations were undertaken from 20 November 1994 to 31 December 2010. The simulation period was guided by the availability of meteorological data required for DYRESM. Only gauged stream flows were used in modelling.

Data

DYRESM requires bathymetric relationships (Figure 3), daily time series of meteorological data consisting of wind speed and vapour pressure (5**Figure**), global radiation or shortwave and air temperature (Figure 6), longwave, and rainfall (Figure 6), and daily time series of stream flow (Figure 7), water temperature and salinity. Reservoir overflows are calculated by the model. Regulated outflows from the reservoir can be provided in the form of a daily time series.

OWBM used the same bathymetric data (Figure 3), gauged stream flow (Figure 4) and rainfall (Figure 7) in addition to the daily time series of pan evaporation in Figure 7. Average annual pan evaporation and rainfall for the period of 1994 to 2010 are 3262mm and 384mm respectively.

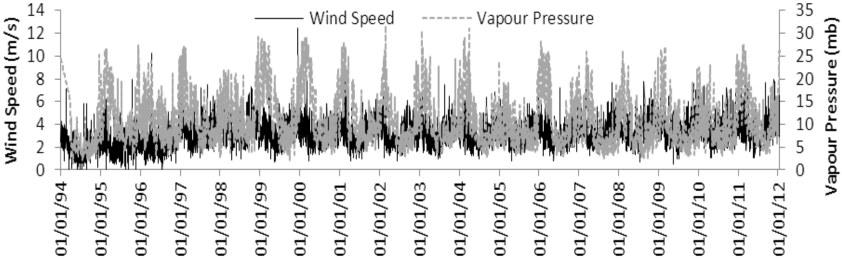

***Figure 5** Time series of wind speed and vapour pressure measured at Newman Aero (BOM7178)*

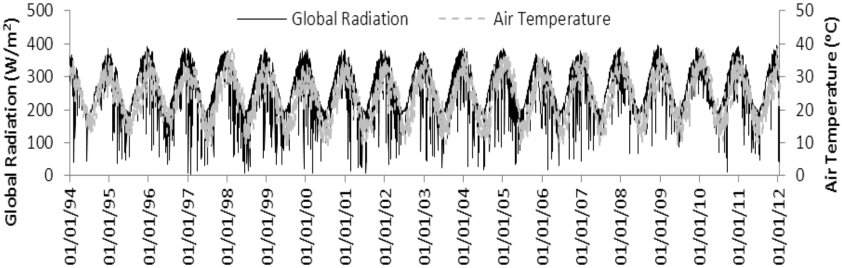

***Figure 6** Time series of global radiation and air temperature measured at Newman Aero (BOM7178)*

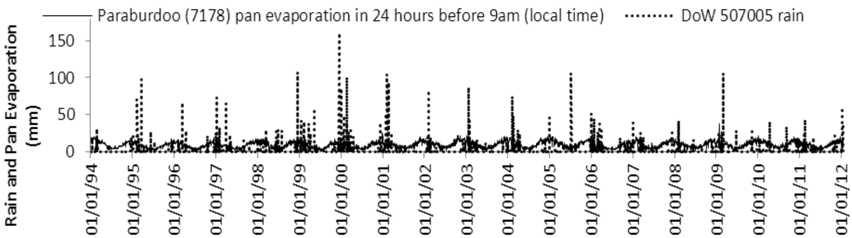

***Figure 7** Time series of pan evaporation from Paraburdoo Aero (BOM7178) and rainfall from DoW507005*

All required meteorological time series were obtained from BOM7176, Newman Aero (see Figure 2). This station is less than 10km south-west of Ophthalmia Dam. Longwave radiation was estimated from cloud cover data within DYRESM. Rainfall data measured at the DoW gauging site 507005 located adjacent to the stream flow gauging site 708011 was used. This station is 9km south-west of the dam. The DoW site 708011 is 1.82km north-west of Newman Aero. The data gaps in meteorological time series were filled by regression relationships with data from the BOM station at Wittenoom (5026). The nearest pan evaporation time series was available at the BOM station Paraburdoo Aero (7178). The Wittenoom and Paraburdoo Aero stations are 194km and 216km west of the dam (see the inset map in Figure 2 for location).

Results

Figure 8 shows simulated Ophthalmia Dam water levels and vertical distribution of salinity from DYRESM. This figure suggests that the Ophthalmia reservoir remained fully mixed during the simulation. The water level simulated from DYRESM was matched by OWBM to calibrate a single pan factor value for the Ophthalmia reservoir. The OWBM time series in Figure 9 was produced by using a pan factor of 0.54. Differences in gauged and OWBM simulated water levels of Ophthalmia reservoir provided estimates of seepage, which was estimated to range from 5mm/day to 7mm/day.

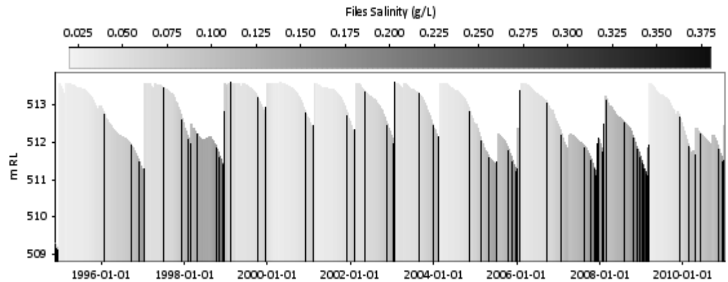

Figure 8 *Simulated Ophthalmia Dam water levels and vertical distribution of salinity using DYRESM*

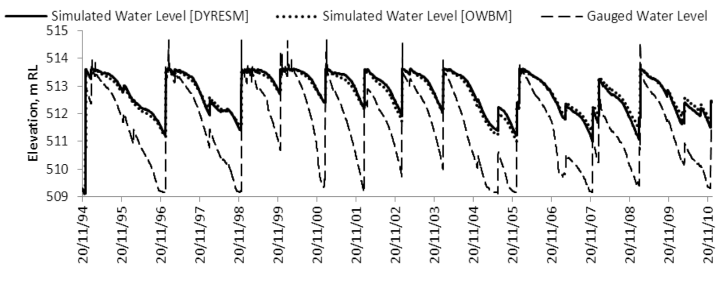

Figure 9 *Comparison of gauged water levels with simulated water levels using DYRESM and OWBM without dam seepage loss, with gauged Fortescue River stream flows and a pan factor of 0.54.*

Sensitivity analyses were undertaken in DYRESM by increasing time series values for global radiation (short wave), air temperature, wind speed and stream flow water temperature. The scenarios and results of the sensitivity analyses are summarised in Table 1. The purpose of the sensitivity analyses was to explore meteorological conditions that would increase evaporation in DYRESM, such that the back calculated pan factor in OWBM would be equal to the regional value of

0.62. The data for Scenario 5 and Scenario 6 (Table 1) indicate that all of the listed variables need increasing by 8.5% to obtain a pan factor of 0.62 for Ophthalmia Dam.

Table 1 *Summary of sensitivity analyses results*

Variables	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario
Global Radiation	1.00	1.00	1.00	1.30	1.10	1.07
Air Temperature	1.25	1.00	1.00	1.00	1.10	1.07
Inflow Temperature	1.00	1.00	1.25	1.00	1.10	1.07
Wind Speed	1.00	1.25	1.25	1.00	1.10	1.07
Mean daily elevation difference from base case	0.22	0.05	0.05	0.21	0.19	0.11
Pan Factor	0.75	0.57	0.57	0.65	0.64	0.60

The temperature gradient from Newman Aero to Wittenoom (194km away) indicates that air temperature at Ophthalmia Dam could only increase by 0.5%. The regional maps for air temperature and solar exposure from BOM (http://www.bom.gov.au/climate/averages/ maps.shtml) also support this. Hence the pan factor for Ophthalmia Dam is likely to be less than 0.6.

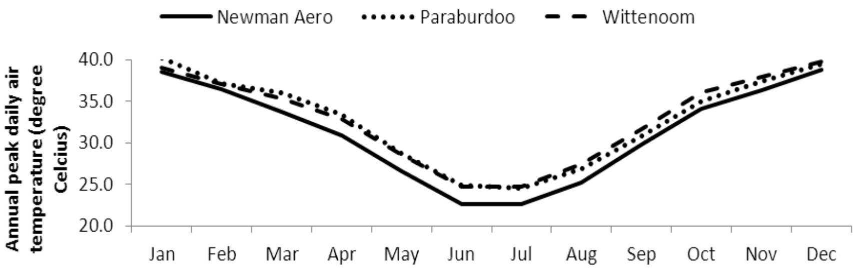

Figure 10 *Comparison of annual average daily maximum air temperature from Newman Aero, Paraburdoo and Wittenoom (1997 to 2010)*

Conclusions

The pan factor for Ophthalmia Dam near Newman was found to be 0.54, which is 0.08 less than 0.62 as per Map14 in Luke et al. (1987). This finding for Ophthalmia Dam suggests that the pan factor for areas within 220km from Ophthalmia Dam is likely to be less than 0.6. The choice of a pan factor for designing evaporation ponds or other mine water assessments depends on local site conditions and measured data. However, consideration should be given to the impact resulting from using a pan factor value lower than Map14 in Luke et al. (1987) by up to 0.1 prior to decision making.

Acknowledgements

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