Hydrological modelling of four ephemeral claypans in south-west Australia

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Abstract

Water depth were modelled at four ephemeral claypans in south west Australia using simple bucket models that were based on daily precipitation and evaporation data. The claypans covered a rainfall gradient from 457 to 766 mm and the models predicted average winter inundation periods of between 189 to 221 days, much longer that recorded for vernal pools of California's Central Valley. The model for the Ellen Brook wetland suggeted a 16% longer inundation period than an alternate more highly parameterised model.

Introduction

Models of water depth in four claypans were constructed for the period May 1979 to December 2017 based on simple bucket models that rely on input of daily precipitation and evaporation following the methods outlined in Vanschoenwinkel et al. (2009) and Tuytens et al. (2014). This model is defined as:

dt = d(t-1) + (P*R) - E, where:

- dt = water level at day t (mm);
- dt-1 = water level at day t-1 (mm);
- P = cumulative rainfall on day t (mm);
- R = pool-specific catchment factor representing water depth increase in wetland for each mm rainfall (estimated from data);
- E = pool-specific daily evaporation (mm)

and where E = daily Pan Evaporation * lake_pan coefficient (estimated iteratively)

The original model used the parameters – ***Area class A Pan*, *Area of Pool* and *C coefficients*** to calculate E. These were combined into a single *lake_pan coefficient*. This coefficient was estimated by iteratively fitting the model for the calibration period and testing against actual depth measurements. The lake_pan coefficient giving the highest correlation between the simulated and measured depth data was used (adjusted r-squared $\geq$ 0.80 across all wetlands).

Simple bucket models assume impervious substrates, perpendicular sides and no inflow or outflow of water. Claypans break these assumptions in a couples of ways. The substrate is not impervious. These cracking clays require some initial rainfall to initiate swelling and sealing of pool floor. The sides are not perpendicular. In addition the Ellen Brook claypan is not isolated and at height of ca. 200 mm it is symmetrically connected to several hectares of other claypan pools.

Data Sources

Four claypans were sampled, at two sites (Ellen Brook and Mogumber) two years of daily water depth data and a variable number of independent depth gauge measurements were available (736 and 153 respectively). Water depth was measured by data loggers at claypans in Drummond Nature Reserve (2011-2017) and in Brixton Street wetlands (June to October 2017). Some independent gauge measurements were also available for Brixton Street.

- Daily water depth data Ellen Brook and Mogumber - N. Gibson
- Long term depth data Ellen Brook and Mogumber - G. Kuchling
- Depth data Drummond Nature Reserve - D. Cale
- Depth data Brixton Street - L. Bourke
- Daily rainfall and daily & monthly evaporation data - Bureau of Meteorology (BoM).

Ellen Brook and Mogumber

Daily depth: collected for the two wetlands from 2016-03-10 till 2017-12-31 from daily photographs of a depth gauge using Reconyx PC-900 cameras. Vegetation obscured the depth gauge at Mogumber from 2016-09-15 to 2016-11-05.

Daily pan evaporation: Daily data is available from Perth Airport (BoM Station 9021) for the period 2009-01-01 till 2017-12-31. Monthly pan evaporation is available for the same station from 1968-10 till 2017-05. Estimates of daily data pre 2009 were calculated by (monthly pan evap / days in month).

Daily rainfall: extracted from closest BoM station with sufficient time series. For Ellen Brook data was extracted from Perth Airport (BoM Station 9021, 22 km away). For the Mogumber claypan Wannamal (BoM Station 9040, 7.2 km away) was used. Perth Airport had few missing data. Wannamal had approximately 10% missing. The vast majority of these occurred when the gauge was not read for 2-4 days following/during a rainfall event. These missing days were coded to zero which will have the effect of delaying depth increases in claypan for 1-3 days. In addition rainfall data was missing for April 2017. As no rainfall was recorded over this period at a station 10 km away these data were set to zero.

Model validation: Manual depth gauge readings taken from Ellen Brook over period May 1979 - December 2014 at a previous depth gauge located within 2 m horizontally of current gauge (G. Kuchling pers.comm.). Depths of the current gauge were corrected to same height as historical data. Modelling of water depth was projected back to May 1979 covering the same period as the gauge readings.

Water depth data (2000-2015) was available from 3 gauges (in three different wetlands) at the Mogumber claypans, one of which is within 2 m horizontally of new gauge (G. Kuchling pers.comm.). The old gauge had fallen over before the installation of new gauge. Half a dozen readings of the other two gauges and the new gauge suggest the height difference of 40 - 50 mm. No correction was made and assessment of model validation need to take this into account.

Brixton Street and Drummond

Water depth at the Brixton Street and Drummond claypans were measured using data loggers.

Daily depth data: Data logger depth measurements were collected from the NE wetland at Drummond NR from April 2011 till December 2017 (D. Cale pers. comm.). Data logger depth measurements were collected at Brixton Street April 2017 to October 2017 (L. Bourke pers. comm.). A few independent depth gauge readings were also available.

Daily pan evaporation: As described above

Daily rainfall: extracted from closest BoM station with sufficient time series. For Drummond data was extracted from Wattening (BoM Station 10134, 12 km away). For Brixton Street, Gosnell City (BoM Station 9106, 5 km away) was used. Missing data treated as above.

Model validation: For Drummond the last 3 years of data was used to build the model, the previous three years was used to validate it, in addition to a number of depth gauge measurements. At Brixton Street 23 depth gauge measurements were available for validation taken over the same time period as the data logger data.

Results

Wetland water depth for the period 1979-2017 was modelled for the four wetlands, with the main focus of the study being the timing and variability of the long winter inundation (Table 1). An overview of the fitted models is provided below.

Table 1. *The location of the four claypans which covered a geographic range of some 110 km and with mean annual rainfall varying from 460 to 770 mm (BoM weather stations).*

Parameter	Brixton	Ellen.Brook	Mogumber	Drummond
Mean annual rainfall (mm)	766.1	653.1	583.8	457.5
Latitude	-32.031	-31.7548	-31.0934	-31.3126
Longitude	115.9707	116.0361	116.0355	116.4108
Datum	WGS84	WGS84	WGS84	WGS84

The lake_pan coefficient calculated on a daily basis was higher than literature findings for coefficients calculated on a monthly basis but in line with earlier work reported by Vanschoenwinkel et al. (2009) using the same methodology reported here. Model fit was measured by adjusted r-squared on the calibration data (Table 2, Figure 1). The model for the Drummond claypan showed a distinct lag between commencement of rainfall and wetland filling in one year. The reasons for this are not clear but may represent local variability in rainfall events or the initial permeability of the claypan floor.

Table 2. *Parameters used in models, R coefficient (representing increase water depth for each mm of rainfall - estimated from the data), lake_pan coefficient (representing variation in evaporation in relation to a class A pan - fitted iteratively) and maximum depth. Adjusted r-squared represents correlation between measured data and modelled data over calibration period.*

Parameter	Brixton	Ellen.Brook	Mogumber	Drummond
r coefficent	1.9	3.12	2.33	2.7
pan to lake coefficent	0.88	1.51	1.42	1
max depth	325	425	600	480
model adj r-square	0.9521	0.9107	0.8294	0.8012

An example of model fit versus measured depth is shown for Ellen Brook (Figure 1). The model shows reasonable accuracy for iniation and drying of the wetland and for inital and final filling rates. The model over estimates pool depth above about 200 mm due to its symmetrical connection to other claypan pools above this height, a factor not accounted for in the model.

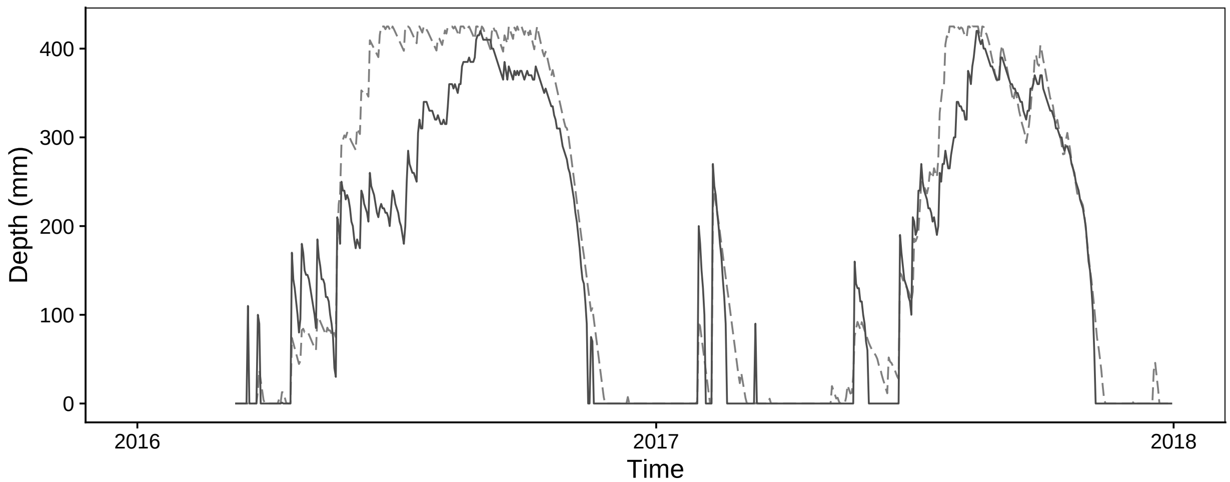

Figure 1. *Measured depth (solid line) vs modelled depth (dashed line) for Ellen Brook claypan. The model is less reliable above 200 mm when the pool overflows.*

Model validation show high adjusted r-squared values (all ≥ 0.70) with somewhat better fits for the Brixton Street and Drummond claypans than for Ellen Brook and Mogumber (Table 3).

Table 3. *Model validation statistics showing slope, aspect and correlation (adjusted r-squared) between model and independent data collected over the validation period.*

Parameter	Brixton	Ellen.Brook	Mogumber	Drummond
slope	1.02	0.88	0.82	1.25
intercept	56.7	164.8	912	33.3
n	23	736	153	998
adj r-square	0.9119	0.7021	0.7329	0.9263

The models predicted mean length of the winter inundation varying between 189-221 days (Table 4). While similar levels of variability seen across all wetlands the two claypans from the drier region were somewhat more variable than the two claypans from the wetter region. In addition to main winter inundation period summer rainfall can effect wetland filling outside of the normal season trend. The models suggest all four wetlands were filled for periods of 29-66 days in the summer period at least once over the 39 years from 1979 to 2017 (Table 4).

Table 4. *Mean number of the days (with standard deviations) the claypans were flooded in winter and the maximum number of days they were flooded on at least one occasion over the summer period of the 39 years modelled.*

Parameter	Brixton	Ellen.Brook	Mogumber	Drummond
mean days inundation	220.6	204.1	188.6	204.6
sd days inundation	25.35	23.86	31.84	31.3
longest summer inundation	50	57	29	66

When model predictions grouped into three 13 year periods there was no significant difference between the predicted numbers of days of the winter inundation between these time periods (Table 5). However there was a clear trend with increasing variability in the length of inundation of the wetlands over time (Table 5).

Table 5. *Temporal variation in mean number of the days (with standard deviations) the wetlands flooded in winter for subsets of 13 year periods covering the 39 years modelled.*

Parameter	Brixton	Ellen.Brook	Mogumber	Drummond
mean days inundation 1979-1991	223.8	206.3	194.3	209.4
mean days inundation 1992-2004	216.9	203.4	193.2	203.1
mean days inundation 2005-2017	221.1	205.3	178.2	201.5
sd days inundation 1979-1991	23.6	17.2	22.1	20.9
sd days inundation 1992-2004	20.9	23.2	20.5	27.3
sd days inundation 2005-2017	31.8	28.5	46.1	43.3

Timing of fill events of the winter flooding was similar for the two wetter claypans (Brixton Street & Ellen Brook) and the two drier claypans (Mogumber & Drummond). Duration was more variable (Table 6). Note duration is one day less than the number of days inundated.

Table 6. *Mean duration of flood events with mean day of year the claypans began to fill and the mean day of year on which the claypans dried.*

Parameter	Brixton	Ellen.Brook	Mogumber	Drummond
Average duration (days)	220	203	188	204
Average start (day of year)	125	127	139	137
Average end (day of year)	344	330	327	340

The modelled hydrological cycle at Ellen Brook for the period 1979-2017 (Figure 2) shows increased variability in recent decades.

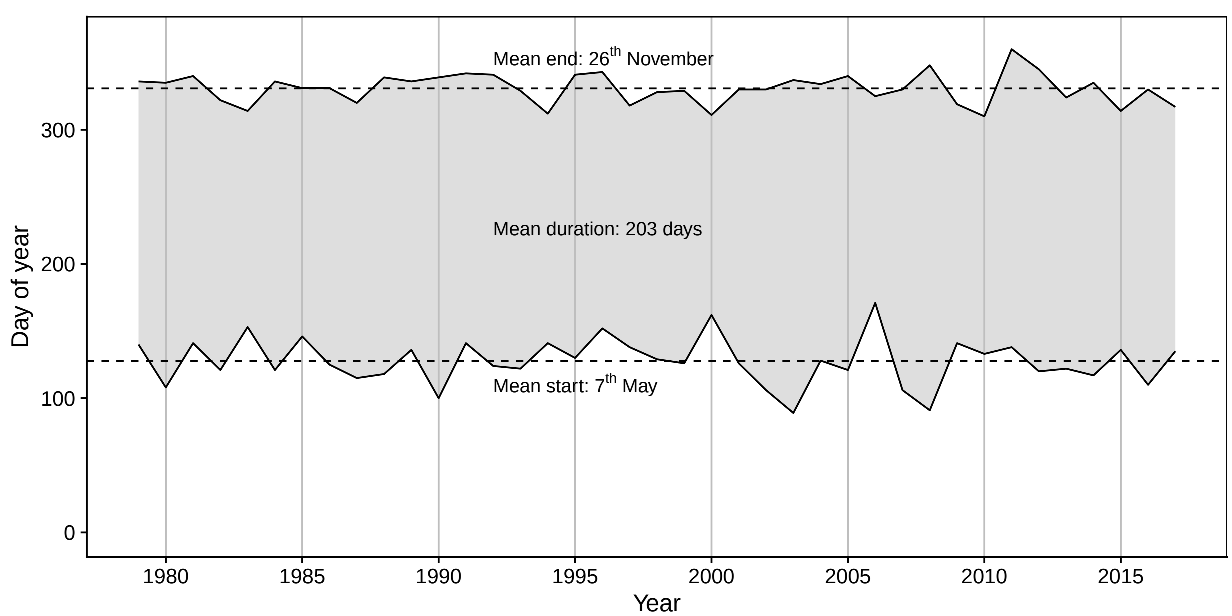

Figure 2. *Modelled hydrological cycles at Ellen Brook covering the period 1979-2017.*

Discussion

A more highly parameterised model has been recently been developed for Ellen Brook (Mitchell et al. 2012; Tareque 2016) but is not yet publicly available (Coletti et al. submitted).

The calibrated model shows high correlation with measured depth data but no validation has been undertaken. Mitchell et al. (2012) model predicts average hydroperiods for the period 1990–2009 of 176 days cf. 205 days for a simple bucket model with an r-squared value between the two model predictions of 0.50 (Figure 3 - data extracted from their Table 1, conversion assumed 30.44 days / month).

The high degree of parameterisation required by Mitchell et al. (2012) model would make it difficult to apply to other wetlands without the commitment of significant resources.

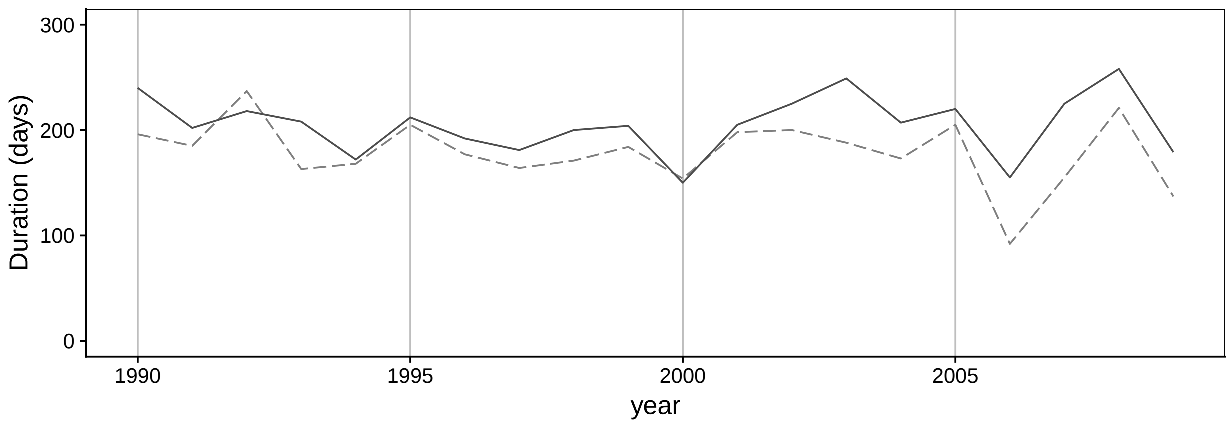

Figure 3. *Comparison modelled duration of wetland inundation for the period 1990 - 2009 for the simple bucket model (solid line) versus Mitchell et al. (2012) more parameterised model (dashed line).*

Conclusions

While the simple bucket models used to predict claypan water depth do not accurately reflect all facets of wetland hydroperiod they appear to give reasonable estimates of the timing and duration of the long winter inundation period. The four wetlands showed largely congruent patterns with differences related to local variation in annual precipitation. Average predicted winter inundation period based on our simple bucket model was ca. 2.5–3 times that recorded in Californian vernal pools of the Central Valley. A more sophisticated model for Ellen Brook suggests our model may overestimate hydroperiod by 16.5% but that model is yet to be validated (Mitchell et al. 2012).

References

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Acknowledgements

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