EVAPCALC SOFTWARE FOR THE DETERMINATION OF DAM EVAPORATION AND SEEPAGE

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ABSTRACT

Irrigation accounts for approximately two thirds of fresh water use across Australia, and evaporative loss from a million or so small dams constitutes a significant wastage of this valuable resource. The Pressure Sensitive Transducer / Automatic Weather Station (PST/AWS) technique can be used to quantify the rate of evaporative loss from farm dams, and distinguish this from seepage occurring through the dam walls and floor. EvapCalc version 3.0 software calculates dam evaporation based upon established Penman-Monteith theory, and also Morton's dry to wet transition algorithm for small ponds. Model outputs will be compared against direct measurements of moisture flux obtained using floating Eddy Covariance (ECV) equipment, and also DamCFD, a FLUENT based model developed at the University of Southern Queensland.

Keywords Evaporation, Farm Dam, Advection

INTRODUCTION

Background and aims

A technique to evaluate dam evaporation and seepage known as the AWS/PST method was developed as part of the Queensland Dept of Natural Resources and Water (NRW) Evaporation Control Project (Craig et al 1995). The method relies on an accurate independent estimation of dam evaporation – and that is what EvapCalc software attempts to do. The procedure is based on an industry standard method FAO56 described adequately by Allen el al 1998. From recorded meteorological variables, the FAO56 method predicts reference evapotranspiration (ETo) according to Penman-Monteith theory (P-M), with albedo and aerodynamic and surface resistance values fixed and appropriate for moist grass with a height of 12mm. The measured evapotranspiration from a particular crop is then related to ETo via a crop factor, k_{crop}. A similar approach is described in this paper, whereby, the evaporation from a particular dam may be related to ETo via a dam factor, k_{dam}.

METHOD

Analysis procedure

The analysis of data simply relies on the water balance of a dam or water storage over a specified time interval which may be expressed as

$$Q_{in} + P + \delta D = Q_{out} + S + E \qquad 1$$

where Q_{in} is the inflow, P is precipitation, δD is the change in level measured using a PST unit, Q_{out} is the outflow, S is seepage and E is the evaporation rate (all in mm/day). To increase accuracy of this analysis, tests on dams are usually carried out when Q_{in} , Q_{out} and P are zero.

The change in water depth δD is measured with PST unit(s). The evaporation term E can be estimated from the Bureau of Meteorology SILO database, or, as indicated above, from AWS-recorded meteorological parameters obtained at the actual dam site using the Penman-Monteith equation (Jensen, 2005 and Craig, 2006). These techniques offer potentially more accurate estimates since cloud cover and local windspeed are actually measured at the site, but precautions have to be taken to ensure that all meteorological parameters are measured and logged accurately, particularly solar radiation.

Water depth measurement using PST instrumentation

Pressure sensitive transducers (PSTs) were used to precisely measure water depth and therefore accurately determine seepage and evaporation loss. Water depth was measured to an accuracy of approximately ±1mm was achieved using submersible PST units with custom (per unit) compensation for water temperature variation. Each PST unit was placed at a constant 30cm height above the dam floor by a float-weight arrangement as illustrated in Figure 1.

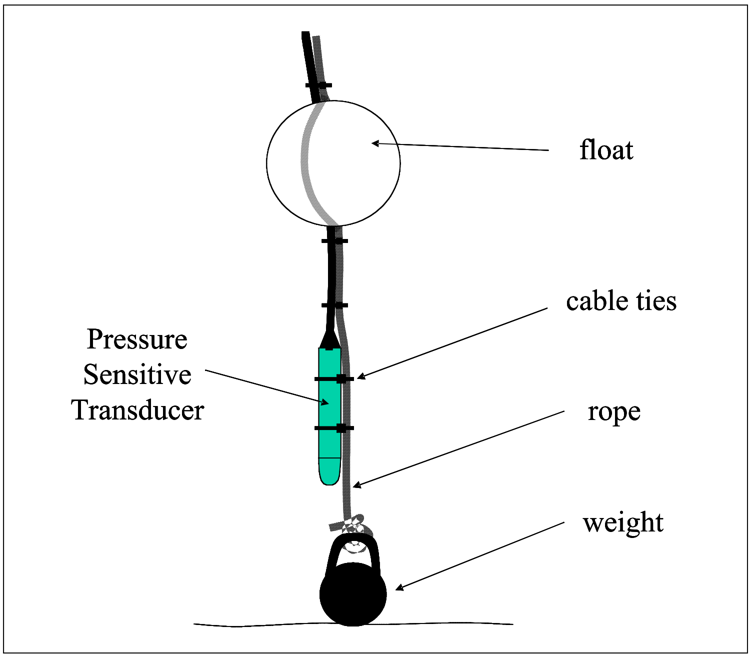

Figure 1 The PST water depth sensor suspension mechanism (schematic).

The PST type used in the original NRW study was a vented Druck (PMP 4030 350mbar sensor) with a stated accuracy of ±0.04% (±1.4mm) over a 3.5m range. The unit measures depth pressure according to the electrical resistivity of a deforming micro-machined silicon crystal, isolated from the water with a corrosion resistant diaphragm. Water pressure is measured relative to atmospheric pressure which is provided by a crushproof air tube inside the transducer cable. An Intech Nomad GP-HR 12 bit datalogger recorded PST outputs including time and date, instantaneous, minimum, maximum and average water depth over 15 minute time intervals.

Evaporation estimation using AWS instrumentation

Environdata WeatherMaster 2000 automatic weather stations were set up to read every second and record 15 minute averages of solar radiation, temperature, windspeed, humidity and rainfall. These meteorological parameters were logged every 15 minutes and then inserted into a standard Penman-Monteith (P-M) equation. For convenience, the industry standard P-M described in Allen 1998 (strictly for crop evapotranspiration or ETo) was used.

The P-M method is known as a combination method, so called because they properly combine both radiation and aerodynamic energies into one equation. They were first introduced by Penman in 1948. The Penman (1948) equation is as follows

$$\lambda E = \underbrace{\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n - G)}_{\text{RADIATION}} + \underbrace{\left(\frac{\gamma}{\Delta+\gamma}\right) f(u)(e_s - e_a)}_{\text{AERODYNAMIC}} \qquad 2$$

The original Penman 1948 equation was modified by Monteith in 1965 to incorporate a surface resistance in addition to an aerodynamic resistance term, and this is the form of the equation used in EvapCalc software. The equations are taken directly from Allen et al (1998) and are as follows :-

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad 3$$

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \qquad 4$$

$$\gamma = \frac{c_p P}{\varepsilon\lambda} = 0.067 \qquad 5$$

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26} \qquad 6$$

$$e_s = 0.6108\exp\left[\frac{17.27T}{T+237.3}\right] \qquad 7$$

$$e_a = \frac{\overline{RH}.e_s}{100} \qquad 8$$

$$R_n = (1-\alpha)R_s - R_l \qquad 9$$

$$R_l = \sigma\overline{T^4}(0.34 - 0.14\sqrt{e_a})(1.35R_s / R_{so} - 0.35) \qquad 10$$

$$R_{so} = (0.25 + 0.5)R_a \qquad 11$$

ET_0 reference evapo transpiration (mm/day)

^{2}/day)

^{2}/day)

$^{-1}$)

specific heat at constant pressure 1.013 x 10 -3 (MJ kg $^{-1}$ °C^{-1})

$^{-1}$) (1/2.45 = 0.408)

total radiation from AWS , or calculated from eqn 19, wher e a= 0.25, b= 0.5, n is actual duration of sunshine hours, N is maximum possible duration of sunshine hours (for clear skies n=N and $R_s = R_{so}$) and R_a is the average daily extraterrestrial solar radiation (from tables)

^{2}/day) where σ is Stefan -Boltzmann constant = 4.903 MJ/m ^{2}/K^4/day

Dam factor based on Morton Dry to Wet transition algorithm

A rough estimate for the seepage loss at a particular dam site is then simply the difference between the δD and E (or ETo) terms of equation (1) derived using FAO56 methodology. However, to increase the accuracy of this analysis, particularly for small dams, it needs to be assumed that

$$E_{dam} = k_{dam} \text{ x } ETo \qquad 12$$

where K_{dam} is a dam factor which relates evaporation of the dam to the FAO56 Penman-Monteith estimate. It was pointed out by Brutsaert (1982) and Morton (1983), that due to the advective flow of warm dry air, there is increased evaporation at the upwind dry to wet transition. This effect can be ignored for large dams and lakes, but is significant and cannot be ignored for ponds or other small bodies of water. The nature of the transition is shown in Figure 2 which show the evaporation from small Petri dishes at the edge of recently irrigated cotton field in the Sudan Gezira.

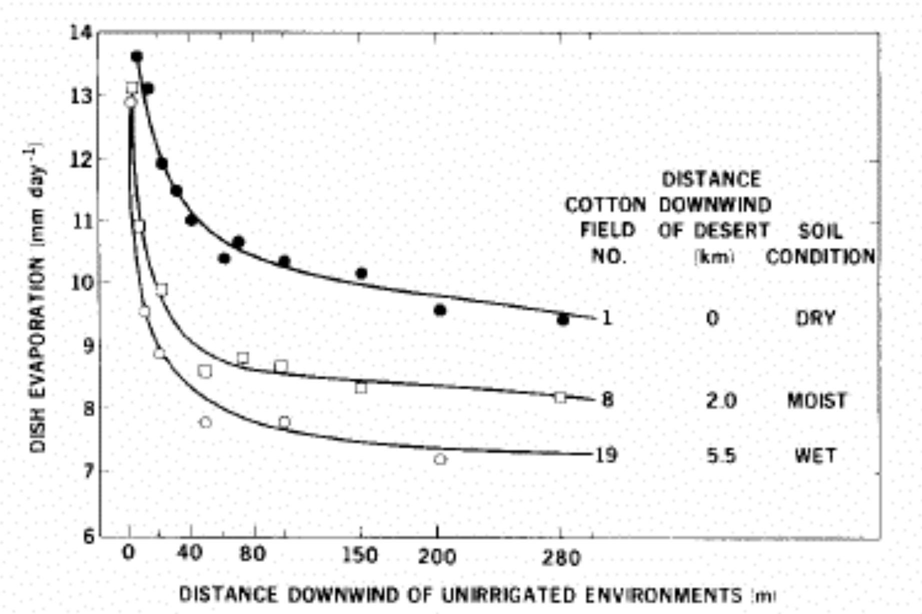

Figure 2 Davenport and Hudson (1967) comparison of evaporation rates (measured using 113mm x 36mm dishes) across irrigated cotton fields on December 27th, 1963

The evaporation in dishes at the upwind edge of the field is analogous to the potential evaporation in the land environment, E_P, whereas the evaporation at the downwind edge of the field approaches a low constant value that is analogous to open water or lake evaporation, E_L. The transition can be approximated by

$$E_{PX} = E_L + (E_P - E_L)/(1 + X/C) \qquad 13$$

in which E_{PX} is the potential evaporation at distance X downwind of the upwind shoreline, E_P is the potential evaporation upwind of the lake, and E_L is the deep lake evaporation (ie. the potential evaporation downwind of the transition) and C is a constant. In Figure 3, the value of C is 8m for the wet field, 10m for the moist field and 30m for the dry field. A simplified representation of the situation for a wet field, assumed broadly similar to that of a lake, is presented in Figure 4.

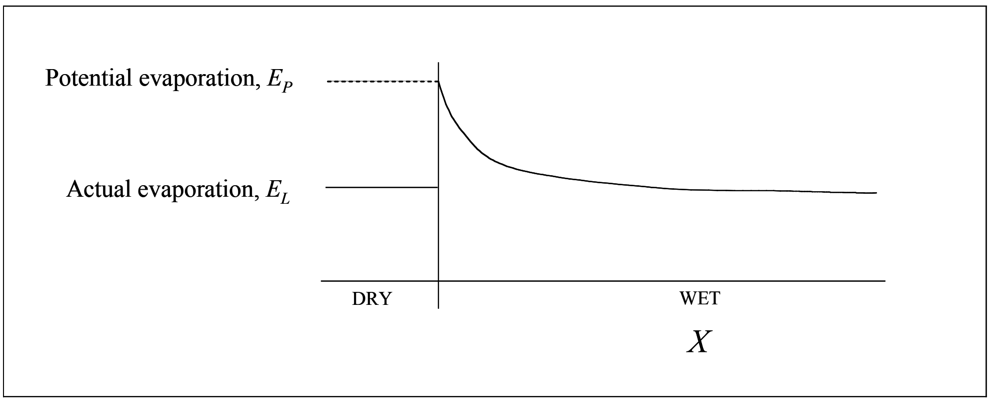

Figure 3 Morton's dry to wet transition

The average evaporation for a lake that is Xm long in the downwind direction and also Xm wide in the crosswind direction, (E_{LX}), can be estimated from integration of equation 1 as follows :-

$$E_{LX} = E_L + (E_P - E_L)\frac{\ln(1 + X/C)}{X/C} \qquad 14$$

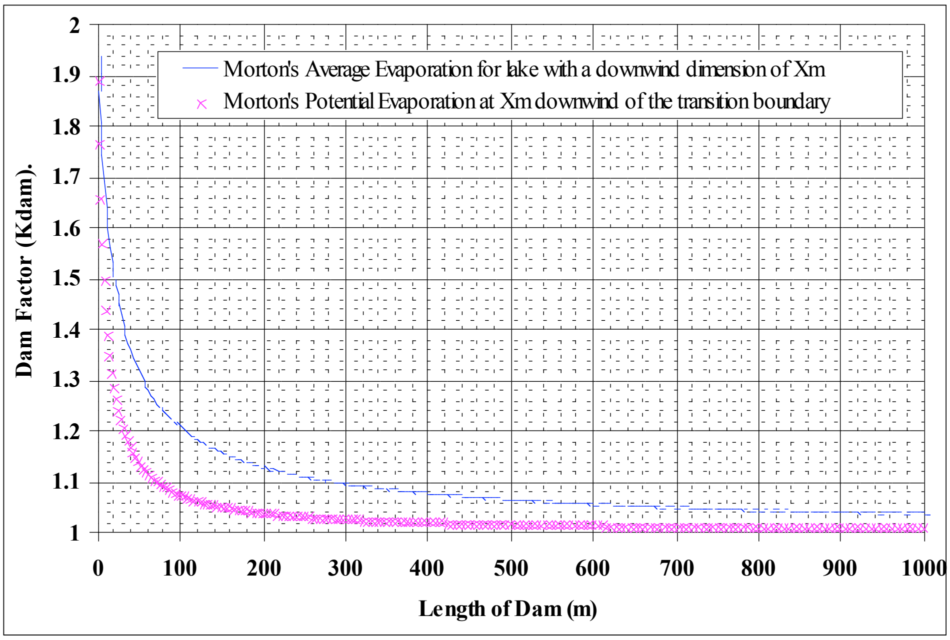

Figure 4 **Results of equations 13 and 14 plotted out with a value of 8m assumed for the constant *C*. *The true value of this constant needs to be verified using the Eddy Covariance Technique.***

RESULTS

Comparison of the P-M with Morton estimates

The appropriateness of using the ETo values derived via the FAO56 formulation of the Penman-Monteith equation (Allen et al, 1998) as indicative of open water evaporation is often regarded as open to question. However, Figure 3 shows a comparison of daily data from the SILO database (patched point datasets available at www.nrw.qld.gov.au/silo/ for the St George region, South Queensland, from the 1st January 2005 to the 26th November 2006, in which four alternative evaporation equations offered by Morton (1983) are plotted against daily FAO56 ETo. These are i) Morton Potential Evaporation (point source evaporation in a dry environment), ii) Morton Lake Evaporation (open water), iii) Morton Wet Environment (representing a recently irrigated field) and iv) Morton Actual Evaporation (limited according to water availability).

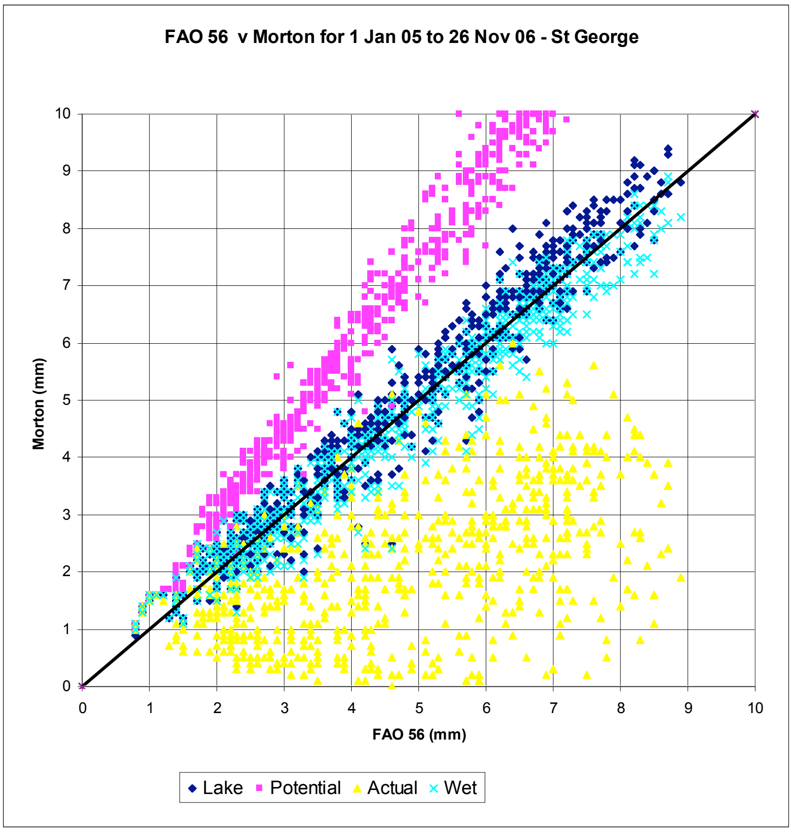

Figure 5 **Comparison of point potential evaporation (square), Morton's Lake evaporation (diamond), Morton's Wet Environment evaporation (triangle) and Morton's Actual evaporation (circle) all plotted against the FAO56 Penman-Monteith ETo estimates.**

Figure 5 shows that both ii) and iii) above are in close agreement with the estimates derived via FAO56 such that the FAO56 ETo equation suggesting that its use is acceptable for the estimation of open water evaporation. (Further analyses are provided in Morrison and Craig, 2007.)

Typical PST/AWS dataset

A typical result set is presented in Figure 6 where eighteen days of water depth data obtained from a Pressure Sensitive Transducer (PST) unit is compared to the AWS dam evaporation estimate predicted using EvapCalc version 3.0 software. Both PST and AWS instruments were continuously logged over the period, with depth and meteorological variables recorded every 15 minutes.

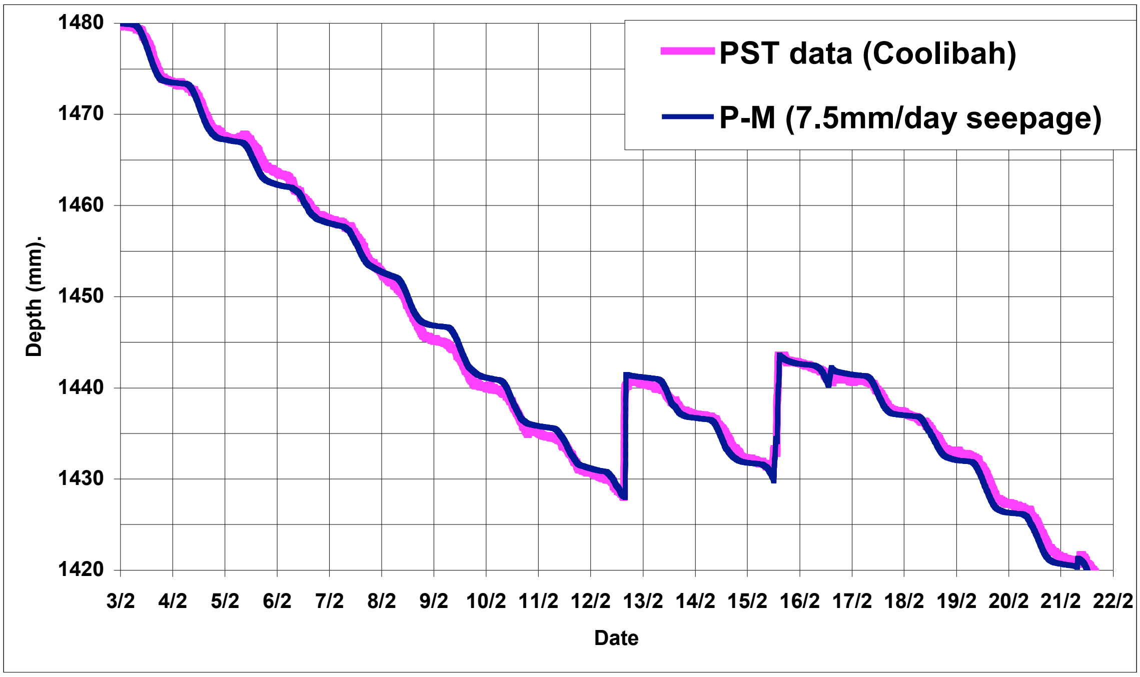

Figure 6 Graph of PST derived water depth data (thick pink line) with two instances where there was inflow of water to the dam from rainfall. Superimposed on the PST trace is a prediction of evaporation produced by EvapCalc software (thin black line) based upon Penman-Monteith (P-M) theory with a Morton based advection correction for the dry to wet transition.

Resulting software design

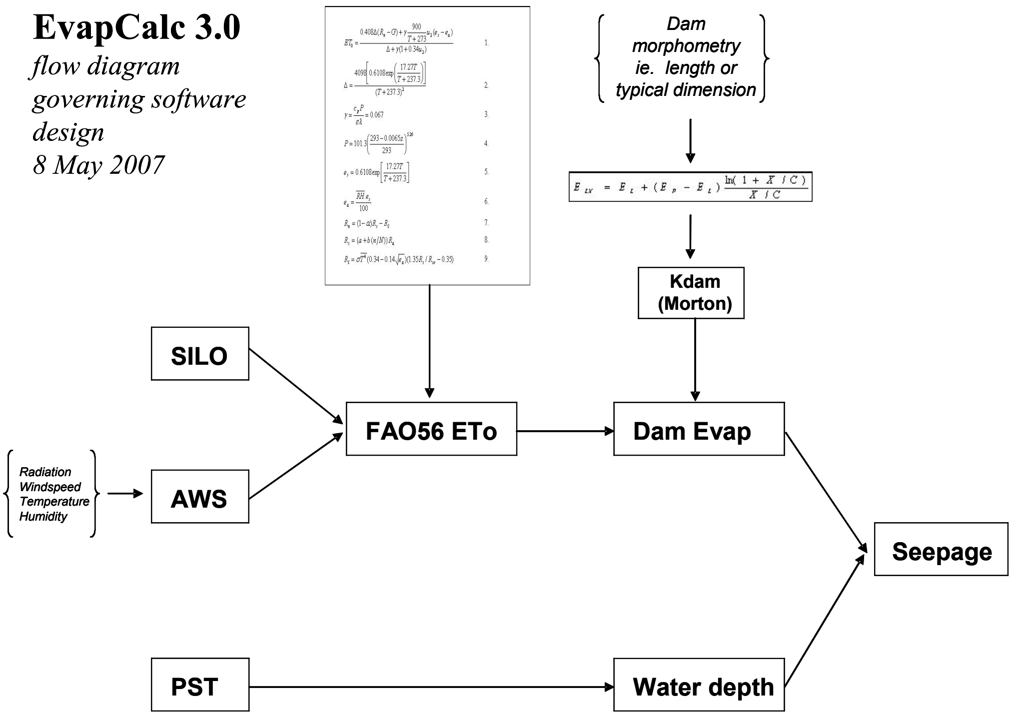

Figure 7 Software design process

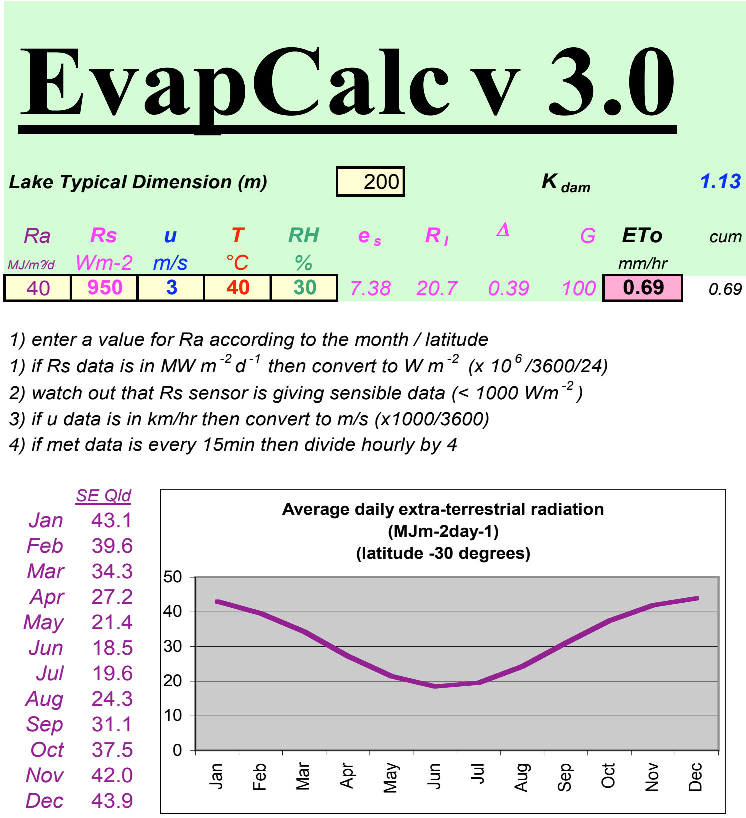

Figure 8 **Layout of EvapCalc version 3.0 data input table**

CONCLUSION

- The PST/AWS analysis method is described where logged water depth data obtained from Pressure Sensitive Transducer (PST) units is compared to 15-minute Penman-Monteith-based estimates of evaporation derived from an adjacent automatic weather station (AWS)

- The PST/AWS method has confirmed that evaporation losses in small farm dams is typically 4-7mm/day in summer, rising to 10mm/day when air temperatures exceeded 40°C.

- The method has enabled dam evaporation to be separated from seepage losses (Craig, 2006). Seepage values for Australian farm dams were found to be very variable, from almost nothing to several millimetres per hour.

- The analysis also revealed that Australian summer night-time evaporation due to heat advection effects (Brutsaert, 1982) ranged from 10 to 30% of the total daily evaporation.

- This paper has implied that that a correction algorithm suggested by Morton 1983 is reasonable to describe the advection effects arising from passage of hot dry air across the dry to wet upwind boundary of a dam

- Clearly, the value of k_{dam} introduced in equation (2) is likely to be a complex function of general dam morphometry, and this may be expected to modify the surface air flow and in turn heat exchange, water vapour exchange and in-dam water circulation.

- With the eventual objective of fully understanding and evaluating the nature of k_{dam}, an analysis of the mass and energy flows over a typical small day has been commenced using computational fluid dynamics (CFD) and dubbed 'DamCFD'. Preliminary results have been described in Craig et al. (2006).

- Data eventually generated by DamCFD for a variety of weather conditions and dam morphometries will hopefully provide the basis for a simple dam factor-based algorithm to relate farm dam evaporation to simple indices such as the P-M formula.

- It is hoped that in time the model will be fully validated using remote sensing, laser or eddy correlation techniques. These will be used to obtain real time non-equilibrium measurements of evaporative flux within the dry to wet boundary transition region and across the dam as a whole, and may be useful for validating the transition algorithm for small ponds suggested by Morton (1983).

- In the shorter term, experimental trials with petri dishes would almost certainly lead to increased confidence and refinement of the value assumed for constant C in Morton's algorithm for the dry to wet transition at a dam boundary.

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