Numerical investigation into the significance of night time evaporation from irrigation farm dams across Australia

Summary Report to National Program for Sustainable Irrigation, Land and Water Australia

Final

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NATIONAL PROGRAM FOR
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The National Program for Sustainable Irrigation focuses research on the development and adoption of sustainable irrigation practices in Australian agriculture.
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1. Abstract

Evaporation is a significant loss component from irrigation dams, and although numerous evaporation reduction methodologies exist, their adoption is hindered since they are deemed uneconomical. Any cost/benefit analyses that are done are generally based on poor evaporation estimates due to the complexities involved in evaporation prediction. One area of uncertainty is the significance of night time evaporation. Similarly, the role of wind-sheltering on evaporation can be significant but is rarely accounted for in any quantitative assessment. There is therefore a need for improved estimates of evaporation so that water management and investment decisions can have a quantitative basis. Specifically, it has been the aim of this project to ascertain the importance of night time evaporation and to provide quantitative estimates of its significance across a range of climatic regions. An additional objective was to compare the current methodology with that presented herein.

For this analysis the 1D hydrodynamic model DYRESM was used to simulate 10 idealised dams ranging in geographic (and climatic) location and morphometry. DYRESM was used to simulate the water balance and thermal structure of the dams, and in particular estimate the evaporative fluxes. The evaporative flux measurements were corrected for non-neutral atmospheric conditions, still-air conditions and for the effect of wind-sheltering.

Irrespective of a dam's size or the climatic region it is located in, the contribution of evaporation during the night was found to be considerable. Predictions from the 10 test dams suggest that between 35 – 45% of the total annual loss of water through evaporation occurred during the night. In a climate where potential evaporation is approximately 1.5 m year^{-1}, this equates to roughly 0.6 m year^{-1}. It was observed that most of the variability seen in the night time evaporation fraction was due to climate.

Although the magnitude of the variation differed between regions, all simulations showed significant seasonal variability in the night time fraction of evaporation. In particular, it was predicted that the night time contribution increased considerably during the winter months, with all sites showing the fraction increasing to 55 – 70%. This increase correlated well with an increase in the number of low wind hours and local instability over the water surface suggesting an increase in the frequency of free convective losses is responsible. Overall however, the analysis concluded that the fraction of evaporation occurring during the night time is largely insensitive to climate or dam morphometry. Evaporation mitigation strategies should therefore target the driving mechanisms causing the evaporative flux by reducing wind speed, and limiting solar heating.

Finally, it was found that using DYRESM without the advanced flux corrections still captured the dominant behaviors and could safely be used over suitably long time integrations for routine water balance assessments. However, the use of the simple flux calculation with poor surface water temperature data or predictions is problematic.

As part of this project, DYRESM (with the improvements implemented during this analysis) is to be made available freely online to aid engineers and water managers design efficient irrigation storages. The advantages of using a common framework for routine water balance assessments are also discussed.

2. Project Objectives:

1. To ascertain the importance of night time evaporation from farm dams across a range of climatic zones.

2. To quantify the day-time vs. night time losses in the different climatic zones and for different seasons.

3. To examine the sensitivity of evaporation predictions to humidity, temperature and atmospheric stability, dam morphometry, wind, and wind-sheltering.

4. To assess the robustness of the current evaporation prediction framework outlined in the scoping study, and provide an improved framework for engineers to estimate evaporation given routine meteorological and morphological information.

3. Methodology:

There are three important considerations in a quantitative analysis of evaporation from irrigation farm dams. First, to resolve sub-daily evaporation variability (i.e., day time vs. night time evaporation fluxes) it is insufficient to apply the commonly used 'bulk-transfer' evaporation equation with a constant evaporation coefficient as is usually done. This methodology assumes a neutrally buoyant atmospheric boundary layer above the water, which is only a safe assumption for daily or longer time integrations. In reality of course, the surface water temperature of the dam varies much less over a day than the air temperature, and so stable and unstable boundary layers will evolve over the course of the day. This variability greatly impacts evaporation and needs to be accounted for in any quantitative assessment. Second, evaporation dynamically affects water temperature and this is an important feed back to consider when predicting evaporative losses. Diurnal water temperature variability will also play an important role in driving night time vs. day time fluxes. Third, under low wind conditions that are typical during the summer months, convectively driven atmospheric motions drive the evaporative flux, and this can form a substantial component of the daily evaporation volume.

Given these three considerations, the model DYRESM was selected for use in this investigation. DYRESM is designed for long-term simulations of lake and reservoir hydrodynamics, and in particular for capturing vertical temperature stratification. It also accounts for sub-daily meteorological variability (including the effects of clouds, humidity, air temperature, wind and solar radiation) and importantly, includes corrections for non-neutral atmospheric stabilities. DYRESM is an easy to use, freely-distributed model developed by CWR that is currently used in over 80 countries with approximately 1500 registered users. For the purposes of this study, we also include a correction for wind-sheltering into the DYRESM evaporation algorithms and a low-wind evaporation equation designed for when convectively driven process dominate. These are of particular importance to farm dams, as these authors have shown that evaporation can still occur when there is no wind and no solar radiation input.

To test the sensitivity of the model to various dam morphometries and climates, a range of test sites were identified typical of those found across Australia. The sites chosen were based on land-use relevance and meteorological data availability. For each site, three different size dam morphometries were developed to shed light on the sensitivity of evaporation to surface-area volume relationship. The sizes chosen are based on the sizes typical of the particular climatic zone.

For each simulation, an analysis was performed to ascertain the role of night time vs. day time evaporation, and the causal factors creating the predicted response. To understand the differences between the framework presented here and the currently accepted framework, the simulations were then rerun with wind-sheltering and no correction for non-neutral atmospheric stabilities.

4. Outcomes

Role of night time evaporation

Irrespective of a dam's size or the climatic region it is located in, the contribution of evaporation during the night is considerable. ***Predictions from this study using 10 test dams in four different climatic regions suggest that between 35 – 45% of the total annual loss of water through evaporation was during the night*** - in a climate where potential evaporation is approximately 1.5 m $year^{-1}$, the night time fraction equates to roughly 0.6 m $year^{-1}$.

Bearing in mind that this was a purely numerical study examining the relative difference in behaviors of realistic but idealized study sites, it was observed that most of the variability seen in the night time evaporation fraction was due to climate. Southwest WA displayed the lowest night time contribution (36%) and Murray-Darling Basin region of Queensland showed the highest (44%). Both northern Victoria and the Barossa region of SA showed contributions of approximately 40% over the simulated year. Nonetheless, ***the analysis highlights the night time evaporation should be considered equally important across all irrigation districts across Australia, regardless of climatic zone***.

All simulations showed significant seasonal variability in the night time fraction of evaporation. In particular, it was predicted that the night time contribution increased considerably during the winter months, with all sites showing the fraction increasing to 55 – 70%. This increase correlated well with an increase in the number of low wind hours and local instability over the water surface suggesting an increased frequency of free convective losses is responsible. Nonetheless, it is emphasised that despite the winter increase in the night time evaporation fraction, the overall magnitude and importance of the night time losses decreases from summer to winter, as does the day time component.

Little variation was predicted for the different sized dams within a common climatic zone, emphasizing the one-dimensionality of the evaporation process. From a management perspective however, the importance of the evaporative loss relative to the overall water balance will vary as a result of different surface area to volume ratios.

Implications for reservoir design and management and evaporation amelioration

The study has highlighted several key design considerations. First, ***availability of necessary meteorological data is important for evaporation flux estimates***. In this study, the focus was mainly on relative differences, but for actual design projects, access to accurate solar radiation and cloud cover (or long wave radiation) data will improve evaporation predictions. Second, the study has found that ***the night time fraction is mostly insensitive to climatic zone or dam morphometry***, and should always be accounted for in water balance investigations and during the design of evaporation amelioration strategies. In particular evaporation estimation methods that solely rely on solar radiation, or use night time water level decline to calculate seepage will be erroneous. Finally, the results highlight that ***evaporation rates are not significantly impacted by storage configuration***, although the overall volume lost through evaporation as a fraction of the total dam water balance can be minimized through careful storage design (i.e. minimizing the surface-area to volume ratio).

However, evaporation rates can be mediated through siting of the dam such that its exposure to winds from the dominant direction are minimized. It should also be noted that although a large fraction of evaporation occurs outside of sunlight hours, mitigation strategies that reduce solar radiation input would still be effective over the entire day since the surface water temperatures will be lower.

5. Technology Transfer

The present study has provided a simple and powerful tool for practitioners to conduct water balance investigations of irrigation farm dams. DYRESM is an efficient way to not only conduct water balance of a water body, but for a relatively small amount of input data, it is also able to accurately capture in detail the vertical thermal structure. As a result, surface water temperature predictions, which are important for evaporation calculation, are predicted to a high level of confidence when compared to other methods. Additionally, since DYRESM is based on a Lagrangian grid, it is particularly useful for long-term investigations that are typically of interest to natural resource managers and engineers.

As part of this project, DYRESM (with the improvements implemented during this analysis) is to be made available freely online to aid engineers and water managers design efficient irrigation storages. Use of a common methodology between routine assessments is advantageous as it encourages reproducible and consistent results. During this study, additions were made to improve the evaporation output to enable simple and more advanced analysis of evaporation time series in third party programs such as Excel of Matlab.

6. Further Information

Further information about the analysis is available in the accompanying technical report "*Numerical investigation into the significance of night time evaporation from irrigation farm dams across Australia*" by Matthew R. Hipsey. This report outlines in detail the theory behind the model, the developments and the data analysis.

For further information about the use of the model DYRESM, readers are referred to the online user and science manuals, available at: http://www.cwr.uwa.edu.au/~ttfadmin/. Users can also obtain assistance in using the model and visualizing the results by joining the online model forum: http://www.cwr.uwa.edu.au/services/model_forum/.

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