

The use of stable isotopes and chloride to
assess evaporation and transpiration
impacts from flood irrigation

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Summary

Flood irrigation is traditionally believed to be particularly inefficient in terms of its salinity impact on the aquifer due to evaporation of the surface water from delivery channels and flood irrigation bays. During flood irrigation the loss of water to the atmosphere occurs through evaporation and transpiration. Both processes concentrate salts of irrigation and soil waters, however evaporation can be managed and is the undesirable component of water loss from any irrigation practice. In principle, the higher the proportion of water loss by transpiration through crop plants relative to evaporation, the higher the efficiency of water use.

Whilst transpiration by a crop can be reasonably estimated using the standard FAO56 Pan evaporation methodology, the evaporation of both irrigation water and shallow soil water at different points in a flood irrigation network can be much more difficult to quantify.

Enrichment of stable isotopes $\delta^2\text{H}$ and $\delta^{18}\text{O}$ in residual irrigation and soil waters can provide a sensitive indicator of evaporation losses, exclusive of transpiration and thus provide a parameter relevant to water use efficiency in flood irrigation systems. Isotopic techniques for measuring evaporation from lakes is theoretically sound (Dincer, 1968; Gonfiantin, 1986; Gat 1981, 1991; Simpson et al., 1987, Froehlich et al., 2005) but few applications to irrigation waters are reported.

The body of this research aims to address: 1) the development of new techniques on the basis of stable isotopes $\delta^2\text{H}$ and $\delta^{18}\text{O}$ to quantify evaporations losses from flood irrigation and 2) increase the understanding of the sources of salinity via assessment of the independent impacts evaporation and transpiration have on infiltrating irrigation waters. It does so by examining the isotopic and chloride signatures of irrigation water, soil water, groundwater and rainfall at four flood irrigation study sites in the South East of South Australia.

This research begins with the trial of two analytical models to determine evaporation rates from a variety of flood irrigation settings, on the basis of stable isotopes and calibrated against Class A pan experiments conducted in parallel. The isotopic models applied in this setting were previously developed to calculate evaporation from lakes and river systems, and the validity of applying the two

models in this setting was achieved by comparison with conventional non-isotopic methods. In contrast to nearly all of the established empirical techniques employed in agricultural water budgets which lump E and T together, the approaches applied here offers a method to quantify E losses, independent from T in a flood irrigation setting.

Results showed that heavy isotope enrichment of applied irrigation waters varied between each of the study sites. Isotope enrichment was notably different between irrigation bays that drained rapidly (+0.05 ‰ to +0.18 ‰ for $\delta^{18}\text{O}$ and +1.7 ‰ to +2 ‰ for $\delta^2\text{H}$) to those where ponding occurred for up to 18 h post application (+1 ‰ to +2 ‰ for $\delta^{18}\text{O}$ and +2 ‰ to 7.5 ‰ for $\delta^2\text{H}$). When compared to local pan enrichment, these isotope enrichments corresponded to evaporation losses of 0.2 % to 2.7 % (0.5 mm to 4 mm) and 2 % to 5 % (4.5 mm to 7 mm) respectively per irrigation.

This work was then extended to consider and quantify the independent impacts transpiration and evaporation have on infiltrating irrigation waters and residual soil waters. This research has provided new insights into the sources of salinity during flood irrigation. The combination of $\delta^2\text{H}$, $\delta^{18}\text{O}$ and chloride measurements of irrigation water and soil water, along with soil moisture monitoring post irrigation, was successful in identifying transpiration as the dominant cause of water loss from flood irrigation. Results showed that transpiration amounted to 88% of atmospheric losses and the largest contributor to salinity impacts during flood irrigation. The salinity impact (accumulation of salts in the soil) as a result of transpiration was 3 to 50 times greater than the salinity impacts caused by evaporation, and was therefore the dominant mechanism responsible for groundwater salinity increase beneath flood irrigated areas.

In the final stages of this research a Local Meteoric Water Line for the South East of South Australia was developed, to which a qualitative comparison of evaporation rates from the soil zone and irrigation waters could be compared. The LMWL developed here represents the first published LMWL based on direct precipitation for any location in the South East of South Australia.

This thesis presents the first fully integrated assessment of evaporation and transpiration in a flood irrigation setting. Ultimately this research assists in the understanding of these processes during flood irrigation and valuable new insights

into evaporation losses and sources of salinity across different flood irrigation systems and thus suggests which management strategies are more likely to improve water use efficiency and water quality.

Declaration of Originality

I hereby declare that this thesis does not include (without acknowledgment) any material previously submitted for a degree or diploma in any university other than Flinders; and that to the best of my knowledge it does not contain material published or written by another person (except where reference is made in the text).

Jason van den Akker

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Notations

I	Irrigation	mm
P	Precipitation	mm
D	Drainage	mm
ΔS	Change in soil water content	mm
ET	Crop Evapotranspiration	mm day ⁻¹
E	Actual Evaporation	mm day ⁻¹
E_p	Potential Evaporation	mm day ⁻¹
E_{pan}	Pan Evaporation	mm day ⁻¹
E_a	Isothermal Evaporation rate	(kg/m ² s)
K_c	Crop Coefficient	-
K_p	Pan Coefficient	-
Δ	Slope of saturation vapor pressure curve	kPa °C ⁻¹
R_n	Net radiation	MJ m ⁻² day ⁻¹
G	Soil heat flux	MJm ⁻² day ⁻¹
γ	Psychrometric constant	kPa °C ⁻¹
λ	Latent heat of vaporization	MJ kg ⁻¹
E_f	Enrichment factor	-
δ_i	Isotopic composition of input water or irrigation water	Per mil (‰)
δ_s	Isotopic composition of ponded irrigation water or surface water	Per mil (‰)
$\bar{\delta}_s$	Isotopic composition of atmospheric vapour	Per mil (‰)
e^*	Equilibrium fractionation factor	-
ϵ	Kinetic enrichment factor and $\epsilon = e^* - 1$	-
h	Mean relative humidity	%
Δsal_{sw}	Change in soil water salinity	mg/l
Δsal_{IW}	Change in irrigation water salinity	mg/l
SI	Salinity Impact	t/h/y
TDS	Total Dissolved Salts	mg/l
$\delta^{18}O$	Oxygen isotope	Per mil (‰)
δ^2H	Hydrogen isotope	Per mil (‰)
SL	Suction Lysimeter	-
LMWL	Local Meteoric Water Line	-
LEL	Local Evaporation Line	-