# Water Balance and Deep Drainage: Where does the water go

Willem Vervoort[1] and Mark Silburn[2]

School of Land, Water and Crop Sciences, The University of Sydney, NSW 2006[1]
Department of Natural Resources and Mines, Toowoomba, QLD 4350[2]

## 1 Introduction

Water-use efficiency of cotton production and minimising the impact of the cotton industry on the environment have emerged as issues of great importance. To improve these issues two major questions need to be answered:

1. How much water is draining from the irrigation system?
2. Where does the water go once it moves below the rootzone.

Resolving these issues is strongly dependent on a good knowledge of the water balance of the soil types used to grow cotton. The water balance describes the hydrological inputs and outputs of a farm or field in terms of irrigation (I), precipitation (P), evapotranspiration (ET), runoff (R) change in storage (ΔS) and deep drainage (DD):

$$\Delta S = (I + P) - ET - R - DD \qquad (1)$$

Of these components, the most difficult to measure is DD, which means that this term is generally estimated or calculated by difference.

Although some research has been carried out to quantify the different components of the hydrological cycle of such soils (e.g. the Australian Cotton CRC project 1.5.1), this work has been limited to a few sites, and many unknowns remain. Direct measurements of DD and complete water balance studies have generally concentrated on the uplands (dryland cropping) areas and the Southern Murray Darling Basin where the occurrence of salinity through DD is perceived as a more pressing issue. Measurements from these areas are not readily transferable to the alluvial plains of the Northern Murray Darling Basin (NMDB) due to differences in soils (extensive areas of Vertosols) and climate (summer rain versus winter rain). Until recently this was not regarded as a problem, since deep drainage on Vertosols was considered minimal, due to their low hydraulic conductivity. In fact, the Salt Audit (MDBMC, 1999) ignores deep drainage from the Vertosol plains in the NMDB. A recent review of research (Silburn and Montgomery, 2001) however suggests that deep drainage from irrigated agriculture in the area could be anywhere between 50 and 300 mm. Deep drainage can be considered a loss to the irrigator, but some losses are inevitable and, in fact, essential to prevent salts from building up in the soil profile. The leaching fraction (LF) defines the amount of water needed to flush out unwanted salts in the profile and, depending on the water quality, is generally between 10 and 20% of the applied water. If we thus apply 6 ML $ha^{-1}$ $year^{-1}$ or 600 mm, we can expect to lose 60 to 120 mm $year^{-1}$ as deep drainage due to the required LF. Considering our earlier estimate of the leaching fraction, the lower estimate seems justifiable, but the higher estimate clearly constitutes an economic loss. In addition, depending on the answer to question 2, and the quality of this water, this might be a threat to the underlying groundwater resources. The farm and landscape-scale water balances are further complicated by the existence of lighter bands of soil (palaeochannels), which are found intertwined with the Vertosols. Infiltration rates in these channels are much higher than the surrounding clays, but their spatial extent is too irregular to exclude the areas from production. The exact hydrology of these channels and their influence on the depth and quality of the local groundwater and the interaction between the channels and the river is completely unknown.

This paper describes the current state of knowledge on these issues and discusses the projects the Northern Murray Darling-Water Balance Group has been trying to establish to address the lack of knowledge in this area.

## 2 Assessing Deep Drainage

The first issue to address is the amount of deep drainage from irrigation in the NMDB. Most of the studies reviewed by Silburn and Montgomery (2001) indicated that the assumption that deep drainage is minimal, based on water content changes in the lower profile, or due to low hydraulic conductivities, is erroneous. However there generally is a high level of uncertainty associated with all these estimates of deep drainage. This means it is difficult to determine whether the deep drainage from irrigated agriculture is significant compared to deep drainage from other soil types and land uses, develop management alternatives for the different land uses to minimise deep drainage, and develop policy guidelines for water quality and estimate future trends using simulation modelling. Therefore, in order to improve the long-term sustainability of agriculture and set realistic water quality guidelines on the Vertosol plains of the NMDB, better measurements of deep drainage are desperately needed.

It raises the following question: Why is it so difficult to assess deep drainage accurately? There are two main reasons:

1. It is occurring below the rootzone that is, at 1.5 to 2 meter below the soil surface;
2. It is highly variable in space and time, similar to estimates of hydraulic conductivity (Kutilek and Nielsen, 1994).

It is the combination of these two reasons, which has made it expensive and time intensive to come up with good estimates of deep drainage in all types of soils. The first problem can be addressed by such intensive measurement techniques as a lysimeter. This involves installing a tray to catch the percolating water at 1.5 m depth in the soil. There are several technical and operational problems, which in most soils can be addressed given sufficient long-term investment. The two lysimeters operated by Queensland DNRM in Dalby, and CSU's long term lysimeter experiment in Wagga Wagga are examples of these instruments (Dunin et al., 2001; Moss et al., 2001). However, lysimeters deliver data for one point in space, with the total area generally being less than 2 – 3 $m^2$. Given the spatial variability, this value can hardly be considered representative for a 2,500,000 $m^2$ cotton field. Any accurate measurement of deep drainage therefore needs to be matched by an extrapolation of this measured value in space. Simulation models or geostatistical interpolation using ancillary data could be employed for such extrapolation. However, the shrink-swell nature of the Vertosol soil type, on which much of the cotton is produced, is an added complexity that limits the possibilities for standard measurement techniques and means current simulation models have limited predictive value (Bethune and Kirby, 2001). In addition, the quality of irrigation water can have significant temporal effect on the magnitude of the deep drainage on Vertosols, due to changes in soil structure. Clearly there is a need for a concentrated effort to develop new measurement and simulation techniques to accurately estimate deep drainage and to be able to rapidly extrapolate these measurements in space.

## 3 Where does the water go?

The second issue to address is the pathway of any of the DD after it has passed through the rootzone. Quite clearly, if the DD is irrigation water of reasonable quality and it does not raise a shallow water table or leach salts into the river, there would not be a problem. But the experience from the Southern Murray Darling Basin has taught that if it is occurring, it will create costly problems. In principle water draining past the rootzone can either, go down to an underlying aquifer (and subsequently further downwards to another aquifer), or move laterally to connected surface water.

**Table 1. Parameters used for modeling groundwater table changes due to cotton production using FLOWTUBE (Argent, 2001) and VS2Dt (Lappala et al., 1987).**

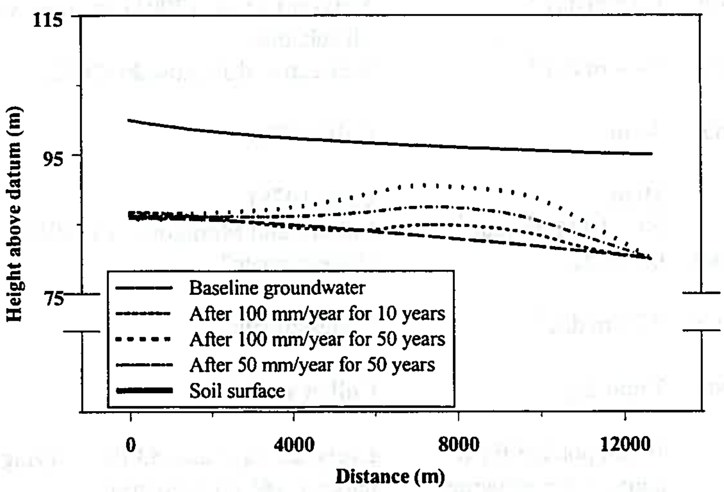
| Property | Value | Source |
|---|---|---|
| Hydraulic conductivity of the Vertosol | 0.15 m day$^{-1}$ | Vervoort et al. (2001) average value for all subsoils |
| Horizontal hydraulic conductivity aquifer (Flowtube) | 5 - 4 m day$^{-1}$ | McLean and Jankowski (2002) |
| Thickness of upper unconfined aquifer (Flowtube) | 30 m | Calf (1978) |
| Depth of water table | 10 m | Calf (1978) |
| Drainage rates cotton | 50 – 100 mm year$^{-1}$ | Silburn and Montgomery (2001) |
| Hydraulic conductivity Palaeochannel (VS2Dt) | 0.7 m day$^{-1}$ | "Guesstimate" |
| Vertical hydraulic conductivity aquifer (VS2Dt) | 0.35 m day$^{-1}$ | "Guesstimate" |
| Evapotranspiration from Cotton (VS2Dt) | 7 mm day$^{-1}$ | Cull et al. (1981) |
| Applied water (VS2Dt) | 10 cm ponded for 8 hours, 6 per growing season | Every 25 days and 53 days drying before harvest. 185 days no crop |

As pointed out earlier by Silburn and Montgomery (2001), groundwater data has given little evidence of the deep drainage moving down. Calf (1978) found that the water table of the upper unconfined aquifer in the Namoi valley around the Australian Cotton Research Instute was around 10 – 20 m depth. A recent drilling program in the Queensland part of the Murray Darling Basin has identified very saline ground water (14,000 to 45,000 EC units) at 10 -25 m deep in some parts of the MacIntyre floodplain. Some longer term monitoring bores in other parts of the floodplain, indicate rising groundwater trends. Similar salinity and sometimes even shallower groundwater tables have been encountered in other isolated areas of Southern

Queensland. In NSW no such data is available, and in fact, most attention is currently focused on declining groundwater tables in productive aquifers (McLean and Jankowski, 2002). A combination of pumping (and lower pressures in the lower aquifers) and higher pressures (due to drainage in the upper (unconfined) aquifers would increase the fluxes through the aquifer system (Jankowski et al., 2002). If salt is stored in the aquitards (lower conductivity layers) separating the individual aquifers, and flow through these is increased, it could create salinity problems in the productive aquifer system.

In order to estimate the hydraulic pressures building up in the aquifers, a simple groundwater flow model called FLOWTUBE (Argent, 2001) was used. This model has been designed to demonstrate the increase water level in an unconfined aquifer from recharge. We used literature values (Table 1) to mimic the cotton production system. FLOWTUBE results indicated that both under a 50 and 100 mm year $^{-1}$ drainage rate, significant rises in the water table can be expected in the next 50 years. Note that the extra drainage was simulated to occur only in a small part of the landscape (between 6000 and 10,000 m) and the increase in water table is localized. The exercises were all conducted with the initial water table at 10 m depth. This might be a rather high estimate, but changing the depth of the water table had little effect on the groundwater mound, which formed under the cotton production. The maximum rise was about 5 m in 50 years (Fig. 1) for the 100 mm year $^{-1}$ scenario. But all is not gloom and doom, FLOWTUBE is a very simplistic model, which uses steady state assumptions and a no-flow bottom boundary. The modeling exercise presented here uses very broad assumptions, but the modeling suggests that conservative estimates of the amount of water lost from the cotton production system could, in time, have an effect on the water table height.

**Figure 1. Changes in water table levels under different rates of deep drainage**

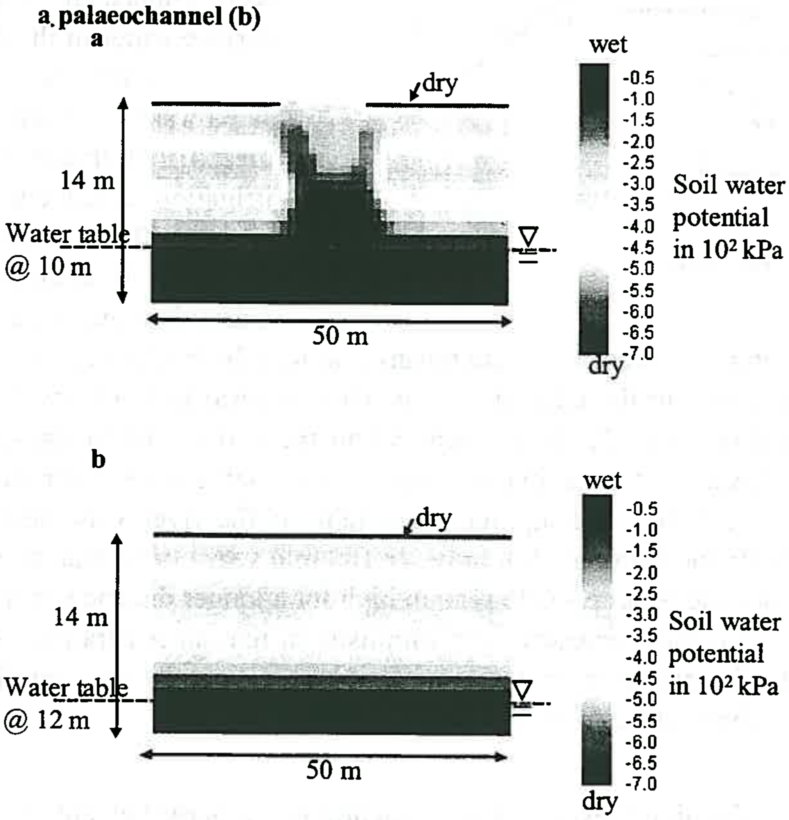



These results seem somewhat confirmed by the work by McLean and Jankowksi (2002), who observed a 2 m rise in 30 years in one bore and little or no change in the water level in most of the bores in the upper aquifer in the lower Namoi valley, even though pressures in the lower aquifers were all falling due to pumping. This lack of change in most bores is explainable using a simple calculation: The lower Namoi aquifer is reported to be 7630 km$^2$ in size and the upper aquifer is between 20 to 30 m thick (Draft Water Sharing Plan, Upper and Lower Namoi

Groundwater Sources). If irrigated cotton makes up 1.5% of the landscape and drains at 100 mm year$^{-1}$ this means, annually, a volume of $0.015 \times 7630 \times 10^6 \times 100 \times 10^{-3}$ = 11445 ML leaks into the 22890 GL aquifer (at 30 m thickness and assuming 0.1 cm$^3$ cm$^{-3}$ effective porosity). This equates to only 0.05% of the volume of the aquifer, but the real effect cannot be asserted without taking into account the exact irrigated area, local anomalies and concentrations of salts.

Palaeochannels or relict riverbeds are one of these anomalies influencing the flow of water, both in the alluvium and in the aquifer. These areas are characterized by coarser textures and therefore higher hydraulic conductivities than the surrounding alluvial material. Most of the aquifers in the alluvial plains are, in fact, located in larger palaeochannels, which can be up to several km wide. However, smaller branches of the extensive palaeochannel network can be found everywhere in the plains. The textures of these features can vary widely depending on the depositional history. Lack of expression (only small differences in texture) and or small size generally does not warrant exclusion from irrigated production. But these areas are still characterized by higher conductivities. Using a 2-dimensional finite difference model called VS2Dt (Lappala et al., 1987), the soil water profile after 2 years of irrigation can be predicted in the presence of a 15m wide palaeochannel, and without a palaeochannel (Fig. 2). Even without the benefit of colour in the figure, it is clear that water moves deeper much quicker in the presence of a palaeochannel than without (Fig. 2), and causes a rise in the ground water table, even though the difference in hydraulic conductivity between the palaeochannel and the clay is only small (Table 1). The fact that the channels form a network could also indicate that the features could support lateral movement of water through the landscape, which leads to the possibility of lateral movement of water to surface water bodies.

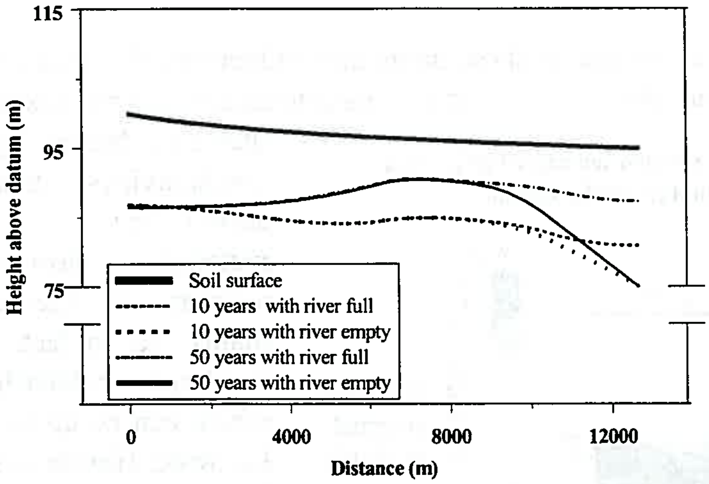
**Figure 2. Movement of water after two seasons of irrigation in the presence of a palaeochannel (a) and without a palaeochannel (b)**



Lateral movement of irrigation drainage to surface water bodies has generally not been considered, because of the low hydraulic conductivity of the alluvium. However if faster pathways exist and the hydraulic gradients are steep enough, water will move laterally. It has been suggested that the aquifers in the lower Namoi are well connected with the surface water in the Namoi river (McLean and Jankowski, 1992). This means that drainage from irrigation could contribute to return flows to rivers, in particular if a connection exists between the local, shallow ground water table and the river. This also means that high hydraulic pressures from the river might contribute to flows in the other direction. This scenario is demonstrated with another FLOWTUBE simulation (Fig. 3). In this simulation the end of the landscape was assumed to be at a constant head of 10 m above the aquifer water table if the river was full, and at a constant head of 5 m below the aquifer water table if the river was empty. All scenarios were again run for 10 and 50 years, but only for 100 mm year$^{-1}$ deep drainage. Note that the mostly full river causes the water table to remain high for a longer distance, then when the river is mostly empty. Again these scenarios are simplistic in that an Australian lowland river is never full or empty for 50 years, but the scenarios predict long time equilibrium situations, which can be used for relative comparisons.

**Figure 3. Predicted rise in groundwater using Flowtube in the presence of a mostly full or mostly empty river.**

**Assumed deep drainage from irrigation is 100 mm year $^{-1}$**




*Where does the water go?*

To tell you the truth: We really don't exactly know. Identifying exactly "where the water goes" is currently severely hampered by the lack of reliable data in terms of deep drainage, groundwater layering and degree of interaction between aquifers and surface water. The increase in computing power has meant that in recent years much effort has been spent on developing better and more sophisticated simulation models. This was more cost effective than endless field observations and has given us a much better understanding of how the natural system behaves in general. But it has also indicated where the gaps in our knowledge are, which is mainly in the uncertainty of hydraulic properties, similar to the lack of knowledge in the deep drainage estimates mentioned earlier. We believe that now is the time to reinvest in field measurements, which will drive the development of the next generation of modelling efforts. The recent drilling program in Queensland is one of the initiatives that will deliver a wealth of field information and, if sustained, could go a long way in resolving many of these issues. A similar program in NSW is urgently needed.

# 4 Northern Murray Darling Water Balance Group (NMB-WBG)

The Northern Murray Darling Water Balance Group is an ad-hoc cooperation of researchers and institutions under the auspices of the Australian Cotton CRC. Its existence is very much based on the groundwork done by Brian Hearn c.s. which has highlighted the need for better knowledge of the components of the water balance to improve the water use efficiency of the irrigated industry. The NMD-WBG has been working on establishing an integrated program to accurately measure deep drainage in the alluvial plains in the Northern Murray Darling Basin. This program considers all components of water balance in the Nothern Murray Darling Basin at the field and farm-scale. Particular emphasis would be placed on deep drainage and the complexities involved in working with the heavy clay soils in the area (Vertosols). It considers:

- Irrigation, Dryland Agriculture and Native Vegetation on Vertosols and lighter soils
- Surface and Sub-Surface Water Quality and Quantity Interactions – including the role of palaeochannels
- Uncertainty due to Measurement, Episodic Rainfall Events and the Spatial Variability of Soils

The work would:

- gather required data using a combination of heavily instrumented key sites and satellite sites,
- better understand the water balance with particular emphasis on deep drainage and its response to differing management practices, land uses and climatic events,
- enhance and validate models at the farm and field scale to improve sustainable management, and
- link these models to sub-catchment scale models to improve prediction of in-valley water quality targets.

This program would thus include both accurate measurements of deep drainage (using the lysimeters) and develop methods to extrapolate these accurate measurements in space. Thus far funding has been secured from the CRDC to construct a lysimeter at ACRI. Further funding is currently being sought from other funding organisations.

# 5 Acknowledgements

Helpful comments from Ian Heiner and Andrew Biggs are gratefully acknowledged.

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