Recharge Estimation in the Liverpool Plains (NSW) for input Groundwater Models

L. Zhang, M. Stauffacher, G.R. Walker and P. Dyce

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Abstract

Dryland salinity, caused by rising watertables, is a potential major land degradation issue on the Liverpool Plains, in northern NSW. This study aims to provide recharge estimates for the modelling of the Tertiary/Quaternary alluvial groundwater system, believed to be the origin of the surface salinisation problem in the Liverpool Plains. In particular, it aims to indicate the relativity of different sources of recharge, namely localised recharge derived from runoff-interflow from the Ranges and hillslopes, and diffuse recharge on the low lying alluvial flats. The salinity control options depend on which recharge component is predominant. This report details the methodology used to get recharge estimates for the groundwater modelling.

The runoff and interflow is estimated, using a relationship between rainfall and evapotranspiration developed by Holmes and Sinclair in 1986. This relationship relies on field data at a catchment scale, namely mean annual rainfall and percent of catchment forested. Various checks were made to assess the transferability of this relationship from 13 Victorian catchments to the Liverpool Plains. The fraction of runoff-interflow that becomes recharge to the alluvial system is not estimated here. However, unless this fraction is less than about 10%, it is expected that the localised recharge dominates the diffuse recharge processes. Full reafforestation would not reduce the current amount of runoff by more than 38% on average.
1. Introduction

Dryland salinity has been identified as a potential major land degradation issue in the Liverpool Plains. Rising water tables which lead to salinity have been caused by an increase in recharge to the groundwater system. A number of factors could cause increased recharge including tree clearing, changed agricultural practices, changed flooding regime, irrigation and increased precipitation. As the control options depend on which recharge component is dominant, it is important to sort out their relativity.

This report details the procedures that led to the water balance estimates used in the modelling of the groundwater system. This modelling was undertaken as part of an NRMS1- and LWRRDC-supported project involving AGSO, CSIRO Land & Water, NSW-DLWC and ABARE. It was initiated to provide integrated modelling tools to support decision-making on the control options at a catchment scale. As recharge is the driving force to much of the salinity, it is a key variable to this modelling exercise. The recharge estimates need to be on an appropriate time and space scale. No additional fieldwork was done as part of the task, and data from previous studies formed the basis of this work.

It should be noted that the purpose for the recharge estimation is different from that of CSIRO Land & Water in a LWRRDC-supported project grant. In that grant, the emphasis is on the difference in recharge under different agronomic practices on different land units. This is related to land management and is at the paddock scale. The focus of this study is in the catchment scale input of water into the groundwater system rather than in the detailed land management impact on recharge and its temporal variation. The aim is to understand the various components of the groundwater balance and how these may need to be changed to control salinity. An outcome of this may be that halving the recharge is needed to control salinity and then it would be necessary to go back to the more detailed recharge work to see what land management would lead to such a reduction.

In the conceptual model described in a companion report (Stauffacher et al., 1997), two types of recharge are delineated. The first is the recharge due to runoff-interflow from the Liverpool Ranges and lost to the alluvial groundwater system in the transition zone between the Ranges and the Plains. This is called localised recharge, since part of this non-evapotranspirated water from the Ranges and Hills will ultimately recharge the alluvial aquifer. The second type of recharge is the drainage of water that occurs

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under the crops, pastures and trees on the Liverpool Plains. This is called *diffuse* recharge. Control options for recharge from these two different sources can be quite different, and it is therefore important to quantify the relativity of these types of recharge. Lake Goran is also identified as a third potential recharge source to one of the sub-catchments.

Previous studies on the groundwater systems and recharge on the Liverpool Plains provide a solid background for this work. Broughton (1994 a, b, c) and Gates (1980) provided a general understanding of the groundwater processes and aquifers whereas Abbs and Littleboy (1997), Bradd *et al* (1994), Greiner (1997) gave us some insight into regional to local scale recharge processes.

The aim of this study is to build upon these local scale results so as to provide estimates from the two types of recharge in dryland affected catchments on an appropriate space and time scale for groundwater modelling. These estimates need to be linked to land and water management options in the Liverpool Plains to enable prediction of the impact of changed management practices. This publication is one of a series of publications that individually deal with the different steps involved in the biophysical side of the overall project, and does not aim at proposing sustainable management options. It will provide a framework within which different land management options can be evaluated for the socio-economic modelling work.

This report will briefly review the work on recharge estimation in the area and describe large space and time scale methodology in the context of these studies. In particular, partial afforestation of the Liverpool Ranges as a potential land change option will be considered.

2. Site description

2.1 Physiography

The Liverpool Plains catchment is situated in eastern Australia, northern New South Wales (see Fig.1). These plains encompass an area of 11,728 km² and are bounded to the South by the Liverpool Ranges which form part of the Great Dividing Range, to the east by the Melville Ranges and to the west by the Warrumbungle Range and Pilliga Scrub. Two rivers, the Mooki and Cox’s Creek, drain northwards into the Namoi River, which is a tributary of the Murray-Darling river system.
2.2 Hydrogeology

The conceptual model for the groundwater system is described in Stauffacher et al. (1997). Only the Tertiary/Quaternary unconsolidated alluvial deposits are considered to be important to the salinity process, as the underlying fractured rock systems are thought to have too low a conductivity to be significant. These alluvial groundwater systems can be sub-divided into five almost independent groundwater systems (Fig. 2). In each of these sub-systems, the deeper part of the alluvium, the Gunnedah Formation, contains gravels and sands, while the upper part, the Narrabri Formation, contains mostly clays and silts. These two formations are in partial hydraulic contact. All of the sub-systems are constricted at their outlets by basement highs. Over the lower half of the catchments, the Narrabri groundwater system is saline with EC values up to 35 dS/m, while the Gunnedah is uniformly fresh (EC<2dS/m).
This study will focus on the three most salinised catchments, the Pine Ridge catchment (no. 4), the Upper Mooki catchment (no. 3) and the Lake Goran catchment (no. 2). These catchments are characterised by poor surface drainage and the bedrock topography (outcrops) is impeding groundwater flow in the alluvial aquifers. The groundwater outlets of these catchments are laterally and vertically constricted by bedrock highs, leading to discharge and evaporative salt concentration on the lower reaches.

2.3 Landuse

European settlement began in the 1830’s and the land was predominantly used for sheep and cattle grazing until the 1880’s. Then cropping became an important land use on the lighter textured “red soils” on the footslopes, resulting in tree clearing. In the early fifties, the heavy clays of the low lying alluvial flats became the main agricultural areas. Cropping on the footslopes was progressively abandoned and replaced by grasslands used for grazing. The steep ridges of the Ranges are nowadays covered by different species of eucalypts.

The land surface has been divided into a number of so-called Unique Mapping Areas (UMA’s, Fig 3). These areas represent biophysically homogeneous landscape units used as a framework for research and management within the catchment. Initially, 11 UMA’s were defined for the Liverpool Plains (Johnston et al, 1995).

For the purpose of the groundwater modelling, they were simplified and some were merged according to their hydrogeological characteristics (Fig 3, Table 1), resulting in three remaining UMA’s. The first of these are the Liverpool Ranges and Hills, which comprise the non-alluvial component of the land surface. Generally, these are the higher rainfall zones and the soils comprise shallow red-brown earths. Because of the low transmissivity of the underlying bedrock, any water not evaporated or transpired moves laterally as surface runoff or sub-surface flow. The second UMA comprises the colluvial/alluvial rims, defined as Tertiary/Quaternary alluvial areas with slopes greater than 1%. In the conceptual model, these are the localised recharge (runoff-interflow from the Ranges and Hills) area to the semi-confined Gunnedah Formation. The third UMA is the component of the Tertiary/Quaternary alluvial system with slope less than 1%. These are considered to be the diffuse recharge areas of the Narrabri Formation and consist mainly of Black Earths. The surface area of these three UMA’s are 55, 24 and 21% of the Liverpool Plains respectively.

<table>
<thead>
<tr>
<th>UMA</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMA 1</td>
<td>Ranges and hills. Low permeability, runoff.</td>
</tr>
<tr>
<td>UMA 2</td>
<td>Colluvial/alluvial rims. High permeability. Local recharge.</td>
</tr>
<tr>
<td>UMA 3</td>
<td>Alluvial plains. Diffuse recharge.</td>
</tr>
</tbody>
</table>

Table 1.- Description of unique mapping areas in the Liverpool Plains
2.4 Climate

The annual rainfall decreases from over 1000mm at the top of the Liverpool Ranges (elevation up to 1000m) in the south east to 600mm on the flats near Pine Ridge (elevation: 310m) (Fig. 4). It falls predominantly in the summer months, often in short duration, high intensity rain or thunderstorms. Rainfall is extremely variable between years and seasons, resulting in drought, low river flows or flood conditions. Annual average potential evaporation of the area is 1900mm, with a maximum monthly average of 275mm in December and a minimum of 65mm in June.
3. Methodology

3.1 Estimation of diffuse recharge

Greiner (1997) calculated diffuse recharge in the Liverpool Plains using APSIM (Agricultural Production System Simulator, Keating et al., 1995) and the results are summarised in Table 3. APSIM is a software environment that combines plant growth and soil water balance models. The plant growth model consists of sub-models that simulate wheat, sorghum and pasture growth. The soil water balance is considered as a tipping bucket. Daily rainfall data measured at Gunnedah for the period of 1878-1992 was used in the simulations and the soil was considered as red-brown earth (Greiner, 1997). The average recharge in the Liverpool Range was obtained by extrapolating the APSIM simulations from the dryland plains.

In a separate study, Abbs and Littleboy (1997) evaluated the major environmental and management factors influencing recharge on the Liverpool Plains. They calculated recharge for combinations of two sets of weather data, 47 soil types and 11 land management practices using the cropping system model PERFECT. The model incorporates dynamic crop growth modules, a water balance module, and an erosion module. The water balance module calculates the volume of water in a soil column on a daily time-step with a simple bucket model (Littleboy et al., 1992). Their results are summarised in Table 3.

Steady state deep drainage estimates were made on the Liverpool Plains by Kalma and Gordon using the SaLF model. The calculations are based on a steady state salt balance estimates using soil sample data (CEC, clay %, exch. Na). The calculations indicate that 55% of the 92 sampled sites would have recharge values less that 20 mm/y (Table 3).

Based on these studies, a constant value of 20mm/y of diffuse recharge was chosen for the groundwater modelling. Should the groundwater modelling reveal this value to be critical to the overall waterbalance of the catchments, then it will be re-examined.

3.2 Estimation of localised recharge

Much of the recharge into the Gunnedah Formation is thought to occur in the transition zone (UMA 2: alluvial/colluvial rims, Fig. 3) between the Ranges and Plains, by direct runoff-interflow from UMA 1 (Ranges and Hills, Fig. 3). The approach developed for this study involves two steps: the first is to provide estimates of runoff-interflow from the uplands, and the second, which is only partially addressed in this report, is to estimate the fraction of this “lost” water from the uplands that actually recharges the alluvial aquifer.

The runoff-interflow yield from the Ranges and lower Hills was calculated in a GIS applying the Holmes and Sinclair (1986) relationship (Fig. 6). This relationship relies
on two information layers, mean annual rainfall and forest cover, and basic GIS manipulations provide a runoff-interflow layer for the Ranges and Hills.

### 3.2.1 Estimation of runoff- interflow

Given high rainfall in the Ranges (over 1000 mm per annum), the localised recharge may become a significant part of the overall catchment water balance. The major land use change that could impact on the upper catchment water yield would be either clearance of forests or reafforestation. Three considerations guided the choice of methodology:

- has to be based upon field data at a similar temporal and spatial scale as required for this project
- has to rely on mean annual rainfall since the key driving variable is rainfall and that there is a lack of other meteorological information in the Ranges
- must be able to accommodate the options for the Ranges (afforestation, deforestation).

The adopted approach uses the relationships derived in Holmes and Sinclair (1986). In their work, data from 13 Victorian catchments with varying degrees of forest cover were used to derive relationships between rainfall and evapotranspiration from catchments which were fully forested and totally cleared (Fig. 5). The results for catchments with partial forest cover fell between these two limits. Evapotranspiration differences from fully afforested catchments (upper curve) and totally cleared catchment (lower curve) for any given mean annual runoff is indicated by the vertical interval labelled “A” in Fig. 5. These differences in evapotranspiration were responsible for catchment water yield differences of the same magnitude.

![Graph showing relationship between rainfall and evapotranspiration](image)

**Fig. 5.** Relationship between rainfall and evapotranspiration adapted from Holmes and Sinclair (1986) (---); obtained from the WAVES model (●).

The relationships presented in Fig. 5 are empirical and based on Victorian data. However, because the data are field-based and at the catchment-scale, the relationships
are suitable for this study, provided they can be transferred to the Liverpool Plains. To test the transferability of the relationships, two methods are used. The first was to compare with results from elsewhere in Australia, the second was to use a plot-scale soil-vegetation-atmosphere model, WAVES.

Ruprecht and Schofield (1989) presented results of a study from Western Australia showing an increased catchment water yield following clearing and the results are consistent with the Victorian data of Holmes and Sinclair. Similar results were reported by Silberstein et al. (1997) for two catchments in Western Australia. Cornish (1993) studied the effects of logging on water yields in a eucalypt forest in New South Wales (mean annual rainfall 1600mm) and found water yields increased by 150 - 250 mm per year after logging. The magnitude of this increase in water yield is consistent with the results of Holmes and Sinclair.

To put the relationships into context, the WAVES model (Appendix A) was used to simulate evapotranspiration from forests and crops with different mean annual rainfall. The simulated mean annual evapotranspiration for forest and crops is shown in Fig. 5 and 6. It is clear that the WAVES results are in good agreement with the relationships obtained by Holmes and Sinclair (1986). The difference in mean annual evapotranspiration between forest and crop varies from 140 mm to 300 mm. The differences in rainfall interception accounted for 50 to 95 % of these differences. For the purpose of recharge estimation, the results shown in Fig. 5 can be expressed as rainfall and runoff relationships based on a water balance (Fig. 6). These results showed that the relationships obtained by Holmes and Sinclair are very close to the WAVES estimates and can be considered as good approximations of the catchment water balance. However, it should be mentioned that these relationships were obtained from long-term averages and errors in the estimated runoff could be large. Nevertheless, these relationships can provide a simple and useful tool for studying the effects of forest clearance on catchment water yields.

![Fig. 6.- Relationship between rainfall and runoff adapted from Holmes and Sinclair (1986) (---); obtained from the WAVES model (●).](image-url)
3.2.2 Estimation of the hydrological connections as used in the economic model

Greiner (1997) considers that a certain percentage of the non-evapotranspirated water (runoff-interflow) from the Liverpool Ranges and the Sedimentary Hills recharges the alluvial aquifer. These percentages (Table 2) are accounted for in the economic model and were estimated based on experience by Ray Evans (AGSO) and George Gates (NSW-DLWC). These numbers are “…the percentage of total recharge and runoff from the uphill areas that is assumed to contribute to the groundwater pool under the plains.” (Greiner, 1997). It was found that the model is sensitive to these values (Greiner, pers. comm., April 1997), it is therefore important to be confident in them. The best way to estimate these percentages is through groundwater modelling, which will be the topic of a further report.

<table>
<thead>
<tr>
<th>Source area</th>
<th>Liverpool Ranges</th>
<th>Sedimentary Hills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge and lateral shallow groundwater flow (%)</td>
<td>60</td>
<td>33</td>
</tr>
<tr>
<td>Runoff infiltration depending on in-season rainfall (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very dry season</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Average season</td>
<td>50</td>
<td>27</td>
</tr>
<tr>
<td>Very wet season</td>
<td>30</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 2.- Hydrological connection within the catchment defined as proportion of uphill area recharge and runoff contributing to groundwater system under dryland plains (Greiner, 1997).

3.2.3 Estimate of recharge from Lake Goran

The Lake Goran catchment is a sub-catchment of the Liverpool Plains (Fig 4.). The total area of the catchment is 1550 km$^2$. The eastern and western boundaries of the Lake Goran catchment are minor water divides between Bundella Creek and the Mooki River to the east. Rainfall in the catchment is summer dominated with annual average rainfall of 640 mm. Extreme summer convective rainfall can cause significant local flooding which leaves the catchment via Native Dog Gully (on average once every 5 year), but most of the time, this catchment is internally draining. It is also believed that hydrogeological connections exist between Lake Goran and the Cox’s Creek catchment to the north.

Lake Goran is an ephemeral lake located in the north of the catchment. The surface area of the lake is 82.40 km$^2$ when full. During flood events, Lake Goran spills east into the Mooki River. Lake level records for the period of 1974 to 1992 showed that evaporation loss from the lake did not account for the observed fall in the water level and this was more likely due to seepage losses from the lake bed. During the period of 1920 to 1989, the long-term average annual runoff in the catchment has increased by
15% as a result of land use changes from pasture to cropping (DWR, 1995; Crapper et al., 1993) and this has led to increased inflow to the lake. Average water level of the lake is 295.4 m AHD and the average area of the lake is 55 km² (DWR, 1995). It is estimated that seepage from the lake is 28.5 mm per year and 80 per cent of time the lake was dry (DWR, 1995). Therefore, on average the annual seepage (recharge) under Lake Goran is estimated to be approximately 6 mm/yr.

4. Results

4.1 Estimation of diffuse recharge

No modelling or field work was done for diffuse recharge estimates in this study but a review of previous studies was undertaken to get confidence in the input values as used for the groundwater model.

Based on the results of previous studies and as well as general experience on similar kind of soils and landuse, an estimate of diffuse recharge for the alluvial plains of 20 mm/y seemed reasonable for the first runs of the groundwater model. At this stage, a constant value was chosen in spite of spatial land use and soils characteristics variability, to provide some insight into the relativity of diffuse to localised recharge. If the diffuse recharge component in the overall recharge becomes an important driver for the groundwater modelling, this estimate will be reconsidered and refined. The results of the diffuse recharge estimates using different modelling techniques are presented in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Liverpool Range</th>
<th>Sedimentary Hills</th>
<th>Alluvial Plains</th>
</tr>
</thead>
<tbody>
<tr>
<td>APSIM (recharge / runoff)</td>
<td>157 / 127</td>
<td>72 / 29</td>
<td>24 / 18</td>
</tr>
<tr>
<td>PERFECT</td>
<td>–</td>
<td>71</td>
<td>32</td>
</tr>
<tr>
<td>SaLF</td>
<td>–</td>
<td>70</td>
<td>&lt; 20</td>
</tr>
</tbody>
</table>

Table 3.- Estimates of mean annual recharge and runoff (mm)

4.2 Estimation of localised recharge

4.2.1 Runoff-interflow

The conceptual model describes the runoff-interflow (i.e. non-evapotranspirated water) from the Ranges as a potential major contributor to the recharge of the alluvial aquifer. The Holmes and Sinclair relationship tells about the total amount of this runoff-interflow from the Ranges and Hills, under different forest cover scenarios in the three modelled catchments (Table 5). This “lost” water spreads on the alluvial plains, where part of it will:

- recharge the alluvial aquifer (infiltrating alluvial fans on the lower hillslopes)
- leave the catchments (during major flooding events)
- be evapotranspirated on the alluvial flats
The partitioning of this “lost” water from the Ranges and hills is not the topic of this report and will be addressed in a further report on groundwater modelling. Nevertheless, preliminary results give some insights into the catchment’s water balance.

The modelling results for different landuse scenarios (Table 5) demonstrate that planting trees is effective in reducing runoff-interflow. The reduction between current landuse and 100% afforestation is about 38% on average for all the catchments. However, a 100% afforestation of the Ranges and Hills target is not realistic, and any sensible afforestation option will therefore have less impact on the runoff-interflow.

The amount of runoff-interflow determined between extreme scenarios (0% and 100% tree cover) will be used as input into the groundwater model. This envelope gives the range of possible scenarios within which landuse options for the upper-catchment can be analysed.

<table>
<thead>
<tr>
<th>Catchments</th>
<th>Runoff-interflow for different forest covers (10^6 m³ yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
</tr>
<tr>
<td>Pine Ridge</td>
<td>64.7</td>
</tr>
<tr>
<td>Upper Mooki</td>
<td>52.3</td>
</tr>
<tr>
<td>Lake Goran</td>
<td>29.9</td>
</tr>
</tbody>
</table>

Table 4.- Runoff-interflow in Mm³ per year for different tree covers on the Ranges and Hills

Assuming that 100% of the runoff-interflow under current landuse recharges the alluvial aquifer, the percentages of localised recharge over the total recharge for the three salinised sub-catchments are listed in Table 5. Runoff-interflow recharge accounts for 72 to 94.8% of the total recharge, and appears to be the potential major recharge mechanism. However, these recharge values appear to be unrealistically high in the Upper Mooki and Pine Ridge catchments. Local knowledge indicates that no perennial stream leaves the Pine Ridge catchment and waterlogging is not an issue in both catchments. Therefore, the assumption that all the runoff-interflow is recharge needs to be re-examined.

To get an acceptable recharge range, the amount of runoff-interflow effectively recharging the alluvial aquifer should be as low as around 5 to 10% of the total runoff-interflow. In this case, diffuse recharge would have to be considered in the overall groundwater balance. It is therefore critical to determine the percentage of runoff-interflow that actually recharges the aquifer to be able to check out whether reafforestation of the upper catchments is an effective mean to stabilise or reduce salinisation.
The recharge values obtained for the Ranges and Hills by APSIM (Table 3) are not readily comparable with the results obtained from the Holmes and Sinclair relationship. The Holmes and Sinclair relationship gives an estimate of the water “lost” by the upper catchment (i.e. non evapotranspired water from the Ranges and Sedimentary Hills), based on the spatial distribution of both forest coverage and mean annual rainfall. The percentage of this “lost” water that will become recharge to the alluvial aquifer will be determined by groundwater modelling. In this first stage of recharge estimation, it was assumed that 100% of the runoff-interflow is recharging the alluvial aquifer (Table 5). APSIM gives point scale recharge and runoff estimates for the Ranges and Sedimentary Hills. Using the hydrogeological connections (Table 2), the Range and Sedimentary Hills area and the aquifer area, it is possible to calculate the amount water “lost” by the Ranges and Hills and to turn this fraction of the recharge and runoff (Table 3) into recharge to the alluvium (Table 6). The results of this procedure need to be taken with caution and are used here only as a mean of comparison with the Homes and Sinclair results (Table 5).

### Table 5. Estimates of diffuse and runoff-interflow recharge (under current forest coverage)

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Aquifer area km²</th>
<th>Diffuse Recharge (20mm/y)</th>
<th>Runoff-interflow recharge mm</th>
<th>% runoff-interflow recharge of total recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine Ridge</td>
<td>200</td>
<td>4.0</td>
<td>323</td>
<td>94.2</td>
</tr>
<tr>
<td>Upper Mooki</td>
<td>145</td>
<td>2.9</td>
<td>360</td>
<td>94.8</td>
</tr>
<tr>
<td>Lake Goran</td>
<td>602</td>
<td>12.04</td>
<td>49</td>
<td>71</td>
</tr>
</tbody>
</table>

The comparison shows some similarities in the relativity of diffuse vs localised recharge. But once again, the recharge rates in the Pine Ridge and Upper Mooki catchments appear too high to be realistic. The hydrogeological connections used by Greiner (1997) were based on “educated guesses” (paragraph 3.2.2), and need to be reconsidered in the light of the groundwater modelling.

### Table 6. - Localised recharge estimations based on APSIM results

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>Aquifer area (km²)</th>
<th>Hydrogeological connections (%)</th>
<th>Localised Recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ranges</td>
<td>Sed. hills</td>
<td>Ranges</td>
<td>Sed. hills</td>
</tr>
<tr>
<td>Pine Ridge</td>
<td>394</td>
<td>48</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>Upper Mooki</td>
<td>368</td>
<td>44</td>
<td>145</td>
<td>60</td>
</tr>
<tr>
<td>Lake Goran</td>
<td>158</td>
<td>122</td>
<td>602</td>
<td>60</td>
</tr>
</tbody>
</table>

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2 The aquifer area estimates are based on extensive geological cross sections, which are the topic of a CSIRO Technical Report by Dyce and Richardson (1997). This area covers UMA 2 + UMA 3.
4.2.2 Recharge from Lake Goran

In the Lake Goran catchment, the contribution of the ephemeral lake to the total recharge can be considered as negligible. With a weighted average annual seepage rate of 6mm/y under a 55 km$^2$ area, the infiltrated water volume is only $0.33 \times 10^6$ m$^3$ yr$^{-1}$. The contribution of the lake to the total recharge to the alluvial aquifer is then of 0.8% (assuming 100% of the runoff-interflow is recharge). Some other indications that the recharge component of the lake is likely to be minimal is the high salinity of the shallow groundwater tables in its vicinity, and that the groundwater contours show the lake area to rather be a regional discharge site.

5. Summary and conclusions

This study applied Holmes and Sinclair’s relationship to get an estimate of runoff-interflow in three salinised catchments of the Liverpool Plains. This approach was used because it is based on field data on a similar scale, it was dependent on mean rainfall and it could be related to change in forest cover. The validity of transferring their relationship between rainfall and evaporation in 13 Victorian catchments to the Liverpool Plains was demonstrated using data from other Australian catchments and WAVES modelling. This approach, based on simple relationships derived from previous accepted scientific work, is believed provides a credible base for simple catchment scale waterbalances.

Under the assumption that 100% of the runoff-interflow becomes recharge, localised recharge accounts for 72 to 94% of the total recharge. Unless the amount of runoff-interflow that becomes recharge is less than 10%, the localised recharge from the Ranges and Hills will dominate diffuse recharge on the flats.

According to the Holmes and Sinclair relationship, the use of forest cover on the Ranges and Hills to lower the runoff-interflow is unlikely to reduce the current water loss by more than 38%. The effectiveness of such an option to reduce localised groundwater recharge is dependent on stream-bed permeability. In a recent large scale study, Hatton (1996) demonstrated that to significantly reduce stream salinisation in the Namoi, the Liverpool Plains tree coverage should be about 50%. Similarly, preliminary results of a Catchment Health study conducted across NSW indicates a 30% afforestation threshold to prevent stream salinisation (Joe Walker, pers. comm.). This detailed study on the Liverpool Plains added to the groundwater modelling will give a better appreciation of the efficiency of an eventual reafforestation option.

Runoff-recharge being potentially much higher than diffuse recharge directs towards managing the upper areas of the catchment to reduce salinisation of the lower plains. Nevertheless, the groundwater modelling results should be awaited to draw any conclusions. Ultimately, following the groundwater modelling, the economic sustainability of the available management options will be evaluated by the economic
model SMAC\textsuperscript{3}.

The focus of the work to come will be the determination of the relativity of localised versus diffuse recharge in the different sub-catchments, since this is a key element in the management options. A methodology to determine the amount of runoff-interflow that gets into the alluvial groundwater system needs to be developed. This is the topic of an up-coming publication on the groundwater modelling on the Liverpool Plains.

The potential importance of localised recharge into the alluvial/colluvial rims forming the lower hillslopes is believed to characterise the Liverpool Plains groundwater system and a range of similar catchments on the western side of the Great Dividing Range, with implications for dryland salinity control.

**Acknowledgments**

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\textsuperscript{3} Spatial optimisation Model for Analysing Catchment management (Greiner, 1996)
References


Appendix A

Waves modelling

The WAVES (Water Vegetation Energy and Solute) model is designed to simulate water, energy, and solute balances of a one-dimensional soil-plant-atmosphere system (Dawes and Short, 1993). The soil water balance module of WAVES handles rainfall infiltration, overland flow, soil and plant water extraction, moisture redistribution, and drainage (recharge). Soil water movement in both the unsaturated and saturated zones is simulated using a fully implicit finite difference numerical solution (Dawes and Short, 1993) of the Richards equation (Richards, 1931). A full description of the Richards equation solution can be found in Short et al., (1995). Overland flow can be generated from the excess of precipitation intensity over soil infiltrability, and the occurrence of precipitation over saturated surfaces. Both of the mechanisms are considered explicitly in WAVES. Water table may develop anywhere within the soil profile. If non-zero slope is specified as input, then lateral subsurface flow occurs via the saturated water table and is described by Darcy’s law. WAVES emphasises the physical aspects of soil water fluxes and the physiological control of water loss through transpiration. Thus, the model is well suited to investigations of responses to changes in land-use.

WAVES was run using daily values of maximum and minimum air temperature, precipitation, vapour pressure deficit, and solar radiation. The meteorological data were measured at Gunnedah Research Station. For the purpose of simulating water balance regime under various mean average rainfall, the daily rainfall data from Gunnedah was manipulated to generate annual rainfall variations. A constant leaf area index of 2 was used for trees and leaf area index of pasture (crop) was modelled. The dominant soil type in the Liverpool Ranges is red-brown-earth and its hydraulic properties were estimated based on Greiner (1997). The Broadbridge-White soil parameters $\lambda$ and C were estimated from an evaluation of the soil texture profiles (Table 1). The simulation commenced at 1 January 1966 and ended on 31 December 1975.

<table>
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<tr>
<th>$K_s$ (m/d)</th>
<th>$\theta_s$ (cm/cm$^3$)</th>
<th>$\theta_r$ (cm/cm$^3$)</th>
<th>$\lambda$ (m)</th>
<th>C (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.28</td>
<td>0.07</td>
<td>1.0</td>
<td>1.2</td>
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</tbody>
</table>

Table 1.- Values of the Broadbridge-White soil parameters for red-brown earth