Optimising Landuse for Management of Shallow Watertables: A Test Case for the Box Hill Catchment

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Abstract: A methodology was developed to assist in recharge management by evaluating various agronomic options. The study involved the development of two models for the Box Hill Catchment which is located in the Gwydir River Basin in NSW. First a model was used to estimate net recharge to the unconfined aquifer for three consecutive years from July 1990 to July 1993 from historic piezometric levels. The net recharge values were then used to evaluate optimum recharge control and management options for the catchment. An assessment of potential use of vegetation for recharge control was undertaken by targeting a large area of the catchment under pasture for recharge manipulation measures. Four runs were made for each year to determine the spatial distribution of lucerne given that the final water level over the entire catchment should be lowered from July 1991 observed levels by 1, 2, 3 and 4 m respectively. The 1990-91 simulation predicted that for the watertable to be lowered by 4m would require strategic planting of 98 ha of lucerne as opposed to 69 ha for 1991-92 and 85 ha for 1992-93. The decrease in lucerne for 1991-92 was due to a dry year, and the increase in lucerne area to 85 ha for 1992-93 was due to a wet year. In order to examine the variability of climate on the estimated area to be planted to lucerne three runs were carried out using the 1990-91 period by varying recharge for each run. The three recharge scenarios used were for an average, dry and wet period. The area predicted for strategic planting varied from 74 ha for the dry period to 121 ha for the wet period. The maximum area to be planted to lucerne was 121 ha for the wet year which is the area recommended for lucerne planting for the Box Hill catchment. The advantage of this approach is that it can be precisely determined how much lucerne would have to be strategically planted in each model cell for a given set of constraints.

Keywords: Groundwater; Recharge; Watertable; Agronomic Options; Wateruse Efficiency

1. INTRODUCTION

Dryland salinity is the build up of salt in surface soil as a result of a rising watertable and subsequent groundwater seepage. The rise in the watertable can mobilise salts stored at depth in the soil profile, causing saline seeps where the groundwater reaches the surface. These salts are then concentrated at the surface by evaporation. The rise in watertables can be attributed to a change in the catchments water balance as a result of land clearing and the replacement of native grasses and trees with annual crops and pastures.

The Box Hill Catchment located in the Gwydir River Basin in New South Wales (Figure 1), has experienced water logging and salinisation due to water levels rising to the ground surface with consequent loss of production. It is therefore desirable to maintain water levels below a critical depth from the soil surface. In order to lower the piezometric levels below critical depths a recharge management system has to be developed for the catchment. Recharge management may include several options such as on-farm management, groundwater pumping, and agronomic manipulation. In recent years the widespread planting of trees and/or lucerne has been promoted to minimise groundwater recharge and for reducing groundwater levels and water logging. The effectiveness of tree planting can be enhanced by planting trees in high recharge zones of a catchment. If an optimal recharge control and management scheme could be devised, it would offer a cost effective means to control piezometric levels and to maintain them at or below the critical depth.

The approach taken in this study was to quantify the water balance and the spatial distribution of recharge in the catchment. Next to determine how the water balance of the catchment could be modified by strategic planting of high water use efficiency crops. Finally, devising a strategy for long term management for the catchment by evaluating various agronomic options [Punthakey et al 1995].

This approach allows the catchment to be treated on a selective basis and to target specific areas for recharge remediation measures. The advantage of this approach is that it can be precisely determined how much lucerne would have to be strategically planted in each model cell for a given set of constraints.

2. THE BOX HILL CATCHMENT

The Box Hill catchment is located in the upstream portion of the Gwydir River Basin as shown in Figure 1. It is a sub-catchment of the Mount Russel catchment which drains west into the Myall creek system of the Gwydir River valley [Punthakey et al 1995]. The catchment shown in Figure 1, covers an area of about 640 ha and is approximately 4 km by 2 km. The catchment is drained by a creek which drains into Turrawarra Creek which is a tributary of Myall Creek which in turn flows into the Gwydir River. The elevation ranges from 740m AHD at the catchment divide in the east to 660m AHD in the west where the creek leaves the catchment. Lytton et al [1994] reported that a saline area of migratory extent had appeared close to the creek around the 670m AHD contour. Mean annual rainfall at Inverell is 809 mm, of which 35 percent occurs during December, January and February. Mean annual pan evaporation at Inverell, NSW is 1614 mm. Lytton et al [1994] reported that the dominant soil types are neutral to alkaline red soils which are strongly structured with clay content increasing with depth, some evaporation will occur from the watertable even at depths of 6m.

The predominant landuse is pasture which covers almost 80 percent of the catchment. Tree cover is mainly confined to the upper catchment on basalt slopes, where White Box and Black Wattle are growing. Trees also grow along drainage lines mainly Yellow Box, and on the granite in the lower catchment mainly Redgum. Lytton et al [1994] indicated that the saline area close to where the creek leaves the catchment, is bare and unable to support vegetation although salt tolerant native grasses grow on the periphery of the salted area.

A total of 11 piezometers in hard rock areas at six sites, and 21 piezometers into weathered rock at sixteen sites were used to monitor water levels and salinity of the groundwater. Piezometric levels in the Box Hill catchment are relatively close to the surface. In July 1990, approximately 45 ha of the catchment had watertable within 2 m of the surface, and 66 ha within 3 m of the surface.

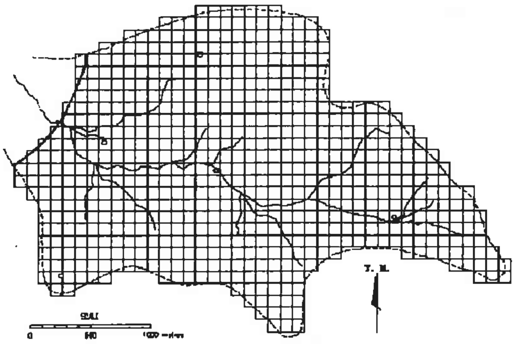

Figure 1. Model grid for the Box Hill catchment.

Three types of hard rock have been identified in the catchment. Basalt is underlain by Permian granite which outcrops and also directly underlies recent colluvial sediments at the western end of the catchment. The basalt occupies the eastern half of the catchment and has an estimated thickness of 200 m at the eastern edge of the catchment where the topography is highest. The granite was deeply weathered prior to the basalt flow, thus the basalt is thickest where there were deep valleys in the granite and thinnest where the granite was high. Silcrete outcrops occur in the lower third of the catchment. Williams & Saunders [1990] found that the granite experienced significant rises in water levels.

3. MODEL DEVELOPMENT

The study involved determining net recharge model for the Box Hill catchment in order to estimate the spatial variability of recharge across the catchment. The net recharge values were then used to evaluate agronomic options for minimising recharge by planting high water use efficiency (WUE) crops in selected locations.

3.1 Net Recharge Model

A linear programming model was used to estimate net recharge to the unconfined aquifer for three consecutive years from July 1990 to July 1993 from historic piezometric levels. The LP model was based on a finite difference grid of 100x100 m imposed on the unconfined aquifer for the Box Hill catchment. Net recharge to the unconfined aquifer was estimated using historic piezometric levels.

The recharge model uses linear programming to determine the distributed recharge for a selected region of the Box Creek catchment. The area is modelled using a 100x100 m grid. The objective is to optimise recharge for the model domain given observed water levels for any two points in time and suitable aquifer characteristics [Punthakey et al., 1994]. In this case we used observed water levels measured each year in July to obtain recharge rates for each grid cell. Aquifer properties were estimated from Lytton et al. [1994].

The equation for flow in the aquifer was represented in a linearised form and embedded as the groundwater flow constraint in both the Net Recharge and Agronomic Options Model [Punthakey et al., 1995].

$$T\frac{\partial^2 h}{\partial x^2} + T\frac{\partial^2 h}{\partial y^2} = S\frac{\partial h}{\partial t} + R(x,y,t) + Q(x,y,t)$$

where T is transmissivity ($m^2 d^{-1}$), h is piezometric head (m), S is the storage , x and y are cartesian coordinates (m), R is the net recharge rate ($m^3\ d^{-1}$) where positive values are recharge and negative values discharge, and t is time (d), and Q is groundwater pumping ($m^3\ d^{-1}$).

3.2 Agronomic Options Model

A preliminary assessment of the potential for using high water use vegetation for recharge manipulation measures was conducted using a second Linear Programming model. An assessment of potential use of vegetation for recharge control was undertaken by targeting a large area of the catchment under pasture for recharge manipulation measures.

In addition, the following constraints were imposed in the agronomic options model:

- Lucerne was restricted to designated pasture areas only.
- Model cells which were designated for lucerne must have a minimum of 10 percent of the cell planted to lucerne.
- Crop water use in designated model cells cannot exceed the maximum water use prescribed for that cell.

Three runs were conducted using observed water levels in July 1990, 1991 and 1992 respectively, as initial heads, and observed water levels in July 1991, 1992 and 1993 respectively, as final heads. In each run four land management scenarios were generated by constraining water levels at or below specified critical depths ranging from 1 to 4m below the observed final heads.

The area of the catchment selected for recharge manipulation was bounded by rows 4 to 22 and columns 1 to 30. The present landuse in the catchment consists of tall trees, low trees and pasture as shown in Figure 2. Only the model cells with pasture and those falling within the above area were targeted for changed vegetation strategy.

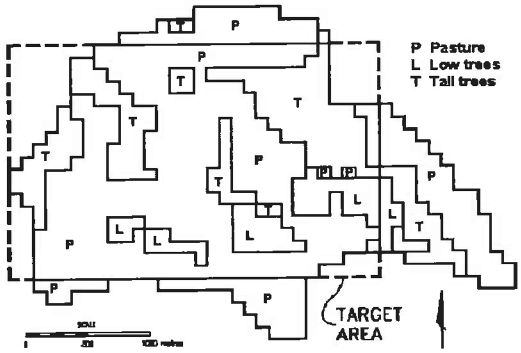

Figure 2. Present landuse in the Box Hill Catchment, Pasture **P**, Tall trees **T**, Low trees **L**.

4. RESULTS AND DISCUSSION

4.1 Analysis of Net Recharge

A series of runs were undertaken to estimate the spatial distribution of recharge using the net recharge model described in 3.1. These runs were undertaken for each year from July 1990 to July 1993. The estimated net recharge varied from -1.0E-5 to 1.0E-5 md^{-1} for each year however the spatial distribution varied considerably from year to year. In the 1991-92 year, a large part of the catchment had net recharge rates of <-1.0E-4 md^{-1} indicating a dry year with watertables declining. In contrast in 1992-93 a large area in the northern and southwestern part of the catchment had recharge rates >1.0E-4 md^{-1} indicating rising water levels. The recharging and discharging cells change from year to year depending on the position of the watertable. Total net recharge estimated with the model for three years from July 1990 to August 1993 is shown in Table 1.

The total upward and downward leakage for the catchment is shown in Table 2. The net leakage indicated a consistent decreasing trend in downward flow from the upper to the lower aquifer. Upward leakage also consistently increased over the three years indicating groundwater pressure in the lower aquifer is gradually increasing. During this period the area of the catchment contributing to upward leakage also increased.

Table 1. Recharge and discharge for the Box Hill Catchment.

Year	Catchment recharge/discharge ($mm\ yr^{-1}$)		
	Recharge	Discharge	Net Recharge
1990-91	81	-72	9
1991-92	46	-148	-102
1992-93	163	-42	121

Table 2. Upward/Downward Leakage for the Box Hill Catchment.

Year	Upward/downward leakage ($mm\ yr^{-1}$)		
	Leakage up	Leakage down	Net leakage
1990-91	0.5	-10.4	-9.9
1991-92	0.6	-9.0	-8.4
1992-93	1.2	-6.3	-5.1

Lytton et al. [1994] reported that in the upper catchment areas recharge to the deeper aquifer was occurring by leakage from the watertable aquifer and by direct recharge from rainfall via fractured rock outcrops. Discharge from the shallow aquifer was by upward movement of groundwater, due to a combination of thinning of the aquifer thickness, capillary action, and evapotranspiration. In the discharge zone groundwater was removed by evaporation from the top portion of the unconsolidated material thus salts dissolved in the groundwater were left behind at the surface.

4.2 Analysis of Agronomic Options

A part of the catchment bounded by rows 4 to 22 and columns 1 to 30 was targeted for recharge manipulation measures. The landuse in the catchment consisted of tall tree cover, low tree cover and pasture. Model cells with pasture within this area were targeted as potential sites for changed vegetation strategy. Water use of lucerne was estimated at 1300 mm yr^{-1} and the evaporation from the discharge area was estimated at 365 mm yr^{-1}.

The objective was to determine how much of each model cell should be converted to lucerne given that the final water level in the target area had to be reduced from the observed value by 1, 2, 3 and 4 m respectively. These scenarios were run for each successive year of observation 1990-91; 1991-92; and 1992-93. The results are shown in Tables 3, 4 and 5 respectively.

Table 3 shows that the catchment would require at least 33 ha of lucerne for the watertable to be lowered by 1m below the 1991 level. With a more severe constraint, such as lowering the watertable in the catchment by 4m, the total area planted to lucerne would need to be at least 98 ha. Similar trends are shown for the other years.

Table 3. Area to be planted to lucerne 1990-91.

Desired drop in 1991 water level (m)	Area to be planted to lucerne (ha) [1]
1	33
2	52
3	75
4	98

Table 4. Area to be planted to lucerne 1991-92.

Desired drop in 1992 water level (m)	Area to be planted to lucerne (ha) [1]
1	21
2	32
3	49
4	69

Table 5. Area to be planted to lucerne 1992-93

Desired drop in 1993 water level (m)	Area to be planted to lucerne (ha) [1]
1	29
2	43
3	62
4	85

[1] *Aggregate of all model cells to be planted to lucerne*

Two important points need to be highlighted here. Firstly, the area to be planted to lucerne for a given set of conditions changes from year to year depending on the rainfall and climatic conditions. Secondly, the total area planted to lucerne shown in Tables 3, 4 and 5 are aggregates of a percentage of each cell that would be required to be planted to lucerne to control the watertable spatially. The total areas are not intended to imply that planting a part of the entire catchment to lucerne will necessarily control watertables at all locations within the catchment.

The 1991-92 simulation predicted that for the watertable to be lowered by 4m would require at least 69 ha of lucerne as opposed to the 98 ha predicted for 1990-91 simulation. The decrease in the total area planted to lucerne is due to 1991-92 being a dry year in comparison to the previous year.

In order to examine the variability of climate on the estimated area planted to lucerne three runs were undertaken using the 1990-91 simulation period by varying the recharge for each run. Three recharge scenarios corresponding to an average rainfall year (1990-91), a low rainfall year (1991-92) and a high rainfall year (1992-93) were used to estimate the area required for lucerne. Table 6 shows that the area planted to lucerne varied from 74 ha for a dry year to 121 ha for a wet year.

Table 6. Impact of dry and wet years on 1990-91 estimated area of lucerne (1991 watertable lowered by 4m).

Recharge scenario	**Area to be Planted to lucerne (ha)** [1]
Dry (1991-92)	74
Avg (1990-91)	98
Wet (1992-93)	121

[1] *Aggregate of all model cells to be planted to lucerne*

The advantage of this approach is that it can be determined precisely how much lucerne would have to be planted in each model cell for a given set of constraints. However, the disadvantage from a practical viewpoint is that planting parts of a model cell to lucerne would not be acceptable from a farm management perspective. The next phase of this study should therefore incorporate a set of farm planning constraints. Various scenarios such as planting lucerne in strips could also be investigated.

5. CONCLUSIONS

The application of optimisation models to estimate the spatial distribution of net recharge and to identify zones for recharge remediation measures is demonstrated in this study. The results show that the watertable can be controlled by strategic planting of high water use efficiency crops such as lucerne. Three recharge scenarios were used for a dry, average and wet period. The area predicted for strategic planting varied from 74 ha for the dry period to 121 ha for the wet period. The maximum area to be planted to lucerne was 121 ha for the wet period which is the area recommended for lucerne planting for the Box Hill catchment. The advantage of this approach is that it can be precisely determined how much lucerne would have to be strategically planted in each model cell for a given set of constraints. The inclusion of additional constraints such as planting lucerne in strips will further refine the area to be planted to lucerne. This will also allow easier implementation of model results from a practical perspective.

6. REFERENCES

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