JEMALONG LAND AND WATER MANAGEMENT PLAN.

SOIL SALINITY ASSESSMENT
BASED ON THE
REGIONAL WATER BALANCE

Contents:

JEMALONG LAND AND WATER MANAGEMENT PLAN.

SOIL SALINITY ASSESSMENT BASED ON THE REGIONAL WATER BALANCE

1. Introduction

As part of the Jemalong Land and Water Management Plan process the author was invited to contribute by preparing the present and future soil salinity assessment for various parts of the district. The purpose of this information is to establish trends which subsequently can be used for the agricultural productivity assessment for the Land and Water Management Plan, which in turn is used to determine whether specific management options are economically soundly based.

The science of soil salinity assessment is still in its infancy. A number of attempts to establish process models to estimate soil salinity from crop types, soils, rainfall, irrigation practices and watertable behaviour have failed in producing credible estimates. This is not really surprising considering the complexity of interaction between factors, many of which are highly variable. Most previous research is based on forecasting conditions for a single site.

For Land and Water Management Plan purposes an assessment of land salinity over the planning period is necessary, for three reasons :

- to assess whether the current landuse practices indeed are sustainable or otherwise.
- to provide a background scenario for planning remedial measures, on-farm and regionally and to determine their beneficial effect.
- to allow the economic evaluation of individual options and the preferred option package to proceed.

This report provides an assessment of present and furure salinity conditions in the Jemalong and Wyldes Plains district, including its variations in land use and hydrogeological conditions. The methodology described in Chapter 2 essentially circumvents the research problems still to be resolved. It was developed and used for the Coleambally and Murrumbidgee Irrigation Areas Land and Water Management Plans, and subsequently also used as a check for the other methodologies of the Berriquin and Wakool plans. The method of soil salinity assessment is based on the relationship between the observed soil salinity of the district and the distribution of watertable depth. The equilibrium watertable levels are a function of all the components of the water balance for the district. Chapters 3, 4, and 5 discuss the assessment of these factors for the Jemalong and Wyldes Plains Irrigation Districts. This information is used in the model, resulting in the soil salinity assessment of Chapter 6.

2. Outline of Methodology

The nature of the empirical soil salinity prediction functions was determined for the Shepparton Salinity Management Plan and described by Merrilees of the MDBC (1992). The soil salinity at time “t’ is the soil salinity at time “t-1”, plus the added salts from irrigation, plus the net added salts from capillary rise mines leaching, minus the removed salts by runoff. Calibration coefficients were determined for each of these three factors. The main problem was that for many districts only limited data exist which allows accurate predictions over longer periods.

In the MIA soil salinity surveys on a sub-district scale have been carried out on three occasions, 1991, 1992, and 1994. A total of eight sub-districts have been surveyed. Each of these sub-districts has a different history of high watertables, varying between 0 and 40 years. This difference was used to calibrate the MDBC functions against the data.

Soil salinity does not start to increase until (some time after) a new high watertable equilibrium is reached. The soil salinity assessment therefore concentrates on the high watertable part of the sub-district. In this part there is a variation of watertable depth around the average. Where the irrigation practices are fairly consistent and crops are rotated the highest watertables would be expected in the more depressed locations of the landscape, and the deeper watertables near the more elevated areas. Groundwater tends to move through shallow aquifer systems to the more depressed locations, or locations where the watertable is deeper for other reasons, for instance not irrigated paddocks of the same elevation. Where these processes of groundwater flow exist the highest soil salinity would be expected in those locations to which the groundwater has moved. At such locations there would be a strong relationship between average watertable depth, how long this condition has existed and salinity or salinity risk.

Table 2.1 shows the coefficients of the polynomial equations which represent the soil salinity prediction functions as used in the MIA. The assessment for Jemalong has been based on these equations, however with some modifications and these are discussed at Chapter 6.

Table 2.1. Polynomial Equations Coefficients for estimating Soil Salinity over Time (as found for MIA conditions)

Watertable Category	a (x Y2)	b (x Y)	c
<0.7 m	-1.13	224	300
0.7-0.9 m	-0.21	55	300
0.9-1.1 m	-0.09	27	300
1.1-1.3 m	-0.04	17	300
1.3-1.5 m	-0.02	8.5	300

In the Jemalong and Wyldes Plains Districts the landscape consists of an irrigated part and a not irrigated part. It would be incorrect to apply soil salinity prediction equations based on the above principles equally to both parts. Hence it was decided to separate these two parts and treat them separately. It does not matter that the irrigated part and the not irrigated parts do not have nicely shaped boundaries. What needs to be considered however is that there may be a (small) groundwater flow between the two parts, that this affects the depth to the watertable in both. It is also unlikely that the salinity prediction functions apply equally.

The Jemalong and Wyldes Plains districts have been split in four sub-districts to further distinquish soil and hydrogeological features. The four sub-districts were named Jemalong North East, the Warroo area, the Cadow area and the Wyldes Plains district. Later, the Lake Cowal area was also added. Each sub-district (except Lake Cowal) was divided in an irrigated part and a not irrigated part, giving 9 sub-regional areas altogether. Figure 2.1 shows the locations of the main sub-districts and Table 2.2 gives some statistics.

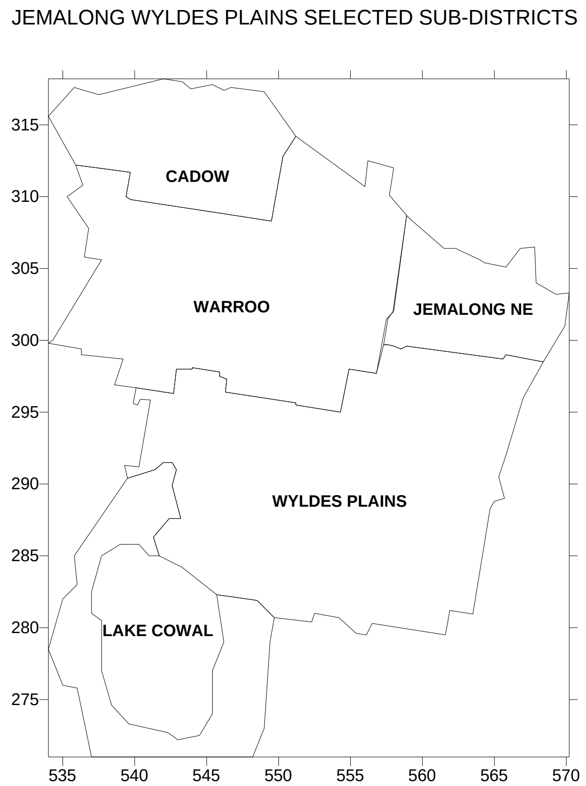

Figure 2.1 : Boundaries of Selected Sub-districts of Jemalong Wyldes Plain ID.

Table 2.2. Basic Information for Four Selected Sub-districts of the J&WP ID (*1)

Factor	Jemalong NE	Warroo	Cadow	Wyldes Plains	Jemalong Total
Dry Area (ha)	5650	15740	7550	22170	51110
Irrigated Area	3180	13410	3890	17460	37940
Total Area (ha)	8830	29150	11440	39630	89050
Irrigation Deliveries (Ml)	6500	23000	6500	24000	60000

(*1): Areas supplied by NSW Agriculture, Irrigation data by J&WPID. The areas of Fig 2.1 are not identical, since the district extends beyond the boundaries shown. This affects the later assessments but not in terms of proportions of total areas.

As mentioned the soil salinity assessment is based on watertable depth and its distribution around a mean. Only the high watertable part of the sub-district is being considered. The definition of what is considered to be the high watertable part is further discussed at Chapter 5. Most reporting relies on the "within 2 metres" area (eg MDBC), but this is not necessarily a good reflection of the salinity risk.

Where a larger time frame is considered the area of high watertable increases and incremental areas are being added. For the model 5 years was considered for this feature. The soil salinity prediction function starts at time equals zero for each of the incremental parts, whilst for the older parts 5 years are added. Since the assessment starts in 1995 the age of the high watertable condition has to be estimated for this part from groundwater maps.

The watertable depth in the irrigated or not irrigated parts of districts depends on all components of the groundwater balance. Accessions occur from rainfall, irrigation and flood events. Groundwater discharge occurs as capillary rise and uptake by trees. The volumes seeping into Bogandillan Creek need to be considered but are relatively small. Groundwater flow occurs between irrigated and not irrigated parts of a sub-district, between sub-districts and between shallow and deeper aquifers. Each factor needs to be assessed as accurate as possible, based on available data, analysis and reports.

The values determined for the groundwater balance are schematically shown at Figure 2.2. The units used are in Gigalitres per year (Gl/year). One Gl equals 1000 Ml. The diagram shows the volumes reaching the rootzone under both the irrigated and not irrigated parts. From this movement to the shallow aquifers and between aquifers occurs, as described. The discussion regarding the values shown at Figure 2.2 may be found at Chapters 3 and 4.

The calculations for the soil salinity assessment consist of the following sequence:

1. Compilation and addition of all Recharge factors.
2. Compilation and addition of all Non-Capillary Rise Factors.
3. Assessment of average watertable depth in high watertable zone of area considered.

4. Assessment of Capilary Rise in conjunction with
    - the volume which represents the watertable rise factor, and :
    - the expansion rate of the high watertable area
5. Assessment of the watertable level increase and the expansion in high watertable area from the volume added to the watertable.
6. Calibration of the assessed high watertable area expansion with the area expansion determined from groundwater maps and hydrographs.
7. Identification and assessment of all incremental high watertable areas.
8. Calculation of areas for all watertable depth categories, for instance 0-90, 90-120, 120-150, 150-180 and deeper than 180 cm.
9. Soil Salinity Assessment for each watertable category using the predictive function.
10. Collating all areas each having a certain salinity into salinity classes and production of salinity results in tables.

The large amount of data to be compiled, each of which subject to a probable error of a minor or larger magnitude may create the impression that the methodology is not reliable. However, there are a number a checkpoints during the calibration process.

- At step 3 the calculated average watertable should be consistent with typical values monitored in piezometers.
- At step 4 the volume for the watertable rise factor may be converted to a watertable rate of rise. This value needs to be consistent with hydrograph results for the district (eg 4-15 cm/year).
- At step 5 the calculated increase in high watertable area is adjusted to the groundwater map derived value using an area coefficient.
- At step 9 the found values must be within a credible range. The rate of increase in salinity post 1995 should be about the same as the rate of increase pre 1995. Even where no survey data exist there will be some observed evidence to indicate whether the calculated salinities are too high or too low.

Provided that these checks can be carried out, the approach used is believed to provide a credible assessment for soil salinity of a district.

3. Watertable Behaviour

3.1 Depth to Groundwater

A system of about 100 piezometers exists to monitor depth to groundwater. Extra piezometers have been added recently in the Lake Cowal Area. Baden Williams (draft 1995) describes the watertable levels and estimates the rates of rise for future years. It was found however that to arrive at meaningful conclusions for this report more detailed analysis was necessary :

1. The volume of accessions for flood events can only be determined on watertable levels before and after such events.
2. The increase in area with watertable within 2 metres is not necessarily a good predictor of areas at risk of salinisation. More about this at Chapter 5.

Consequently, depth to watertable maps were determined and analysed for all years that a sufficient data set was available. This resulted in 20 maps between 1968 and 1995, as attached at Appendix 1.

The method of compiling these maps was as follows. GEOTERREX produced a set of data representing the surface contour map from satellite imagery. Next, the natural surface levels near each piezometer location was determined by Dr Baden Williams from the four nearby cells, each of a 1 km2 grid. Subsequently, using SURFER software the Australian Height Datum (AHD) grids of both the natural surface and the groundwater levels for each date were calculated. The grid cell size used was 0.5 km over the whole study area. Substraction of the two grids then produced the grids for depth to groundwater as related to the GEOTERREX surface. These grids were used for mapping (Appendix 1) and calculation of watertable statistics using SURFER. Table 3.1 gives the statistics of the groundwater information.

Table 3.1 : Average Depth of groundwater in J&WPID and areas within 2, 3 and 4 metres from the surface.

Decimal Date	Depth (m) AveWT	Area(ha) Area<2m	Area(ha) Area<3m	Area(ha) Area<4m
68.9	-6.54	368	5302	16633
69.6	-6.27	520	6184	18745
70.6	-6.18	591	6930	19061
71.6	-5.58	2956	9068	22436
72.9	-5.68	1487	8237	21468
74.3	-6	1831	9306	19914
74.9	-4.98	7922	22582	35985
82.2	-5.21	4542	10614	23826
83.2	-5.63	1899	7468	23052
85.9	-5	5382	17359	35418
87.3	-5.3	2801	9768	27000
88.3	-5.34	2745	10698	26435
89.5	-5.14	3816	12934	31119
90.2	-4.92	3900	12992	34021
90.7	-3.72	29071	44333	53333
91.7	-4.33	8597	25211	47402

Table 3.1 : CNTD

Date	AveWT	Area<2m	Area<3m	Area<4m
92.2	-4.38	9022	24849	47394
93.1	-4.31	10914	26446	46146
94.3	-4.51	6223	22148	42977
94.7	-4.72	5127	16604	36335
95.3	-5.19	2264	10913	25351

For October 1994 the groundwater statistics were assessed for each of the five selected sub-districts separately. This was necessary because watertable predictions need to be made separately for each sub-district. Table 3.2 provides key information.

Table 3.2: Areas (ha) within selected depth categories for individual sub-districts for October 1994 (*1).

OCT 94	CADOW	JEMNE	WARROO	WP	JEMWP	L.COWAL	TOTAL
<2.0M	315	0	4812	0	5127	159	5286
<2.5M	927	0	8718	0	9645	367	10012
<3.0M	2648	199	13437	320	16604	911	17515
<4.0M	6712	3765	22983	2875	36335	4058	40393
AREA	10352	7198	28945	37630	84125	10550	94675

(*1) The area around Lake Cowal of Figure 2.1 is shown separately from the Jemalong Wyldes Plain (JEMWP) area.

3.2 Groundwater Trends.

Table 3.1 allows examination of the trend in average depth to groundwater levels. This is shown at Figure 3.1.

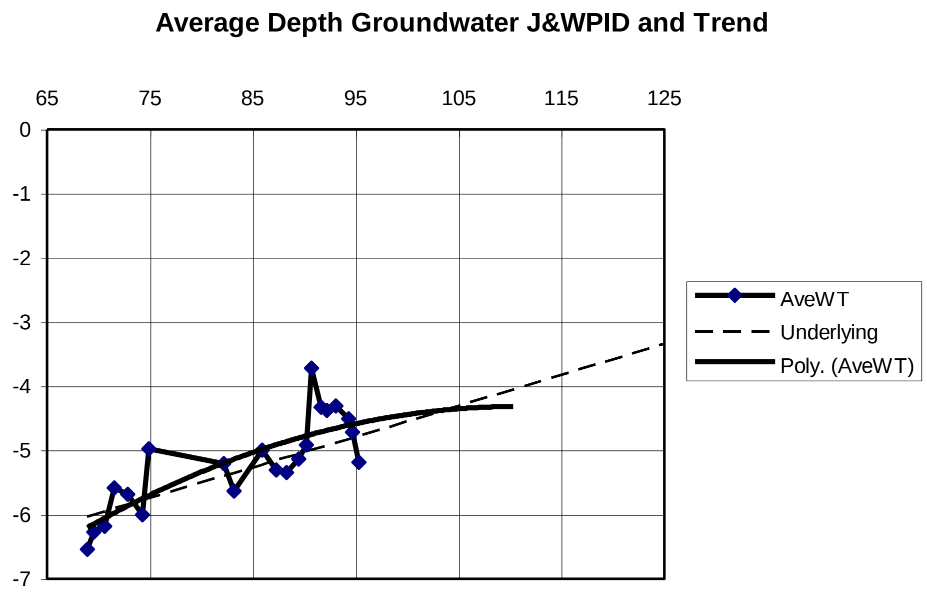

Figure 3.1. Plotted average depth to groundwater, with linear underlying trend and polynomial trend for J&WPID.

From Figure 3.1 an underlying trend may be identified, which indicates on-going increase in levels. The levels will reach some equilibrium in the future but it is not known at this stage at what level the tapering of may begin. The polynomial trend is an alternative trend just for illustration. The data do not allow extrapolation over the next 30 years, but only allow a statement of what the current trends are.

Table 3.1 also shows the area with depth to groundwater within 2 metres, 3 metres and 4 metres from the land surface. There is a general rate of rise in areas but there are also falls. These relate to flood events, wet and dry periods. The large areas affected by high watertables was dramatically high from 1990 to 1994, but during late 1994 and early 1995 a fall in these areas is very obvious. Figure 3.2. shows the data points, the predicted expansion from maps and the underlying trends.

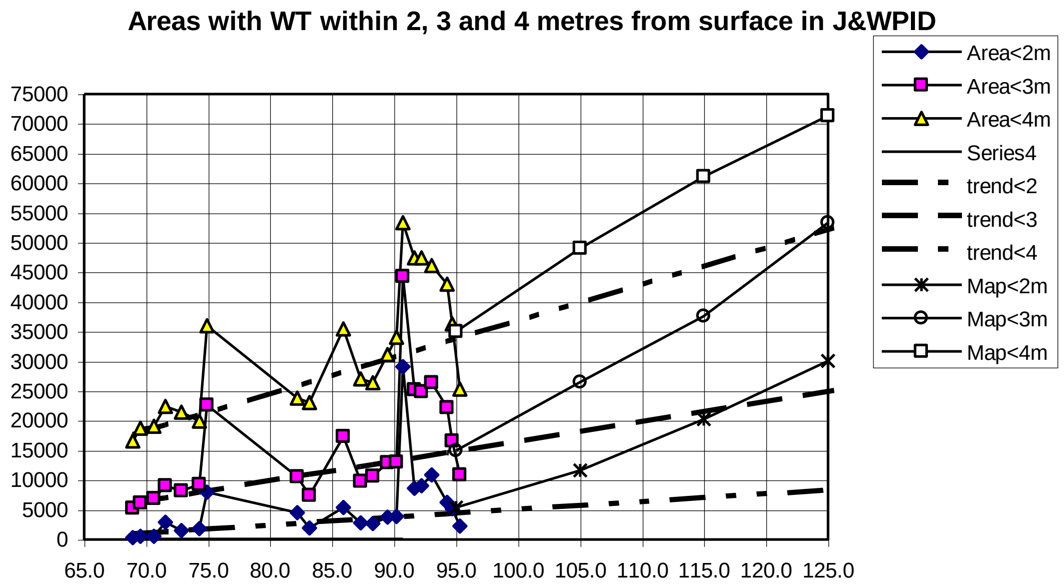

Figure 3.2 : Areas with groundwater within 2, 3 and 4 metres from the surface.

The April 1995 area with watertables within 2 metres is only 2,200 hectares or 2.5% of the district.. Apparently, after an extended dry period the area with watertables within 2 metres decreases to quite small values, whilst the 3 and 4 metres areas also decrease. When comparing the underlying trends however the 3 and 4 metres areas have larger slopes.

For the assessment of future areas with watertables within 2, 3 and 4 metres the graphs need to be extrapolated by some method. Figure 3.2 shows these extrapolations, based on two methods :

1. Based on the 2005, 2015 and 2025 groundwater contour maps based on extrapolation of all individual piezometer data using the average rate of increase based on the difference between March 1969 and October 1994.
2. Extrapolation of the underlying trend of Figure 3.2 :

Appendix 2 shows five maps. Map 1 is the average increase in metres per year. The average rate varies from 0.04 to 0.16 metres per year. Map 2 is the October 1994 depth to groundwater map. Map 3 is the 2005 map based on October 1994 plus 10 times the rate of increase. Map 4 is for 2015 (20x) and Map 5 is for 2025 (30x). The map predictions of Figure 3.2 are based on maps 2 to 5 of Appendix 2.

October 1994 was chosen as the starting point and not April 1995 or April 1994 because the underlying trend line goes through October 1994.

There is a significant difference between the two predicted trends of Figure 3.2. Normally the map predictions would be the more valid, however a tapering off effect for the 2 metres areas can not be ignored in a district in which irrigation intensity is low compared to the natural events. If the area within 2 metres increases and decreases to very small values this means that an equilibrium is being approached and the upward trend in watertable rise has started to taper off.

Groundwater level predictions need to be restricted to information of which it is fairly certain that it can be used for subsequent analysis. This means that groundwater contours that will not be reached should not be shown. For instance, if watertables are now at 4 metres and rising 0.2 metres per year, this does not mean that the 1 metres contour will be reached after 15 years and the soil surface after 20 years. Similarly, although a 2 metres contour may be realistic in many locations after 10 years, it may take longer in many other locations, and in some locations the 2 metres level will never be reached.

The map predictions avoid the main effect of the 1990-1993 floods, nevertheless the areas increase rather dramatically compared to the underlying trends. At this stage it is not certain what the final scenario will be. Much will depend on the processes in the landscape which may cause increased discharge as the watertables come up. If many trees succumb to a waterlogged conditions the outlook may be poor and the map predictions (top lines) will be correct. On the other hand, if trees survive the increases in the areas may be arrested at a slower rate.

For this analysis it is assumed that the 4 and 3 metres depth levels will be reached at the rates of rise as predicted by the watertable maps. With regard to the areas within 2 metres, the underlying trend line could have more meaning.

Figure 3.2 applies for the whole district. The information based on mapping has also been compiled for individual sub-districts. This is shown ate Table 3.3 for 2005, 2015 and 2025.

Table 3.3. Predicted areas of high watertables for individual sub-disticts in J&WPID

2005	CADOW	JEMNE	WARROO	WP	JEMWP	COWAL	TOTAL
<2.0M	1266	5	10130	284	11685	1401	13086
<2.5M	2829	78	14906	811	18624	3312	21936
<3.0M	4573	690	19718	1714	26695	4618	31313
<4.0M	9571	5225	26017	8423	49236	7520	56756
AREA	10352	7198	28945	37630	84125	10550	94675

Table 3.3 cntd

2015	CADOW	JEMNE	WARROO	WP	JEMWP	COWAL	TOTAL
<2.0M	3020	48	15862	1443	20373	5117	25490
<2.5M	4714	376	20313	2715	28119	6317	34436
<3.0M	7189	1711	23203	5739	37843	7856	45699
<4.0M	10496	5890	27645	17247	61277	9045	70322
AREA	10352	7198	28945	37630	84125	10550	94675

2025	CADOW	JEMNE	WARROO	WP	JEMWP	COWAL	TOTAL
<2.0M	4812	242	20618	4360	30032	8112	38144
<2.5M	7414	1109	22963	8051	39537	8780	48317
<3.0M	9376	3610	25345	14967	53298	9217	62515
<4.0M	10443	6179	28236	26444	71302	9633	80935
AREA	10352	7198	28945	37630	84125	10550	94675

Comparison between Tables 3.2 and 3.3 shows that the largest increases are expected in the Warroo area, to about 65% of the landscape. The over 4,000 ha increase in the Cadow and Wyldes Plains area represents a smaller proportion of those sub-district.

The increase in the Lake Cowal area is based on extrapolation of the Rate on Increase contours to outside the network of data points for which it was compiled (Appendix 2, map 1). As such it has a much lower reliability. It is recommended that a further 5 years of data are collected for the Lake Cowal area before any conclusions are drawn regarding trends. As a minimum it would not be responsible to base decisions regarding capital works expenses to “reclaim” the area on this data alone.

3.3 Contributing Factors.

Factors contributing to watertable behaviour and trends relate to the magnitude and variation in the volumes of the surface and sub-surface water balance. This subject is discussed at Chapters 4 and 5.

4. Surface and Sub-Surface Water Balance

4.1 Irrigation Data

Data of water volumes diverted at Jemalong Weir into the Channel 1 and Channel 2 systems were supplied by District staff. The average diversions since 1962 have been 73 Gl/year, whilst the deliveries have been about 56 Gl/year, suggesting that losses are in the order of 17 Gl/year. There is some uncertainty about these numbers however, particularly the losses. Irrigation usage has increased somewhat since 1970. There are also some direct diversions in the north of the district from the river. For this report it is assumed that the irrigation deliveries are 60,000 Ml. These have been distributed across the selected sub-districts as shown at Table 2.2.

The areas of irrigation in each sub-district have been supplied by NSW Agriculture, Forbes and were shown at Table 2.2. They may be compared to the total areas and the remaining dry areas of the sub-districts.

Table 2.2 indicates that the irrigation intensity if the irrigated part varies from 1.5 to 2.0 Ml/ha/year in the irrigated part of the district and less than 1.0 Ml/ha overall. This is low compared to any other Irrigation Area or District in southern NSW. Sally McGrath (1994), discussing the Warroo Area waterbalance from a plant water demand perspective found that generally the district suffers a significant under supply of water.

4.2 Floods

Floods traverse the district on a regulare basis, when the river levels exceed a certain height. Sally McGrath of NSW Agriculture has tabulate the floods between 1943 and 1990 and found 35 floods exceeded the gauge height for overflow into the district. Three very significant events occurred, 1956, 1974 and 1990. The latter flooded the district for about 6 months over large areas.

The extent of flooding on each occasion is not well known. For a few of the largest events maps have been prepared.

4.3 Accessions from Irrigation

Accessions from irrigation depend on the type of crop, the soil types, the irrigation system, and the irrigation management. In most irrigation districts values of 5-10% for clay soils are not uncommon. In the Jemalong District lucerne is grown, and whilst this is a deep rooting crop the soil types used are more sandy in many locations, eg the Warroo Prior Stream Formation soils. Irrigation is mostly by the border check method.

For this study it is assumed that the proportion of irrigation that will reach the watertable varies from 8% in Wyldes Plains and Cadow to 15% in the Warroo part of the district. This gave a total of 6.1 Gl/year as shown at Figure 2.2.

4.4 Accessions from Rainfall

Rainfall is about 500 mm/year in the Jemalong District. It falls on the irrigated lands and the dry zones. Because of the clayey nature of the soils in most of the area it was assumed that only about 5-8% of rainfall will result in accessions in the irrigated parts of the districts and 4-6% in the dry area, where soil moisture levels at the onset of irrigation are lower. These accession coefficients result in significant amounts overall. Figure 2.2 shows that rainfall accessions are about 12.3 Gl/year in the irrigated partsa nd 12.8 G;/year on average in the dry zones (which are larger).

4.5 Channel Seepage

The worst channel seepage is known to occur along the Warroo channel system, and some sections between Jemalong weir and Constable road. Seepage measurements along the former system identified a maximum of about 2,600 Ml of seepage along a thirty km section. Overall the total losses due to seepage are assumed to be 5.7 Gl/year and these have been distributed between the four sub-districts. The groundwater system under the dry area receives channel seepage loss because some parts of the channel system is assumed to run through this zone.

4.6 Accessions from Floods

Accessions from major floods have been estimated from groundwater maps before and after a major flood event, eg the 1974 and the 1990 floods. The watertable rise on these occasions was in the order of 1.1, resp. 1.2 metres (compare Figure 3.1). Over an area of 80,000 ha, being the size of the study area, and an effective porosity of 8% this represents 73,600 Ml on each occasion for these two large floods. Since there have been about 3 of these floods over the last 50 years this represents about 4,500 Ml/year of accessions from big floods alone

For the lesser flood events it was estimated that both the duration and the extent of flooding was less. Each flood therefore was assumed to contribute about 1/8th of a major flood. However the number of occasions was greater (Table 4.3). If 16 significant minor flood events are assumed over the last 50 years calculations would give a total about 146,000 Ml of accessions or 2,930 Ml/year.

The big flood events and the smaller events combined suggests that an average of 7,400 ML/year of accessions occur each year. This volume has been distributed between the sub-districts based on the relative area that is likely to become flooded during major events. Obviously the dry area is relatively more affected since most irrigation development would be situated on the less flood prone areas.

4.7 Groundwater Flow

4.7.1. From Irrigated to Not Irrigated Areas

The irrigated areas in the Warroo part of the district may be somewhat elevated compared to the dry areas. This will establish a gradient for groundwater flow. More importantly however, the watertable in the not irrigated part will be lower than in the irrigated part. This will be the main reason that a small groundwater flow will exist, which will contribute to leaching in the irrigated parts and salt accumulation in the dry areas.

If the following factors are known the flow rate can be assessed from analytical models. The factors are: transmissivity of aquifer, gradient, perimeter of boundary between irrigated part and not irrigated parts. The factors vary across the district. None of these factors is known accurately, however estimates are possible. For instance there are some estimates for transmissivity from pumping tests, the difference in watertable depth is probably in the order of 0.5 to 1.0 metres, the perimeter can be estimated by assuming the size of typical fields. This has been done and the values are listed at Table 4.4..

Table 4.4. Assessment of Groundwater flow between irrigated and dry zones in Jemalong District

Factor	**Assumed Value**	**Comment**
Size Typical Irrigated area	200 hectares	
Transmissivity Aquifer	10 m2/day	Pump tests indicate even lower values
Head Difference	0.4 metres	
Distance for flow	400 metres	
Length of Effective Perimeter	3000 metres	Only half the 1000 by 2000 metres perimeter contributes
Flow over 365 days	11 ML	for 200 hectare area.

The above values were modified slightly between sub-districts, eg Warroo received a 13 Ml/200 ha value and Wyldes Plains an 8 Ml/200 ha value. Subsequently the groundwater flow was multiplied by the area of irrigation divided by 200 to get the total groundwater flow for the sub-district. Figure 2.2 shows that the overall volume so assessed is about 1000 Ml/year, a smallish component in the overall water balance.

Because the total volumes involved are relatively small the probable error in this estimate does not have major consequence for the overall groundwater balance.

4.7.2. Between Sub-Districts

The flow between sub-districts is dependent on the transmissivity along the boundaries and the gradients in groundwater flow. The latter can be estimated from groundwater maps, eg Figure 3.1. The transmissivity values may be derived from groundwater pumping tests, and the length of boundaries from Figure 2.1.

For each sub-district there is a volume entering and a volume leaving the district. These have been estimated and the outcome of the assessment is shown at Table 4.5.

Table 4.5. Assessment of Net Groundwater Flow out of each Jemalong Sub-Districts

	Warroo		**Jemalong**		**Cadow**		**Wyldes Plains**	
Source	Irr.	Dry	Irr.	Dry	Irr.	Dry	Irr.	Dry
From River	-400	-600	0	0	-200	-200	0	0
Internal	1000	-1000	200	-200	200	-200	500	-500
Other Districts	100	100	100	100	50	50	0	0
Totals	700	-1500	300	-100	50	-350	500	-500
Net Out	-800		200		-300		0	

The final values of Table 4.5 were entered in the soil salinity assessment model. Figure 2.2 only shows the net groundwater flow in and out of the whole district. This is about 1.4 Gl/yr influx from the river and 0.2 Gl/year seepage into Bogandillan Creek.

4.7.3. Between Aquifer Systems.

The report by Coffey partners (1994) identifies a three layer aquifer system. A deep lead Paleo Channel occurs in the central part running from the Marsden area to the north west. This deep lead is relatively narrow compared to the distribution of shallow shoestring sands, which covers the whole district. The report suggests that there are extensive clays and that the interaction between shallow and deep systems is minor only.

To asssess the leakage rate between aquifers, data are necessary for the hydraulic conductivity of the intermediate restrictive layers and of their thickness. These are only approximately known. An other way of visualising the leakage rate is by assuming a constant 10 metres head difference and then expressing the leakage rate as mm/year. Then the actual leakage rate can be calculated by multiplying the actual head difference and dividing by 10. This procedure was followed.

For the leakage rate between aquifers values of 10 to 50 mm/year/10 metres head difference were assumed. These are based on values determined for the Riverine Plain near Griffith, because pumping tests are not available for the Jemalong District.

The head difference between shallow and deep aquifers was based on Figure 9 of the Coffey Partners report (1994). The head differences were small and the resultant leakage was also small, and this achieved the effect as recommended by the hydrogeologist on the team (Mr George Gates). Figure 2.2 shows that the modeled values were 0.3 Gl/year upward leakage in the dry zones of the district and 0.1 Gl/year downward leakage under the irrigated zones. The net difference of 0.2 Gl/year is consistent with the observation that the groundwater inflow through the Jemalong Gap near Jemalong weir is greater than the outflow through the Manna Gap to the north west.

4.8 Extraction of Groundwater by Trees

The trees scattered throughout the plain areas may contribute significantly to groundwater extraction, particularly where the groundwater is getting closer to the surface and is not too saline. The problem is how to assess the areas of trees in each sub-district and how much the contribution to groundwater extraction is.

Where groundwater is very saline, above 20,000 uS/cm, it would be expected that the trees do not contribute significantly to extraction, except if a fresh grondwater lense is created after an accessions event. This happens to the north west and south west of the district. Where the groundwater is less saline the groundwater extraction still depends on the groundwater movement to the site where the tree is located and how permeable the clays of the rootzone are. Since the Jemalong Wyldes Plains area mostly consists of extensive clay depositions it would be expected that the groundwater extraction is mostly of a local nature (say 10-20 metres distance from a tree). In flood prone areas on the other hand it would be expected that trees contribute significantly to groundwater extraction after floods.

It has been observed that following the 1990 flood many trees in the flooded areas have succumbed and are no longer effective as groundwater pumps. Consequently groundwater levels after floods will receed more slowly unless these trees are re-established.

Well established trees with abundant supply of fresh groundwater may extarct up to 15 Ml/ha/year in addition to the 500 mm of rainfall. For the Coleambally Irrigation Area values up to 6 Ml/year were used for the purpose of the Land and Water Management Plan. Because of the more extensive clays and the higher groundwater salinity it appears that for the Jemalong district values are unlikely to exceed 3 Ml/ha/year.

Advice from NSW Agriculture suggests that the following tree areas exist:

scattered	5,200 ha
light tree cover	2,065 ha
medium	4,211 ha
dense tree cover	728 ha

Assuming that scattered trees occupy 10% of the landscape, light 20% and medium 35%, a total of 3,200 ha of trees can be calculated. This is about 4% of the district. This area was distributed over the sub-districts in proportion of total area. The total volume of extractions by trees therefore would be about 9.6 Gl/year, which is shown at Figure 2.2.

4.9 Capillary Rise.

Capillary rise varies with watertable depth and soil characteristics, particularly hydraulic conductivity. The latter factor is also a function of the soil moisture level.

In the groundwater balance model capillary rise balances the recharge minus the discharge and the increase in groundwater storage. It is calculated from two equations derived from groundwater modeling for the Wakool District (van der Lely, 1988), and based on lysimeter work and comparison with theory. The two equations represent the range of likely values for Riverine Plain clay soils. The calibration of the model selects an equation within the range that satisfies the groundwater balance for the sub-district. This procedure is part of the Soil Salinity Assessment Model

Typically the capillary rise rates calculated average about 0.1-0.15 mm/day, which is an average over all watertable depth categories within the high watertable zone. Overall, about 30 Gl/year of capillary rise discharge is involved for the whole district (20 Gl/year for the irrigated zone and about 10 Ml/yr for the dry zone).

4.10 Watertable Rise

Watertable rise is the balancing factor in the groundwater balance. If it is zero the watertable level has stopped to rise. This situation has not yet been reached in the Jemalong and Wyldes Plains District. Groundwater maps suggest that the rise varies from as low as <0.04 metres/year to over 0.16 mteres/year (Map 1, Apendix 2).

Baden Williams (1994) in a report on groundwater conditions assessed that the net additions to groundwater were in the order of 8 Gl/year. However his assessment applies for the whole area of a rectangular grid that he considered (160,000 ha). Nevertheless most of the increase is likely to occur within the 80,000 hectare J&WPID.

The groundwater balance component of the Soil Salinity Assessment Model gave a result of about 6.5 Gl/year, see Figure 2.2. This applies for the J&WPID area only. It is considered that the values of net groundwater accessions between Williams and this assessment are close, although not exactly the same. The effective porosity value in both cases was assumed to be 0.08 (see section 5.3).

5. Other Groundwater Factors

5.1 Groundwater Equilibrium

In all irrigation areas a groundwater equilibrium level will eventually be reached in all locations. This equilibrium level will depend on the recharge and discharge factors that apply for the location considered. Where recharge tends to be high and discharge is small the watertable level will be high. However where discharge is large compared to recharge the watertable level will be deeper. With a deeper watertable the gradient for flow away from the site becomes less, and capillary rise decreases, until the discharge matches the recharge. With higher watertables the capillary rise increases, again until an equilibrium is reached.

Seasonal variations in recharge and discharge causes variations in watertable level. The variation may extend over a longer timeframe where the factors are not linked to seasons or climatic factors, for instance some years flood events cause the watertable to rise and this effect may take years to dissipate through capillary action or extraction by dep rooting plants (trees).

In the MIA the equilibrium levels are in the order of 1.2 to 1.4 metres. The irrigation hydraulic loading on the landscape is about 6 Ml/ha and rainfalll is 400 mm/year. There is only little dissipation by groundwater flow and most discharge occurs by capillary rise.

In the northern part of Coleambally the same irrigation hydraulic loading occurs, but groundwater flow away from this part of the district is such that an equilibrium level of 3 to 4 metres exists. Capillary rise is only minimal.

In the Berriquin District irrigation intensities of 2-3 Ml/ha seem to cause equilibrium levels between 1.5 and 2.0 metres. Whilst large areas are likely to come within the 2 metres "magical" danger limit, the average levels will be deeper compared to the MIA.

In the Jemalong and Wyldes Plains area the average irrigation intensity is only about 1 Ml/ha on average, and about 2-3 Ml/ha in the irrigated zone. It would be expected that the equilibrium watertable would be deeper than in the Berriquin District, all other factors being equal. However, all factors are not equal. There are large accessions from floods during some years or sequences of years, and the rainfall is 500 mm/year, 100 mm/year above the Berriquin district. On the other hand, there are still significant areas of trees (4%) contributing to discharge. Irrigation is mostly for lucerne, and no ponded rice areas exist. The volumes involved were discussed at Chapter 4.

The conclusion is that the expected equilibrium average depth to the watertable should be around about the 2 metres level or even slightly deeper. There are considerable periods when it rises above this level over large areas. These conclusions are confirmed by comparison of the the watertable maps after the 1990 flood events and the April 1995 map (Appendix 1), as well as Figure 2.1, which shows that the areas within 3 and 4 metres continue to increase at a higher rate than the within 2 metres area.

Another aspect is that because of the variable (stochastic) nature of the watertable levels it is likely that locations where watertables average 2.0-2.5 metres there may still be a salting process taking place in a proportion of the landscape, particularly the dry zones of the landscape. This was assumed for the soil salinity assessment model by applying the soil salinity prediction functions of Table 2.1 over a larger range of watertable depths. This is further discussed at section 6.1.

5.2 Groundwater Salinity Effect

The rate of salinisation will be more rapid where the salinity of the shallow goundwater condition is more saline. The soil salinity prediction curves of Table 2.1 were established for the MIA, where the average goundwater salinity is about 5,000 mg/l (about 8,300 uS/cm). Where the salinity is less the rate of salinisation would be proportionally less.

For the Jemalong district the groundwater salinity of the shallow groundwater was considered for each sub-district and the models scaled accordingly. Map 6 of Appendix 2 shows the groundwater salinity for the district.

5.3 Effective Porosity

The effective porosity represents the volume of moisture that needs to be removed from the soil profile to lower the watertable by one unit. Typically, this factor is about 20% or more for sands, anout 5-10% for loams, and only 1-2% for heavy clays. For a district and average weighted effective porosity could be calculated from soil stratigraphical profiles. For Coleambally a value of 8% was so calculated. In the Jemalong district the average would be similar and probably somewhat higher for that part of the district where prior streams are more active (Warroo) and less in the Wyldes Plains area. The value also depends on the depth range in the profile over which the watertable fluctuates. This will vary over a thirty year period in some districts, but perhaps not so much in the Jemalong district.

The effective porosity is important in water balance models, because it determines the rate of rise as a consequence of a certain volume of accessions, or the drop resulting from pumping or discharge by trees.

5.4 Deep Aquifer Influence

The Paleo channel of the Bland Creek and Lachlan catchments meet to the west of the Jemalong gap. The extent of the Paleo channel is more limited than that of the shallow aquifers. The Coffey partners report and the Hydrogeology section of the Department of Land and Water Conservation (LAWC) advise that there is little interaction between the shallow and deeper aquifer systems. This is a little surprising, for two reasons:

1. There is a good relationship right across the district between shallow and deeper pressure levels (Coffey partners maps). The levels seem to follow each other well.
2. The watertables in the not irrigated lands to the west of the district tend to be consistently high at the 2 metres level. Since pump tests of the shallow aquifer systems near Bogandillan creek show very low transmissivity it is unlikely that the irrigation groundwater mound under the Warroo area could supply a sufficient groundwater flow through the shallow aquifer to satisfy the capillary rise and tree extraction requirements as well as the groundwater seepage into Bogandillan creek.

Although the author has doubts regarding the lack of importance of the deeper aquifer system in distributing groundwater across the district, the assessments of this report have been based on the conclusions of the previous hydrogeological work.

6. Soil Salinity Assessment

6.1 Predictive Functions

Soil salinity predictive functions were discussed at section 2.1. The watertable categories for which these apply are based on four 20 cm intervals between 70 and 150 cm (MIA conditions). Watertables deeper than 150 cm are considered “safe”. For the Jemalong district capillary rise from watertables may occur from greater depth, as discussed at section 5.1. There is less off-setting leaching, both in the irrigated areas and in the dryland areas. Following this reasoning the watertable categories were changed to four 30 cm intervals between 75 and 195 cm for the irrigated areas and four 40 cm intervals between 90 and 250 cm for the dryland zones. The fifth category in both cases is the one shallower than 75, respectively 90 cm.

Some critics may consider this categorisation arbitrary. Whilst not disagreeing, in the opinion of the author, if an additional error is introduced by this procedure, this would be in the direction of tending to over-estimate the rate of salinisation, rather than under-estimating.

6.2. Areas at Risk of Salinisation

The area in which there is a risk of saliniation is confined to the area in which watertables are within a certain depth of the surface. In much of Australian reporting the area within 2 metres is used as a benchmark. However several factors need to be considered, for instance:

- Different soils behave differently, capillary rise may occur from over three metres depth in some loam soils, whereas for some clay soils capillary rise almost ceases once the watertable drops below 1.2 metres, especially under drying conditions.
- In irrigated areas there is an off-setting effect due to leaching, causing the risk to be less for the same watertable depth than in not irrigated soils.
- The area actually becoming salinised is not only related to watertable depth, but (probably more importantly) to the balance between accessions and capillary rise that exist at every site of the landscape. In this the net inflow or net outflow to these sites is critical.

In conclusion, the 2 metres depth is not as magical as some would believe, but is merely a reference depth for comparison only. There is no reason not to depart from this criterion if this is justifiable.

The irrigated parts of the district are more easily compared with other irrigation areas for which assessment have already been made. Therefore, for the J&WPID LWMP the area with watertables within 2.0 metres from the surface was selected for soil salinity assessment of the irrigated area. Because the author believes that in the dry areas a watertable deeper than 2 metres may still involve a risk, the areas within 2.5 metres were chosen for the dry zones.

To get the areas needed the total area within 2 and 2.5 metres was measured from maps (see Tables 3.2 and 3.3) and subsequently the area for the irrigated part and not irrigated parts were assessed from their relative proportional areas (Table 2.2).

Within the areas so assessed the procedures of Chapter 2 were applied to get the salinity affected areas.

6.3 Initial Soil Salinity Values.

In irrigated areas, when the new equilibrium watertable levels are reached for the first time, the landscape usually has benefited for years by a leaching regime. Soil salinity values will be considerably less than for the virgin condition, when irrigation commenced. A typical low salinity level at that time would be in the order of 0.8 dS/m in a saturation extract (300 ppm in Table 2.1).

Once watertables have become high soil salinity will start to increase. This process may be slow at first because the top layers of the groundwater may consist of a lense of fresh groundwater and the salinisation rate may be slow. Once this is dissipated by capillary rise and evaporation the more regional values of groundwater salinity will apply and the salinisation rate may increase.

The consequence of using the regional groundwater salinity from the outset of high watertable conditions could be an over-estimation of the salinisation process, however this is partially offset by the fact that the soil salinity prediction curves are calibrated against actual soil salinity surveys for conditions which incorporated this effect.

In the dryland areas the situation is different. The topsoil to about 60 cm depth may be low in salinity for the virgin condition, but the subsoil in Jemalong is known to be saline and sodic. Leaching would only have occurred in the areas affected by flooding. In timbered areas the change to high soil salinity is likely to be at depths greater than 60 cm, this depth being a function of average rooting depth and the ability of rainfall to infiltrate. Nevertheless, compared to irrigated areas, when watertables rise to an equilibrium within 2-3 metres from the surface not nearly as much capillary rise needs to occur to increase salts in the rootzone. The distance of travel is also less.

Very few data exist on the initial soil salinity values at the onset of high watertable conditions. Kelly (1970) reports some values which vary greatly.

The soil salinity assessment model has adopted values of 1.0 to 1.5 dS/m (ECex) for the soil salinity, dependent on whether the sub-district was located more to the east or to the west or south west.

6.4 Calculations

As discussed at Chapter 2, the calculations for the soil salinity assessment consist of the following sequence:

1. Compilation and addition of all Recharge factors.
2. Compilation and addition of all Non-Capillary Rise Factors.
3. Assessment of average watertable depth in high watertable zone of area considered.
4. Assessment of Capilary Rise in conjunction with
   - the volume which represents the watertable rise factor, and :
   - the expansion rate of the high watertable area
5. Assessment of the watertable level increase and the expansion in high watertable area from the volume added to the watertable.
6. Calibration of the assessed high watertable area expansion with the area expansion determined from groundwater maps and hydrographs.
7. Identification and assessment of all incremental high watertable areas.
8. Calculation of areas for all watertable depth categories, for instance 0-90, 90-120, 120-150, 150-180 and deeper than 180 cm.
9. Soil Salinity Assessment for each watertable category using predictive function.
10. Collating all areas each having a certain salinity into salinity classes and production of salinity results in tables.

The assessment of the watertable depth is based on regressions in the MIA which found that a base level of about 2.80 metres may be adopted. The actual watertable depth is above this level in proportion to the magnitude of each recharge factor and deeper again for existing non-capilary rise discharge factors. The level change is calculated as volume divided by area and effective porosity. The final depth achieved is compared with typical values observed in the high watertable part of the district and adjusted by calibration

The water balance assessment resulted in the following average values, applying to the high watertable zones (see table 6.1)

Table 6.1. Assessed average equilibrium depths for irrigated and dry zones for all districts from the water balance assessment

Sub-District	Irrigated Zone	Dry Zone
Cadow	1.8	2.1
Jemalong North East	1.7	2.0
Warroo	1.8	2.0
Wyldes Plains	1.8	2.1
Ave J&WPID	1.8	2.1

Capillary rise is based on functions from the Wakool groundwater model by A. van der Lely (1988). Basically, two curves were compiled from research data, one for a less permeable clay and one for a more permeable clay. The calibration consists of choosing a curve in between these limits which suits the groundwater balance.

The calculation of areas belonging to each watertable category is based on a standard deviation (SD) of the watertable depth around the average. The SD used was 50 cm based on assessments for Riverine Plains areas in the MIA and Berriquin.

The salinity for every relevant year was calculated for all incremental high watertable areas and then grouped together in soil salinity classes 0-2 dS/m, 2-3 dS/m, 3-4 dS/m, 4-6 dS/m, 6-8 dS/m and > 8 dS/m. The areas found for these classes were smoothed by a root type polynomial function. This was considered justified to avoid unrealistic outcomes due to the rather variable nature of the incremental areas and associated soil salinity for each 5 year period. The final calculation of salinity values with time were also smoothed.

6.5 Predicted Soil Salinity

The results of the soil salinity assessment for the nine sub-districts of the Jemalong Wyldes Plains districts are shown at Appendix 3. Tables 1-5 show the data used in the models for the irrigated and dry zones of Jemalong North East, Cadow, Warroo and Wyldes Plains, and the combined J&WPID. Tables 6-10 give the predicted salinity, in terms of the area (hectares) likely to be affected for the five year intervals between 1995 and 2025 for each soil salinity category, as well as the proportions of land in the sub-district.

Tables 6-10 represents the aimed for outcome of the report. The totals should not be interpreted as being areas which will be lost to agricultural production, rather it is the land which is predicted to be affected, meaning that a yield loss may be suffered for part of this land. For some land (say the over 6 dS/m category) the yield loss may be quite serious or total.

Figure 6.1 and 6.2 show in graphical form how the increase in salinity is expected to take place.

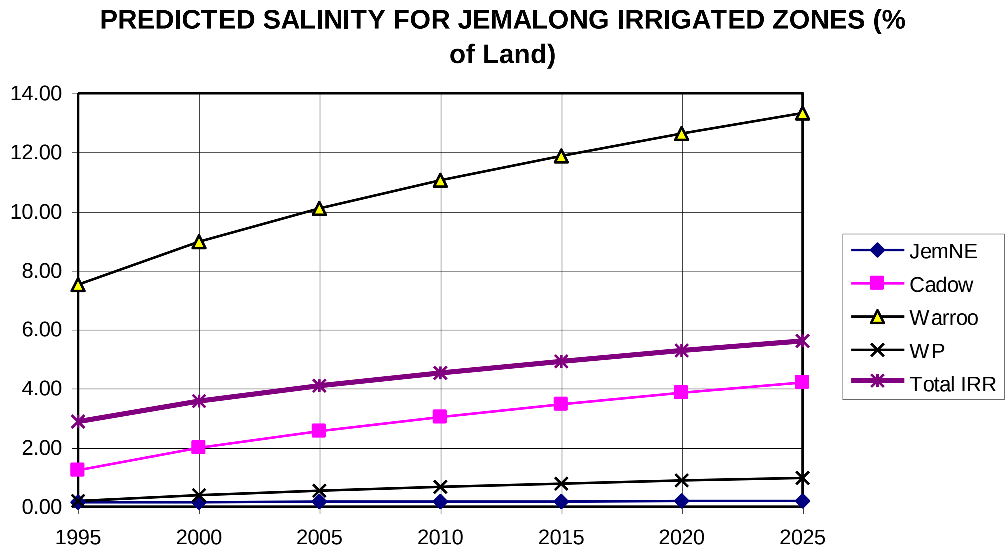

Figure 6.1 : Predicted increase in % of Land affected by salinity in the Irrigated zones of the J&WPID.

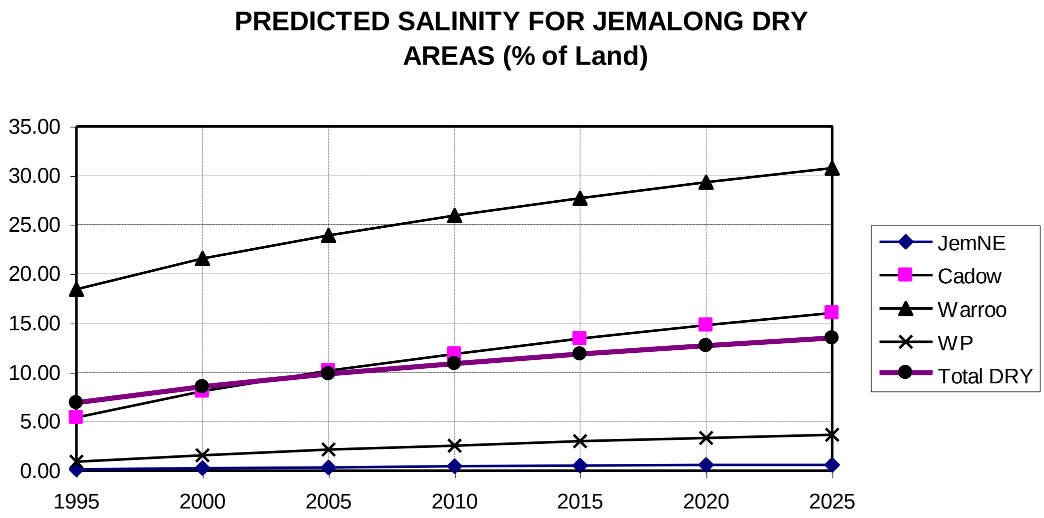

Figure 6.2 : Predicted increase in % of Land affected by salinity in the Dry zones of the J&WPID.

For both the irrigated and dry zones the Warroo area will be the worst affected because it will have such a large proportion of its landsurface with watertables within the chosen groundwater depth. However the 30 year average is estimated to be less than 6% for the irrigated lands and less than 15% for the dry zones.

7. Discussion

7.1. Extent of Salinity

It would be very useful if the results of this study were checked and verified by field surveys. This would give a better handle on the 1995 extent of salinity than what is now available. Such surveys should become a regular feature in the district and become part of performance monitoring of the LWMP.

High watertables have occurred longest in the Warroo area and this shows up in the proportion of land that is and will be affected (Figure 6.1). Yet even in the Warroo area the future extent of salinity appears very limited (Figure 6.1). The higher proportion in the dry zone reflects the conditions which exist towards the Bogandillan Creek.

Salinity will never be a serious problem in the Jemalong North East area, but in the dry zones of Wyldes Plains and Cadow there is a gradual increase, but not alarmingly so from these results.

Because the areas of high watertables are only starting to increase more rapidly from now onwards (section 3.3), and the slow development of salinity it is likely that any upward trend in salinity will continue after year 30, perhaps for half a century or more.

7.2 Sensitivity Analysis

No specific sensitivity analysis was carried out by early June 1995. The following comments are made:

- There are many factors for which assumptions have been made, or where the knowledge base in imperfect. To carry out sensitivity analysis in this context is not meaningful and may create incorrect impressions.
- The factors in the models are based on averages, stochastic interpretation using scientific methods is not possible at this stage.
- There is a reasonable degree of cross checking in the methodology, as discussed at section 6.1. To at least some degree this mitigates errors introduced by a particular factor.

Factors which affect the sensitivity of the result most are believed to be :

- The reference high watertable area and its increase over time for the irrigated zones and the not irrigated zones.
- The relevance of the soil salinity prediction curves from the MIA for the J&WPID.
- The accuracy of the assessed watertable depth.

The assessment of capillary rise and volumes going into increased groundwater storage are less critical because they were determined more to complete the water balance rather than assessing the salinity risk directly. In this regard it was found that it is very difficult to adequately calibrating the water balance with these two factors for all of the 5 year intervals for which the assessment was made. This means that there are likely errors in some of the future water balance factors which could not be reconciled. This is not surprising. The water balance for current conditions is dificult enough. To do the same for future watertable conditions must involve a larger error in the various water balance components.

The critical aspect is that for the high watertable areas selected the salinity trends are linked to an observed rate of increase for a range of specific conditions. This means that despite the uncertainties and many associated factors there is still a reasonable confidence in the predictions made.

7.3 Land and Water Management Plan Context.

Most Land and Water Management Plans have as their primary objective the achievement of sustainability in terms of groundwater conditions and salinity trends. This objective is pursued subject to a number of constraints, eg the downstream water quality must not be degraded, or natural resources within the area should be protected.

The outcome of this assessment points at an only moderate continued rise in watertable levels and increased salinisation. The salinity increase will mostly affect the dry zones of the district. Where some irrigation land is becoming affected the landholder is likely to shift his water resource to a not affected part of his farm, thereby avoiding economic loss. Because of this possibility it will be very difficult to economically justify a lot of expenditure to protect the irrigation industry. The effort will largely be devoted to protecting the dry zones and the still existing natural environment.

The experience in the Murrumbidgee and Murray regions of recent years suggests that large scale groundwater pumping schemes to increase discharge and lower watertables can not be justified in the typical mixed farming irrigation areas.   High value crops are needed to justify the expense. This means that such schemes are also unlikely to be economic for the J&WPID. Instead, most reliance have to be placed on on-farm options.   To devise a suitable strategy of such options to tackle as effective as possible, probably with limited resources, all the major sources of accessions identified in this report will be the challenge of the LWMP committee.

8. References.

DWR (1993) “Review of Technical Reports J&WPID” RepNo G364/1AB

Coffey partners, (1994) Groundwater Modeling Study Jemalong Wyldes Plains.” Report G375/2-AB.

Kelly, ID., (1971) “J&WPID, Geomorphology, Soils and Groundwater Conditions” WC&IC, Leeton, NSW.

Kelly, ID., (1991) “Review of shallow groundwater hydrology in the J&WPID 1944-1991”. Report LN-91/005, DWR Leeton.

McGrath, S., (1994) “J&WPID LWMP NSW Agriculture Water Balance” Report NSW Agriculture, Forbes, NSW.

McGrath, S., (1994) “Impact of Flooding in the Jemalong Wyldes Plains Irrigation District” Report NSW Agriculture, Forbes.

Van der Lely, A, (1988) . Groundwater models for the Wakool Irrigation District” DWR report, Leeton NSW.

Williams, B,. (1993) “The Shallow Groundwater Hydrology of the J&WPID”

Williams, B. (1995) “Prediction of Groundwater Trends in JWP district”