LOXTON IRRIGATION AREA
Groundwater modelling of irrigation management options

REPORT BOOK 97/00048

by

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PRIMARY INDUSTRIES AND RESOURCES SA

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LOXTON IRRIGATION AREA
Groundwater modelling of irrigation management options

N.L. Watkins

The groundwater model described in this report was used to quantify the changes in salt loads to the River Murray and induced discharge to the degraded river flats of proposed future management options for the Loxton Irrigation Area. The options included maintaining the status quo (including current accession rates for current irrigation levels), irrigation channel rehabilitation to minimise transmission losses, improving irrigation practices and expanding the irrigated areas.

A two layer MODFLOW model showed that partial rehabilitation by replacing the channel water delivery system with pipelines, could result in a reduction of induced salt loads to the river of 30% by 2047 compared with the no change scenario. If in addition, the irrigation efficiencies can be improved to 80%, the salt loads can be reduced by 50%, even if an additional 1600 ha are irrigated to the east of the existing irrigation area. As far as groundwater discharge to the northern and southern river flats are concerned, the model suggests partial rehabilitation (Option 2) will result in a reduction by 25% and 30% respectively, below the no change scenario levels by 2047. There is little difference between the impacts of Options 3 and 4, both resulting in a reduction of discharge by about 55% and 65% respectively.

Future detailed modelling of the impacts of the management options will benefit from a greater knowledge of the distribution of groundwater salinity within the Pliocene Sands aquifer, particularly where the watertable mound is in direct contact with the river.

INTRODUCTION

The Loxton Irrigation Area (Figure 1) was established in 1947 adjacent to the River Murray in South Australia's Riverland Region. The current volume pumped from the river exceeds 31 000 ML/year to irrigate about 2750 ha of mainly vines and citrus crops. It is estimated that of the water applied by both irrigation and rainfall, about 30%, or almost 15 000 ML/year is not used by crops. This excess water is lost by seepage, overflow from the distribution channels, direct evaporation, and infiltration to the underlying watertable.

A portion of this excess water (about 5500 ML) is intercepted by the Comprehensive Drainage Scheme (CDS) which discharges to Katarapko Island evaporation basin (KIEB).

The infiltration of drainage water has created a groundwater mound in the Pliocene Sands aquifer with an elevation of 15 m above adjacent river pool level. The mound is still growing at a rate of 20 cm/year and induces discharge of saline groundwater to the river and floodplain environment. The native groundwater salinity is more than 25 000 mg/L, but this has been diluted by drainage water to less than 5000 mg/L below the irrigated areas in places. Stream salinity surveys carried out in the main river channel adjacent to the Loxton Irrigation Area indicate that about 120 tonnes/day of salt is discharged to the river due to the effects of the groundwater mound and the KIEB. This compares with an estimated pre-irrigation natural salt discharge of about 20 tonnes/day. The resulting salinity impact at Morgan of the extra salt discharge is about 20 EC units at a cost to consumers of about $2 million/year.

Mitigation options for this salinity impact include improving irrigation efficiencies through upgrading the delivery and supply systems, improving drainage management and/or construction of salt interception schemes. The groundwater model described in this report was used to quantify the changes in salt loads and groundwater discharge to the river flats of proposed future management options for the Loxton Irrigation Area. The options included maintaining the status quo (current accession rates at current irrigation levels), irrigation channel rehabilitation to minimise transmission losses, improving irrigation practices, and expanding the irrigated areas by 1600 ha.

PURPOSE OF MODELLING

The groundwater model described in this report was used to assess the salinity impacts in the River Murray due to the proposed future management options for the LIA. The results were also to be provided for input into an environmental assessment report carried out by PPK Environment and Infrastructure Pty Ltd. The model results were also used to determine the future status of current overflow/swamp areas under the various management options.

HYDROGEOLOGY

The regional hydrogeology of the Loxton-Noora area is described in Barnett (1991). Regional watertable contours, groundwater flow directions and salinity contours developed from that study are shown on Figure 1. A typical geological cross section below the irrigated area at Loxton is shown on Figure 2. The impermeable Blanchetown Clay underlies surficial Mallee sand deposits (Woorinen Sands) at generally shallow depths of less than 5 m. The watertable lies in the Pliocene Sands aquifer which is hydraulically separated from the underlying confined Murray Group limestone aquifer by the Bookpurnong Beds aquitard. The geological units are described more fully in Watkins (1992).

IRRIGATION IMPACTS

Discharge of irrigation drainage water via drainage shafts, drainage bores or infiltration to the watertable has established a large groundwater mound in the Pliocene Sands aquifer. Drainage water has been collected and diverted to the Katarapko Island Evaporation Basin since 1964 and this, together with the groundwater mound, has resulted in induced discharge of native saline groundwater to the River Murray, with an associated increase in salt loads to the river of about 120 tonnes/day. The growth of the irrigation mound is illustrated by a comparison of watertable contours from 1975 (Figure 3) and 1995 (Figure 4).

Seepage of drainage water onto the northern and southern river flats has resulted in environmental degradation, including a decline in floodplain vegetation health and the establishment of large populations of undesirable insects (midges).

In places, native groundwater has been greatly diluted by the irrigation drainage, from more than 25 000 mg/L to less than 5 000 mg/L.

A recent report by Smith (1997) has estimated the growth of key irrigation parameters including hectares irrigated, diversion volumes, transmission losses, application efficiency and accession volumes (the annual volume which ultimately reaches the watertable and contributes to the groundwater mound). This data is detailed in Table 1 and summarised on Figure 5.

MODEL CONSTRUCTION

A two layer groundwater model was constructed for the area shown on Figure 6. The model grid comprises of 92 rows and 92 columns with each model cell having dimensions of 250 m x 250 m. The layers include the Pliocene Sands aquifer underlain by the Murray Group limestone aquifer. The Bookpurnong Beds, the aquitard between these two aquifers, is modelled as a low leakance between the two aquifers. The river and floodplain cells are specified as constant head cells. All model edge boundaries are general head boundaries. Discharges to the river and floodplains are identified as flow to constant head cells in the model water budget. The MODFLOW utility ZONEBUD was used to partition induced discharges to the northern and southern river flats, and to river reaches which abut the cliffs adjacent to the irrigated areas.

The model does not model floodplain processes such as evapotranspiration or river/floodplain aquifer interaction, nor were direct measurements of cliff seepage to the floodplain be obtained from model outputs. The river reaches which show the largest saline increases correspond to where the river abuts the highland area, that is, where the river is not protected from the impacts of the groundwater mound by a floodplain. Because of

***Table 1**: Loxton Irrigation Area - Estimated annual water balance data (Smith, 1997)*

Year	Irrigated area (ha)	Pumped volume (ML)	Rainfall (ML)	Transmission loss (ML)	Adopted application (ML)	Application efficiency	Volume past root zone (ML)	CDS volume (ML)	Accession from transmission losses (ML)	Accession volume (ML)
1948	500	5684	1494	905	6273	0.7	1882	0	597	2479
1949	750	8526	2242	1357	9410	0.7	2823	0	895	3718
1950	1000	11367	2989	1810	12546	0.7	3764	0	1193	4957
1951	1250	14209	3736	2262	15683	0.7	4705	0	1492	6196
1952	1500	17051	4483	2715	18819	0.7	5646	0	1790	7436
1953	2000	22735	5978	3620	25092	0.7	7528	0	2387	9914
1954	2500	28419	7472	4525	31366	0.7	9410	75	2983	12318
1955	2757	31340	8240	4990	34590	0.7	10377	150	3290	13517
1956	2757	31340	8240	4990	34590	0.7	10377	225	3290	13442
1957	2757	31340	8240	4990	34590	0.7	10377	300	3290	13367
1958	2757	31340	8240	4990	34590	0.7	10377	375	3290	13292
1959	2757	31340	8240	4990	34590	0.7	10377	450	3290	13217
1960	2757	31340	8240	4990	34590	0.7	10377	525	3290	13142
1961	2757	31340	8240	4990	34590	0.7	10377	600	3290	13067
1962	2757	31340	8240	4990	34590	0.7	10377	675	3290	12992
1963	2757	31340	8240	4990	34590	0.7	10377	750	3290	12917
1964	2757	31340	8240	4990	34590	0.7	10377	1000	3290	12667
1965	2757	31340	8240	4990	34590	0.7	10377	1250	3290	12417
1966	2757	31340	8240	4990	34590	0.7	10377	1550	3290	12117
1967	2757	31340	8240	4990	34590	0.7	10377	1750	3290	11917
1968	2757	31340	8240	4990	34590	0.7	10377	2350	3290	11317
1969	2757	31340	8240	4990	34590	0.7	10377	2750	3290	10917
1970	2757	31340	8240	4990	34590	0.7	10377	2950	3290	10717
1971	2757	31340	8240	4990	34590	0.7	10377	3250	3290	10417
1972	2757	31340	8240	4990	34590	0.7	10377	3450	3290	10217
1973	2757	31340	8240	4990	34590	0.7	10377	3500	3290	10167
1974	2757	31340	8240	4990	34590	0.7	10377	2800	3290	10867
1975	2757	31340	8240	4990	34590	0.7	10377	2400	3290	11267
1976	2757	31340	8240	4990	34590	0.7	10377	2600	3290	11067
1977	2757	31340	8240	4990	34590	0.7	10377	3050	3290	10617
1978	2757	31340	8240	4990	34590	0.7	10377	3350	3290	10317
1979	2757	31340	8240	4990	34590	0.7	10377	3150	3290	10517
1980	2757	31340	8240	4990	34590	0.7	10377	3300	3290	10367
1981	2757	31340	8240	4990	34590	0.7	10377	3500	3290	10167
1982	2757	31340	8240	4990	34590	0.7	10377	4391	3290	9276
1983	2757	31340	8240	4990	34590	0.7	10377	4823	3290	8844
1984	2757	31340	8240	4990	34590	0.7	10377	5155	3290	8512
1985	2757	31340	8240	4990	34590	0.7	10377	4172	3290	9495
1986	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1987	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1988	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1989	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1990	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1991	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1992	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1993	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1994	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1995	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1996	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167
1997	2757	31340	8240	4990	34590	0.7	10377	4500	3290	9167

this, it is considered that flushing of the native groundwater by diluting drainage water is a significant process in determining induced salt loads. Induced salt loads have been calculated by assuming that the displaced groundwater has a salinity of 10 000 mg/L due to dilution (actual salinities range between 2200 and 14 700 mg/L).

PRE-IRRIGATION BENCHMARK CONDITIONS

The first stage of modelling included the establishment of the initial watertable distribution to be used as starting heads for the generation of current watertable levels and induced groundwater discharges. The modelled head distribution prior to the establishment of irrigation but including post-locking river levels is shown on Figure 4.

CALIBRATION TO CURRENT CONDITIONS

This model run required a detailed estimate of the key irrigation parameters to allow a nett recharge to the watertable to be estimated and incorporated into the model. The data shown in Table 1 was divided into six periods of similar annual recharge volumes as shown on Table 2.

This model recharge function was adopted and MODFLOW's wells package was used to apply the recharge over the area of current irrigation shown on Figure 7. Recharge for stress period 1 was only applied over the northern half of this area where irrigation areas were first established (Ken Smith, pers. comm.). The model was calibrated to current conditions by iterating through numerous combinations of values for aquifer transmissivity, storage coefficient and leakance coefficient between the Pliocene Sands and Murray Group limestone. Table 3 details the ranges of hydraulic parameters used for model iterations, and the final adopted set of parameters which gave the best match to current watertable levels. Current modelled watertable contours are shown on Figure 7.

Table 2 *Stress period data for model calibration*

Stress period	Years	No. of days	Total recharge volume (ML)	No. of wells	Well recharge rate (m^3/day)
1	1947 - 1949	730.5	6 197	236	35.9
2	1950 - 1951	730.5	11 153	236	64.7
3	1952 - 1953	730.5	17 350	236	100.6
4	1954 - 1967	5113.5	180 389	602	58.6
5	1968 - 1981	5113.5	148 938	602	48.4
6	1982 - 1997	5844	146 131	602	41.5

Table 3 *Modelled hydraulic parameters*

Geological Unit	Hydraulic Parameter	Range	Adopted
Pliocene sands	Permeability Storage co-efficient	2 to 15 m/day 0.10 to 0.25	10 m/day 0.25
Bookpurnong Beds	Leakance	2×10^{-7} to 8×10^{-6} day^{-1}	8×10^{-6} day^{-1}
Murray Group limestone	Transmissivity Storage co-efficient	100 to 200 m^2/day 0.05 to 0.1.	150 m^2/day 0.10

Table 4 *Summary of Modelled Future Options*

Option	Description	Pumped volume (ML/year)	Irrigated area (ha)	Applied volume [1] (ML/ha.yr)	Plant water use efficiency	Transmission losses (ML/year)	CDS volume (ML/year)	Accession volume (ML/year)
1. No change	• No irrigation expansion • Retain channels • Continue with current irrigation practices	31 340	2 757	12.5	70%	4 990	4 500	9 167
2. Partial Rehabilitation	• No irrigation expansion • Replace channels with pipes • Continue with current irrigation practices	26 350	2 757	12.5	70%	0	4 500	5 877
3. Full Rehabilitation	• No irrigation expansion • Replace channels with pipes • Improve irrigation practices	18 472	2 757	9.7	80%	0	2 322 [2]	3 027
4. Rehabilitation with new irrigation	• 1 600 ha new irrigation • Replace channels with pipes • Improve irrigation practices	29 192	4 357	9.7	80% for existing areas 90% for new areas	0	2 322 (old) + 155 (new)	3 027 (old) + 1 397 (new)

Notes:
[1] Includes rainfall component of 3 ML/ha.a
[2] Assumes pro rata decrease in CDS volume with drainage flux

FUTURE MANAGEMENT OPTIONS

The model was used to identify the hydrogeological impacts of four possible future directions for irrigation management in the LIA. Details of each of these options are summarised in Table 4. The results will be incorporated into separate environmental and economic studies to allow comparison of the options and to identify the most suitable management directions.

OPTION 1 - NO CHANGE

This case simply assumes that current irrigation levels, efficiencies and management practices are maintained over the next 50 years with an annual accession volume of 9167 ML.

OPTION 2 – PARTIAL REHABILITATION

This case assumes that current irrigation levels and practices are maintained, but the existing channel water delivery system is replaced by pipelines. As such, recharge to the model over the next 50 years is decreased by the level of current transmission losses to 5877 ML/year. Transmission losses comprise channel seepage eg through cracks in the delivery channels (Plate 1), and overflows from the main supply channels (Plate 2).

OPTION 3 – FULL REHABILITATION

This option considers a combination of replacing the channels with pipes and improving irrigation efficiencies at current irrigation levels. Current irrigation efficiencies are below 70%. Rehabilitation has the potential to increase these efficiencies to nearly 80%, which could reduce the requirements for pumped diversions from the river by more than 25%, or more than 8000 ML/year (Smith 1997). The annual application rates will therefore be reduced from 12.5 ML/ha to 9.7 ML/ha. With an increase in irrigation efficiencies, there will be a commensurate decrease in drainage flows. For the purposes of this study, it is assumed that the decrease in CDS flow is directly related to the decrease in water flux past the root zone, as quantified by;

$$CDS_{new} = CDS_{old} \times (DF_{new}/DF_{old})$$

Where DF is drainage flux past the rest zone.
The annual accession volume for the next 50 years is therefore reduced to 3027 ML.

OPTION 4 – FULL REHABILITATION PLUS NEW IRRIGATION

This option considers that the current 2757 ha is fully rehabilitated as for Option 3, and that an extra 1600 ha of irrigation is developed at an even higher level of irrigation efficiency (assumed to be 90%). The new irrigation is assumed to be developed to the east of the current irrigation with 10% of this area requiring the installation of drains (Smith 1997). Annual accession volumes rise from 3027 ML for Option 3 to 4424 ML with irrigation expansion.

MODELLING RESULTS

The impacts of the four future options can be readily assessed by their effect on the height and extent of the groundwater mound. The modelled groundwater mounds for the four options in the year 2047 are shown on Figures 8 to 11 inclusive. Direct disbenefits of the groundwater mound include waterlogging and salinisation of topographically low areas, discharge of groundwater direct to the river and river flats by seepage, raising of groundwater levels below floodplain areas and increased groundwater discharge to the river.

IMPACT ON OVERFLOW / SWAMP SITES

The impact of the four options on seven overflow/swamp sites identified by PPK are summarised in Table 5. The results indicate that by the year 2047, Options 2, 3 and 4 will result in the groundwater level decaying to below ground surface at all sites apart from Site 1. Under Option 2, Site 1 will have groundwater levels at or above surface, but the current area affected will be reduced.

IMPACT ON GROUNDWATER DISCHARGE TO RIVER FLATS

The height of the groundwater mound under the four options directly determines the rate of groundwater discharge to the river flats. This is illustrated on Figure 12 which shows separately the modelled groundwater discharge to the northern and southern river flats over the next 50 years. The graphs also show the modelled increase in discharge from 1947 to the present to allow a possible calibration of the observed decline in floodplain vegetation health to past groundwater discharge.

Changes to the recharge function in the model are reflected by immediate changes to model results, for example the induced discharge to floodplain areas. Detailed studies from sites in the Riverland and Mallee regions, have established estimates of the time lag between changes in recharge rates due to land clearance and/or irrigation and a watertable response. This time lag depends on several factors including soil/sediment properties, natural moisture content of the soil/sediment, and the magnitude of the increase in recharge.

***Table 5**: Predicted Impact of Future Options on Overflow/Swamp Sites*

Overflow/Swamp Site	Option 1	Option 2	Option 3	Option 4
1	**	✓	✓✓	✓✓
2	+	✓✓	✓✓	✓✓
3	?	✓✓	✓✓	✓✓
4	?	✓✓	✓✓	✓✓
5	?	✓✓	✓✓	✓✓
6	?	✓✓	✓✓	✓✓
7	?	✓✓	✓✓	✓✓

✓✓ No longer present
✓ Area decreased
+ No change
** Area increased significantly
? Modelled groundwater level below ground surface

A maximum lag time of about 10 years is estimated for the LIA between start of irrigation and changes in the rate of discharge to the floodplains and salt to the river. The initial part of the curves for Option 1 on Figure 12 have been smoothed accordingly to allow for this time lag. A second time lag has been incorporated into the curves on Figure 12 for Options 3 and 4 which involve improving irrigation practices. It is unrealistic to assume that rehabilitation of existing areas will occur very quickly, so a 10 year time frame has been assumed over which rehabilitation will occur. The modelled benefits of these options have therefore been shifted 10 years into the future.

The model suggests that Option 2 (partial rehabilitation) will reduce groundwater discharge to the northern and southern flats by 25 % and 30 % respectively, below the no change scenario levels by 2047. There is little difference between the impacts of Options 3 and 4, both resulting in a reduction of discharge by about 55 % and 65 % respectively – a considerable improvement.

IMPACT ON INDUCED SALT LOADS

The ZONEBUD utility was used to calculate induced groundwater discharges to river reaches which have previously been identified by instream salinity surveys as showing significant increases in salinity. The modelled results are shown on Figure 13. They indicate that Option 2 will result in a reduction of induced salt loads to about 70% of those which could be expected for the no change case in 2047. Again, there is little difference between Options 3 and 4, both resulting in a reduction of salt loads to about 50% of those for the no change case.

Identical time lags to those described for the impact on groundwater discharge are assumed for salt load impacts, and the curves on Figure 13 have been adjusted accordingly.

The induced salt loads are directly calculated from the modelled groundwater volume discharge by assuming a salinity of 0.01 tonnes/m^3 for the displaced groundwater.

Future detailed modelling of the impacts of the management options will benefit from a greater knowledge of the distribution of groundwater salinity within the Pliocene Sands aquifer, particularly where the mound is in direct contact with the river. This will require a drilling and groundwater sampling program. Solute transport modelling could then be undertaken further to the hydraulic modelling, to more precisely determine the trend of induced salt.

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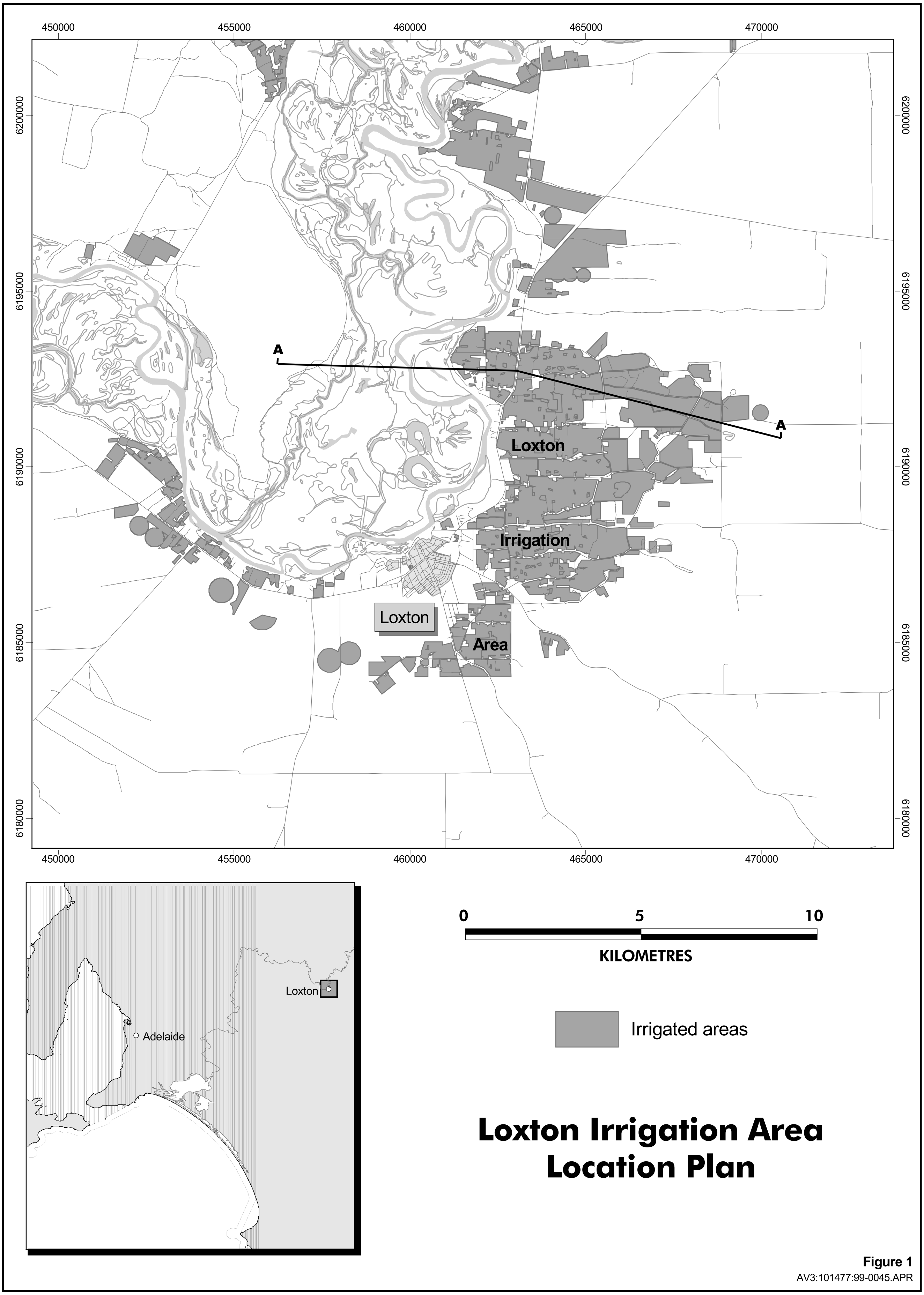
Ken Smith Technical Services, 1997. Drainage Report Loxton Irrigation District. *Loxton Irrigation Advisory Board and South Australian Water Corporation.*

Watkins, N.L., 1992. Loxton salinity and drainage investigation. Status report on hydrogeology. *Engineering and Water Supply Department. Library Reference* 92/20 (unrestricted).



Loxton Irrigation Area Location Plan

Figure 1

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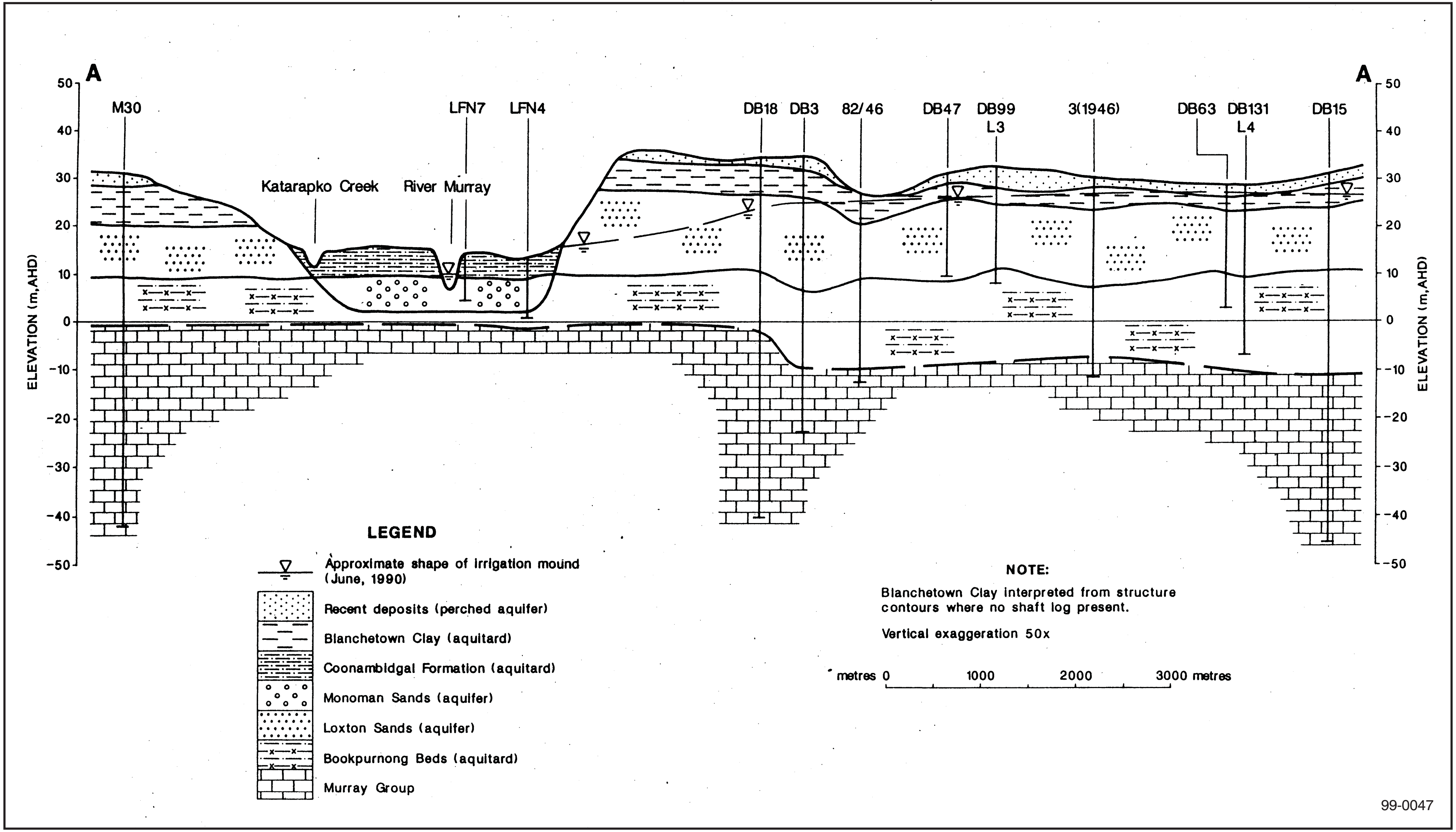


Fig. 2 Hydrogeological cross section

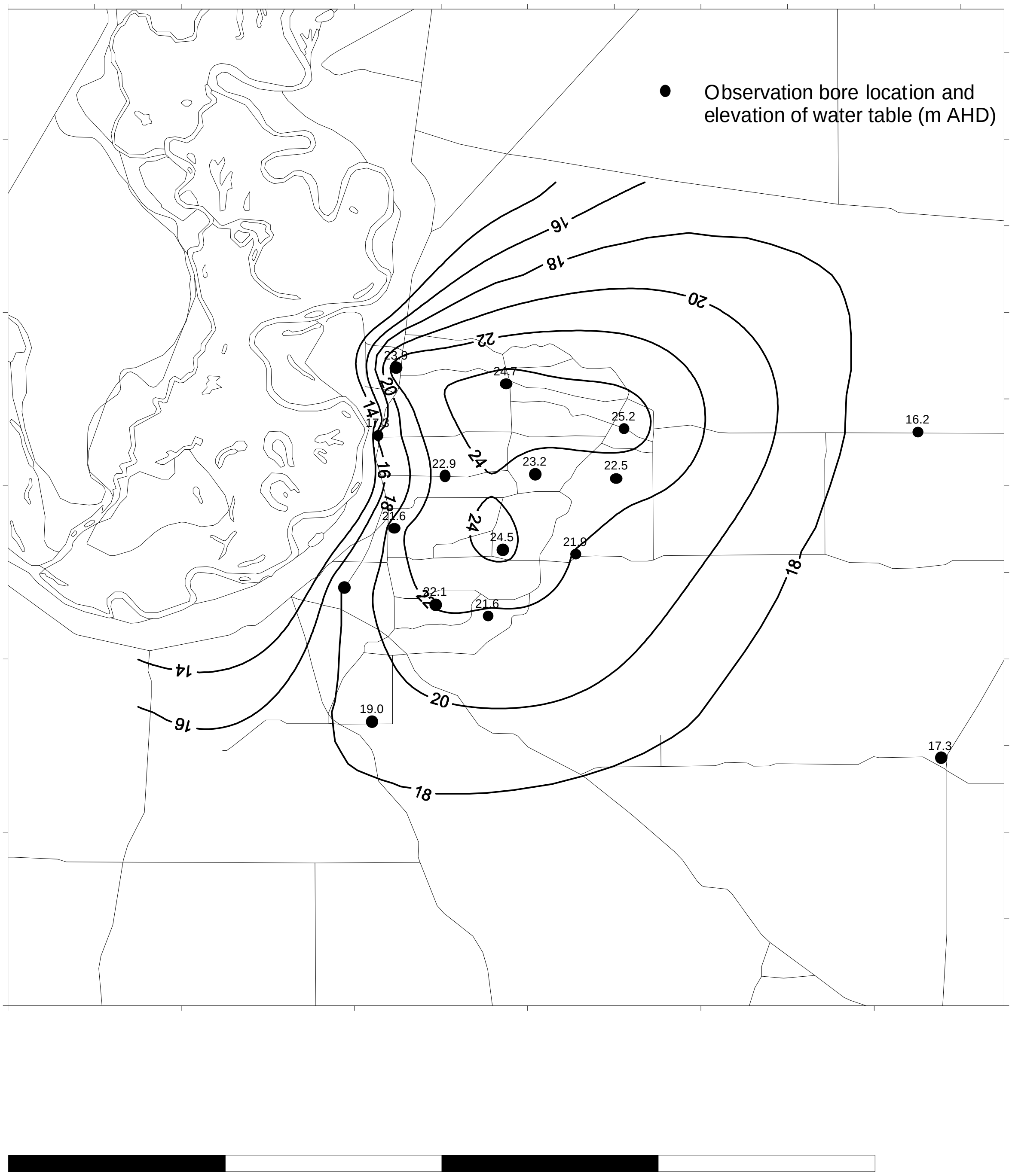


Fig. 3 *Watertable contours - 1975*

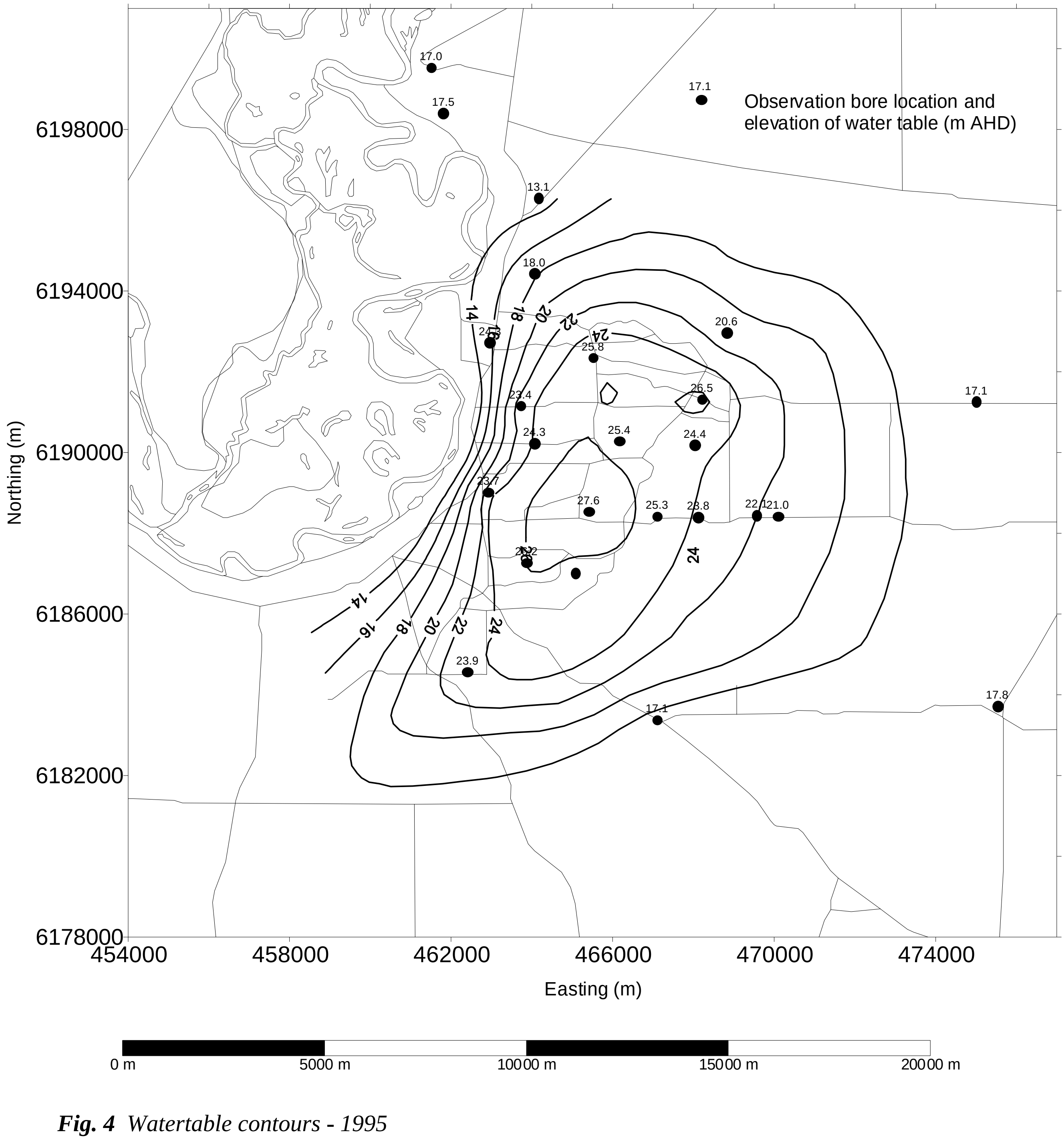
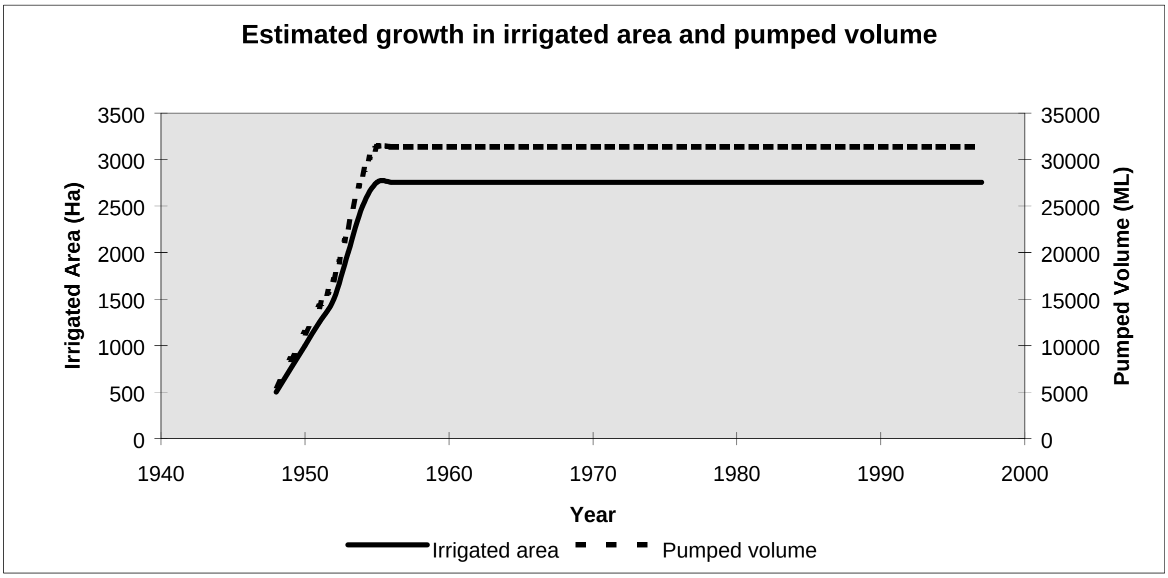
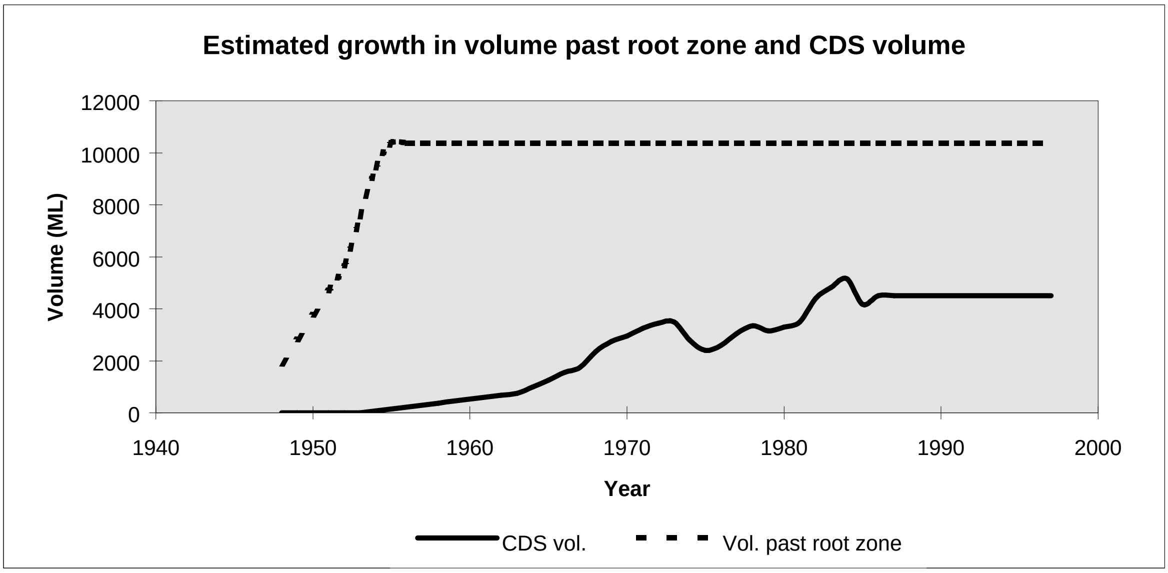


***Fig. 4** Watertable contours - 1995*





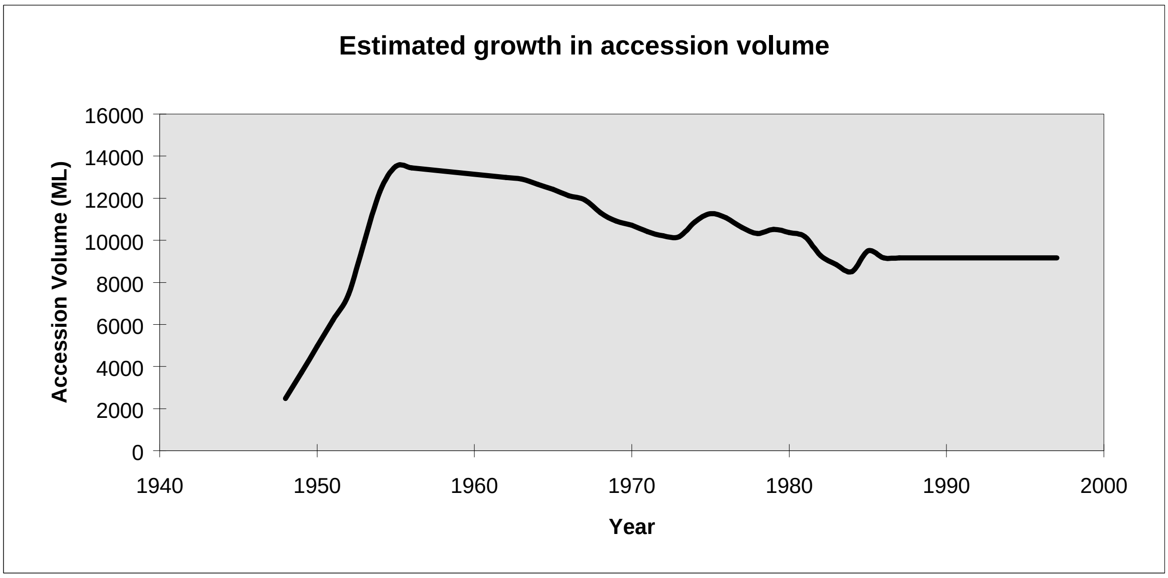


Fig. 5 *Estimated growth in key irrigation parameters*

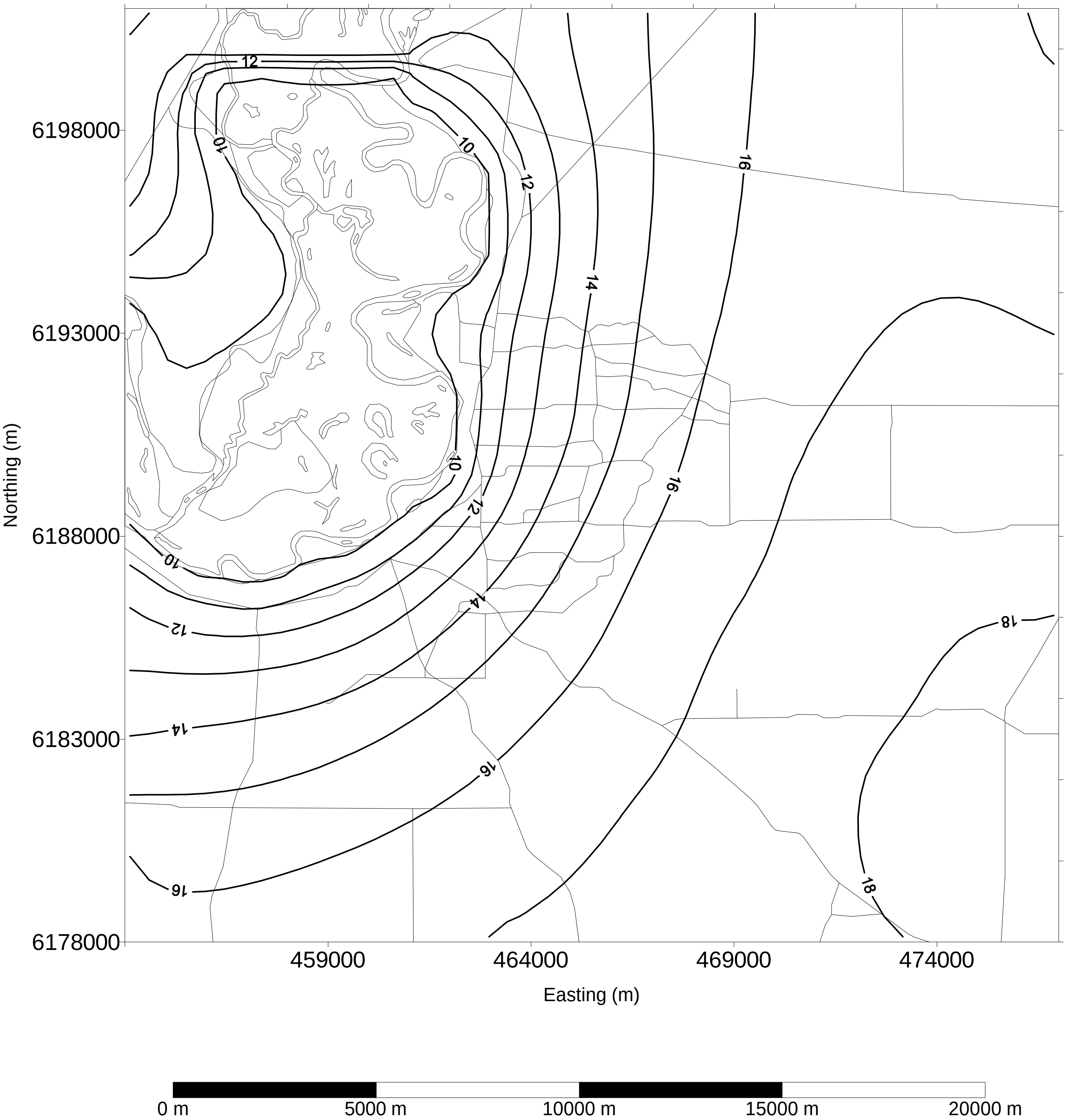


Fig. 6 *Modelled pre-irrigation watertable contours - 1947*

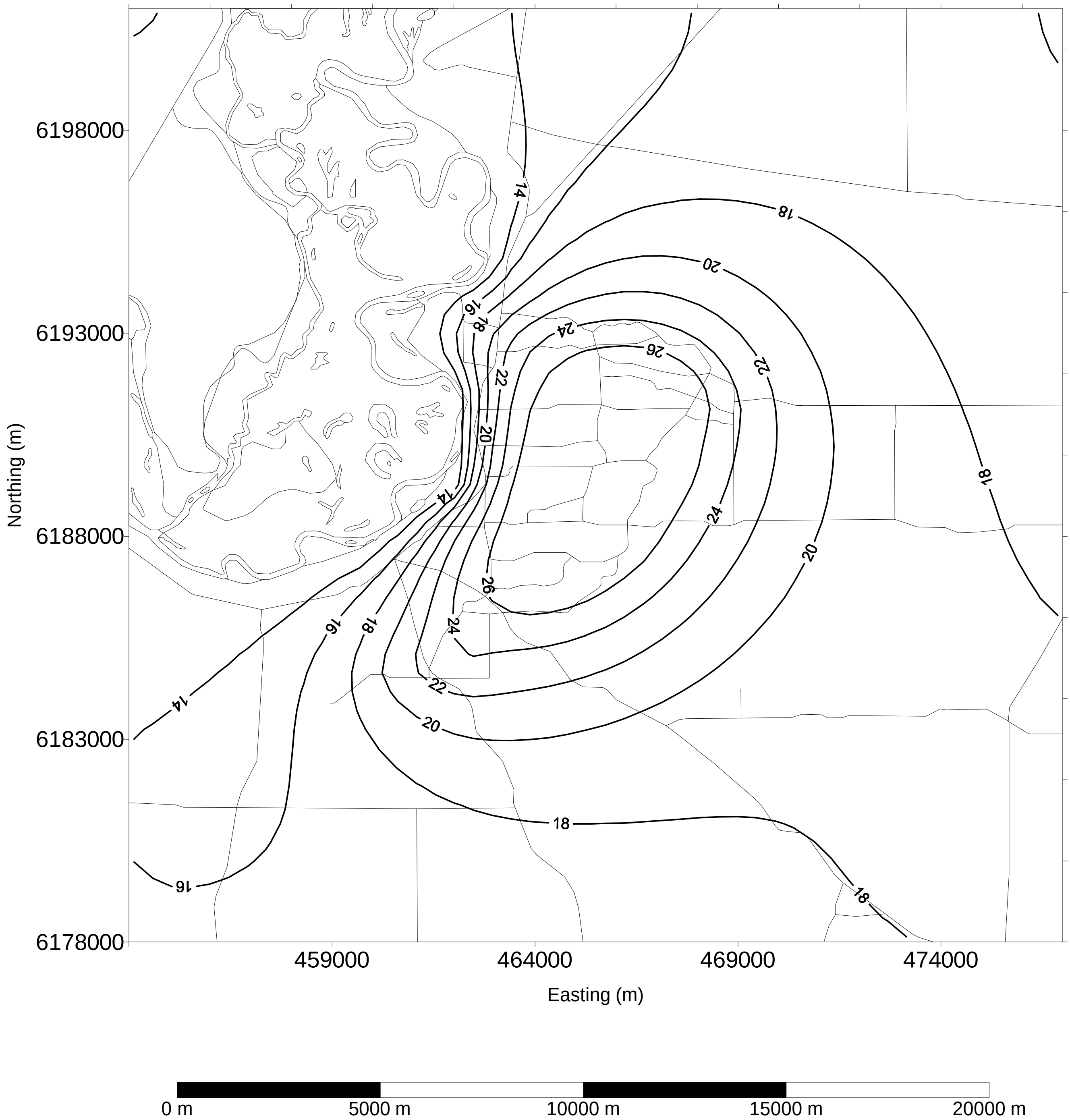


Fig 7 *Modelled current watertable contours - 1997*

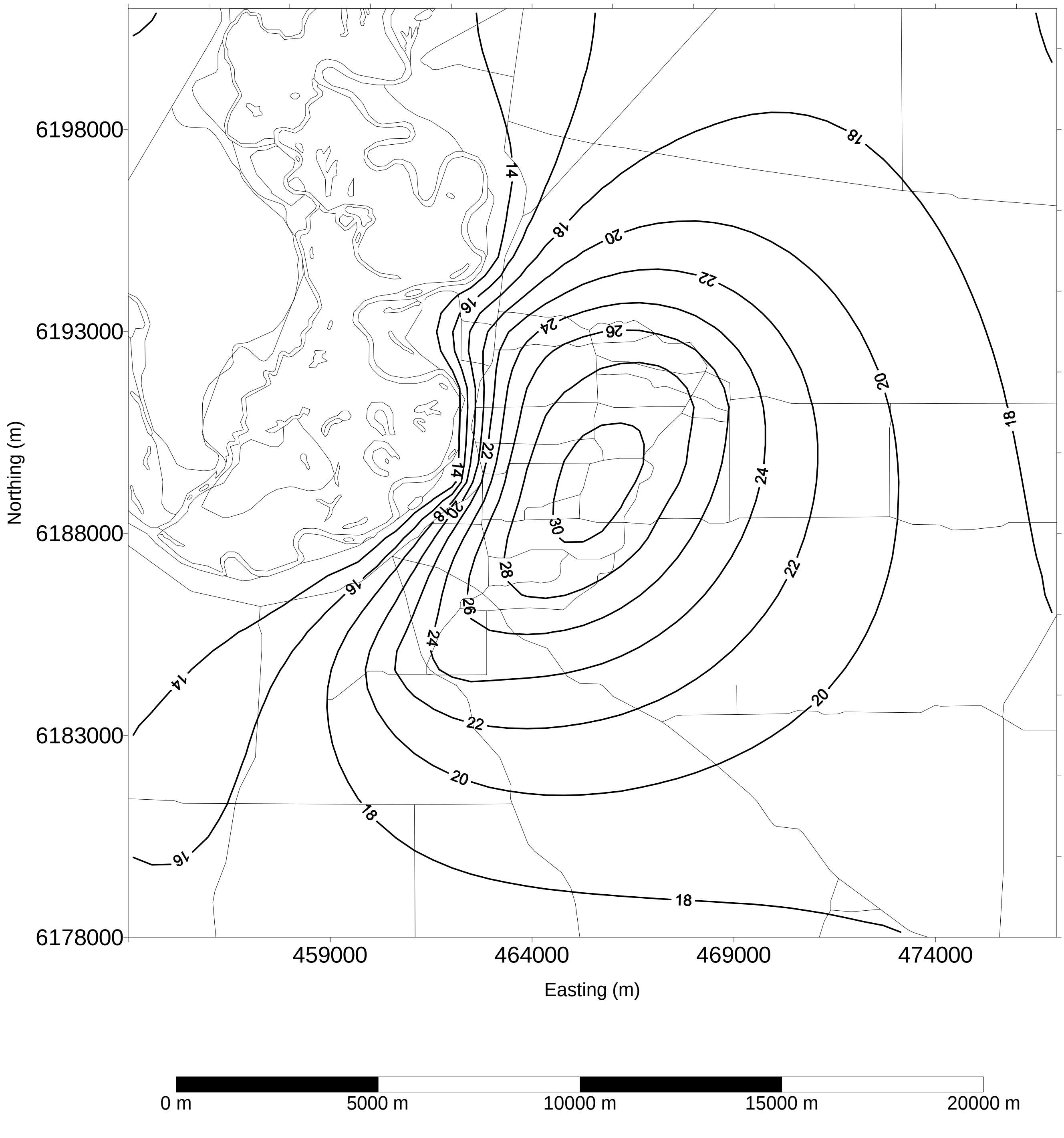


Fig. 8 *Option1 (No change) watertable contours - 2047*

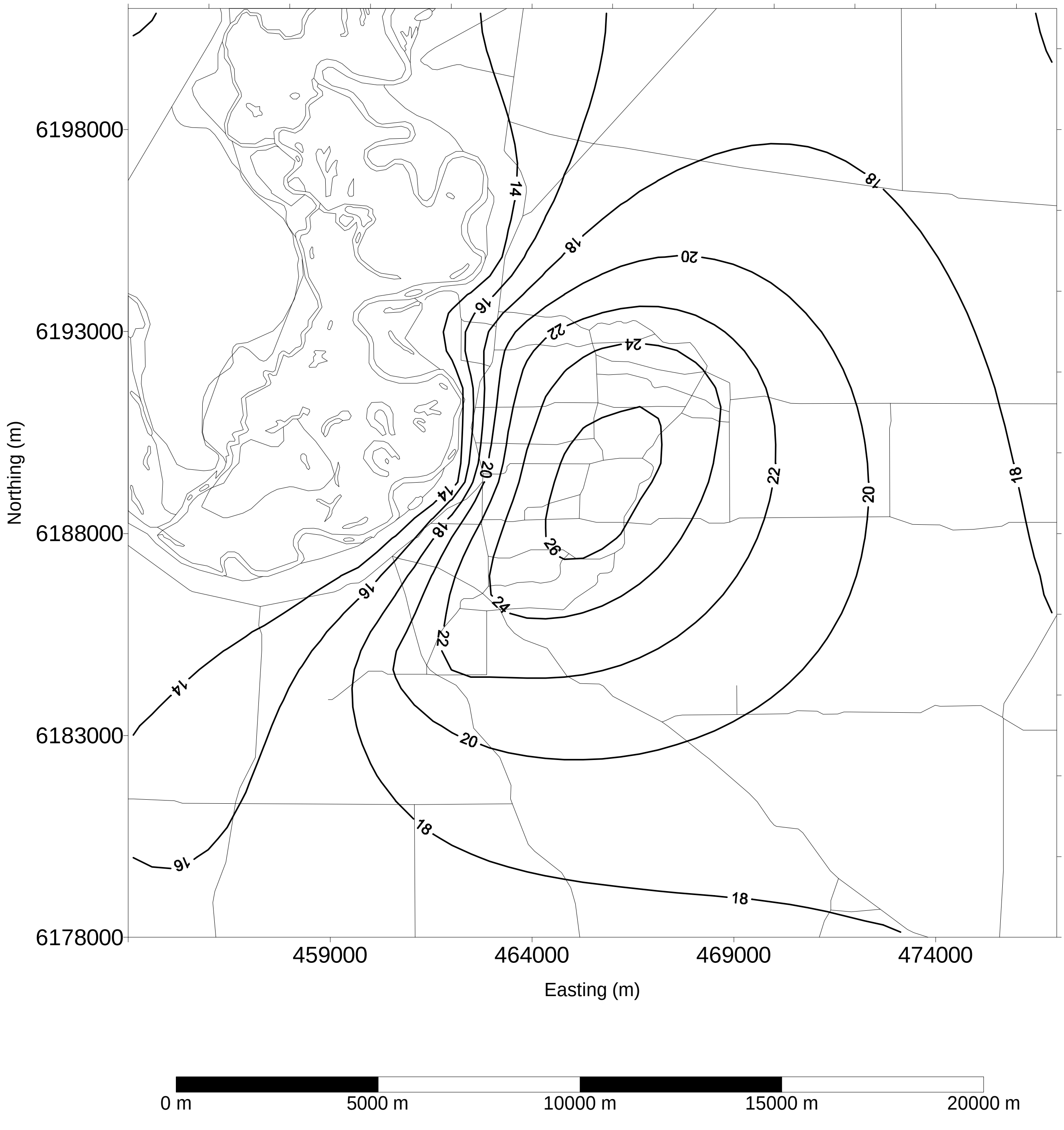


Fig. 9 *Option2 (Partial rehabilitation) watertable contours - 2047*

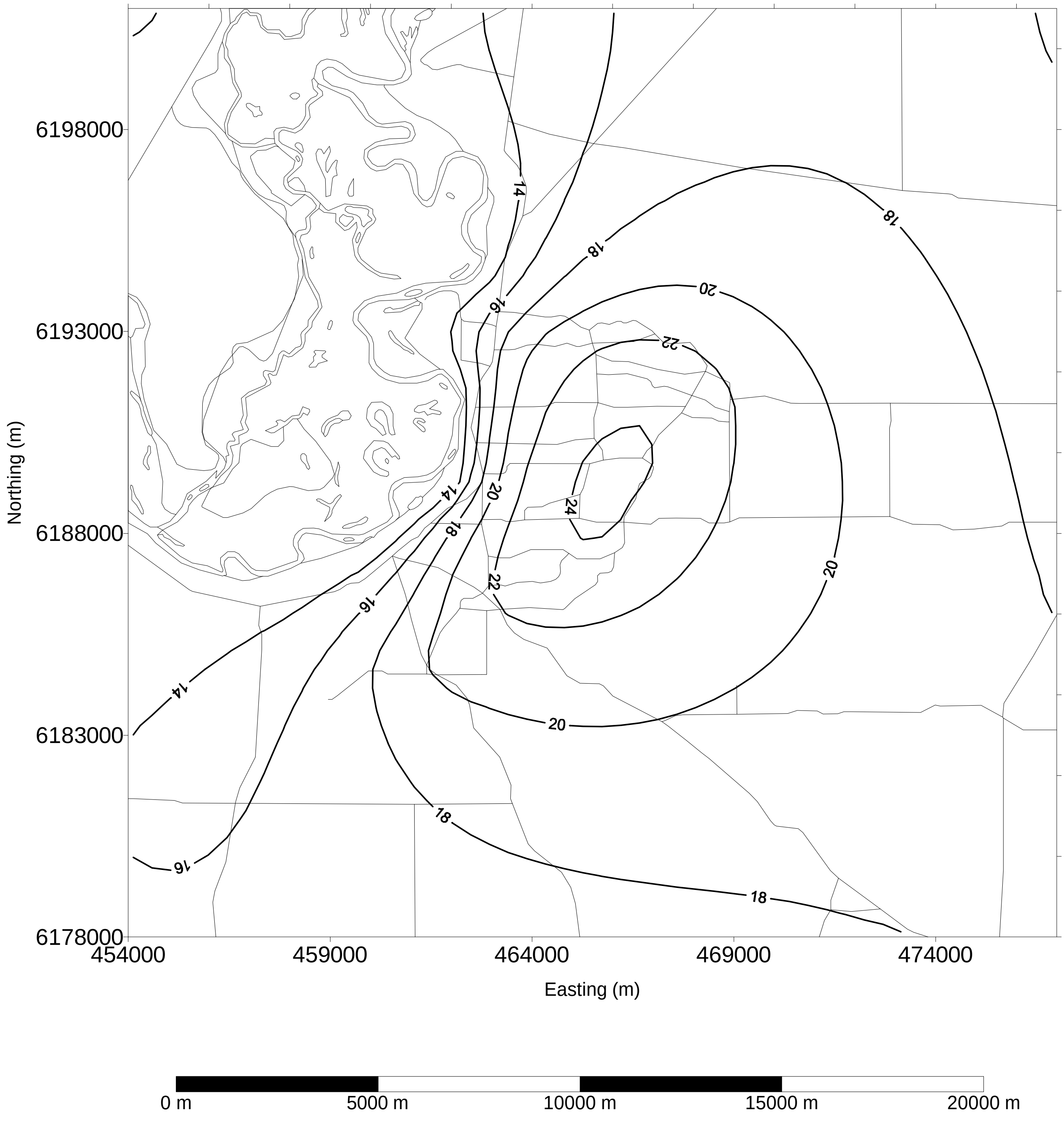


Fig. 10 *Option3 (Full rehabilitation) watertable contours - 2047*

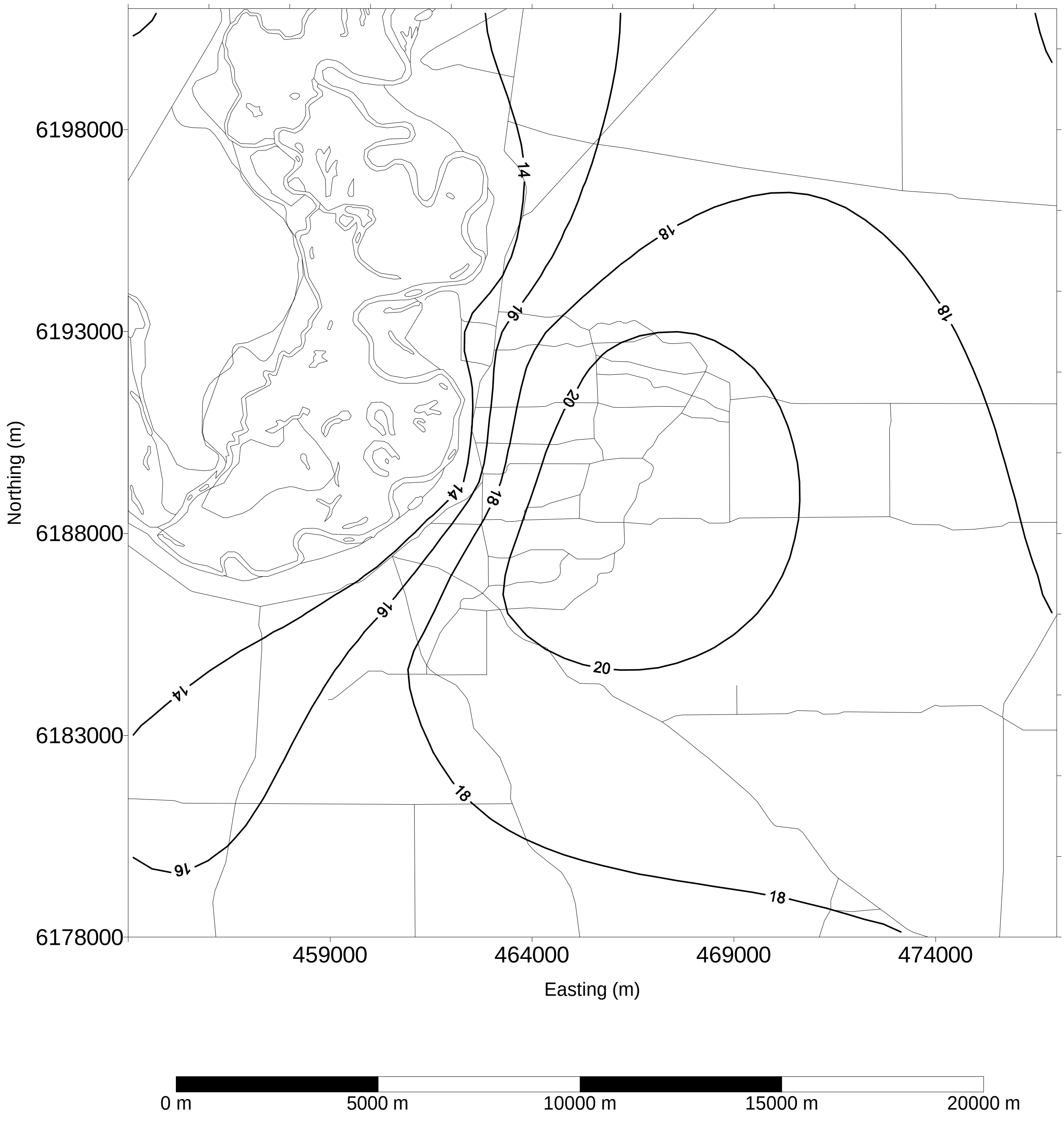
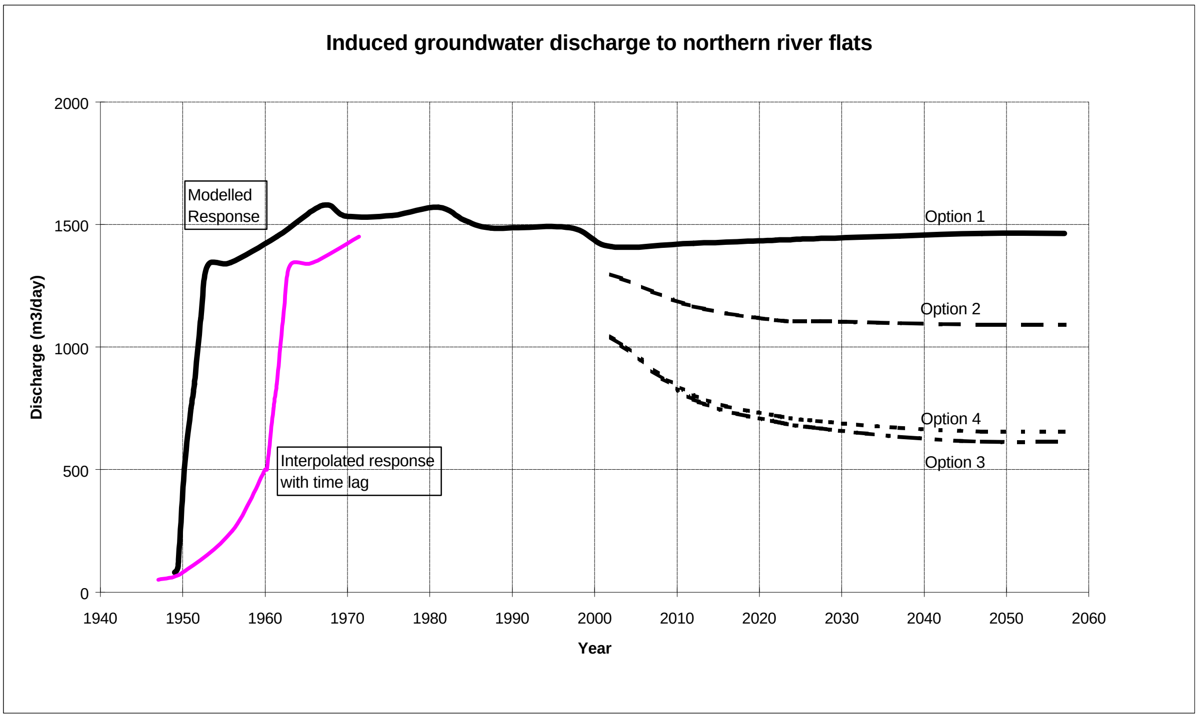


Fig. 11 *Option4 (Full rehabilitation plus new areas) watertable contours - 2047*



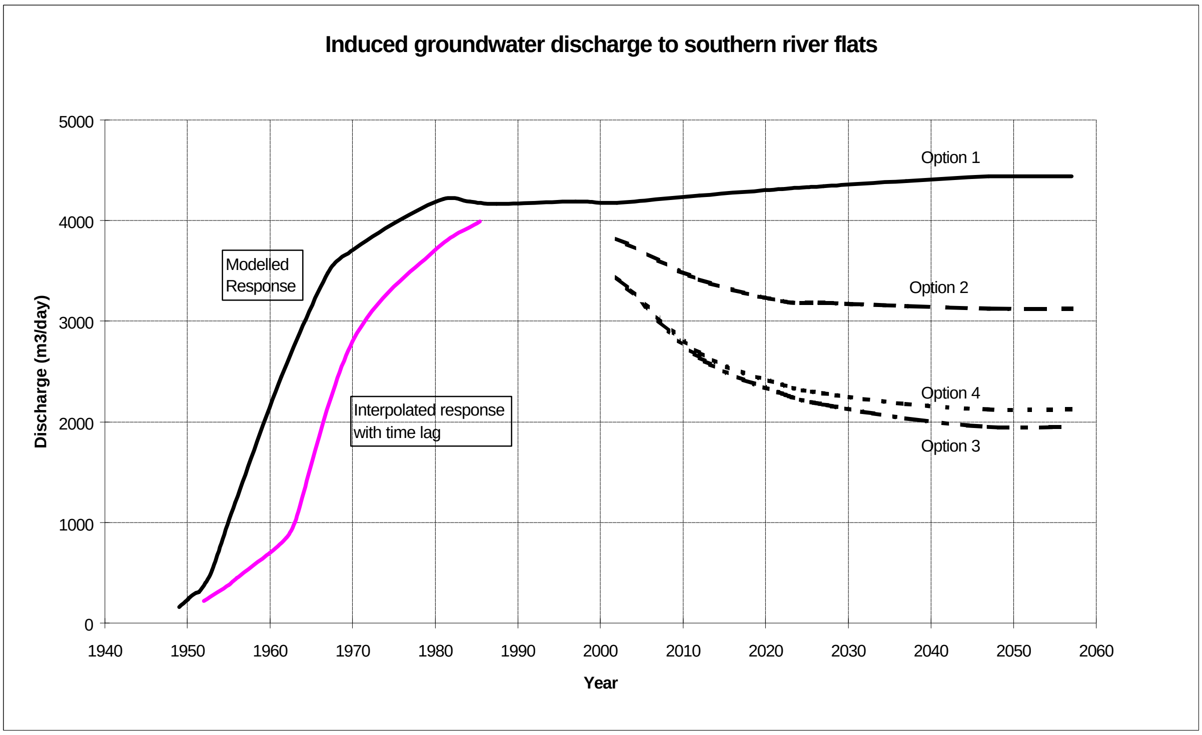
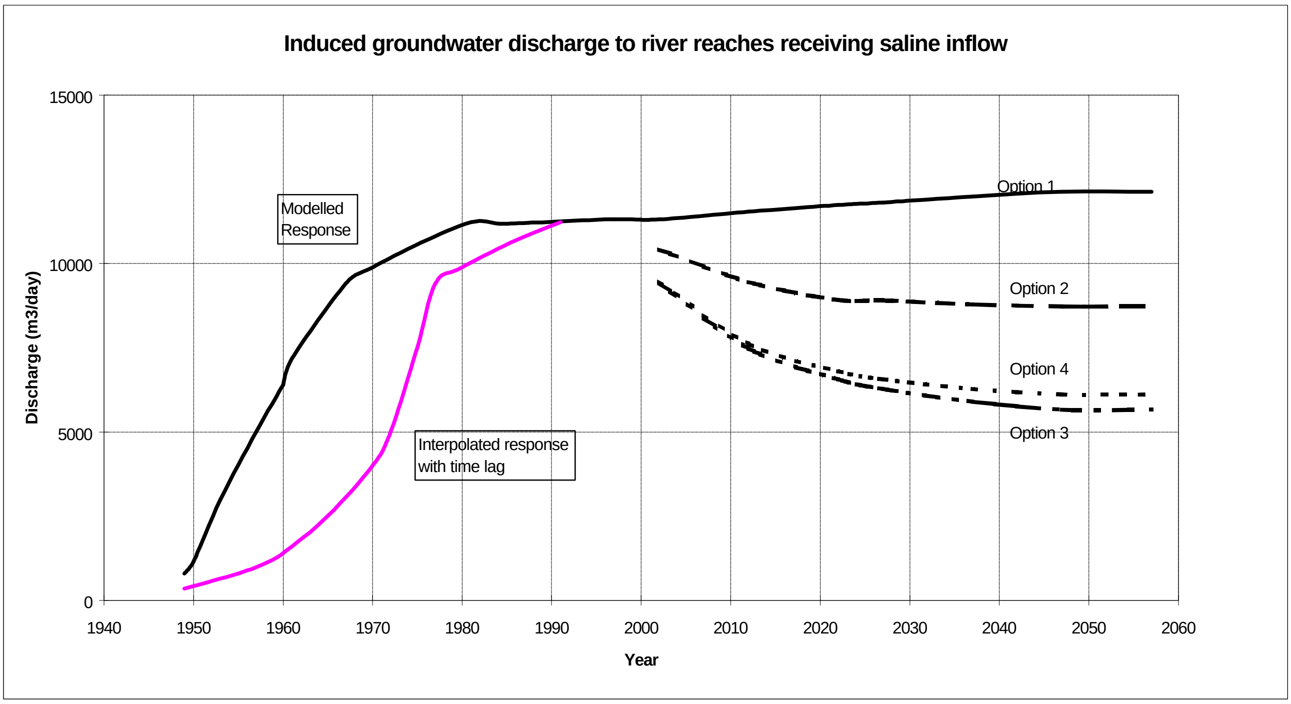


Fig. 12 *Modelled groundwater discharge to river flats*



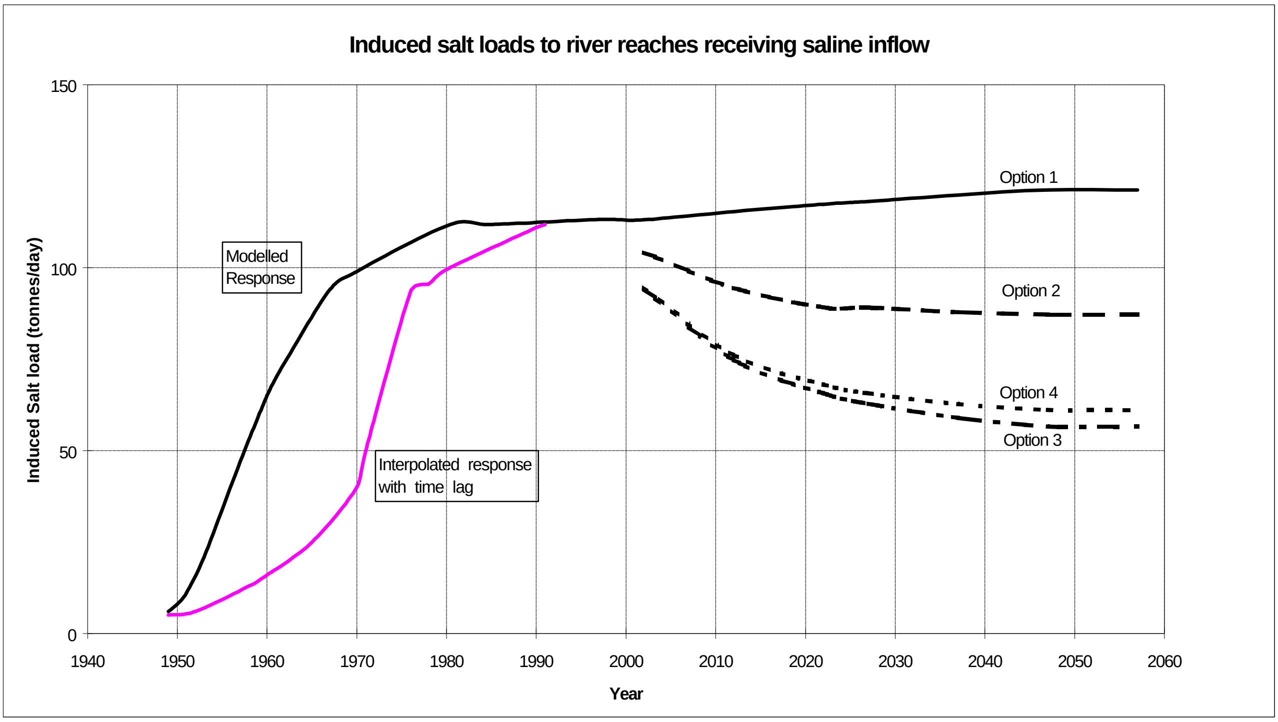


Fig. 13 *Modelled groundwater and salt discharge to river*

Cracks in the delivery channel which allow seepage

Overflow of excess water from a main supply channel