APPENDIX I

GROUNDWATER REPORT

ORD RIVER IRRIGATION AREA STAGE 2 PROPOSED DEVELOPMENT OF THE M2 AREA

Groundwater Report

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CONTENTS

Section Page

1 INTRODUCTION

2 CLIMATE

3 HYDROGEOLOGY

4 GROUNDWATER MODELLING

5 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

6 CONCLUSIONS AND RECOMMENDATIONS

7 REFERENCES

ATTACHMENTS

1 Introduction

This investigation and report was commissioned by Wesfarmers Limited, Marubeni Corporation and the Water Corporation of Western Australia to assess the likely impacts of irrigated broad acre farming predominately of sugar cane upon the groundwater environment within the Project Area. The Project Area is located in the east-Kimberley region of Western Australia and adjoining areas of the Northern Territory and comprises portions of the Weaber Plain, Keep River Plain and Knox Creek Plain.

The hydrogeology of the Project Area has been extensively investigated by the Water & Rivers Commission (WA) and the Department of Lands, Planning and Environment (NT). These agencies provided hydrogeological data that enabled Kinhill Pty Ltd to establish a numerical computer model of the Project Area. This model was used to predict changes to the groundwater environment of the Project Area for a range of groundwater management scenarios.

2 Climate

The East-Kimberley region has a tropical monsoonal climate with the wet season extending from December through March contributing largely to the annual average rainfall of 788mm at Kununurra. Net evaporation is high during the summer months, and ranges from 330mm/month in October to 175mm/month in February. The mean maximum monthly temperature is 38.9ºC in November and the mean minimum monthly temperature is 14.1ºC in July. The relative humidity ranges from a low of 32% in July to 65% in January.

3 Hydrogeology

The geology of the East-Kimberley region has been described by Moray and Beere (1988). Geological descriptions of portions of the Project Area are presented in Laws (1991), Sweet, et al, 1974, and Whitehead and Fahey, 1985.

3.1 BASEMENT GEOLOGY

3.1.1 Weaber Plain

The Weaber Plain is bounded by outcropping basement rock to the north (Weaber Range) and south (Pinicombe Range and Sorby Hills). In the south-west, the Plain is bounded by basement rock with the exception of the Cave Spring Gap region.

Underlying most of the Weaber Plain is a mixture of Precambrian to Permian units of varying lithology, including sandstone, limestone, shale and conglomerate. Through Cave Spring Gap, the basement rocks consist of Precambrian sandstone and shale of the Bastion Group. A major basement inlier within the plain, Folly Rock, is composed of Proterozoic sandstones of the Carr-Boyd Group. North of Folly Rock, the basement changes to being Carboniferous Milligans Formation shale.

In general, Paleozoic sediments underlie the alluvial sequence through the northern Weaber Plain. In the south of the plain, the basement is a thin sequence of Devonian limestone and sandstone overlying Cambrian Antrim Plateau Volcanics. The Sorby Hills range comprises a sequence of complexly folded and faulted Carboniferous sandstone and limestone.

3.1.2 Knox Creek Plain

The geological strike along the Knox Creek Plain is dominantly north-south, consistent with the major axis of the plain. To the west and north, the basement units underlying the plain include the Carboniferous Burt Range Formation, Septimus Limestone and well-bedded limestone and sandstone of the Devonian-Carboniferous Button Beds. Other units of the Landfield Group may be present. The plain is largely underlain by the Milligans Formation shale, incised by a paleochannel and locally overlain by calcrete. To the east, the plain is underlain by undifferentiated Permo-Carboniferous sandstone. Knox Creek does not incise into the basement beneath the plain, except for an area of limited extent in the north of the plain. The creek is generally fully contained within the alluvial sediments.

3.1.3 Keep River Plain

The basement rock underlying the Keep Plain region is for the most part undifferentiated Permo-Carboniferous sandstone. Carboniferous shale is found underlying the plain immediately east and southeast of the Spirit Hill Homestead. The alluvial sediments have incised into and been deposited upon both of these units.

3.2 ALLUVIAL SEDIMENTS

3.2.1 Weaber Plain

Alluvial sediments comprise the upper 5 to 35m of the Weaber Plain (Nixon, 1997b, 1997e). These sediments are presumed to have been deposited by a paleochannel of the Ord River, when it is postulated to have flowed to the north-east beneath the Weaber Plain and then roughly along the course of the present day Keep River. The sequence of sediments is one of a basal coarse-grained unit deposited by the main river channel. These paleochannel sediments are restricted in extent to a narrow valley through the plain and are of considerable importance to the hydrogeology. The extent and nature of the paleochannel sediments are discussed in a later section. Across the entire plain the alluvial sequence becomes progressively finer upwards with varying thickness. Little is known in detail of the variability of these sediments as the drilling which has been undertaken to date is sparse compared to the area being considered and there is little correlation between bore holes for coarser or finer units (Nixon 1997a, 1997b, 1997d, 1997e).

3.2.2 Knox Creek Plain

The alluvial deposition within the Knox Creek Plain differs in part from that in the Weaber Plain by the poorer definition of the paleochannel (although the paleochannel is continuous beneath the eastern side of the plain) and the finer nature of the sediments. The alluvial sediments in the paleochannel become progressively deeper and broader in the northern part of the Plain. A fining upward sequence is postulated, with the basal part of the sequence being finer than the Weaber Plain.

Calcrete is found beneath the western Knox Creek Plain overlying the paleochannel sediments or directly upon the basement complex. The calcrete varies greatly in width and thickness, to as much as 4km wide and 15m thick.

3.2.3 Keep River Plain

It has been postulated that the ancient course of the Ord River passed through the Weaber Plain and into the Keep River Plain, and that the river incised a deep channel which was subsequently in-filled with Tertiary and Quaternary sediments. In the west, the paleochannel is up to 35m deep with a coarse basal unit approximately 10m thick. This is the downstream continuation of the paleochannel as described for the Weaber Plain. Above the coarse paleochannel sediments is a finer sequence with clayey sand at base, fining upwards to a silty clay near surface. Drilling by the Northern Territory Government has delineated the paleochannel extent and thickness (Humphreys et al, 1995).

3.3 GROUNDWATER FLOW

3.3.1 Weaber Plain

The general flow gradient across the Weaber Plain is from the west to the east. Elevated groundwater levels exist in the Cave Spring Gap, as a result of existing irrigation activities. The groundwater elevation just outside of the current irrigation area is around 22 to 26m AHD, which is around 5m below ground surface. From here groundwater flow is through the Cave Spring Gap and under the Weaber Plain. The elevation of the water table decreases to be between 5 and 10m AHD in the vicinity of Folly Rock. This is some 20m below surface, but may be up to 35m below ground in some areas. In the north of the plain, near Point Spring, the groundwater elevation is higher than on the central part of the plain.

A groundwater elevation at around 17m AHD has been recorded (Nixon 1997a, 1997e) and it is postulated that the broad areas of sandy soils in the Border Creek region (north of the Weaber Plain) contribute some recharge to the sediments underlying the plain. This is also an area of relatively shallow bedrock, which may contribute to the higher groundwater elevations. The water table associated with Point Spring occurs within the bedrock system and is entirely separated from the alluvial sediments.

East of Folly Rock, the groundwater elevation is at around 5m AHD and remains above 3m AHD to the eastern end of the plain. This is approximately 15–20m below the general level of the plain. The incised valley of the Keep River is at approximately 12–14m AHD, approximately 10m above the groundwater level. There is no evidence of groundwater interaction with the river in this area, although data are poor. Groundwater recharge across the plain is considered to be very low. The existing groundwater gradient appears to be largely controlled by the paleochannel throughflow from the Ivanhoe Plain and by recharge from the Border Creek area.

In the southern part of the plain, near Sorby Hills, extensive drilling for mining exploration has shown the basement rocks to be limestone and dolomite, which have significant groundwater storage potential. It is presumed that there is little if any upward movement of groundwater from the basement rocks into the alluvial sequence, and that it is more likely that groundwater in this area will move from the alluvial sediments into the bedrock.

3.3.2 Knox Creek Plain

Groundwater flow beneath the Knox Creek Plain appears to be to the north, following the paleochannel beneath the eastern portion of the plain. In the southern part of the Knox Creek Plain the groundwater elevations in the region and south of Milligan Lagoon are approximately 8 m higher than those in the northern part of the plain. Groundwater flow in the southern section is to the north-west, from the Northern Territory section to Western Australia. In the north of the plain the groundwater levels range from around 7m AHD down to 3–4m AHD where the Knox Creek Plain joins the Weaber Plain. This is approximately 10–15m below the ground surface.

Recent drilling undertaken on behalf of Wesfarmers Limited, Marubeni Corporation and the Water Authority of Western Australia has shown that Milligan Lagoon is the surface expression of a local perched water table. The base of the perched aquifer is a clay layer that occurs to a depth of up to at least 9m below the surface. The regional water table is some

20m below the level of the lagoon. The lagoon is fed by rainfall and runoff and, possibly, minor groundwater inflow from the adjacent hills to the west.

The sediments of Knox Creek and its tributaries are not considered to be currently part of the groundwater system as the bed level of these creeks is some 10m above the current groundwater level. However, it is likely that these creeks, due to the general sandy nature of their bed profiles are important groundwater recharge features during the wet season. Recharge from the rest of the plain is considered to be minimal.

3.3.3 Keep River Plain

Groundwater flow beneath the Keep River Plain is a continuation of the flow coming from the west in the Weaber Plain. Groundwater elevations in the west of the Keep River Plain are at or around the level of those in the Weaber Plain. Groundwater flow is generally to the north east, along the line of the plain, with a smaller component to the north west, from the higher Permo-Carboniferious outcrop area towards the alluvium.

The Keep River and Sandy Creek are in connection with the alluvial sediments along their length and where these are tidal or semi-tidal, they provide a natural tidal control on groundwater levels. Beneath the Keep River Plain the basement rocks are in part Permo-Carboniferous sandstone which is highly permeable and contains good quality groundwater. In the eastern end of the plain it appears that the permeable Permo-Carboniferous sandstone and the incised paleochannel sediments comprise a single hydraulic unit. However, the nature, extent and degree of connection between the two systems have yet to be confirmed.

3.4 GROUNDWATER QUALITY

3.4.1 Weaber Plain

Groundwater quality in the Weaber Plain is generally fresh to slightly brackish (Nixon 1997a, 1997b, 1997e). In the Cave Spring Gap groundwater salinity is around 1,000mg/L TDS (Nixon, 1997d) and it is not clear if the salinity of groundwater in this area is influenced by current irrigation or is the result of an older recharge signature. Throughout the southern and central parts of the Weaber Plain, groundwater salinity ranges from 70mg/L to 2,600mg/L. In the northern edge of the plain the groundwater salinity areas appear to be associated with bedrock highs, however, water analyses from Point Spring (Nixon, 1997e) indicate that the groundwater emanating from bedrock in that region is of good quality (50mg/L).

3.4.2 Knox Creek Plain

Groundwater salinity ranges from 60 to 20,800mg/L TDS but in general is around 1,000mg/L. The groundwater is a sodium chloride type with elevated sulphate and bicarbonate. Based on airborne electromagnetic studies conducted jointly by Western Australia and Northern Territory Governments, there is considered to be a significant difference in the groundwater quality in the west of the plain compared to the east, reflecting the nature of the bedrock. Where alluvial sediments overlie the Milligan Formation shale the groundwater appears to be more saline than the groundwater overlying the Permian-

Carboniferous Sandstone. Delineation of the contact between these units and the potential impact on groundwater quality is discussed in Chin et al, 1997.

3.4.3 Keep River Plain

Groundwater salinity varies greatly, between 100 and 51,000 mg/L, across the Keep River Plain (Humphreys et al, 1995). The Department of Lands Planning and Environment have identified six main salinity zones, based on airborne electromagnetic surveys and inferred basement geology. From the west to east across the plain, the groundwater salinity changes from moderate to high (1,000 to 20,000mg/L), through a low salinity region (salinity expected to be less than 2,000mg/L) and then into a more saline region which is within the influence of the tidal reaches of Sandy Creek. The groundwater chemistry is dominated by sodium chloride ions, although bicarbonate concentrations are also commonly high. Nitrate levels are generally below 1–2mg/L.

4 Groundwater modelling

4.1 MODEL DEVELOPMENT

A numerical groundwater model was used to simulate the response of the groundwater environment to irrigation activities on the surface. The model used was MODFLOW (McDonald and Harbaugh, 1984), an internationally recognised code-verified finite difference groundwater model. Model set-up and pre- and post-processing were carried out using the Visual MODFLOW package (Guiguer and Franz, 1996).

The hydrogeological data used to construct the model were obtained from the Water and Rivers Commission (WA) and the Department of Land Planning and Environment (NT). In particular, these agencies jointly compiled a series of sub-surface cross-sections of the geology throughout the area of interest (Attachment A). These sections comprised the basis for the geometry of the model.

All of the scenarios modelled assumed that all of the black soil areas within the perimeter infrastructure would be used for irrigated agriculture. Subsequently, Project planning has included some of these black soil areas in conservation areas, particularly north west of Folly Rock on the Weaber Plain and on the eastern Keep River Plain. The area north west of Folly Rock was shown by the modelling to be prone to rapid groundwater level rises if used for irrigation. Therefore, use of a portion of this area for conservation would partially mitigate these effects predicted by the MODFLOW model for this area.

4.1.1 Model Parameters

The entire Project Area was included in a single continuous model. The model comprised 198 columns and 207 rows having individual cell dimensions of 250 metres by 250 metres. The hydrogeology was simplified into three layers:

- *Layer 1* comprises sandy silty sediments beneath the surface black soil and was assigned a uniform hydraulic conductivity of 5 m/day in accordance with the observations of Nixon (1997c) who suggested an expected range in conductivity between 1 m/day and 10 m/day. This layer was assigned a specific yield of 10%.
- *Layer 2* was assigned two hydraulic conductivity values in order to simulate the paleochannel aquifer. In the Weaber Plain-Keep River Plain area, a central line of cells was assigned a hydraulic conductivity of 100 m/day with the flanking area assigned 25 m/day. In the Knox Creek Plain, the central line was assigned a value of 35 m/day with the flanking area 10 m/day. This approach was adopted to simulate the zones of relatively high permeability known to occur with the paleochannel aquifer. All paleochannel units were assigned a specific yield of 15%. The remainder of the active

cells in the layer were assigned hydraulic conductivity and specific yield values equivalent to those for the basement complex (layer 3).

- *Layer 3* comprised the basement complex of varying lithology and was assigned a hydraulic conductivity of 0.5 m/day and a specific yield of 5%, with the exception of the Keep River Plain where the underlying Permo-Carboniferous Sandstone aquifer was simulated with a hydraulic conductivity of 10 m/day and a specific yield of 10%.

The spatial distribution of hydraulic conductivity values for each layer are supplied in Attachment B.

'No-flow cells' were assigned to areas flanking the Project Area, generally at a distance of about 3km from the nearest proposed development. This action imposes a degree of conservatism as the model does not allow for dissipation of groundwater into these cells.

The northern boundary was set as a 'General Head Boundary' having a fixed head of 0m AHD (mean sea level). Keep River and Sandy Creek were assigned as 'River Cells' for the reaches under permanent water. The ephemeral reaches of the Keep River and Sandy Creek and Knox Creek were defined as 'Drain Cells'.

The southern-western boundary at Cave Springs Gap was also a 'General Head Boundary' having a fixed head of 22m AHD.

The rate assigned to infiltration (accession rate) of irrigation water to groundwater is a critical parameter of the model. The likely accession rate of irrigation water and rainfall from the irrigation area for the irrigation practices proposed for the Project was determined to be 94mm/a by modelling of the unsaturated zone using the LEACHM numerical model (as described in Kinhill Pty Ltd 1999). The groundwater model was therefore run at a rate of 100mm/a as the base case, as well as for a variety of accessions ranging up to150mm/a.

Additional infiltration was simulated from the irrigation water distribution channels and the balancing storage dams. The infiltration rate assumed for this infrastructure was the design criterion of 2mm/day.

The USGS MODFLOW model was used as a design tool as well as for predicting groundwater response for the proposed groundwater management strategy. All of the modelling scenarios assumed a period of fifty years to represent long-term operation of the Project. This period reflects a sensible limit on the use of the available data and the accuracy of the modelling based upon these data.

Sustainability of the irrigation practices over a period longer than the 50 years time horizon used in the modelling was assumed to be demonstrated if the rate of groundwater change at 50 years was shown by the modelling to be small and within the accuracy normally expected of groundwater modelling. This situation was achieved for the base case (100mm/a infiltration rate) by running the model with progressively more dewatering bores and then optimising the time for commencement of pumping and the pumping rate.

Other accession rates that were modelled (50 mm/a and 150 mm/a) utilised the same bore layout and number as that developed for the base case. However, the pumping rate and time of commencement of pumping were different to that used for the base case.

It is noted that none of the modelling scenarios included the effects of field drains that may be used as a groundwater management measure in the future.

Field drains consist of a series of perforated pipes laid below the surface that would allow the entry and collection of groundwater, however, they are only effective when groundwater levels are at or above the level at which the drains are laid.

The omission of field drains was a deliberate action as the model was used to identify the extent of the cropped area that is likely to require this form of management. The result of omitting the field drains from the modelling scenarios is that the model would overstate the rate of groundwater rise, particularly when groundwater levels are within 2 m of the surface.

4.2 SENSITIVITY ANALYSIS

The model was run with various parameters to determine those which would have the most impact upon the model predictions. The parameters examined included hydraulic conductivity, variations in the ratio of vertical to horizontal hydraulic conductivity, specific yield, accession rates and river conductance.

The groundwater accession rate was seen to be the most critical parameter. This parameter controls the actual volume of water entering into the groundwater regime either as increased storage (rising water table) or increased discharge (subsurface outflow or discharge into surface streams).

The ‘River Conductance’ is a parameter that simulates the efficiency of the riverbeds as an infiltration surface to both recharge the aquifer (where river stage is above groundwater heads) or to drain the aquifer (where aquifer heads exceed river stage). ‘River Conductance’ is an important control on the predicted response of the water table for those areas immediately flanking the river nodes. This parameter cannot be directly measured by field testing as it is a relationship of the riverbed hydraulic conductivity, bed thickness and river geometry. The model was run using ‘River Conductance’ derived by calculation and those derived by trial and error by the Water and Rivers Commission and Department of Lands Planning and Environment in their attempt to psuedo-calibrate previous Ord River Irrigation Area groundwater models.

Variations of the aquifer parameters hydraulic conductivity and specific yield affect the ability of the aquifer(s) to dissipate hydraulic head and store the infiltrating irrigation waters. However, the effects are not pronounced in comparison to the regional effects of the accession rate and the local effects of the river.

4.3 MODEL RESULTS

The results from the modelling of a variety of scenarios are described in the following sections. The scenarios include a range of accession rates from the areas proposed for irrigation, and coupled with/without groundwater control via pumping from dewatering bores.

4.3.1 50mm/a Accession Rate without Pumping

The LEACHM infiltration modelling indicated that an accession rate of approximately 50mm/a would be the lowest likely accession rate from the irrigated farmland.

Figure C-1 shows the time predicted for groundwater levels to reach within 5m of ground level while figure C-2 shows the groundwater levels predicted for simulation periods of 10, 20, 40 and 50 years—in all cases there is no use of dewatering bores.

In this scenario, groundwater levels are predicted to remain below 5m beneath most of the eastern Weaber Plain, eastern Knox Creek Plain and the Keep River Plain for the 50-year simulation period. Furthermore, the area north-west of Folly Rock is predicted to experience groundwater levels within 5m of ground level by year 20. The areas of high water levels are predicted to expand with time to surround Folly Rock. An area of waterlogging (defined herein as groundwater levels within 1m of ground level) is predicted north-west of Folly Rock by year 50.

A low-lying area in the north-east of the plain, adjacent to Border Creek, is predicted to encounter water levels within 5m of ground level by year 30. However, these rises would be partially suppressed by the draining effect of Border Creek as the water table reached the bed level of the creek.

The balancing storage dam on the Weaber Plain is predicted to create a groundwater mound with groundwater levels within 5m of the ground surface by year 10. The area of high water level is predicted to expand with time and waterlogging beneath the balancing storage dam would begin by year 20.

The eastern Keep River Plain has relatively shallow water levels and these are predicted to remain within 5m of ground level throughout the 50 year simulation period. The high water levels predicted in the northern Keep River Plain, in particular the short time shown to reach within 5 m (Figure C-1) are a result of the low ground elevation, the high initial hydraulic head adopted for the model and the constant head boundary set at mean sea level. The sub-surface discharge into Sandy Creek attenuates the water level increases in this area.

The western Knox Creek Plain, where underlain by relatively shallow basement rock, has initial depths to groundwater between 15m and 20m. Under the scenario modelled, the water table is predicted to rise to within 5m of ground level by year 50.

The predicted groundwater discharges to the major watercourses are shown in Table 4.1.

Table 4.1 Predicted groundwater discharges to watercourses, 50 mm/a accession rate without pumping

Year	Knox Creek Discharge (ML/a)	Keep River Discharge* (ML/a)	Sandy Creek Discharge* (ML/a)
10	0	4,550	375
20	0	5,072	347
30	0	5,628	361
40	73	6,148	382
50	174	6,579	402

** includes sub-aqueous discharge into permanent tidal reaches*

4.3.2 50mm/a Accession Rate with Pumping

The 50mm/a accession rate was also modelled in conjunction with a series of dewatering bores located within the paleochannels. The effectiveness of pumping to control rising water levels has been investigated by the Water and Rivers Commission and described by O’Boy

(1997, 1998). Figure D-1 presents the time predicted for water levels to reach to within 5m of the ground surface while figure D-2 shows the predicted depth to groundwater for simulation periods of 10, 20, 40 and 50 years.

The model indicated that with a groundwater pumping rate of 12,045ML/a, waterlogging could be avoided over the whole of the proposed irrigation area for the entire simulation period.

Relatively high water levels (within 5m of ground level) are predicted beneath and adjacent to the balancing storage dam on the Weaber Plain within 10 years. The north-western Weaber Plain is predicted to encounter water levels within 5m of groundwater level by year 30. The predicted high water levels in the north-western Weaber Plain are due to the initial shallow water table and the presence of shallow and relatively impermeable basement rocks. The area of high water level associated with the balancing storage dam and the north-western Weaber Plain is predicted to expand laterally with time.

Groundwater levels beneath the Keep River Plain are not predicted to change markedly over time due to the sub-surface groundwater discharge effected through the Keep River and Sandy Creek.

The Weaber Plain, south of Folly Rock and south of the paleochannel, is predicted to experience significant rise in water levels but at 50 years the water table is predicted to still be below 5m from ground level. The western Knox Creek Plain similarly shows groundwater mounding but the water table remains below 5m from ground level for the entire 50-year simulation period.

Comparison of the groundwater levels after 40 and 50 years shown in Figure D2 shows that little or no change is predicted over this time period. These results would indicate that groundwater management would be sustainable for a much longer period than the 50 year period adopted for the modelling.

The predicted groundwater discharges to the major watercourses are shown in Table 4.2.

Table 4.2 Predicted groundwater discharges to water courses, 50 mm/a accession rate with pumping rate of 12,045Ml/a

Year	Knox Creek Discharge (ML/a)	Keep River Discharge* (ML/a)	Sandy Creek Discharge* (ML/a)
10	0	4,550	375
20	0	4,675	255
30	0	4,741	204
40	0	4,784	184
50	0	4,813	177

* *includes sub-aqueous discharge into permanent tidal reaches*

Initially, the pumping discharges from most bores would be of suitable quality to re-introduce into the irrigation cycle. At some locations and over time, the salinity may become unsuitable to be used for irrigation and disposal pipelines to the estuarine environment may be required.

4.3.3 100mm/a Accession Rate without Pumping

The LEACHM infiltration modelling indicated that 94mm/a is the likely average rate of groundwater accession from the irrigation area. For the MODFLOW analysis this rate was rounded up to 100mm/a.

Figure E-1 presents the time predicted in years for water levels to reach within 5 m of ground level, while figures E-2 shows the depth to groundwater for simulation periods of 10, 20, 40 and 50 years—in all cases there is no use of dewatering bores.

Under this scenario, the model indicates that groundwater levels would rise to 5 m of ground level within 5 years in a small area of the Weaber Plain northwest of Folly Rock and within 20 years this area may experience waterlogging. Furthermore, the western Weaber Plain in general is predicted to experience problems with rising water levels within 20 to 30 years. This result is due to the relatively shallow depth to basement and the absence of a paleochannel to assist subsurface drainage of this region.

The western Knox Creek Plain, underlain by shallow basement that were assumed to be impermeable, is predicted to experience water levels within 5 m of the surface within 20 years, and to become waterlogged by year 50.

The Keep River Plain has a relatively shallow water table in the natural state and water levels are predicted to remain high under irrigation. The proximity of the Keep River and Sandy Creek would serve to regulate the water levels and prevent waterlogging.

As for the 50mm/a accession rate scenarios, high water levels are also predicted in the area surrounding the balancing storage dam on the Weaber Plain.

The predicted groundwater discharges to the major watercourses are shown in Table 4.3.

Table 4.3 Predicted groundwater discharges to water courses, 100 mm/a accession rate without pumping

Year	Knox Creek Discharge (ML/a)	Keep River Discharge* (ML/a)	Sandy Creek Discharge* (ML/a)
10	0	7,044	1,118
20	39	8,515	1,288
30	226	9,689	1,427
40	430	10,749	1,535
50	689	11,977	1,615

** includes sub-aqueous discharge into permanent tidal reaches*

4.3.4 100mm/a Accession Rate with Pumping

MODFLOW was utilised to analyse the consequences of a 100mm/a accession rate with groundwater control using dewatering bores installed into the paleochannels with a pumping rate of 12,045ML/a from the dewatering bores.

Regional rises in the water table are still predicted, although the rate and magnitude of water level increases are markedly attenuated, in comparison to the same accession rate without pumping, over most of the Project Area. Figure F-1 presents the time predicted for the water table to reach within 5 m of ground level and figure F-2 shows the predicted depth to groundwater for simulation periods of 10, 20, 40 and 50 years.

Water levels as predicted to remain greater than 5m from ground level over the whole of the Keep River Plain, the eastern Weaber Plain, and the eastern Knox Creek Plain for the entire 50-year simulation.

Higher water levels are predicted in areas not underlain by, or immediately adjacent to, the paleochannels. The western Weaber Plain and western Knox Creek Plain are predicted to begin to experience water levels within 5m of ground level by 5 and 30 years, respectively. Waterlogging is considered possible in some areas of the western Weaber Plain by year 30, and in the western Knox Creek Plain by year 50. The area adjacent to the balancing storage dam on the Weaber Plain is predicted to have water levels within 5 m of ground level by year 10 and local waterlogging by year 30.

The western Knox Creek Plain is underlain by Devonian limestone. These rocks have been hydraulically tested as part of the Sorby Hills mineral project investigations. The limestone comprises a significant aquifer where local conditions have resulted in solution-enhanced secondary permeability. The secondary permeability is likely to be restricted to zones of structural discontinuities such as faults and fractures. Because of the general north-south structural trend, it is possible that permeable zones could be located within the limestone basement beneath the western Knox and be pumped to reduce the groundwater rise in this area. This additional pumping was not modelled due to the unpredictable nature of the spatial distribution of the basement permeability and the uncertainty that pumping from the basement would lower shallow water levels.

Comparison of the groundwater levels after 40 and 50 years shown in Figure F2 show only minor changes over this period, with the changes mainly restricted to the western Weaber Plain and western Knox Creek Plain. These results would indicate that the groundwater management would be sustainable for a much longer period than the 50 year period adopted for the modelling, particularly if groundwater management is augmented by use of field drains in the areas of higher groundwater levels.

The predicted groundwater discharges to the major watercourses are shown in Table 4.4.

Table 4.4 Predicted groundwater discharges to water courses, 100 mm/a accession rate with pumping rate of 2,045Ml/a

Year	Knox Creek Discharge (ML/a)	Keep River Discharge* (ML/a)	Sandy Creek Discharge* (ML/a)
10	0	7,044	1,118
20	0	8,116	1,134
30	25	8,847	1,168
40	61	9,361	1,205
50	96	9,768	1,236

* *includes sub-aqueous discharge into permanent tidal reaches*

Initially, the pumping discharges from most dewatering bores would be of suitable quality to re-introduce into the irrigation cycle. At some locations and with increasing time, the salinity may become unsuitable to be used in the irrigation, and disposal pipelines would be required.

4.3.5 150mm/a Accession Rate with Pumping

A scenario using an accession rate of 150 mm/a was modelled in order to ascertain the behaviour of the groundwater system to an accession rate well above the range anticipated for the Project. Because the previous 100mm/a runs indicated the necessity for active groundwater control at higher accessions, the 150mm/a case was only run with pumping, at a rate of 20,440ML/a from the same bore layout developed for the 100 mm/a scenario. Figure G-1 presents the contours of time for water levels to rise within 5m of the surface while figure G-2 presents the water levels at simulation periods of 10, 20, 40 and 50 years.

In the western Weaber Plain, water levels within 5m of ground level are predicted by year 10, including an area of waterlogging northwest of Folly Rock. The predicted area of high water level expands with time to comprise a significant portion of the Weaber Plain by year 40 and the area of waterlogging is predicted to encompass the western Weaber portion of the Plain by year 50.

In the western Knox Creek Plain, high water levels are predicted by year 20, rising to create waterlogging conditions by year 30. The areas of high water levels and waterlogging are predicted to expand to comprise most of the Knox Creek Plain by year 50.

The Keep River Plain water levels are predicted to remain relatively constant throughout the 50-year simulation. The area of high water levels in the eastern Keep River Plain is predicted to expand slightly with time but no area of waterlogging is predicted to develop. Water levels beneath the upper Keep River Plain are predicted to rise from 10 to 15m below surface to 5 to 10m below surface.

As for the simulations of lower accession rates, high water levels are predicted beneath and adjacent to the balancing storage dam on the Weaber Plain.

Overall, the modelling results would indicate that groundwater management would not be sustainable at the assumed pumping rate for much over 40 years without extensive reliance on field drains. Groundwater pumping from additional bores would be possible and this may extend the sustainable period of groundwater management, however, this scenario was not modelled.

The predicted groundwater discharges to the major watercourses are shown in Table 4.5.

Table 4.5 Predicted groundwater discharges to water courses, 150 mm/a accession rate with pumping rate of 20,440Ml/a

Year	Knox Creek Discharge (ML/a)	Keep River Discharge* (ML/a)	Sandy Creek Discharge* (ML/a)
10	0	6,814	1,508
20	0	7,864	1,665
30	0	8,693	1,780
40	63	9,342	1,863
50	265	9,849	1,923

** includes sub-aqueous discharge into permanent tidal reaches*

5 Potential impacts on groundwater quality

5.1 QUALITY OF ACCESSIONS TO GROUNDWATER

The groundwater recharge from the irrigation area and the infrastructure would gradually alter the existing groundwater chemistry towards that of the accessions to groundwater.

The irrigation water from the Ord River Irrigation scheme has a salinity of approximately 160mg/L TDS, over half of which is bicarbonate. The effect of evapotranspiration by crops would be to increase the concentration of the dissolved salts, with the level of concentration dependent upon the accession rate.

The soils of the Project Area are generally alkaline and under these conditions a significant proportion of the bicarbonate ions would be expected to precipitate from solution as their concentration increases. However, if it is assumed that the salt ions behave in a conservative manner (i.e. remain in a solution and not precipitate onto the soil) during the process of evapotranspiration, the salinity of accession water from the irrigated area, at an accession rate of 50mm/a, would be approximately 6,000mg/L TDS. For the reasons outlined above, this estimate should represent the upper limit of concentrations of dissolved salts in the accession water. Dilution of the accession water from irrigated areas would occur due to the accessions from the irrigation infrastructure, which would infiltrate at a salinity of approximately 160mg/L TDS. Based on the abovementioned assumptions, the net salinity of all infiltrating waters would be approximately 3,800mg/L TDS for the 50mm/a accession rate. When calculated on a similar basis, and with an accession rate of 100mm/a, the net salinity of the accession water would be approximately 1,900mg/L TDS. It follows that the greater the accession rate from the irrigation areas the lower the salinity of the infiltrating waters.

It is anticipated that local variations would occur as a result of downward flushing of the existing soil salts, which would tend to increase the net salinity of the accession water. With time, the contribution of soil salts would diminish as the salts are flushed and the net salinity would approach the calculated values.

5.2 WEABER PLAIN

The groundwater salinity of the Weaber Plain is fresh to brackish. In the western portion of Weaber Plain the salinity is around 1,000mg/L TDS (Nixon, 1997e). Throughout the southern and central parts of the Plain, groundwater salinity ranges from 70mg/L to 2,600mg/L. At an accession rate of 100mm/a the salinity of the groundwater accessions would be approximately 1,900mg/L TDS. This level is within the range of groundwater salinity beneath the Weaber Plain. Therefore, no significant impacts are expected.

5.3 KNOX CREEK PLAIN

The groundwater salinity of the Knox Creek Plain ranges 60mg/L to 13,000mg/L TDS, but in general is around 1,000mg/L (Nixon, 1997a). The higher salinity levels are generally found associated with the shale basement complex where downward flushing is inhibited. At an accession rate of 100mm/a the predicted accession water salinity quality is within the existing range of groundwater salinity and no significant impacts are expected.

5.4 KEEP RIVER PLAIN

The groundwater salinity beneath the Keep River Plain is more variable than for the other plains, ranging from approximately 100mg/L to 51,000mg/L TDS. The higher salinity is likely to be influenced by the proximity of the tidal Keep River and Sandy Creek which are hydraulically connected to the groundwater regime. The predicted salinity of the accession water is lower than the salinity of the existing groundwater beneath much of the lower Keep River Plain and within the general range for the remaining Keep River Plain. In the lower Keep River Plain, it is possible that soil salts may contribute significantly to the net salinity of the accession water in the early years of irrigation, thereby raising the salinity of accessions to salinity levels of existing saline groundwater. No significant impacts are therefore predicted for water quality beneath the Keep River Plain.

6 Conclusions and recommendations

The results of the MODFLOW analysis indicate that broadacre flood irrigation farming would lead to rises in the groundwater levels beneath the irrigated areas. This would be expected of any irrigation development. However, the results also indicate the rate and magnitude of rising water levels could be managed effectively through the utilisation of dewatering bores.

Groundwater levels beneath the irrigated areas underlain by the paleochannel aquifer could be suppressed sufficiently by pumping to prevent unacceptably high levels for the 50 year simulation period for all scenarios except an accession rate of equal to or greater than 150mm/a. The model has indicated that total pumping of the order of 20ML/a is possible from the paleochannel system using the assigned average hydraulic parameters.

The predicted high water levels in the western Knox Creek Plain could be controlled by pumping from the shallow calcrete and/or the Devonian limestone basement rock. A programme of geophysics, exploratory drilling and test pumping would be required to confirm the existence of suitable permeability in this area. This form of groundwater control was not included in the scenarios modelled.

Other areas of high water tables, such as the northwestern Weaber Plain may require use of field drains by year 20. If suitable permeability is not found within the calcrete and limestone basement beneath the western Knox Creek Plain, field drains may also be required in this area by year 40. Groundwater control using field drains was not included in the scenarios modelled.

The groundwater assessment and numerical modelling has indicated that:

- Irrigation should be sustainable for well over 50 years in the Project Area provided that average accession rates from irrigated areas are within the range predicted by the LEACHM modelling (up to 100mm/a) and that suitable groundwater control measures are undertaken;
- The most effective and suitable groundwater control would be by pumping from dewatering bores installed into the paleochannel aquifer;
- Additional groundwater control may be required using field drains in areas not adequately dewatered by bores such as north-west of Folly Rock on the Weaber Plain and the western portion of the Knox Creek Plain;
- In the long-term, groundwater quality would be modified towards that of the infiltrating water after concentration of salts by evapotranspiration;
- Groundwater discharge to the rivers would increase, particularly to the tidal portions of Keep River and Sandy Creek; and

- Groundwater monitoring would be required to adequately assess and manage the local impacts.

Following from these conclusions, it is recommended that:

- several dewatering bores in each of the three plains be installed and tested in the early stages of project development. This would require a programme of geophysics and test drilling;
- The possibility of pumping from the calcrete and/or limestone basement beneath the western Knox Creek Plain should be investigated;
- Transects of monitor bores should be installed adjacent to the Keep River and Sandy Creek to provide data to better understand the interaction between groundwater levels and groundwater discharge to these watercourses. Monitor bores should also be installed in the vicinity of Milligan Lagoon;
- Monitoring bores should be installed throughout the irrigation areas to observe water level trends within individual farm blocks;
- For those areas underlain by the paleochannel or other suitable aquifer, dewatering bores should be installed before water levels are within 5m of the ground level; and
- For those areas where potential waterlogging has been identified, the suitability of field drains should be investigated and confirmed or alternative water control measures demonstrated and adopted.

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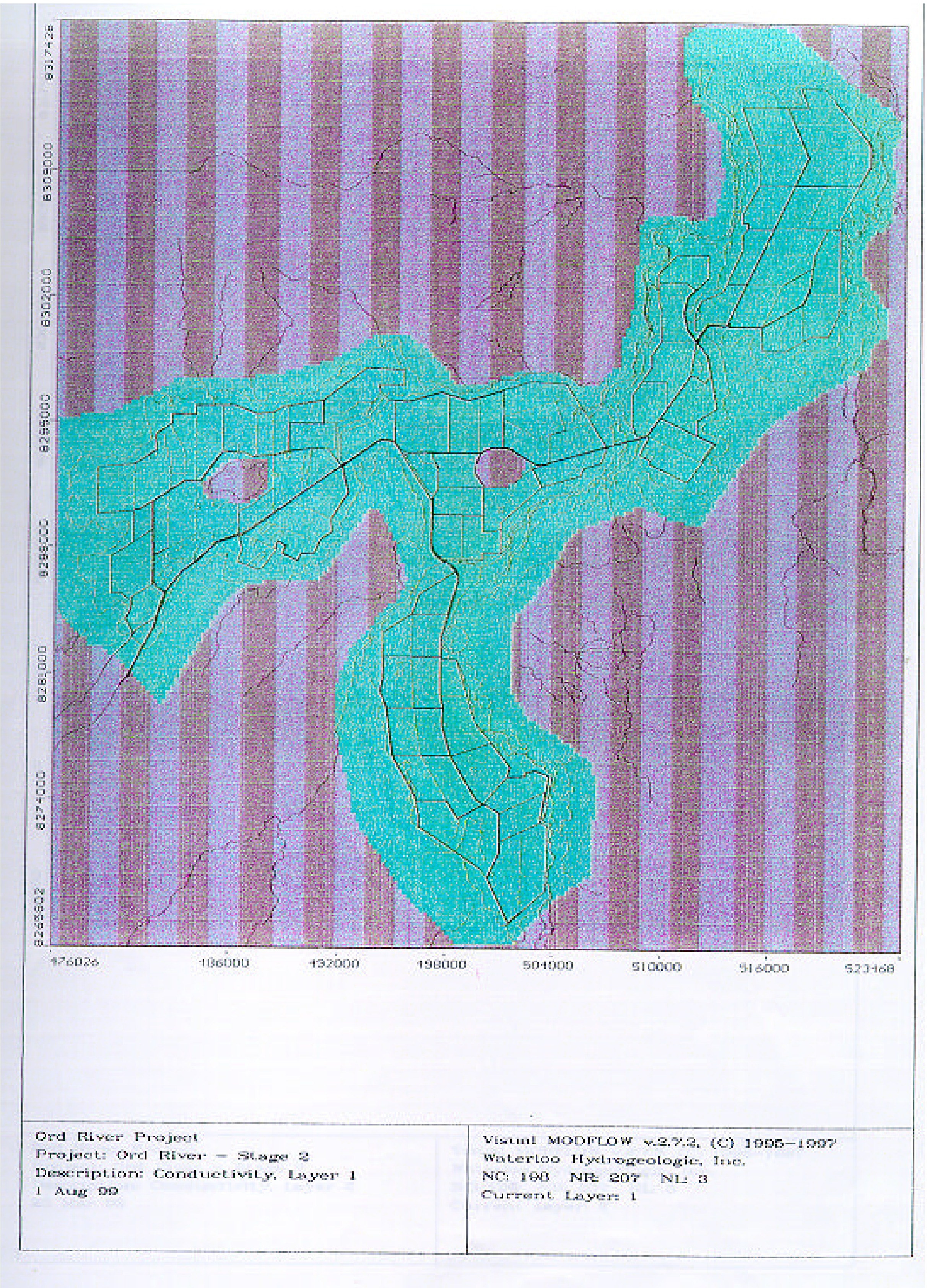
Attachment A

SUB-SURFACE GEOLOGY THROUGHOUT THE PROJECT AREA

[A1 Map to be inserted here]

Attachment B

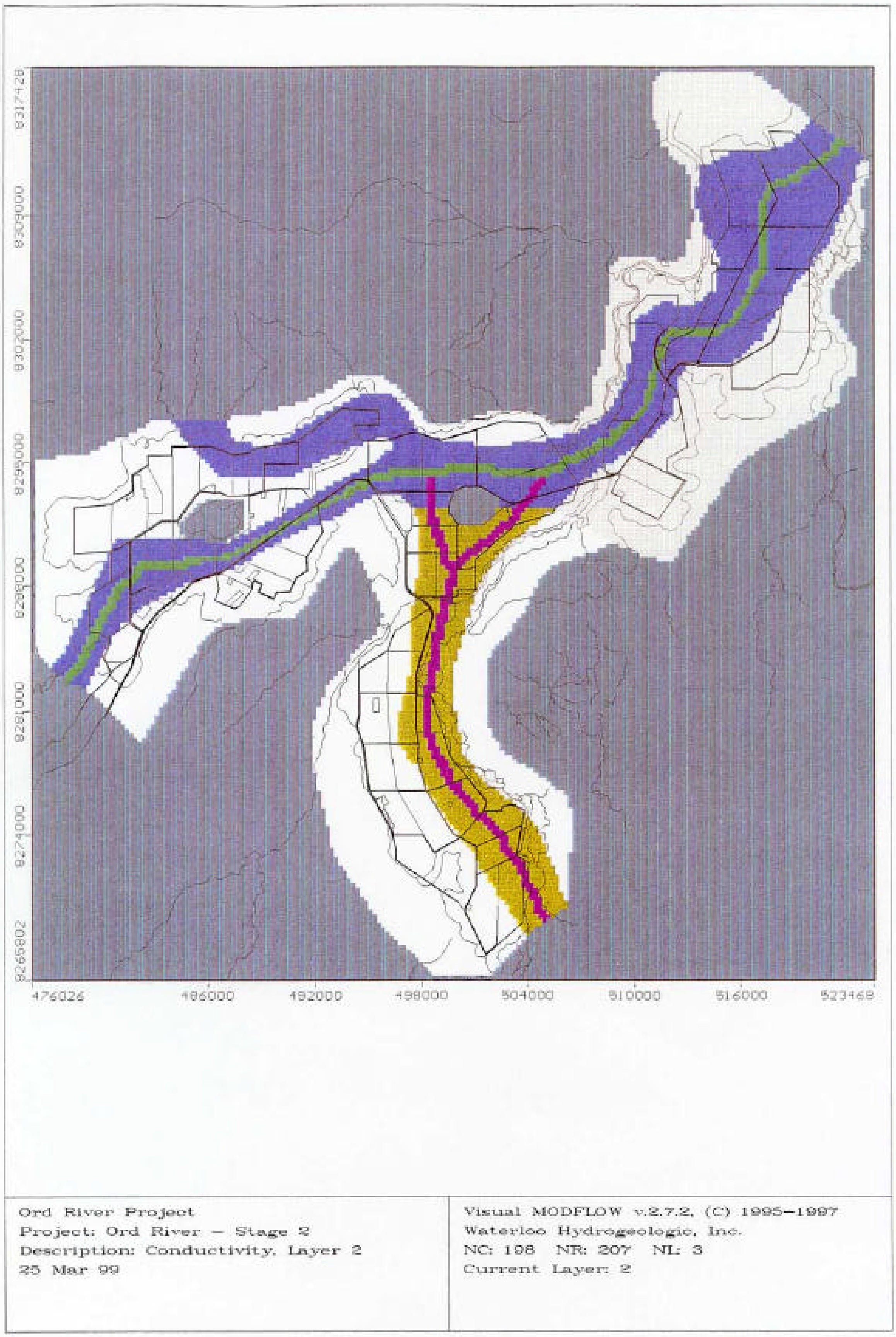
MODEL CONDUCTIVITY DISTRIBUTION



Ord River Project
Project: Ord River - Stage 2
Description: Conductivity, Layer 1
1 Aug 99

Visual MODFLOW v.2.7.2, (C) 1995-1997
Waterloo Hydrogeologic, Inc.
NC: 198 NR: 207 NL: 3
Current Layer: 1

Figure B1 **Model conductivity distribution - Layer 1**



Ord River Project
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Description: Conductivity, Layer 2
25 Mar 99

Visual MODFLOW v.2.7.2, (C) 1995–1997
Waterloo Hydrogeologic, Inc.
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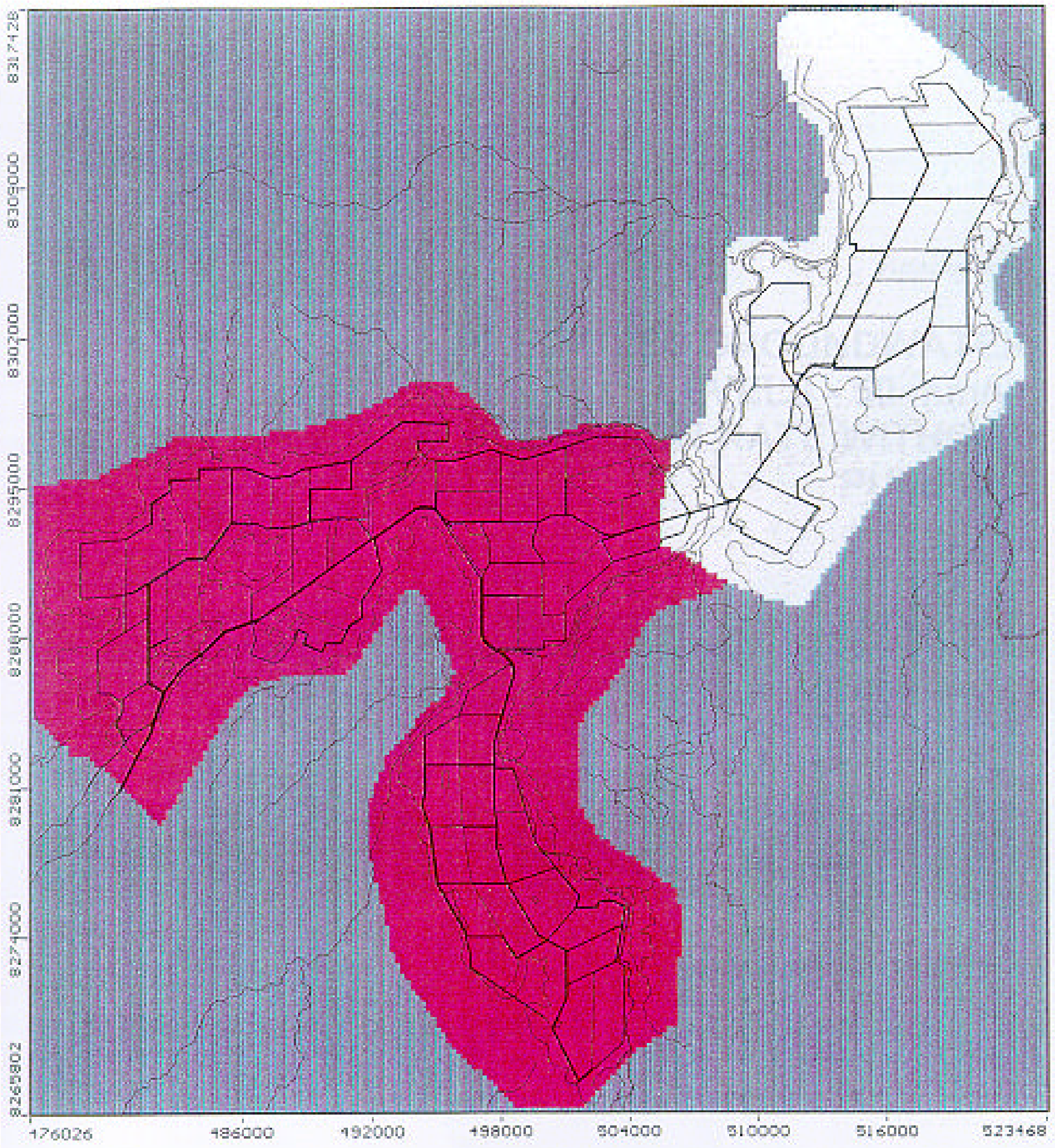
Current Layer: 2

Figure B2 Model conductivity distribution – Layer 2



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25 Mar 99

Visual MODFLOW v.2.7.2, (C) 1995–1997
Waterloo Hydrogeologic, Inc.
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Figure B3 Model conductivity distribution – Layer 3

Attachment C

PREDICTED GROUNDWATER LEVELS - 50 mm/yr ACCESSION RATE WITHOUT PUMPING

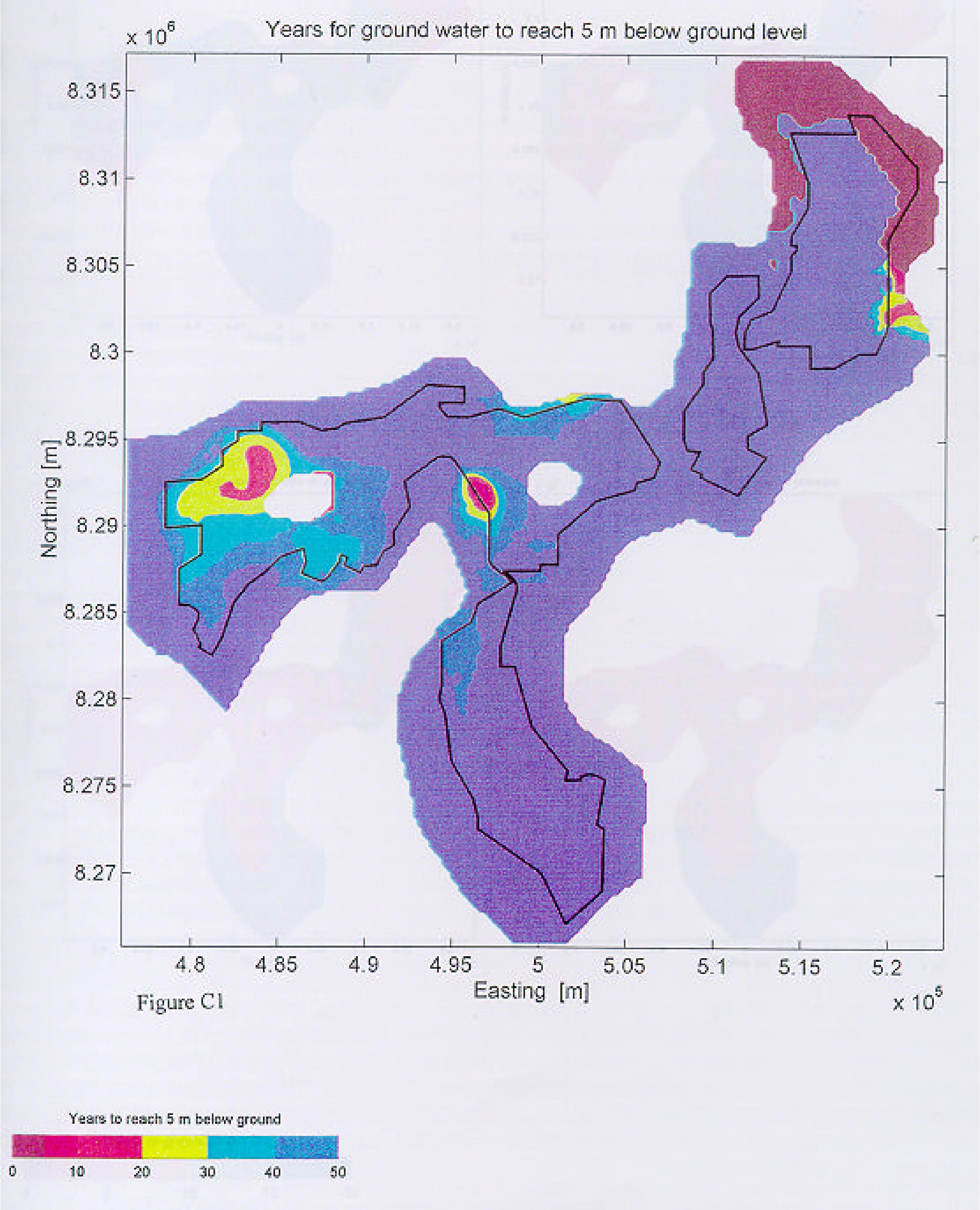
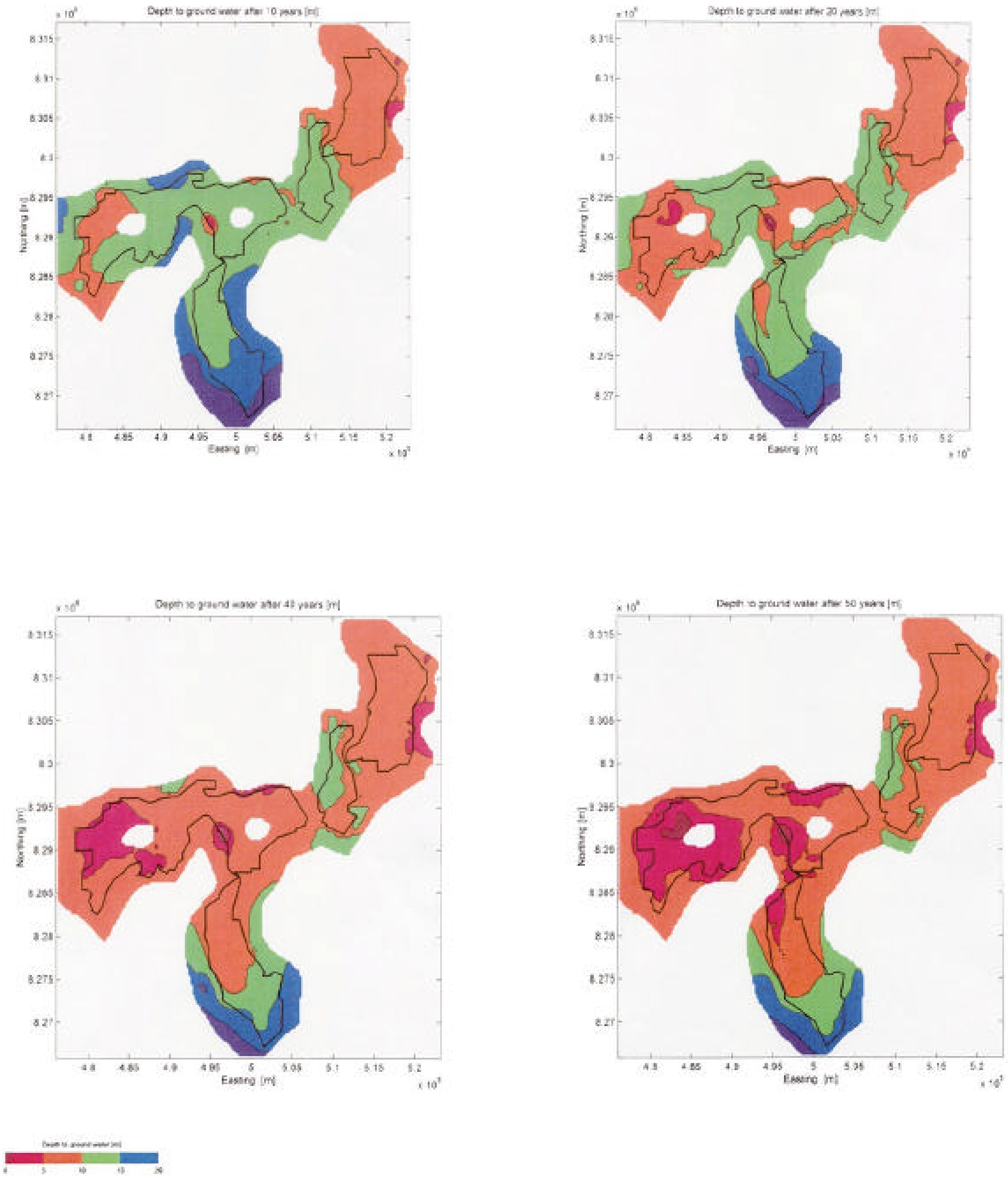


Figure C1 **Groundwater levels – 50 mm/yr accession rate without pumping**



Depth to ground water after 10 years [m]

Depth to ground water after 20 years [m]

Depth to ground water after 40 years [m]

Depth to ground water after 50 years [m]

Figure C2 Groundwater levels – 50 mm/yr accession rate without pumping

Attachment D

PREDICTED GROUNDWATER LEVELS - 50 mm/yr ACCESSION RATE WITH PUMPING

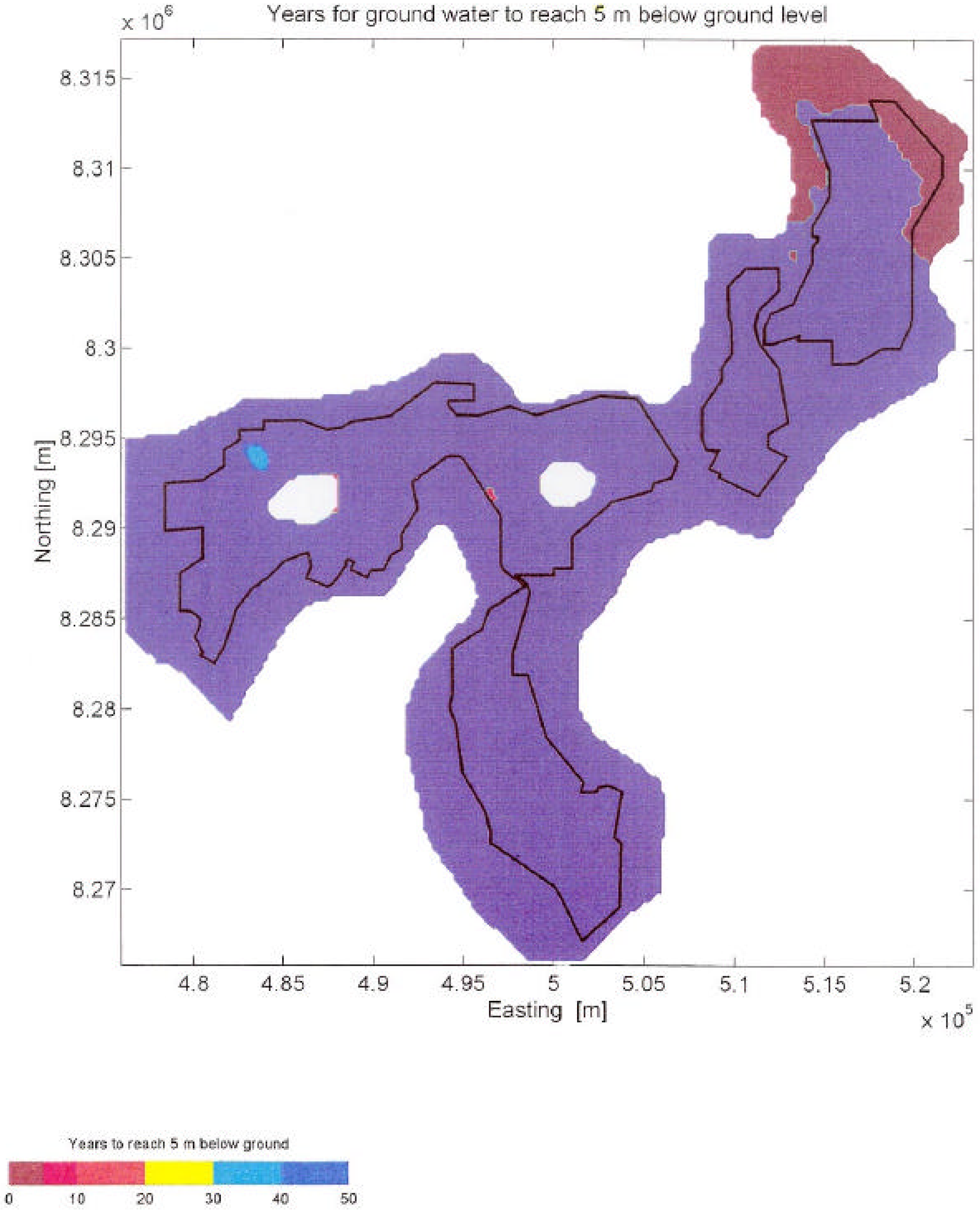


Figure D1 Groundwater levels – 50 mm/yr accession with pumping

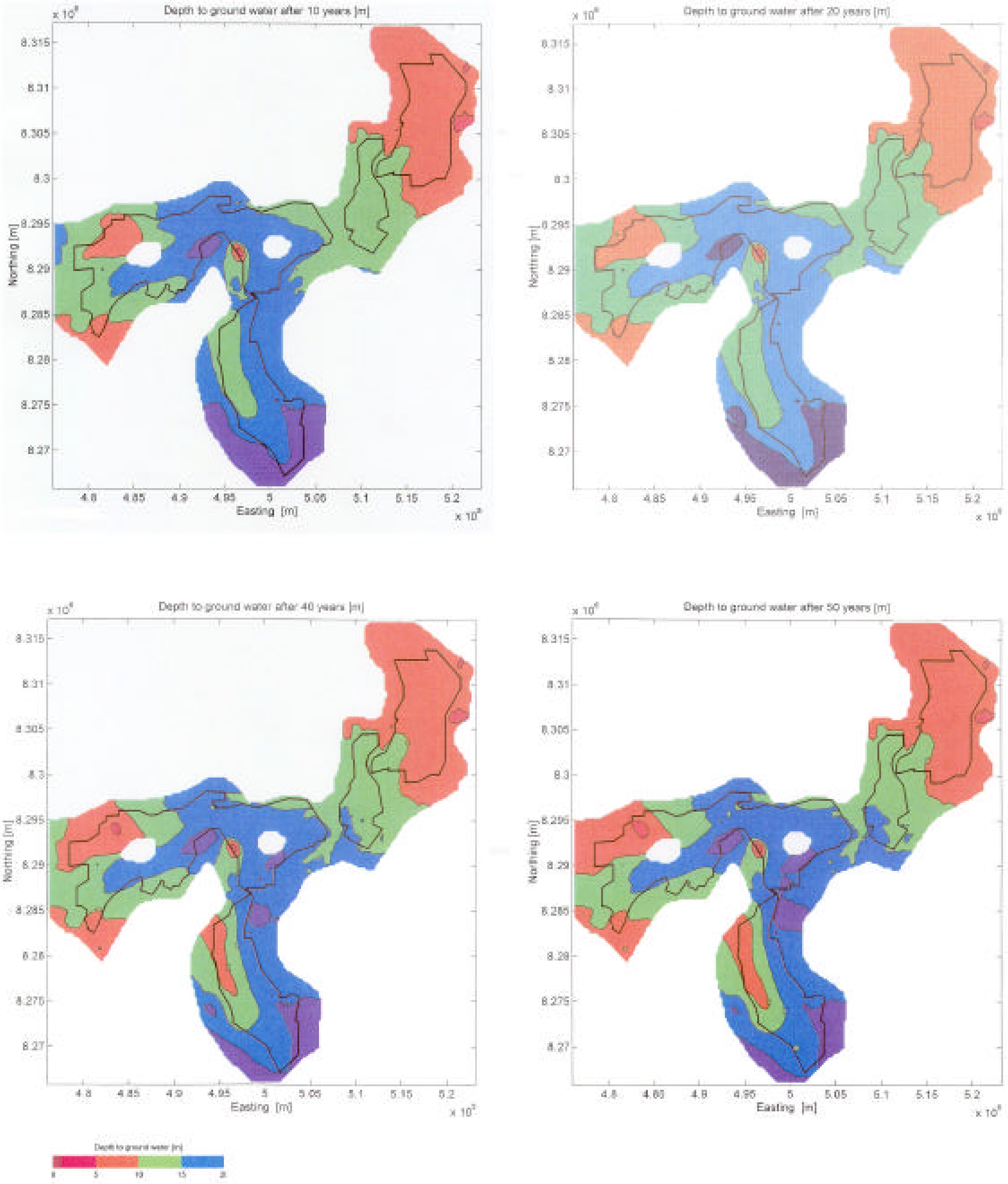


Figure D2 Groundwater levels – 50 mm/yr accession rate with pumping

Attachment E

PREDICTED GROUNDWATER LEVELS - 100 mm/yr ACCESSION RATE WITHOUT PUMPING

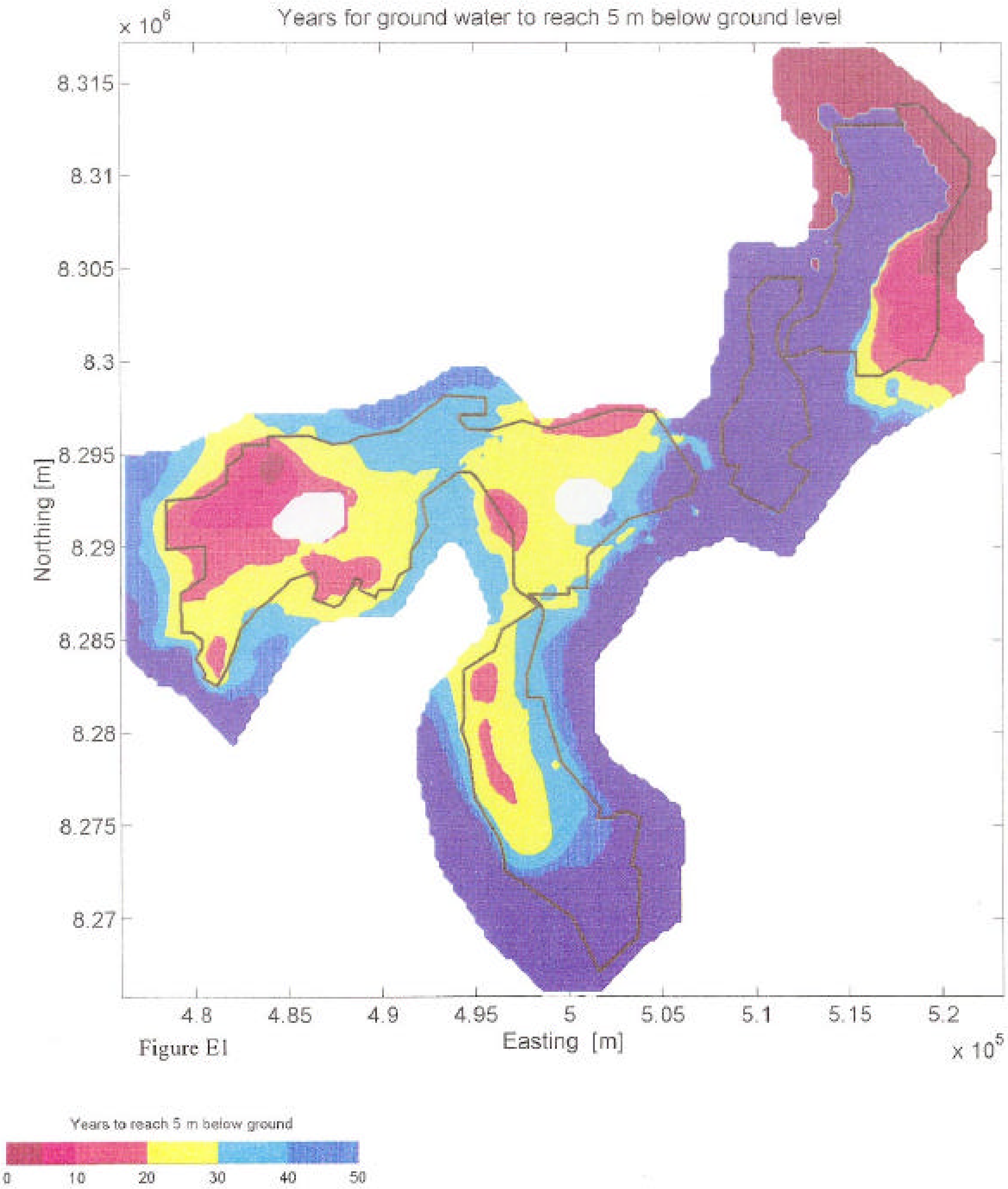


Figure E1 **Groundwater levels – 100 mm/yr accession rate without pumping**

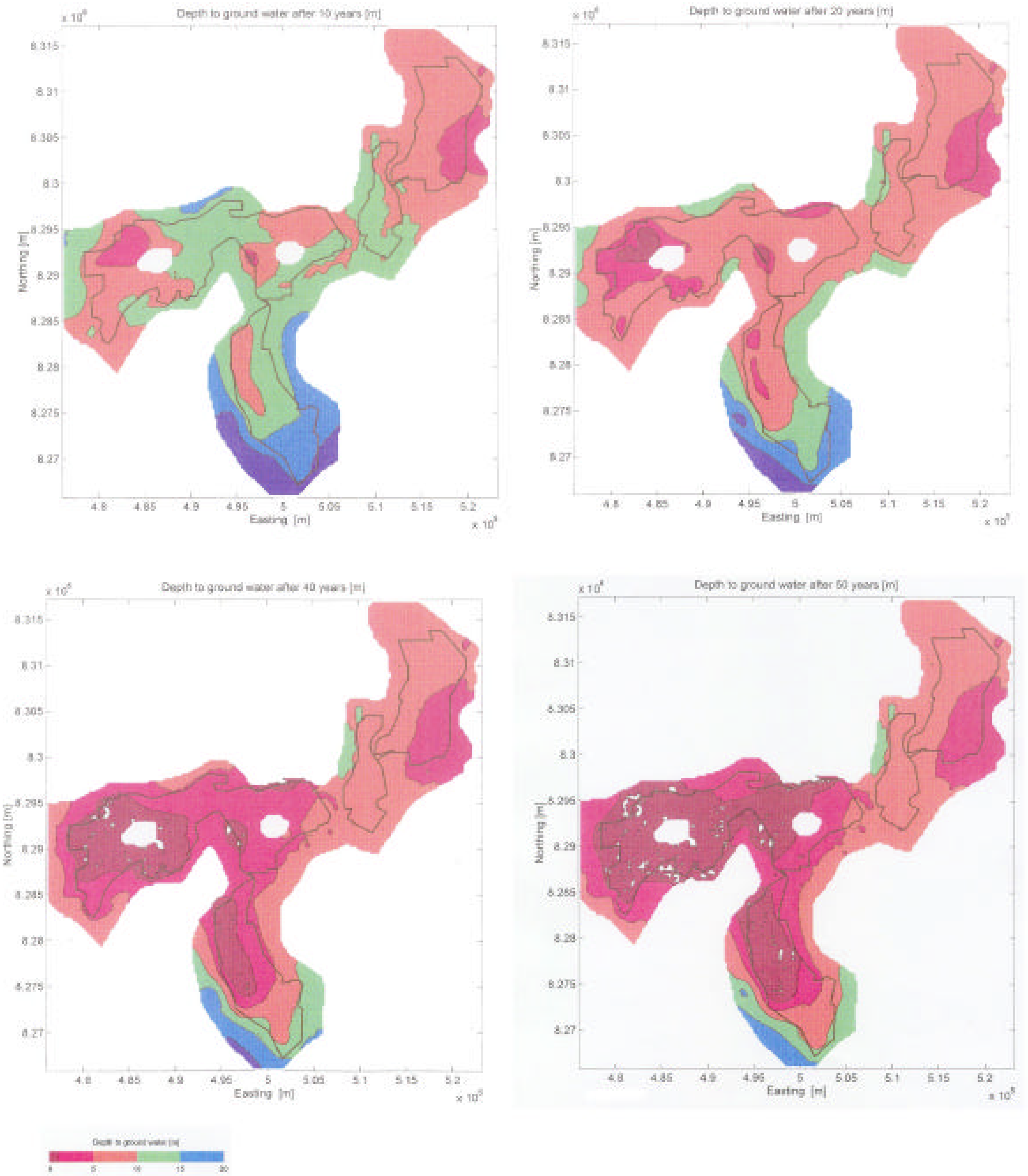


Figure E2 Groundwater levels – 100 mm/yr accession rate without pumping

Attachment F

PREDICTED GROUNDWATER LEVELS - 100 mm/yr ACCESSION RATE WITH PUMPING

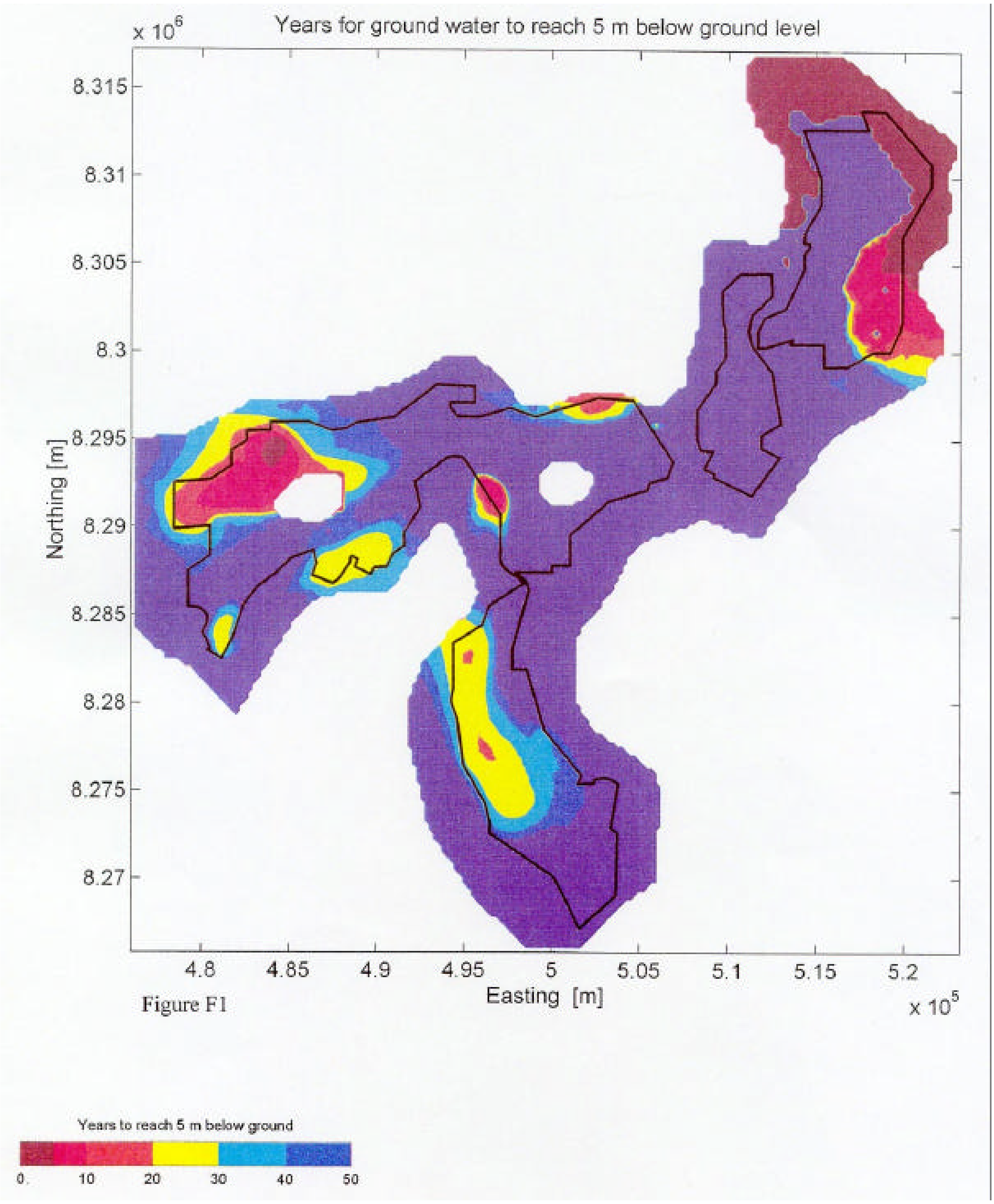


Figure F1 Groundwater levels – 100 mm/yr accession rate with pumping

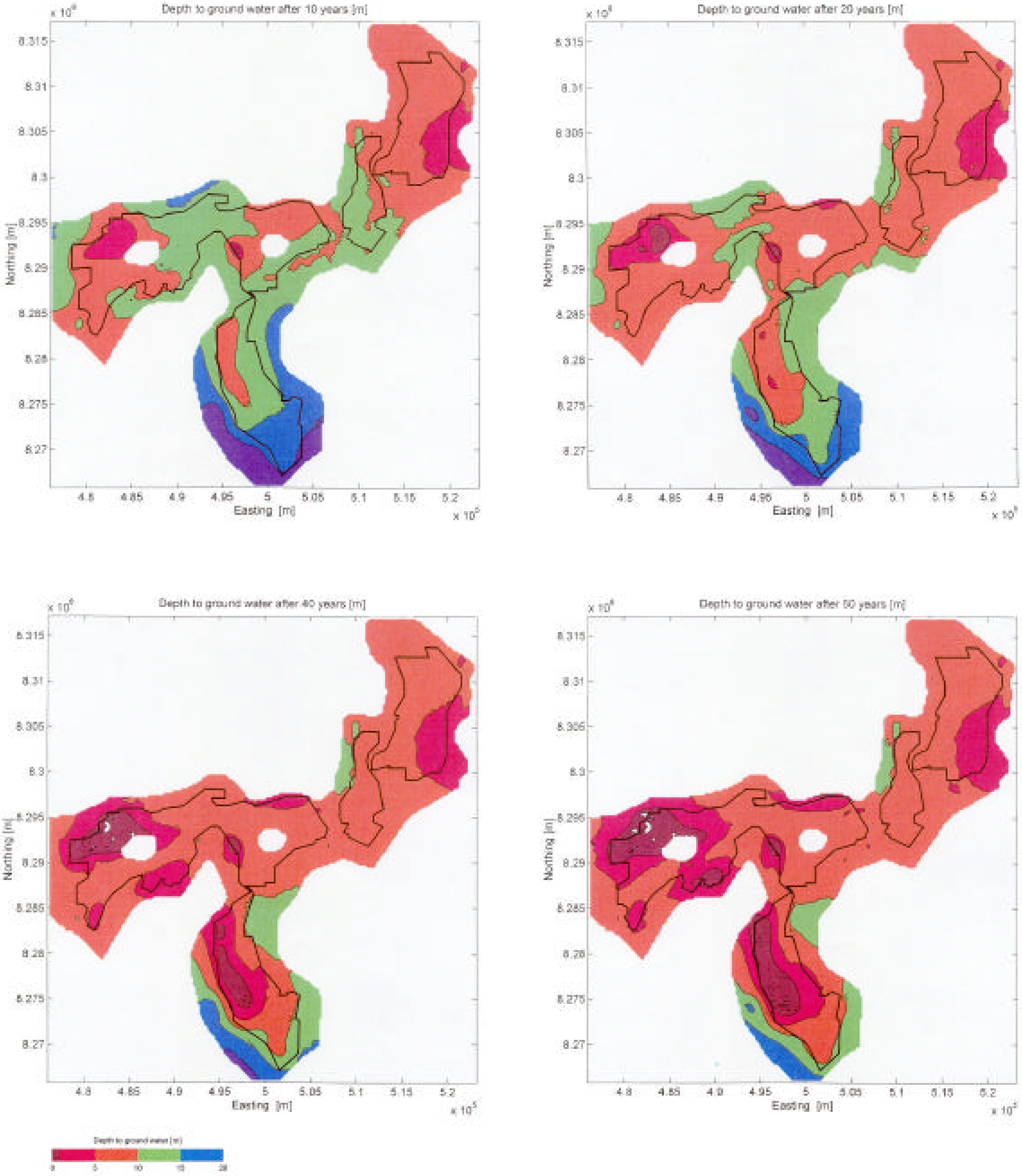


Figure F2 Groundwater levels – 100 mm/yr accession rate with pumping

Attachment G

PREDICTED GROUNDWATER LEVELS - 150 mm/yr ACCESSION RATE WITH PUMPING

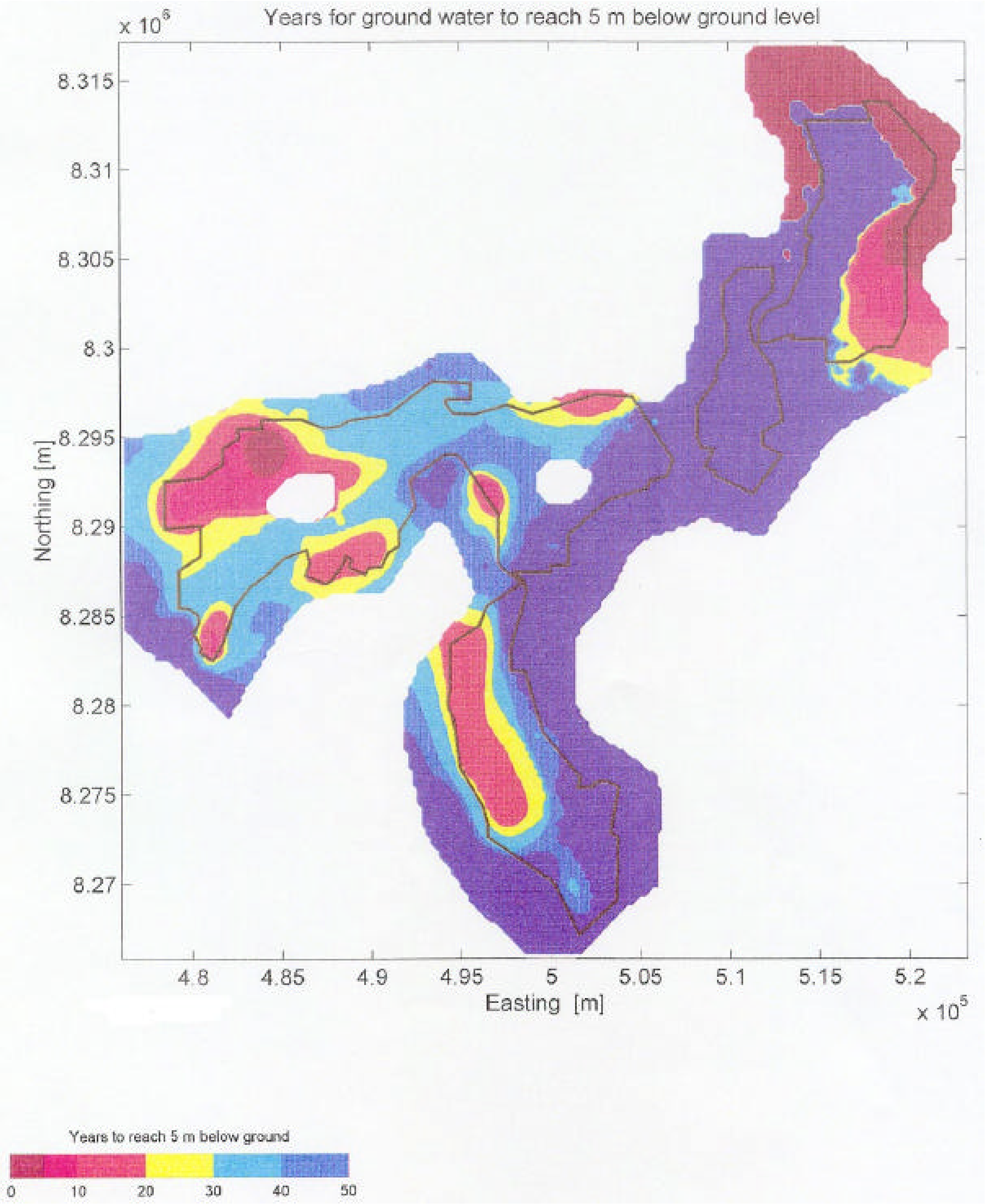


Figure G1 Groundwater levels – 150 mm/yr accession rate with pumping