

The Assessment of Groundwater Resources of the Gascoyne Aquifer System Using GASFAMS V1.1

Volume 2



CyMod Systems Pty Ltd

ABN 072 954 824

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1 INTRODUCTION

The Department of Water (DoW) is undertaking a review of allocation limits and water management rules in the Lower Gascoyne. There is significant groundwater use for both public and private water supplies by the Water Corporation and the local horticulture industry in this area. The DoW will use numerical groundwater modelling to estimate the aquifer yield range and to help inform the allocation limit decisions.

Volume 2 describes sixteen forward simulations using the Gascoyne River Floodplain Aquifers Modelling System (GASFAMS V1.1), an updated groundwater flow and solute transport model of the Lower Gascoyne River. Conclusions and recommendations are made based on the outcomes of these model simulations with respect to the management of water resources in the Lower Gascoyne River.

2 FORWARD MODELLING

2.1 Forward Scenarios

The Lower Gascoyne River is divided into two management areas, Subarea A and Subareas B-L. Each of these subareas has a set abstraction limit. In Subarea A water is abstracted by multiple private users. Subareas B-L is managed as a single borefield and supplies water to the Gascoyne Water Cooperative scheme for irrigated horticulture undertaken in Subarea A and also for public water supply (PWS) for the town of Carnarvon.

In managing the system, the DoW aims to provide the maximum volume of water for abstraction while minimising the risk to groundwater quality, individual licensee source reliability and in-situ values.

The DoW developed thirteen abstraction scenarios for assessment using GASFAMS V1.1. These management scenarios are listed in Table 1. Given the sensitivity of the aquifer system to the distribution and magnitude of river flows, and abstraction patterns, the thirteen scenarios are differentiated by their respective river flow sequences and abstraction schedules. The scenarios simulate both average recharge conditions, designated as moderate frequency recharge, and dry conditions, designated as low frequency recharge. The river flow sequences and abstraction schedules used for the scenarios are described below.

For the purposes of simulation, each abstraction scenario was run either for 8.6 years (May 1991 to January 2000) for moderate frequency recharge conditions or 10 years (January 2000 to December 2009) for low frequency recharge conditions. River flow sequences are as described below, while abstraction in all cases is based on measured (historical) average monthly bore abstraction during the period, scaled proportionally to achieve the required abstraction for Subarea A and Subareas B-L.

In addition to these scenarios, three stochastic simulations were run to estimate the total abstraction under 5%, median and 95% 20 year flow sequences, given applicable water quality criteria.

Water quality criteria used in the forward simulations are:

- Subarea A fresh water has a TDS less than 1000 mg/L;
- Subareas B-L fresh water has a TDS less than 1000 mg/L;
- Water with TDS above these levels is referred to as brackish or saline.

Scenario No.	Scenario Name	Description	Length of simulation	Climate data to be used	Water use
1	Base case – moderate frequency recharge	Flow event approximately every 10 months, though the events vary in magnitude. Average dry spell is 8 months. Longest dry spell 16 months. Maximum stage height at 9 Mile Bridge 6.9m.	Minimum 8.6 years	Moderate Frequency Recharge – 1990 to 1999 climate data	Subarea A – 5.8 GL/year Subareas B-L – 12.2 GL/year Total – 18 GL/year
2	Low recharge frequency scenario	Low Frequency Recharge flow sequence has two no-flow periods of about 30 months, which is likely to represent a conservative (i.e. low) recharge estimate. Maximum stage height 7.7m at 9 Mile Bridge.	Minimum 8.6 years	Low Frequency Recharge – 2000 to 2007 climate data	Subarea A – 0 GL/year Subareas B-L – 18 GL/year Total – 18GL/year
3	Maximise water use during moderate frequency recharge	Use maximised until 20% of current bores run dry or water quality exceeded the criteria in moderate frequency recharge conditions	Minimum 8.6 years	Moderate Frequency Recharge – 1990 to 1999 climate data	Subarea A – 5.8 GL/year Subareas B-L – >12.2 +4 GL/year Total – >18GL/year
4	Maximise water use during low recharge frequency scenario	Use maximised until 20% of current bores run dry or water quality exceeded the criteria in drought condition	Minimum 8.6 years	Low Frequency Recharge – 2000 to 2007 climate data	Subarea A – 0-5.8 GL/year Subareas B-L – >18 +4 GL/year Total – >18GL/year
5	4 GL Brickhouse borefield – moderate frequency recharge	Simulates the abstraction of 4 GL/annum from a modelled new borefield at Brickhouse containing 27 production bores (with 407 m ³ /day abstraction for each bore) during moderate frequency recharge conditions.	Minimum 8.6 years	Moderate Frequency Recharge – 1990 to 1999 climate data	Subarea A – 5.8 GL/year Subareas B-L – >12.2 +4 GL/year Total – >22 GL/year
6	4 GL Brickhouse borefield - low recharge frequency scenario	Simulates the abstraction of 4 GL/annum from a modelled new borefield at Brickhouse containing 27 production bores (with 407 m ³ /day abstraction for each bore) during low frequency recharge conditions.	Minimum 8.6 years	Low Frequency Recharge – 2000 to 2007 climate data	Subarea A – 0-5.8 GL/year Subareas B-L – >18 + 4 GL/year Total – >22 GL/year
7	Grower estimated usage from historical crop area - moderate frequency recharge	Growers have stated that water usage was higher in previous years due to high production of bananas in 1980's. Usage for Subarea A based on theoretical usage and expected Subareas B-L usage (350ha @ 20,000kL/ha)		Moderate Frequency Recharge – 1990 to 1999 climate data	Subarea A – 8.6 GL/year Subareas B-L – >12.2 GL/year Total – >20.8 GL/year
8	Grower estimated usage from historical crop area - low recharge frequency scenario	Growers have stated that water usage was higher in previous years due to high production of bananas in 1980's. Usage for Subarea A based on theoretical usage and expected Subareas B-L usage (350ha @ 20,000kL/ha)		Low Frequency Recharge – 2000 to 2007 climate data	Subarea A – 8.6 GL/year Subareas B-L – >18 GL/year Total – >26.6GL/year
9	Current licensed allocation for Subarea A - moderate frequency recharge	Subarea A is currently over allocated, simulate aquifer if all allocations were activated		Moderate Frequency Recharge – 1990 to 1999 climate data	Subarea A – 11 GL/year Subareas B-L – >12.2 GL/year Total – >23.2 GL/year

10	Current licensed allocation for Subarea A - low recharge frequency scenario	Subarea A is currently over allocated, simulate aquifer if all allocations were activated		Low Frequency Recharge – 2000 to 2007 climate data	Subarea A – 11 GL/year Subareas B-L – >18 GL/year Total – >29GL/year
11	Modified low frequency recharge (very low recharge)	Low Frequency Recharge flow sequence has two no-flow periods of about 30 months but climate scenario includes large recharge prior to and after this period. If recharge before and after no-flow was not as good, the implications for water availability need to be investigated.	Minimum 8.6 years	Low Frequency Recharge climate data preceded and followed by lower recharge events (composite sequence)	Subarea A – 5.8 GL/year Subareas B-L – 12.2 GL/year Total – 18GL/year
12	10,000kL limit in Subarea A	Simulate >10,000kL per month being abstracted (Based on bores with high historical use from 2007-2010 abstracting 15 000KL/month (based on historical use figures) from Oct – Jan.		Moderate Frequency Recharge – 1990 to 1999 climate data	
13	10,000kL limit in Subarea A - low recharge frequency scenario	Simulate >10,000kL per month being abstracted (Based on bores with high historical use from 2007-2010 abstracting 15 000KL/month (based on historical use figures) from Oct – Jan (again based on historically observed high use months).		Low Frequency Recharge – 2000 to 2007 climate data	
14	Current licensed allocation for Subarea A	Simulate dry recharge conditions using the 5 th percentile climate sequence. Abstraction in Subarea A only occurs when river is not flowing.	20 years	Dry stochastic climate sequence, 5 th recharge potential percentile	Subarea A – 11 GL/year Subareas B-L – >22 +4 GL/year Total – >37 GL/year
15	Current licensed allocation for Subarea A	Simulate average recharge conditions using the 50 th percentile climate sequence. Abstraction in Subarea A only occurs when river is not flowing.	20 years	Average stochastic climate sequence, 50 th recharge potential percentile	Subarea A – 11 GL/year Subareas B-L – >22 +4 GL/year Total – >37 GL/year
16	Current licensed allocation for Subarea A	Simulate wet recharge conditions using the 95 th percentile climate sequence. Abstraction in Subarea A only occurs when river is not flowing.	20 years	Wet stochastic climate sequence, 95 th recharge potential percentile	Subarea A – 11 GL/year Subareas B-L – >22 +4 GL/year Total – >37 GL/year

Table 1: GASFAMS Modelling Scenarios

2.2 Recharge Sequences

The conceptual hydrogeology of the Lower Gascoyne River indicates that most freshwater resources are sourced from recharge due to periodic river flow events. The occurrence of these flow events determines the available groundwater resources that can be used for horticultural irrigation and PWS. To ensure that the scenarios are representative, i.e. statistically consistent with historical observations, but also account for the likely impact of climate change, the frequency and magnitude of flows and likely volumes of recharge must have low uncertainty. Due to the sensitivity of the model to flow sequences, the construction of appropriate and representative flow sequences is the most important aspect of scenario development.

There are two approaches to developing representative flow sequences:

1. Generate statistically correct synthetic rainfall/runoff events for the period of interest to generate a synthetic flow sequence; or
2. Use historical flow data.

The construction of a synthetic flow sequence implies sufficient flow and rainfall data to generate statistically relevant datasets via a rainfall/runoff model of the Gascoyne catchment area. Due to the nature of flow in the Gascoyne River this is difficult, as most flows occur due to rainfall on inland catchments. The construction of a rainfall/runoff model of the Gascoyne River catchment is outside the scope of this study.

Alternatively, the use of historical flow data provides a statistically correct data set, but one that may not account for variation in climate. A review of available flow data suggests that recent flow events starting in 1990 may provide a useable dataset for both moderate frequency recharge and low frequency recharge conditions. A review of rainfall data and river flow events identified the rainfall and flow data for the periods 1990 to 2000 and 2000 to 2008 as suitable for input into the model as the moderate frequency recharge and low frequency recharge flow sequences, respectively. Rainfall and river stage heights for the moderate frequency recharge and low frequency recharge sequences are shown in Figures 1 and 2, below.

The moderate frequency recharge flow sequence has a flow event approximately every 10 months, though the events varying in magnitude. The large flow event in 1990 is not explicitly modelled, but is implicitly accounted for in the model by assigning initial conditions based on conditions immediately following that flow. The low frequency recharge sequence uses the recorded flow events from 2000 to 2007. The period from 2008 to 2010 is a replicated sequence from January 2001 to January 2003. This results in the low frequency recharge flow sequence having two no-flow periods of about 30 months, which is likely to represent a conservative (i.e. low) recharge estimate. Table 2 summarises the characteristics of each of the flow sequences used in the scenarios. In the case of the moderate frequency recharge sequence, the actual period was used (i.e. 8.6 years). In the case of the low frequency recharge sequence, the sequence was repeated after 7 years, to construct the 10 year sequence. The modified low frequency recharge sequence (Scenario 11 composite sequence) is simulated as 4 years of no-flow conditions (2000-2004) followed by 6 years of moderate frequency recharge conditions (1994-2000), as shown in Figure 3. All are shown in Table 2.

	Moderate Frequency Recharge	Low Frequency Recharge	Modified Low Frequency Recharge
Period	1991 - 1999	2000 - 2007	2000-2004, 1994-2000
Flow Events	16	11	14
Average Dry Period	8 months	11 months	10
Longest Dry Period	16 months	30 months	30 months
Maximum stage Height	6.9 metres	7.7 metres	7.7 metres
Total Volume of Water	6836 GL	7034 GL	7973 GL
Maximum Flow Rate	$384 \times 10^6 \text{ m}^3/\text{day}$	$501 \times 10^6 \text{ m}^3/\text{day}$	$501 \times 10^6 \text{ m}^3/\text{day}$

Table 2: Scenario Flow Summaries

2.3 Abstraction Schedules

The abstraction of groundwater in Subarea A and Subareas B-L is controlled by the issuing of licenses by the DoW. The distribution of abstraction in Subarea A and Subareas B-L was modelled by using historical measured abstraction as provided by the DoW and the Water Corporation. To represent the most likely distribution of abstraction under changed allocation limits, the abstraction from all licensed bores was averaged on a monthly basis, using measured data for the two simulation periods and then scaled to achieve the desired annual abstraction.

The thirteen abstraction scenarios were then constructed by:

- Calculating the average monthly measured abstraction for private and scheme bores in Subarea A and Subareas B-L, for 1991-2000 (moderate frequency recharge scenarios) and 2000-2008 (low frequency recharge scenarios).
- The average monthly abstraction for each bore, in each subarea, is scaled proportionally, and summed to obtain the desired annual abstraction as specified in the scenario;
- In the case of the Subarea A allocations above 5.8 GL/annum the abstraction bores were duplicated and placed 50 metres north and south of the original bore as shown in Figure 4. In Subareas B-L increased allocations were modelled by the addition of eight bores located between existing bores.
- Bores designated as being able to produce more than 15,000 kL/month are shown in Figure 5.

The above approach ensures that the simulated abstraction is consistent with how bores and borefields have been operated historically. However, for large changes in abstraction (i.e. greater than 50%) which fall outside of previous operating experience the assumed configuration of pumping bores may not be optimum and may result in abstraction targets not being met. In addition, the spatial and temporal distribution of bores used in the moderate frequency recharge and low frequency recharge sequences is different and will account for some of the variation between the results of scenarios run using the different recharge sequences. To reduce this effect, a standard set of production bores, abstracting at set rates, which are scaled appropriately, should be used in both scenarios in future. This will eliminate impacts due to differences in abstraction and ensure scenarios are simulated using the mostly likely abstraction configuration in the future.

All abstraction bores were modelled using the MNW package, completed in the top six layers of the model (CyMod, 2009). In some cases, the proportional increase in abstraction caused bores to go dry. In Subarea A, the loss of bores due to dewatering of the aquifer, in addition to

reduced abstraction, was used as an indicator for when the aquifer could no longer meet allocation demand. In the case of Subareas B-L, bores were completed in layers 1-10, to account for production from deep sandy lenses at many of the production bores. Dry bores were avoided by inserting infill bores and splitting abstraction between the existing bore and the new bores, shown in Figure 6 below. New bores were located between existing bores or to the north of existing bores within 1 km of the river where required (CyMod, 2009). This approach is considered consistent with how the Water Corporation or other operators would manage increased abstraction through the installation of additional bores. CyMod, 2009, Appendix J lists the bores and the abstraction used in each of the scenarios.

2.3.1 Brickhouse Borefield Abstraction

An investigation in the Brickhouse area (Figure 7) completed in February 2006 showed that there was the possibility to exploit groundwater from the area. The program consisted of drilling 40 investigation bores to identify areas of sufficient transmissivity in the OAA aquifer on the northern side of the Gascoyne River. The results of the investigation suggest that sand sequences containing sufficient freshwater occurred north of the Gascoyne River, as indicated in Figure 8. Based on this data, 27 proposed abstraction bores were located in the area (Figure 7).

The Brickhouse scenarios (5 and 6) simulate the abstraction of 4 GL/annum from the 27 proposed production bores (407 m³/day abstraction for each bore).

2.4 Head- and Solute-Time Curves

Ten model observation bores, five each in Subarea A and Subareas B-L, were installed in the model, linearly spaced along the river bed and screened from layers 2 to 6 inclusive and numbered Subarea A-1 through Subarea A-5 and Subarea B-1 through Subarea B-5. The bores represent composite bores with readings from multiple layers, consistent with historical data and bore construction in Subarea A. These ten simulated monitor bores provide representative water levels and water quality time series that can be compared between scenarios. Water levels and TDS concentrations at each of the bores were extracted from the model output and plotted to show any trends occurring with respect to water level and TDS concentration for each scenario. The locations of the scenario observation bores are shown in Figure 9.

2.5 Water Balances

Water balances were performed for each scenario based on the zones shown in Figure 10 for Layers 1 and 2 (River Bed Sand) and Figure 11 for Layers 3 to 10 (Older Alluvium). The water balance algorithm employed summarises flow into and out of the model for each of the zones, summarised by the mechanism of flow, e.g. abstraction, discharge to the ocean, river recharge, etc., and is used to assess the performance of the different abstraction schedules under both moderate frequency recharge and low frequency recharge climate conditions.

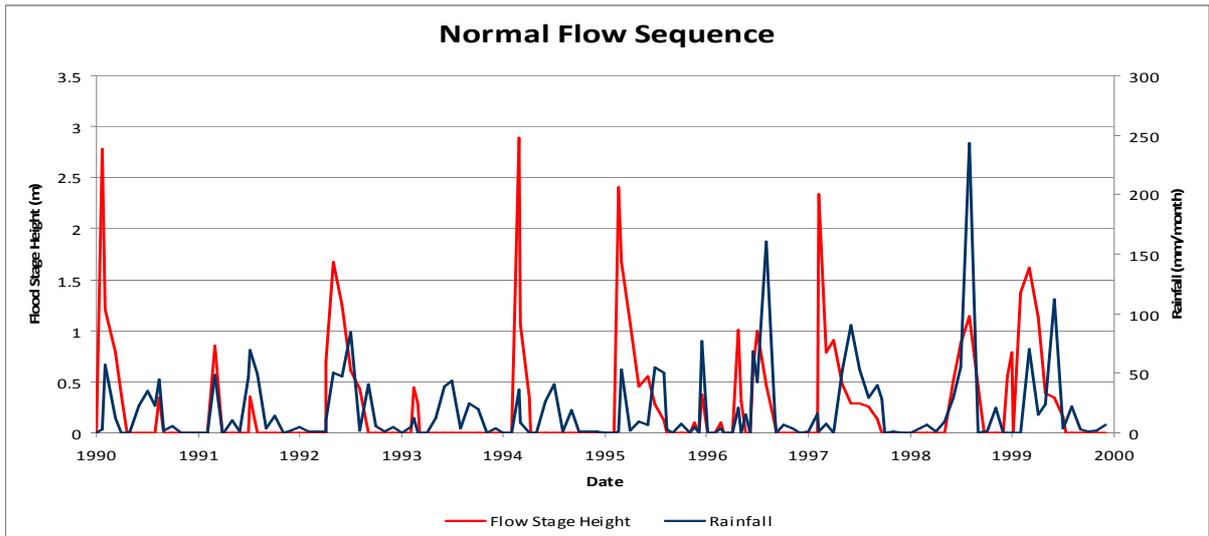


Figure 1: Moderate Frequency Recharge Flow Sequence

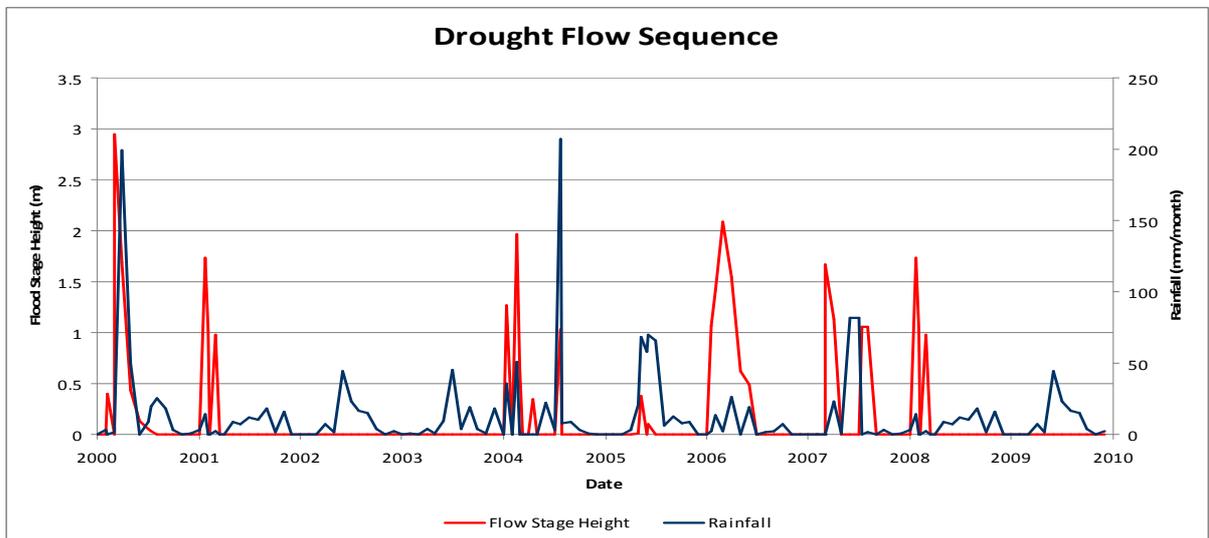


Figure 2: Low Frequency Recharge Flow Sequence

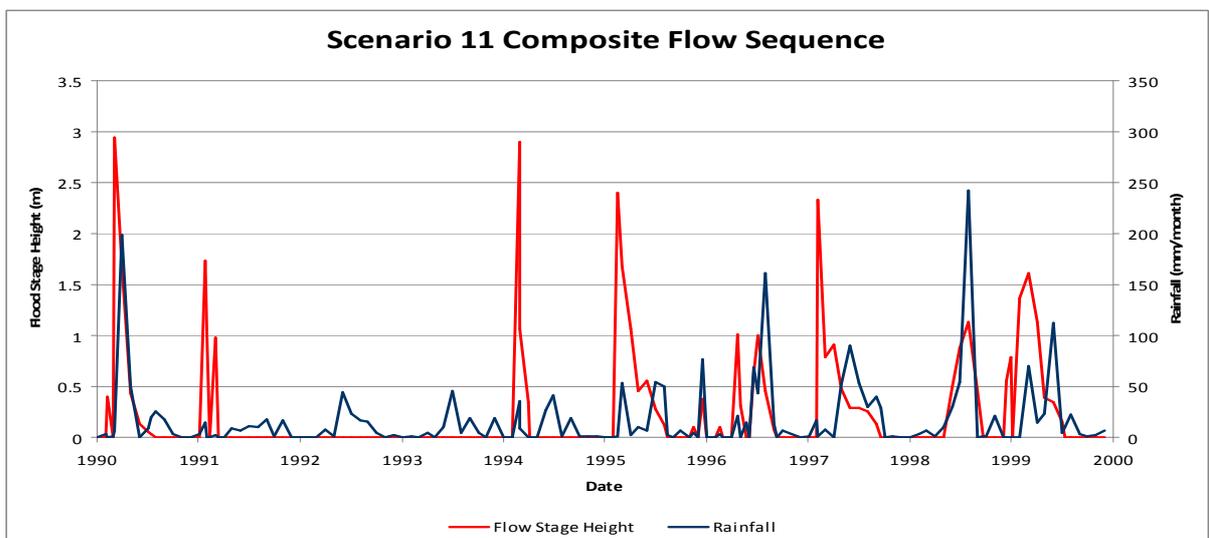


Figure 3: Modified Low Frequency Recharge Flow Sequence



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ACKNOWLEDGEMENT
DATA SOURCES
- Geoscience Australia
- SKM
- Department of Water

SCALE 1:75000



GDA 94
MGA ZONE 50

Legend

 Duplicate Production Bores

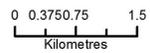
Figure 4: Duplicated Licensed Bores in Subarea A



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SCALE 1:75000



GDA 94
MGA ZONE 50

Legend

-  15,000 kL/month Bores

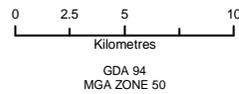
Figure 5: Bores Able to Abstract 15000 kL/month



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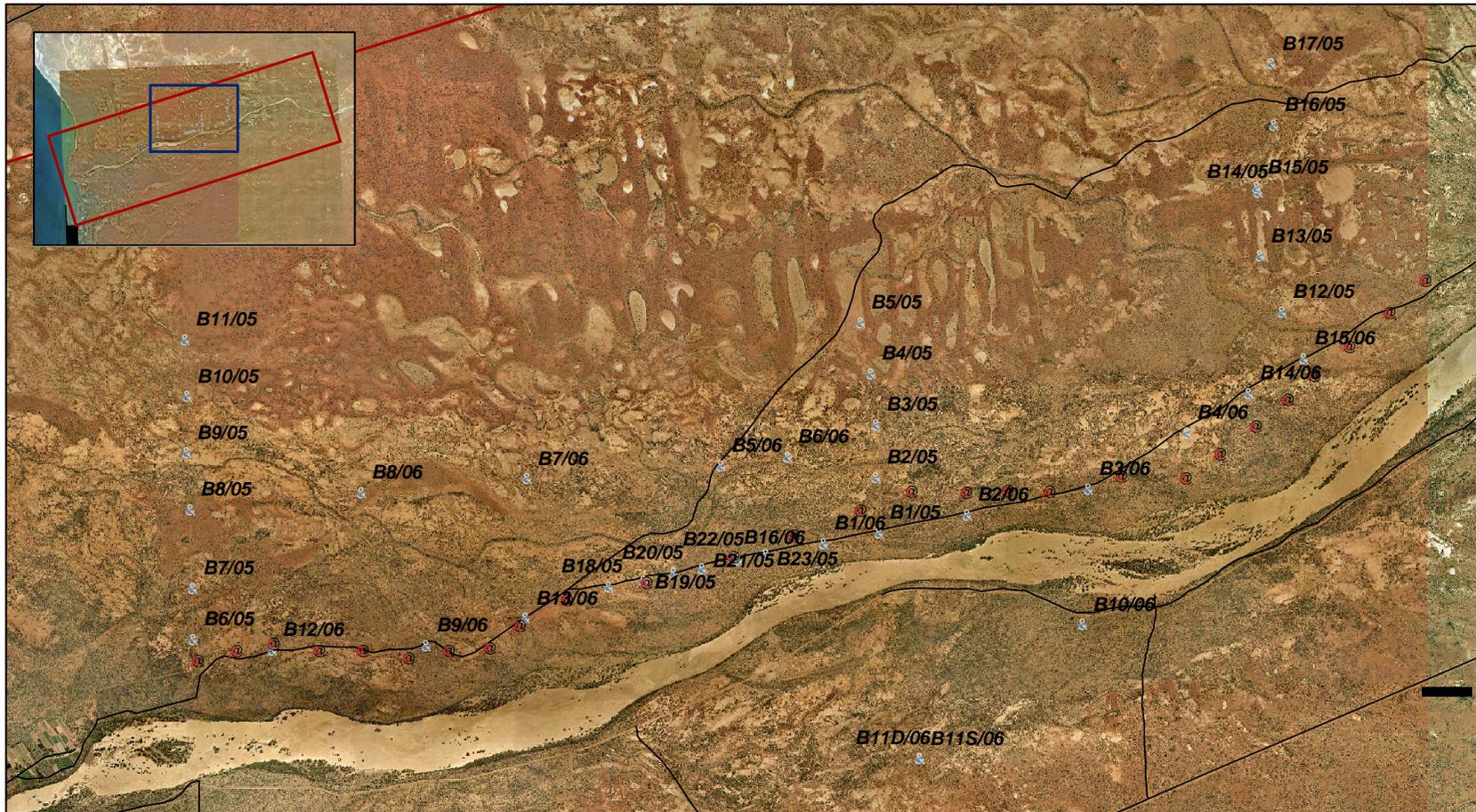
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Legend

-  Infill Production Bores
-  Study Area
-  Roads

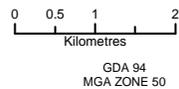
Figure 6: Infill Bore Locations



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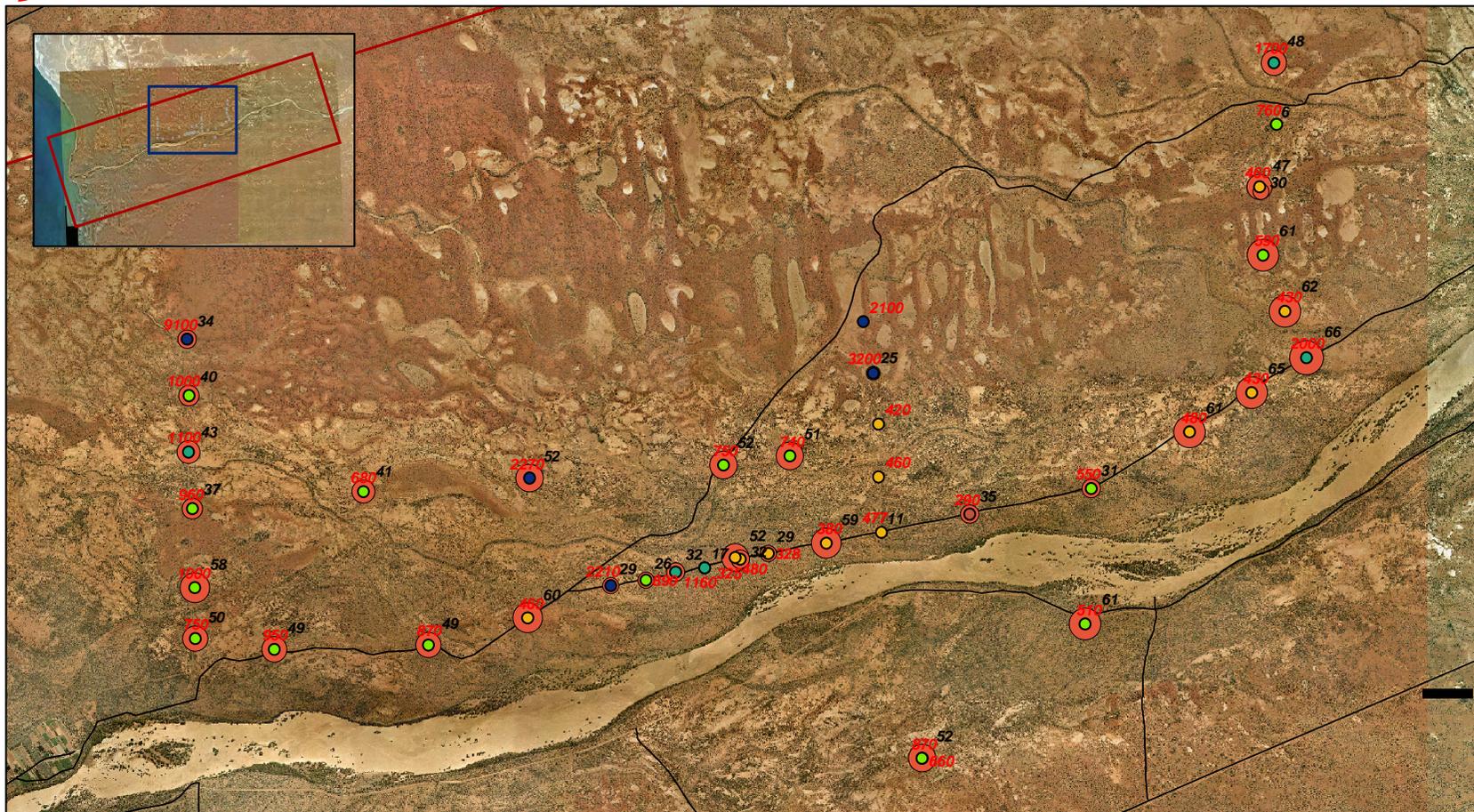
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Legend

- @ Brickhouse Production Bores
- A Brickhouse Investigation Bores

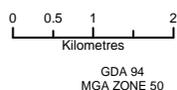
Figure 7: Brickhouse Bore Locations



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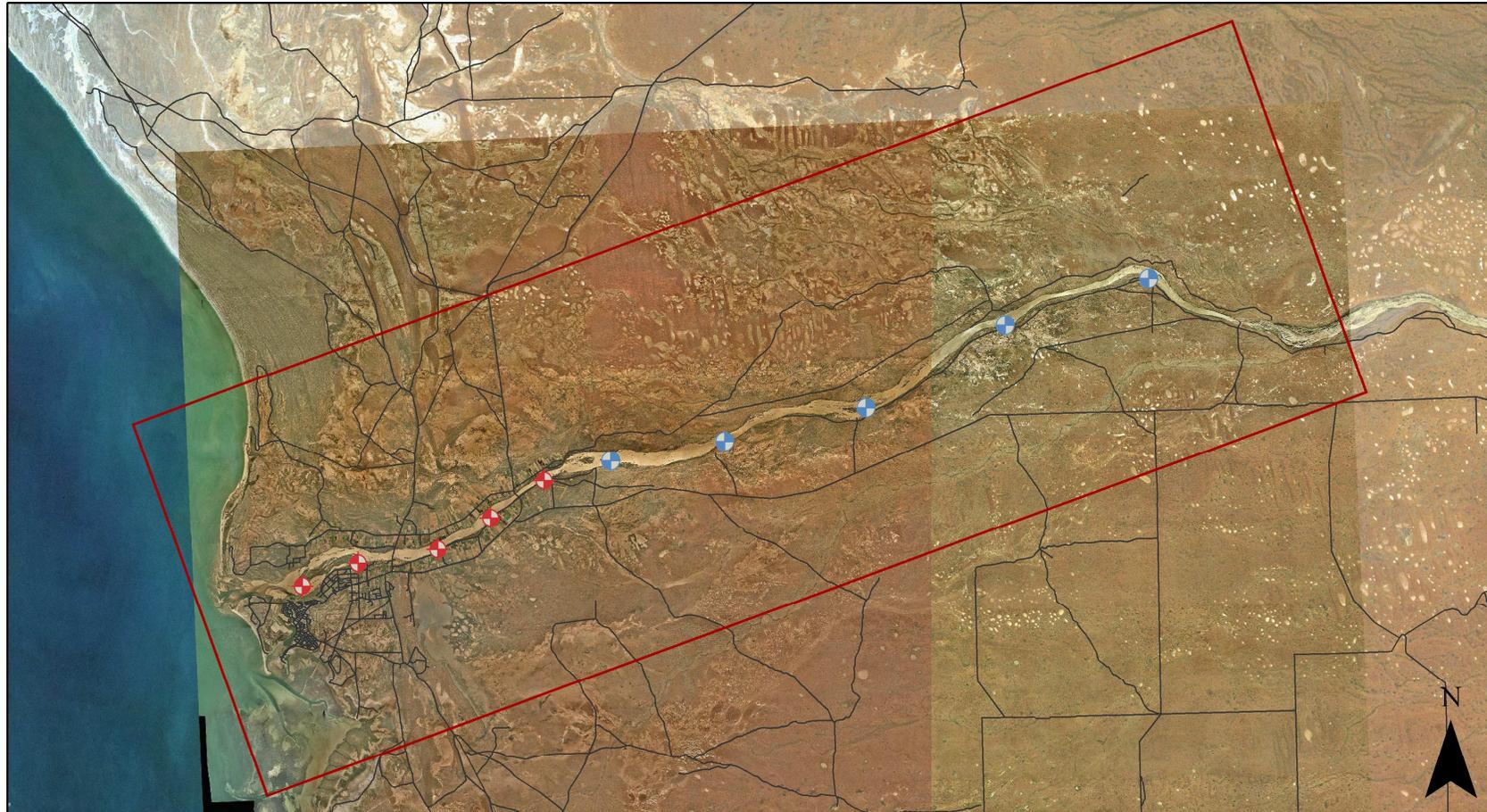
SCALE 1:75000



Legend

Salinity	Sand Thickness (m)	
● < 300	● 6 - 10	● 31 - 35
● 300 - 500	● 11 - 15	● 36 - 40
● 500 - 1000	● 16 - 20	● 41 - 45
● 1000 - 2000	● 21 - 25	● 46 - 50
● > 2000	● 26 - 30	● 51 - 55
		● 56 - 60
		● 61 - 65
		● 66 - 70

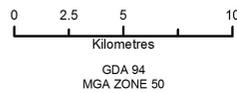
Figure 8: Brickhouse Bore Sand Occurrences and Salinities



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SCALE 1:275000



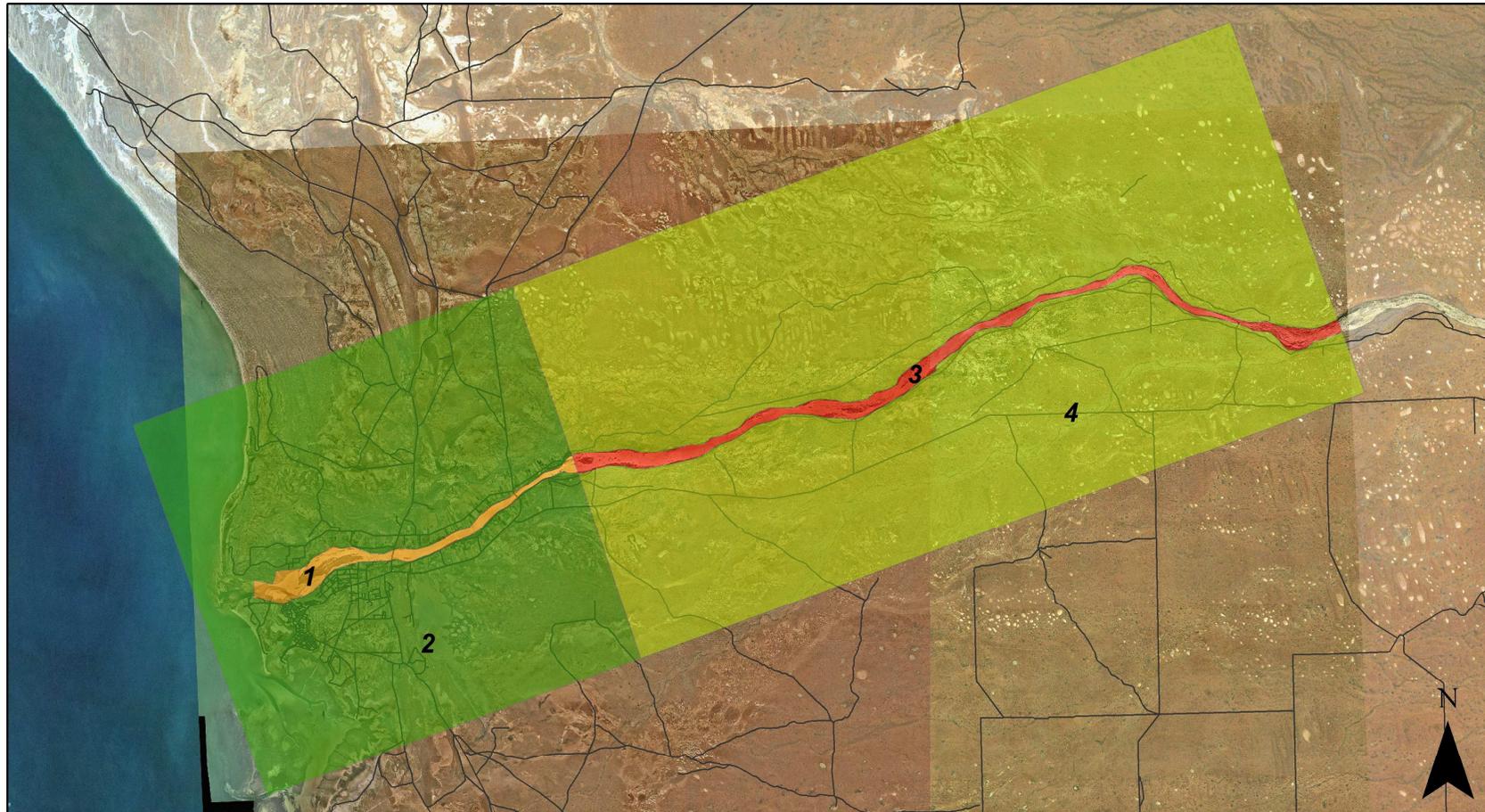
Legend

- Study Area
- Roads

Scenario Observation Locations

- ◆ Subarea A
- Subarea B-L

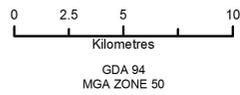
Figure 9: Scenario Observation Bores



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SCALE 1:275000

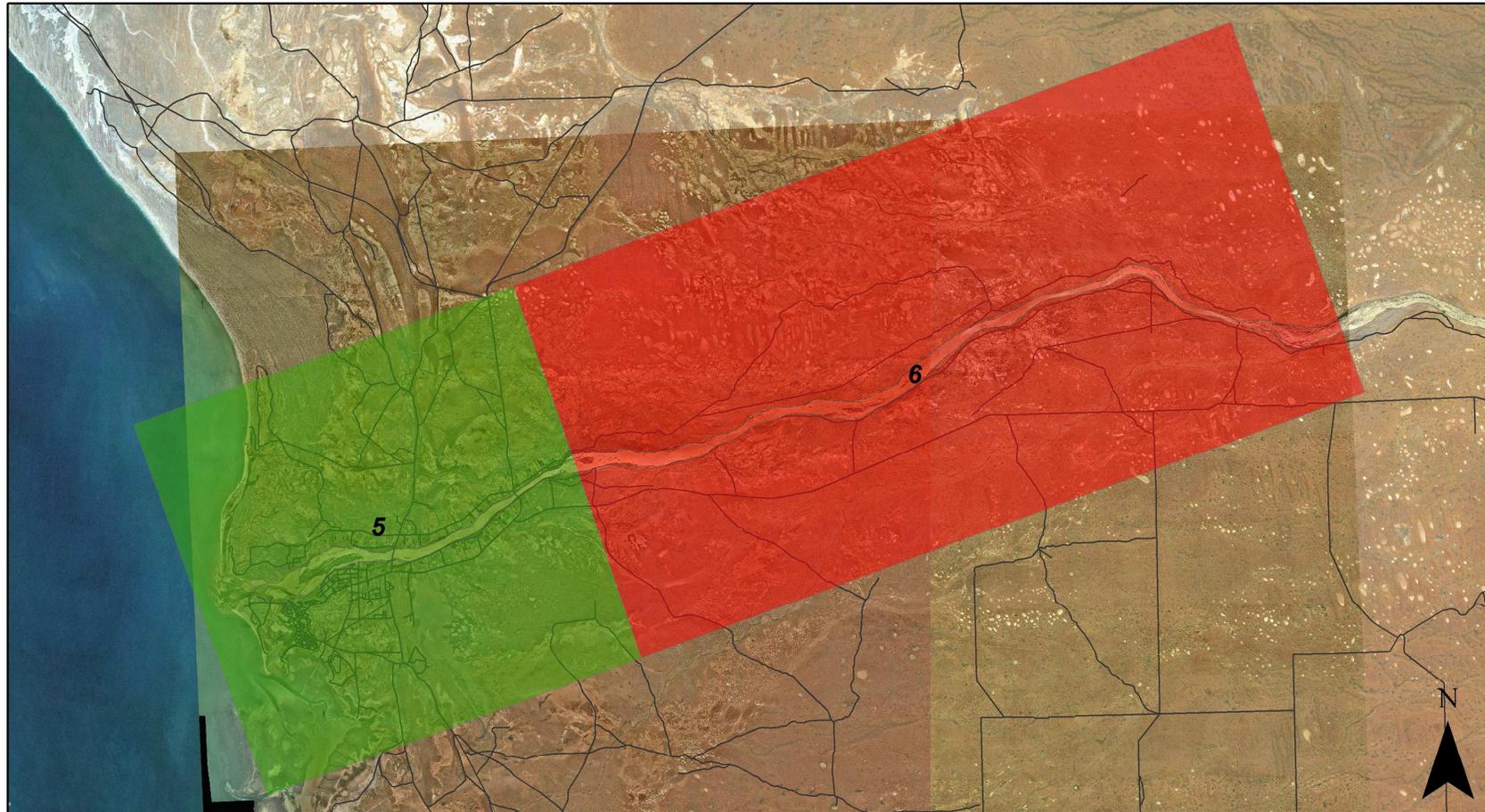


Legend

Water Balance Zones, Layers 1 and 2

- RBS, Subarea A
- RBS, Subareas B - L
- Shallow OAA, Subarea A
- Shallow OAA, Subareas B - L

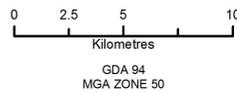
Figure 10: Water Balance Zones, Layers 1 and 2



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Legend

Water Balance Zones, Layers 3 - 10

- Deep OAA, Subarea A
- Deep OAA, Subareas B - L

Figure 11: Water Balance Zones, Layers 3 to 10

3 FORWARD SIMULATION RESULTS

3.1 Abstraction Scenarios 1 - 6

3.1.1 Scenario 1 – Moderate Frequency Recharge Base Recharge

Scenario 1 is designated as the Moderate Frequency Recharge Base Case and represents the present management situation but with abstraction set to the total allocation of 18 GL/annum. The scenario was simulated for moderate frequency recharge conditions, and assessed by:

- examining the water balance for each of the subareas, to assess if total allocations were sustained over the 8.6 year simulation period;
- reviewing changes in water quality in each subarea to determine which bores have exceeded the water quality criteria; and
- reviewing the trend in water levels in each subarea to determine if there is long-term depletion of the aquifer at the end of the moderate frequency recharge flow sequence.

A review of the water balance from the simulation is summarised in Table 3. The table shows that over the course of the 8.6 year simulation, the average abstraction was 16 GL/annum, 2 GL/annum less than the allocation. The loss of abstraction occurred in Subareas B-L (zones 3, 4 and 6), as some bores failed to meet their specified pumping rate. This indicates that some additional new bores may be needed to meet the allocation of 12.2 GL/annum from Subareas B-L. Total abstraction from Subarea A (zones 1, 2 and 5) is 5.65 GL/annum suggesting that the allocation of 5.8 GL/annum represents a reasonable maximum, given existing infrastructure.

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.16	9.08	-2.36	-4.22	0.00
2	2.23	1.17	-1.81	-4.85	0.61
3	-0.31	15.4	-2.65	-4.38	0.01
4	-0.79	1.58	-4.33	-0.53	0.06
5	0.14	0.00	-1.48	0.00	0.51
6	-0.84	0.00	-3.38	0.00	-0.01
Subarea A Total	2.53	10.25	-5.65	-9.07	1.12
Subareas B-L Total	-1.94	16.98	-10.36	-4.91	0.06

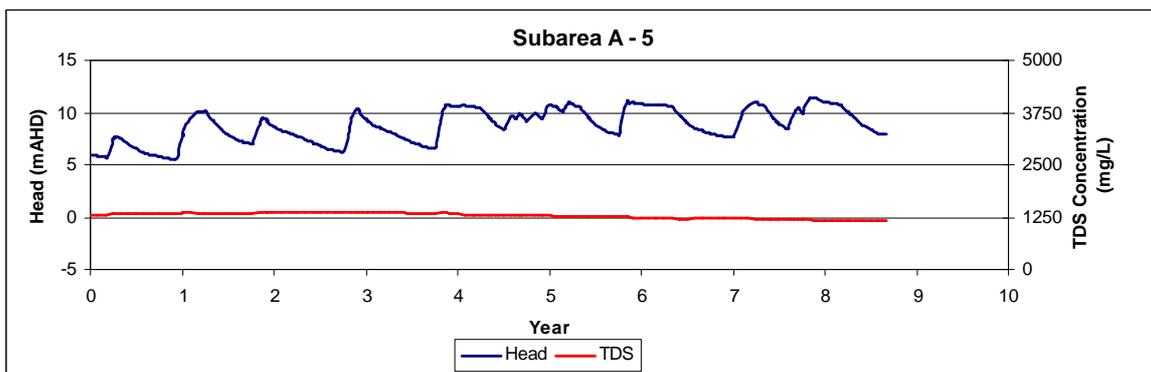
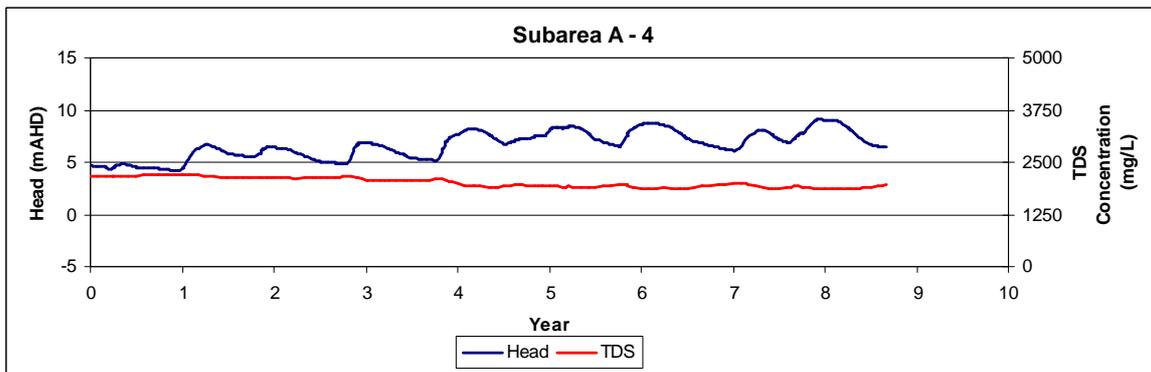
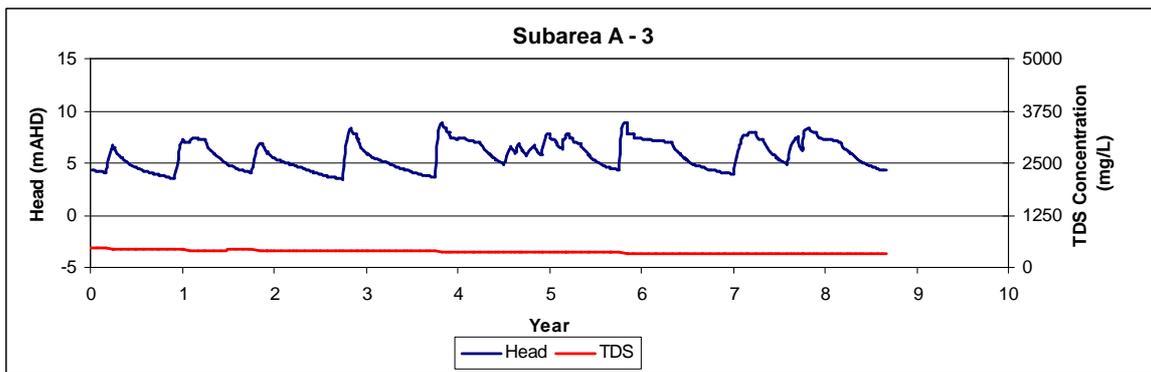
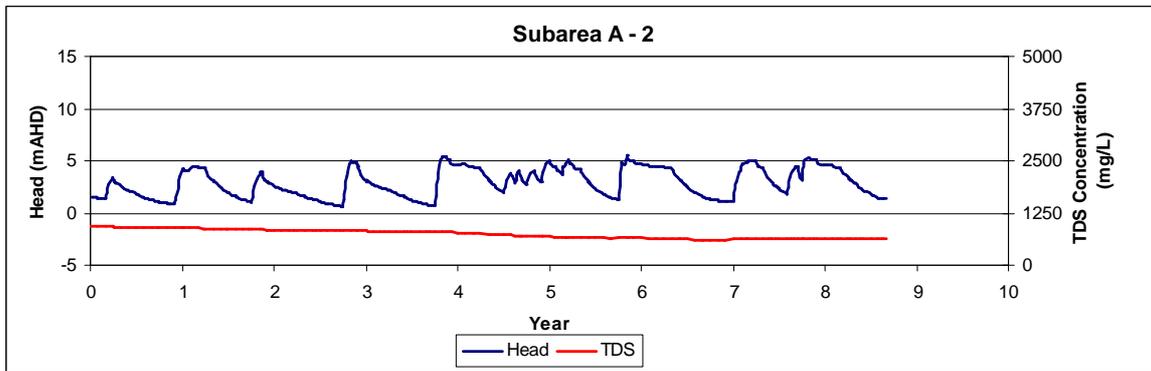
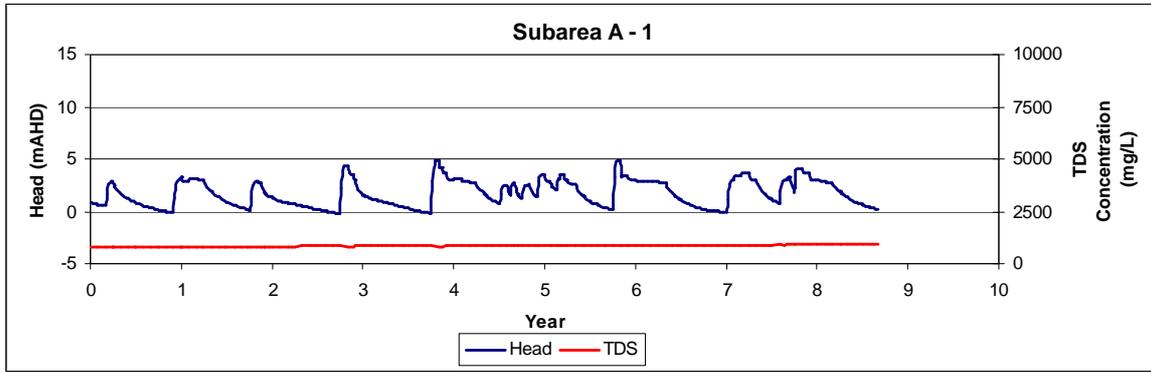
Table 3: Scenario 1 Water Balance Summary

A review of the simulated hydrographs, Figure 12, shows rising water levels over the simulation period in most bores. This is consistent with the hydrogeological conditions, as

river recharge is regular during the simulation period. The final change in water level over the period is small, with water levels in at the end of the simulation at or near the same level as at the beginning.

In terms of water quality, TDS generally declined over the period, as increased abstraction removed groundwater, and lowered water levels, thereby allowing increased recharge by fresher river water, and reduced evapotranspiration. The mass balance shows that TDS in storage decreased over the course of the simulation (i.e. groundwater is getting fresher), with the mass of TDS abstracted declining in the final year of pumping compared to the first year.

Figures 13 and 14 show the simulated water levels and TDS concentrations, respectively, at the end of each simulation.



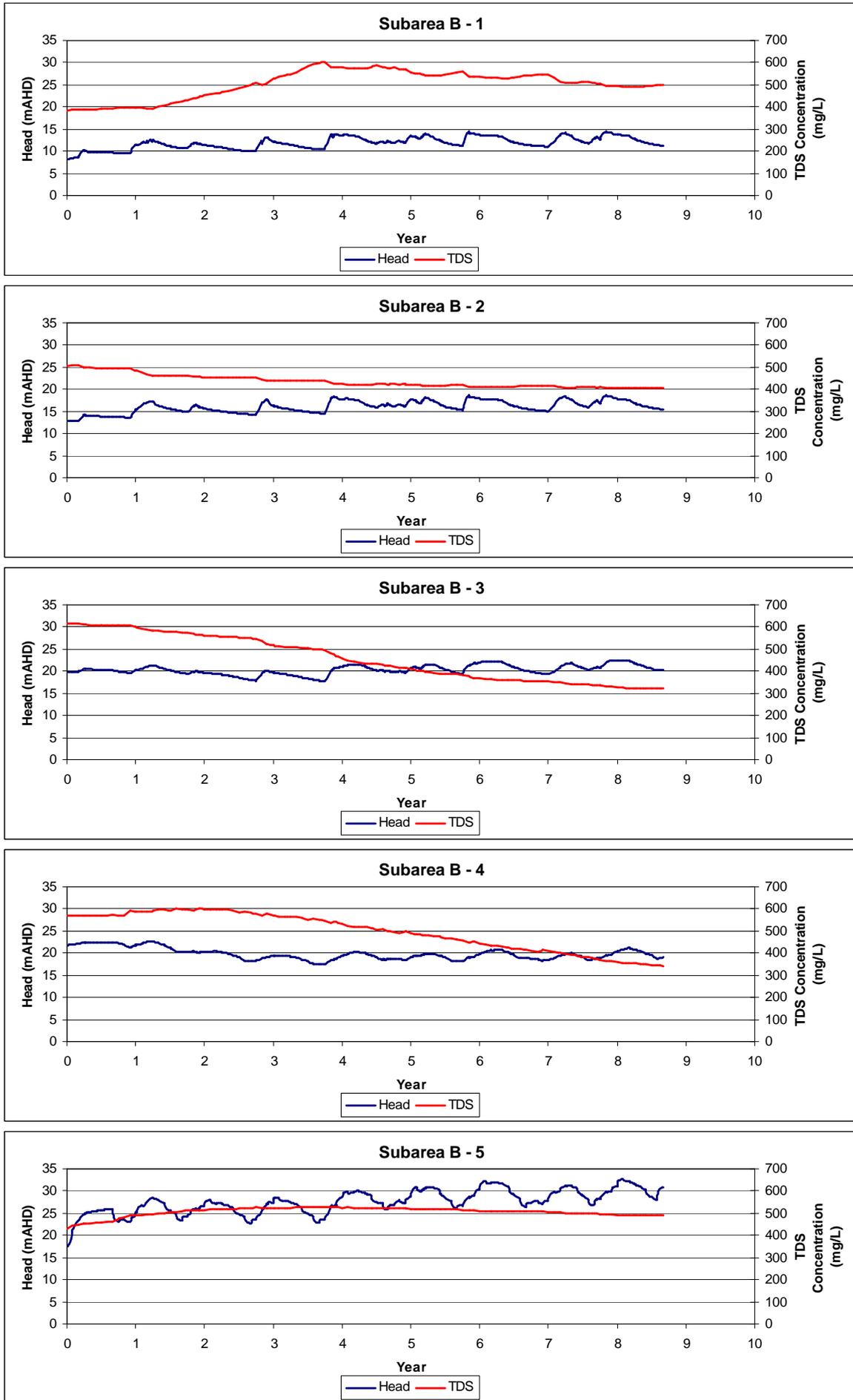
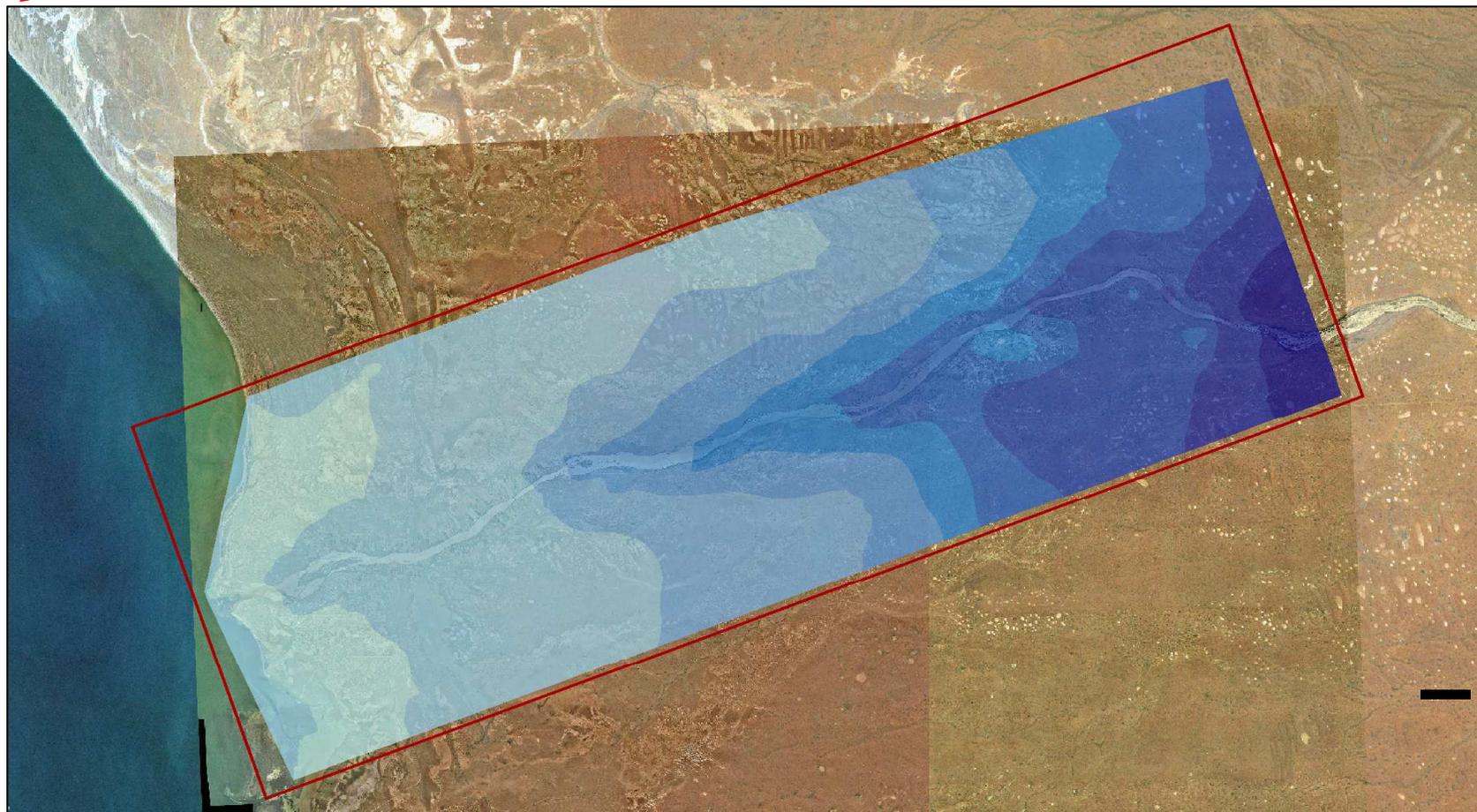
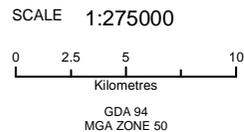


Figure 12: Head- and Solute-Time Curves – Scenario 1



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DATA SOURCES
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- Department of Water



Legend

Study Area

Scenario 1 Head, Layer 4, Stress Period 125

Head (mAHD)

- 35 - 40
- 30 - 35
- 25 - 30

- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- 0 - 5
- < 0

Figure 13: Scenario 1 Water Levels, Year 8.6



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ACKNOWLEDGEMENT
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- Geoscience Australia
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- Department of Water

SCALE 1:275000
0 2.5 5 10
Kilometres
GDA 94
MGA ZONE 50

Legend

Study Area

Scenario 1 TDS, Layer 4, Stress Period 125

TDS Concentration (mg/L)

- | | |
|---|--|
|  > 50000 |  5000 - 10000 |
|  25000 - 50000 |  2000 - 5000 |
|  10000 - 25000 |  1000 - 2000 |
| |  500 - 1000 |
| |  200 - 500 |
| |  100 - 200 |
| |  0 - 100 |

Figure 14: Scenario 1 TDS, Year 8.6

3.1.2 Scenario 2 – Low Recharge Frequency Base Case

Scenario 2 is designated the Low Recharge Frequency Base Case and represents the present management plan when there is a drought. In this case, total allocation remains the same, but abstraction from Subarea A is reduced and replaced by scheme water from Subareas B-L. In the most extreme case, all abstraction from Subarea A would cease and be replaced by scheme water. The scenario was simulated for low frequency recharge conditions, and assessed by:

- examining the water balance for each of the subareas, to assess if total allocations were sustained over the 10 year period;
- reviewing changes in water quality in each subarea to determine which bores have exceeded the water quality criteria;
- reviewing the trend in water levels in each subarea to determine if there is a long-term depletion of the aquifer at the end of the moderate frequency recharge flow sequence

The scenario assumes that all abstraction ceases from Subarea A and is transferred to Subareas B-L. A review of the water balance from the simulation is summarised in Table 4. The table shows that over the course of the 10 year simulation, Subareas B-L can sustain on average 15.8 GL/annum of abstraction during low frequency recharge. The reduced abstraction is due to bores unable to meet abstraction which indicates that additional bores will be required to meet the full 18.0 GL/annum of allocation. Consequently, the limitation on abstraction from Subareas B-L is existing well specific capacity and infrastructure, not aquifer depletion.

Table 5 shows the water balance for the 30-month no-flow period only. Note that abstraction is 16.4 GL/annum from Subareas B-L, indicating a high probability that Subareas B-L can provide 18 GL/annum for at least two years of no-flow. The major difference in the water balance from the entire model run is the change in storage of 19 GL/annum and reduction of evaporation of 11.3 GL/annum. These two sources of water effectively represent 30.3 GL/annum which is comparable to the annual average recharge, which in this case did not occur. The harvesting of evapotranspiration acts to mitigate the effects of abstraction by reducing the volume of water taken from storage. The reduction of evapotranspiration also mitigates the increase in TDS in shallow groundwater, resulting in improved RBS water quality over time.

A review of the simulated hydrographs, Figure 15, shows, unlike Scenario 1, that water levels do not rise over the simulation period, but drop to minimum levels at the end of the no-flow periods and return to pre-no-flow levels upon a river flow event. This suggests that if a drier sequence were to occur (i.e. longer no-flow periods or smaller subsequent flows) it is likely that a declining water level trend would be observed. The actual change in water level over the period is small, as indicated by the change in storage and by water levels at the beginning and end of the simulation period. Monitor locations A3 and A4 demonstrate that TDS decreases after the occurrence of flows, and then increases as evapotranspiration acts to remove water from the aquifer. This also demonstrates that with regular flowing groundwater will tend to freshen. Conversely, in the case of B2, groundwater is becoming more saline due to pumping. In this case, abstraction is from deeper sections of the aquifer less responsive to recharge in the RBS. The change in TDS reflects the lateral or vertical movement of more saline water at depth in the aquifer.

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.14	9.10	0.00	-7.09	0.00
2	0.80	1.51	0.00	-5.89	0.59
3	0.45	14.00	0.00	-5.97	0.01
4	-1.15	10.10	0.00	-1.11	0.06
5	-0.06	0.00	0.00	0.00	0.75
6	-0.36	0.00	-15.80	0.00	-0.01
Subarea A Total	0.60	10.61	0.00	-12.98	1.34
Subareas B-L Total	-1.06	24.10	-15.80	-7.08	0.06

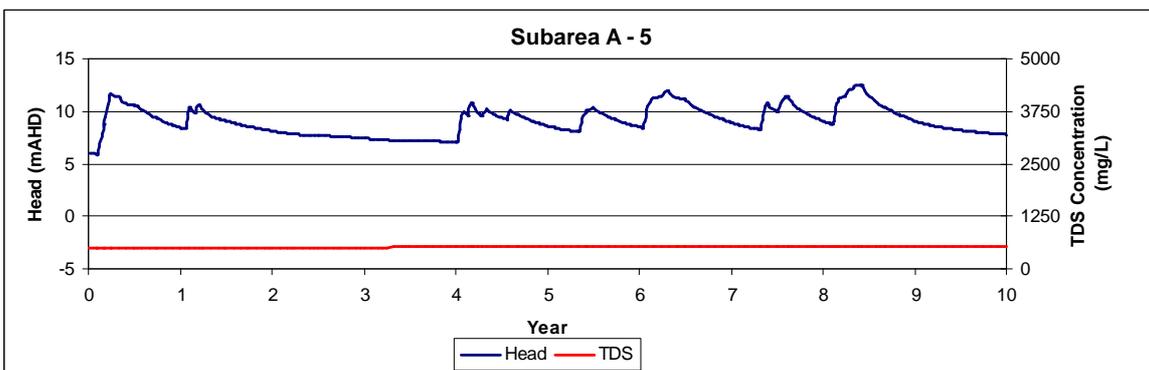
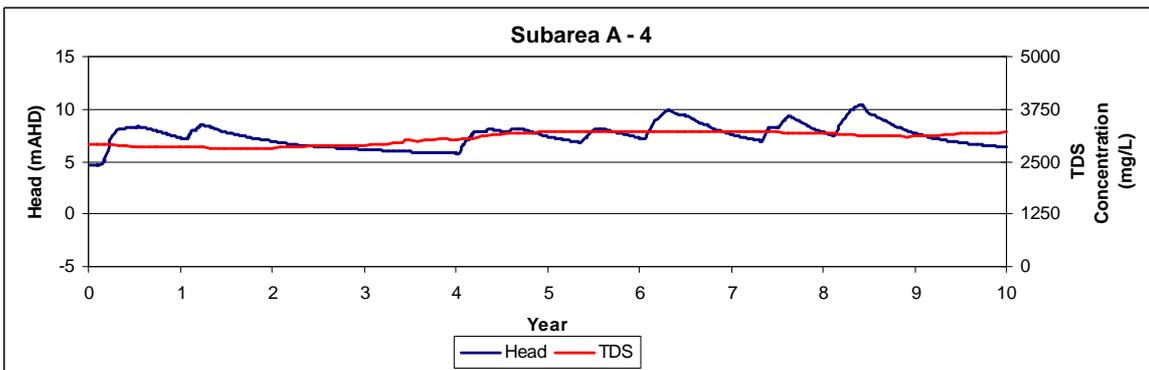
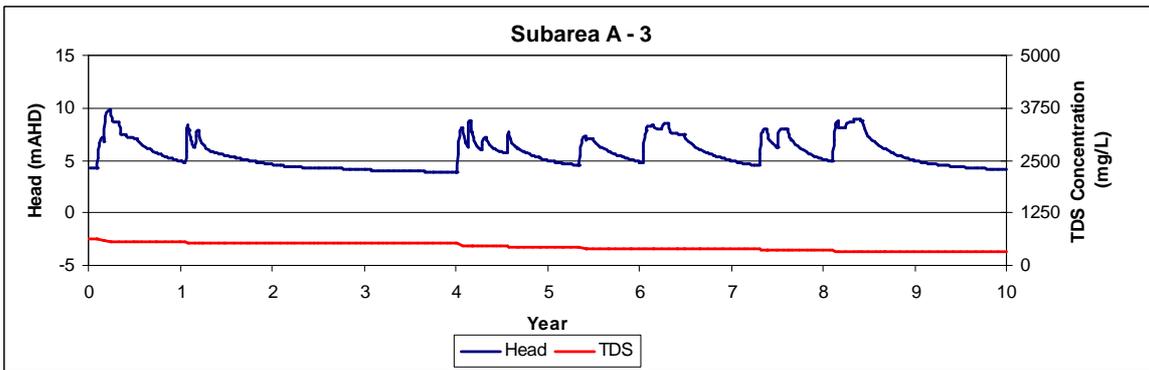
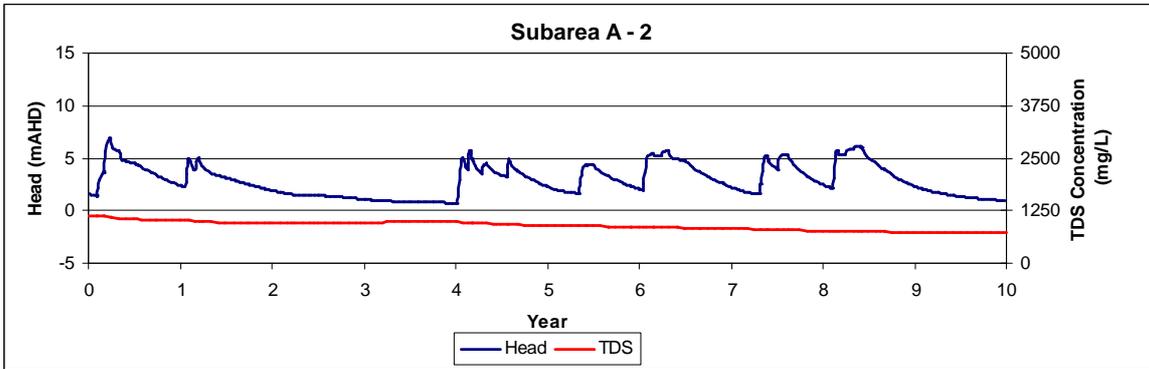
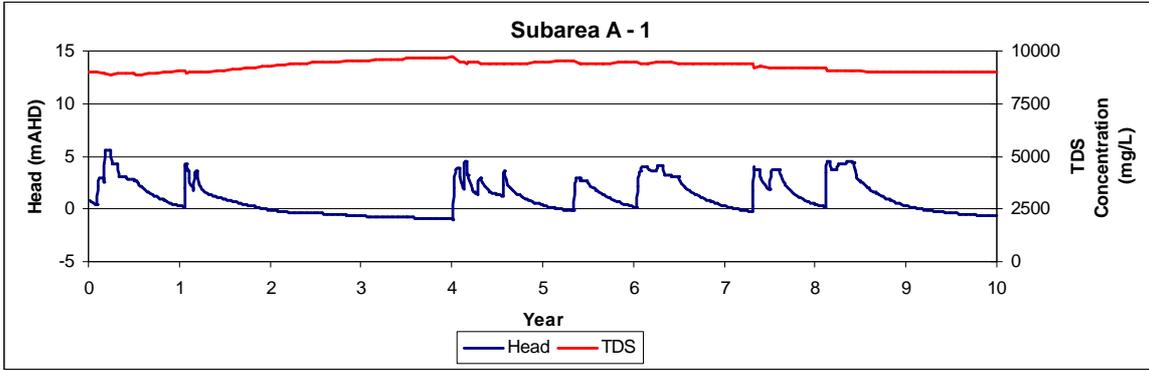
Table 4: Scenario 2 Water Balance Summary – Simulation

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	2.08	0.47	0.00	-3.01	0.00
2	1.57	0.07	0.00	-3.28	0.60
3	5.78	3.50	0.00	-2.18	0.02
4	7.48	0.38	0.00	-0.36	0.06
5	0.41	0.00	0.00	0.00	0.76
6	1.72	0.00	-16.40	0.00	-0.01
Subarea A Total	4.06	0.54	0.00	-6.29	1.36
Subareas B-L Total	14.98	3.88	-16.40	-2.54	0.07

Table 5: Scenario 2 Water Balance Summary – No Flow Period

In terms of water quality, TDS generally declined or stayed the same over the period, as increased abstraction removed groundwater, thereby allowing increased recharge by fresher flow water, and reduced evapotranspiration. However, during the low frequency recharge period, some bores showed an increase in TDS, related to the proximity of higher TDS water either at depth or laterally from the observation bore. The changes in TDS were on the order of 10s of mg/L of TDS rather than 100s of mg/L. The mass balance shows that TDS in storage decreased over the course of the simulation (i.e. groundwater is getting fresher), with the mass of TDS abstracted due to pumping declining in the final year of pumping compared to the first year.

Figures 16 and 17 show the water levels and TDS concentrations, respectively, at the end of each simulation. Figures 18 and 19 show the water levels and TDS concentrations, respectively, at the end of the 2001 to 2003 no-flow period.



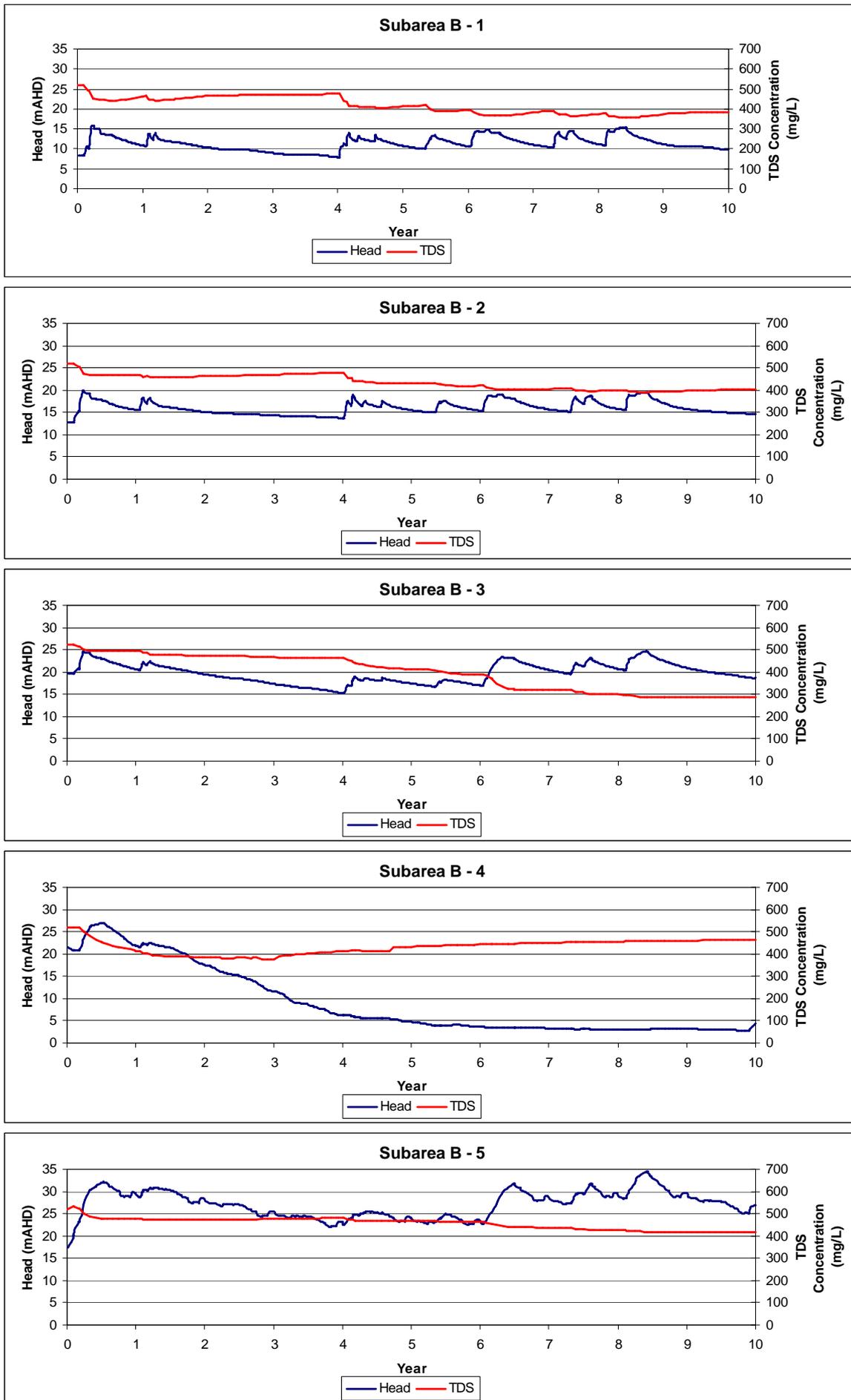
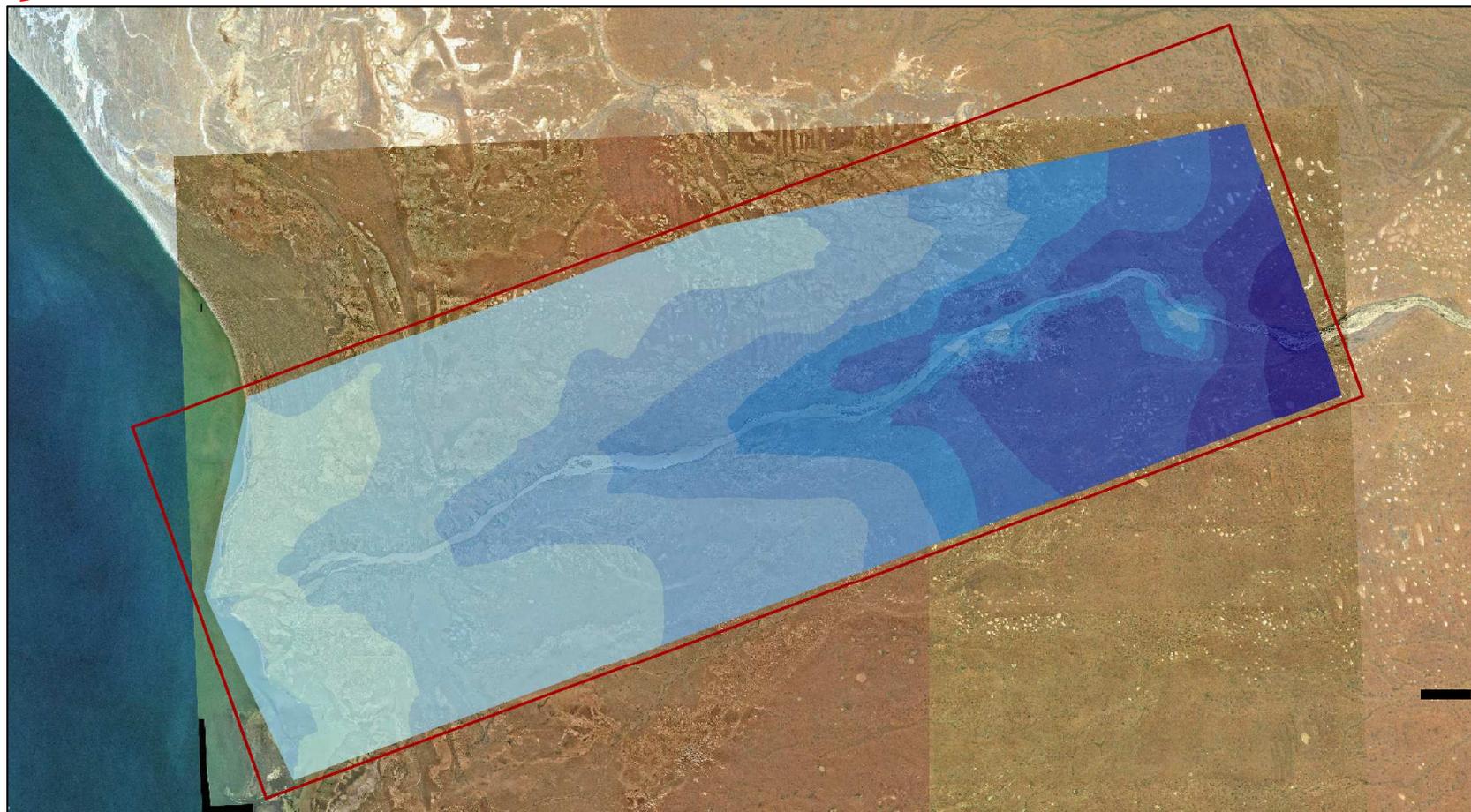


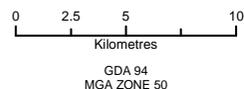
Figure 15: Head- and Solute-Time Curves – Scenario 2



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Legend

Study Area

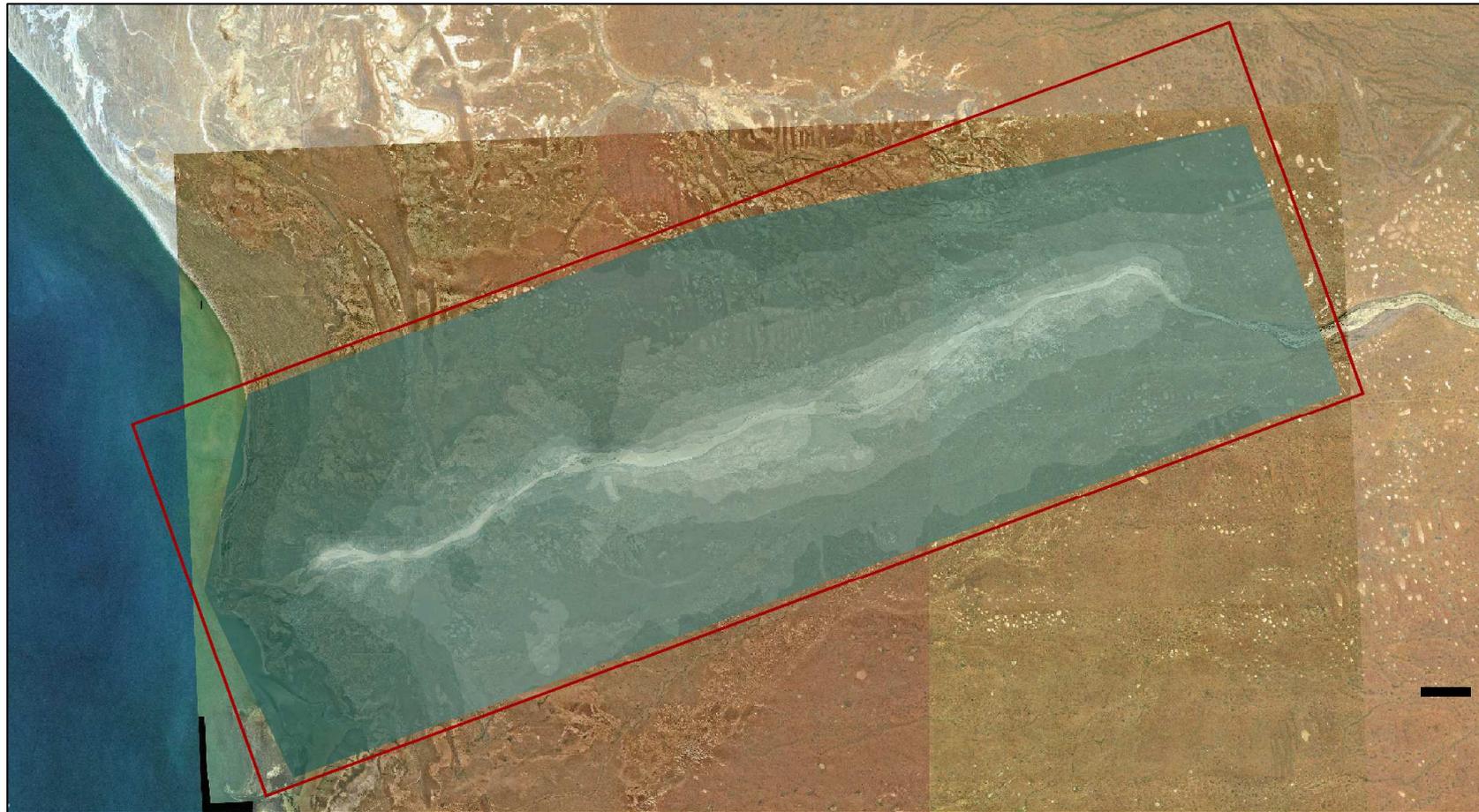
Scenario 2 Head, Layer 4, Stress Period 141

Head (mAHD)

- 35 - 40
- 30 - 35
- 25 - 30

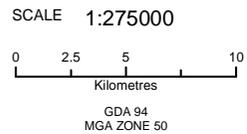
- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- 0 - 5
- < 0

Figure 16: Scenario 2 Water Levels – Year 10



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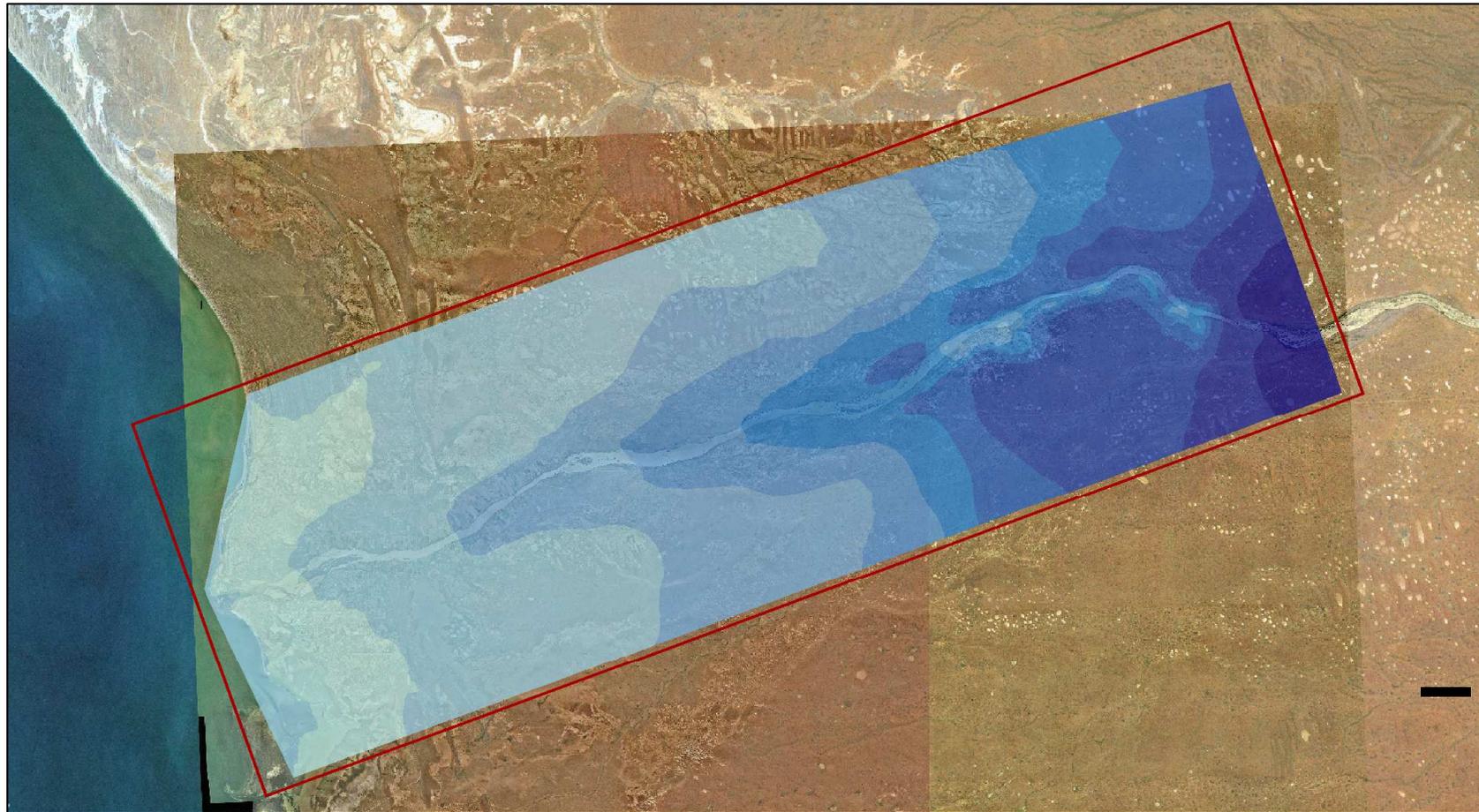
Study Area

Scenario 2 TDS, Layer 4, Stress Period 141

TDS Concentration (mg/L)

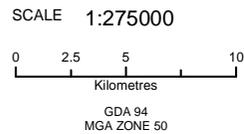


Figure 17: Scenario 2 TDS, Year 10



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Legend

Study Area

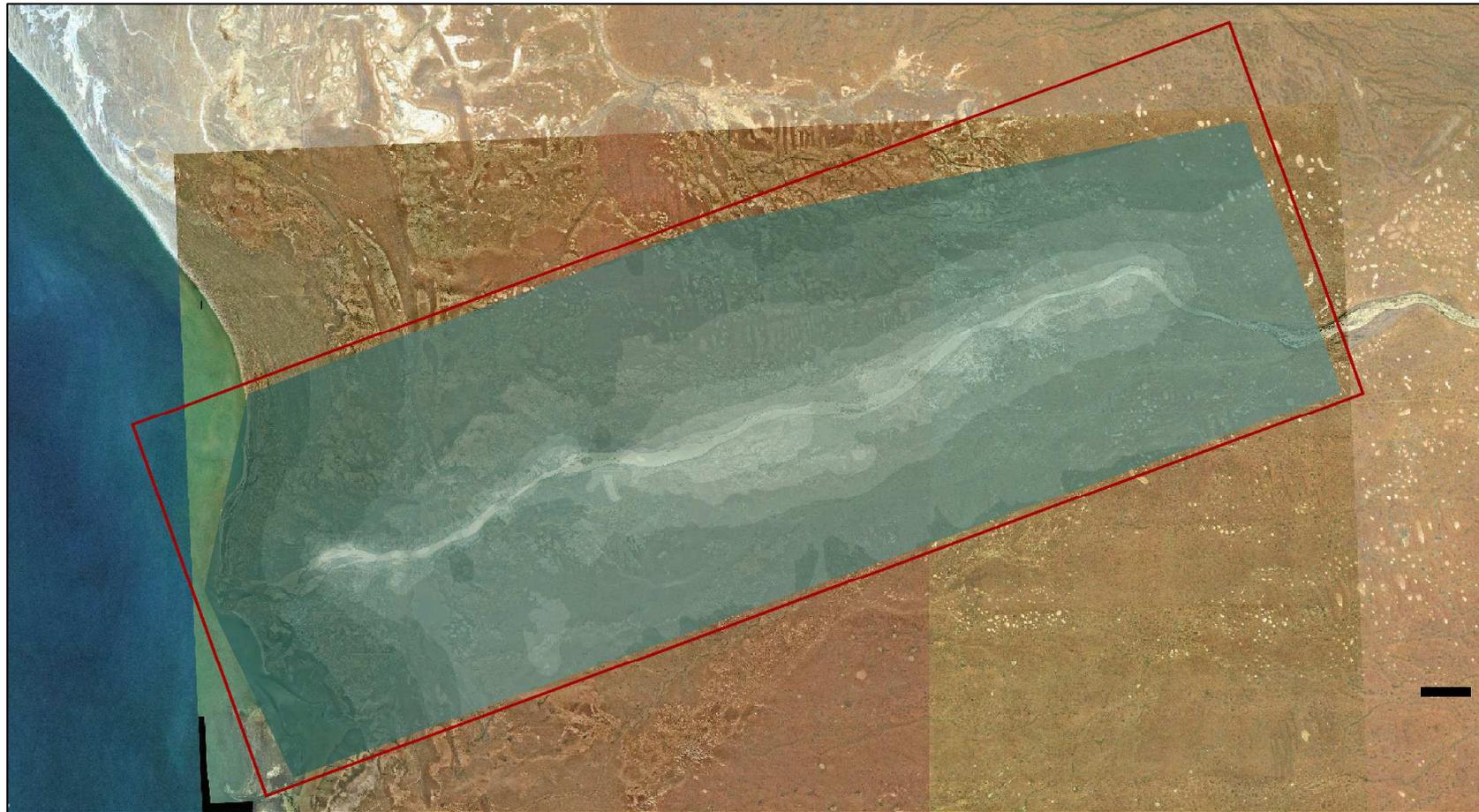
Scenario 2 Head, Layer 4, Stress Period 55

Head (mAHD)

- 35 - 40
- 30 - 35
- 25 - 30

- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- 0 - 5
- < 0

Figure 18: Scenario 2 Water Levels, Year 4



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SCALE 1:275000
0 2.5 5 10
Kilometres
GDA 94
MGA ZONE 50

Legend

Study Area

Scenario 2 TDS, Layer 4, Stress Period 55

TDS Concentration (mg/L)

- | | |
|---|--|
|  > 50000 |  5000 - 10000 |
|  25000 - 50000 |  2000 - 5000 |
|  10000 - 25000 |  1000 - 2000 |
| |  500 - 1000 |
| |  200 - 500 |
| |  100 - 200 |
| |  0 - 100 |

Figure 19: Scenario 2 TDS, Year 4

3.1.3 Scenario 3 – Moderate Frequency Recharge Best Case

Scenario 3 is designated as the Moderate Frequency Recharge Best Case and represents an estimate of the maximum sustainable yield that can be abstracted under moderate frequency recharge river flow conditions from Subarea A and Subareas B-L. The scenario was assessed by:

- examining the water balance for each of the subareas, to assess if total allocations were sustained over the 8.6 year period;
- reviewing changes in water quality in each subarea to determine which bores have exceeded the water quality criteria; and
- reviewing the trend in water levels in each subarea to determine if there is a long-term depletion of the aquifer at the end of the moderate frequency recharge flow sequence.

In this case, an additional 4 GL/annum (from the infill bores, Figure 6) was added to Subareas B-L to provide a basis on which to assess well abstraction from the subarea. Subarea A allocation was left at 5.8 GL/annum based on results of scenario 1, suggesting this area is fully allocated. The MNW package manages the bores to maximise abstraction with respect to well and aquifer hydraulics. The solute transport model results are reviewed to confirm that the water quality criteria are met by bores in Subareas B-L.

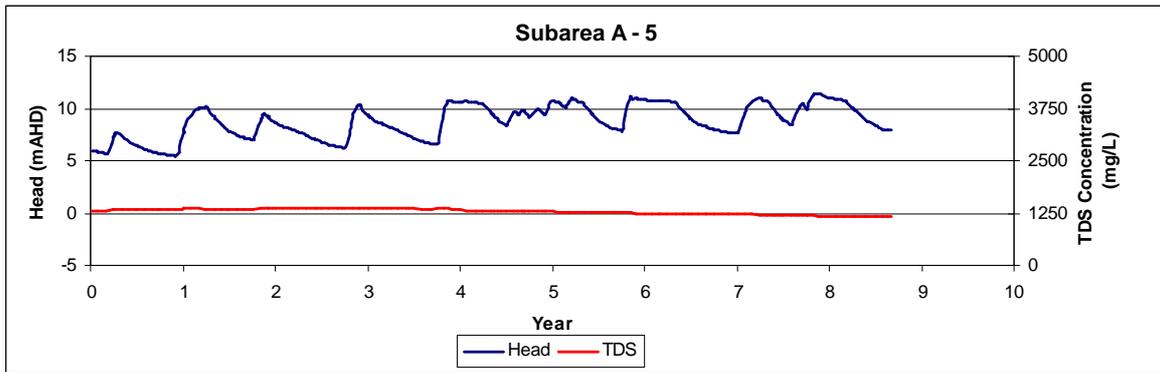
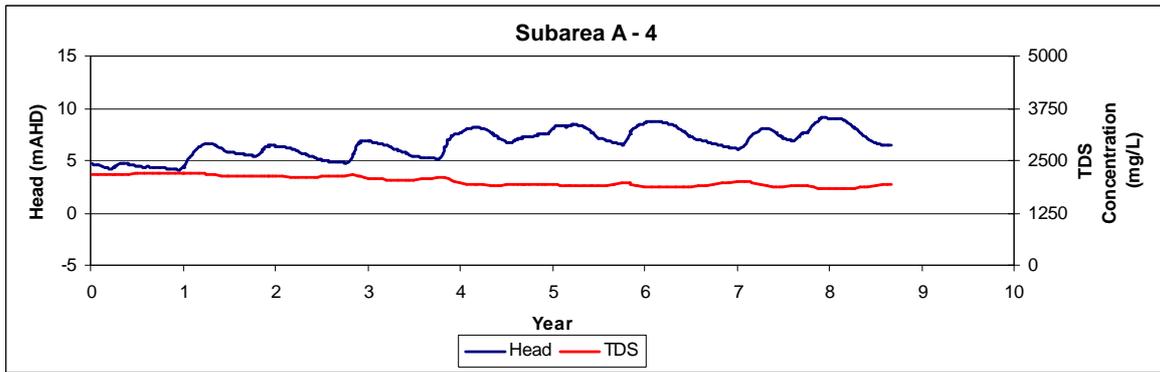
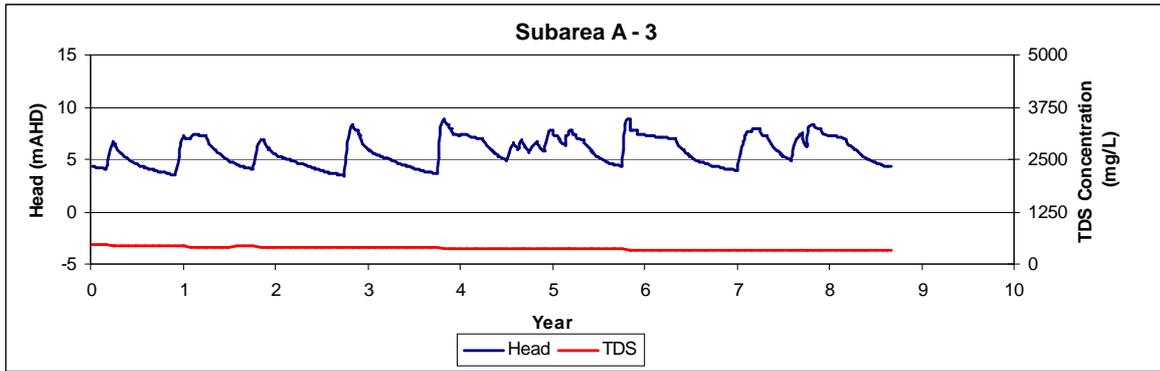
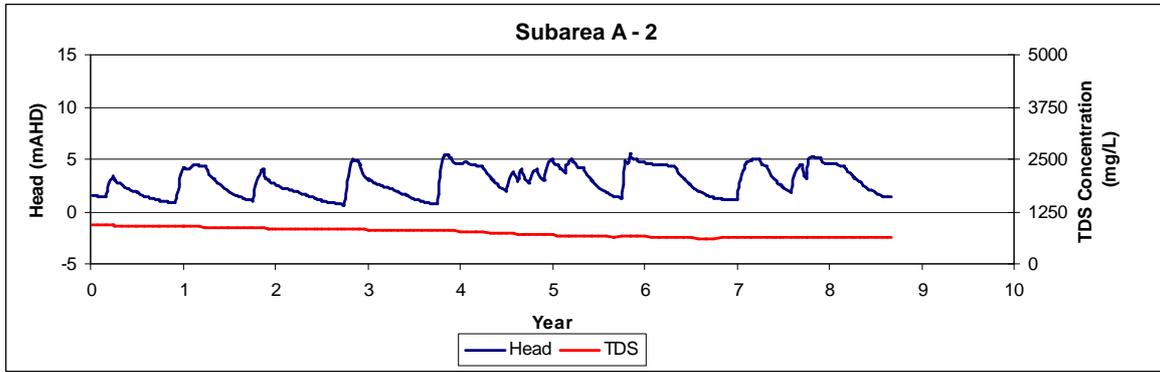
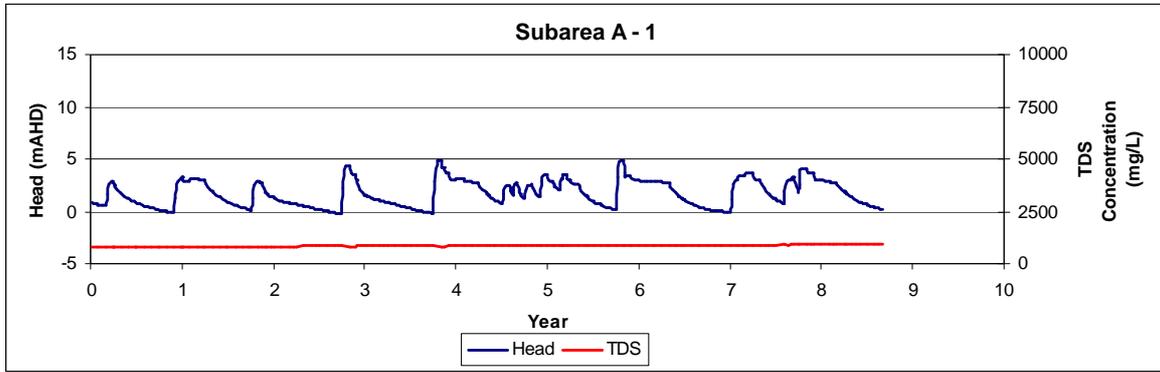
A review of the water balance from the simulation is summarised in Table 6. The table shows that over the course of the 8.6 year simulation, the average abstraction was 19.5 GL/annum, 1.5 GL/annum more than the normal year allocation of 18 GL/annum and 3.5 GL/annum more than the base case. The gain in abstraction occurred in Subareas B-L, with 3.5 of the additional 4 GL/annum being realised, as some bores had their specified pumping rate reduced due to dewatering of the RBS and OAA. Abstraction from Subarea A was 5.65 GL/annum confirming the allocation of 5.8 GL/annum is consistent with the maximum sustainable yield, under the existing well configuration.

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.09	9.27	-1.71	-4.36	0.00
2	2.72	1.26	-1.84	-6.19	0.57
3	0.00	15.80	-5.26	-3.43	0.01
4	-0.14	1.62	-3.59	-0.39	0.05
5	0.25	0.00	-2.08	0.00	1.08
6	-0.57	0.00	-5.03	0.00	0.36
Subarea A Total	3.06	10.53	-5.63	-10.55	1.65
Subareas B-L Total	-0.71	17.42	-13.88	-3.82	0.42

Table 6: Scenario 3 Water Balance Summary

A review of the simulated hydrographs, Figure 20, shows rising water levels over the simulation period. This is consistent with the imposed hydrogeological conditions, as river recharge is high during the moderate frequency recharge flow period. The actual change in water level over the period is small, with water levels at the end of the model at or near the same level as at the beginning, suggesting that abstraction and evapotranspiration is similar to recharge over the period. Figure 20, in terms of water quality, shows that TDS generally declined over the period, as abstraction removed groundwater, and lowered water levels, thereby allowing increased recharge by fresher flow water, and reduced evapotranspiration.

Figure 21 shows the impact of abstraction from Subareas B-L versus the Moderate Frequency Recharge Base Case (Scenario 1 - Figure 13). The impact due to pumping from the additional 8 Subareas B-L bores occurs on both sides of the Gascoyne River, and is generally less than 1 metre, though an area of 2-5 metres of impact occurs in the eastern section of the model. The impact in Subarea A is less than 0.25 metres for the entire subarea. Similarly, Figure 2 shows that water quality changes compared to the Moderate Frequency Recharge Base Case (Figure 14) are less than 100 mg/L after 8.6 years of pumping, with water levels generally freshening of groundwater.



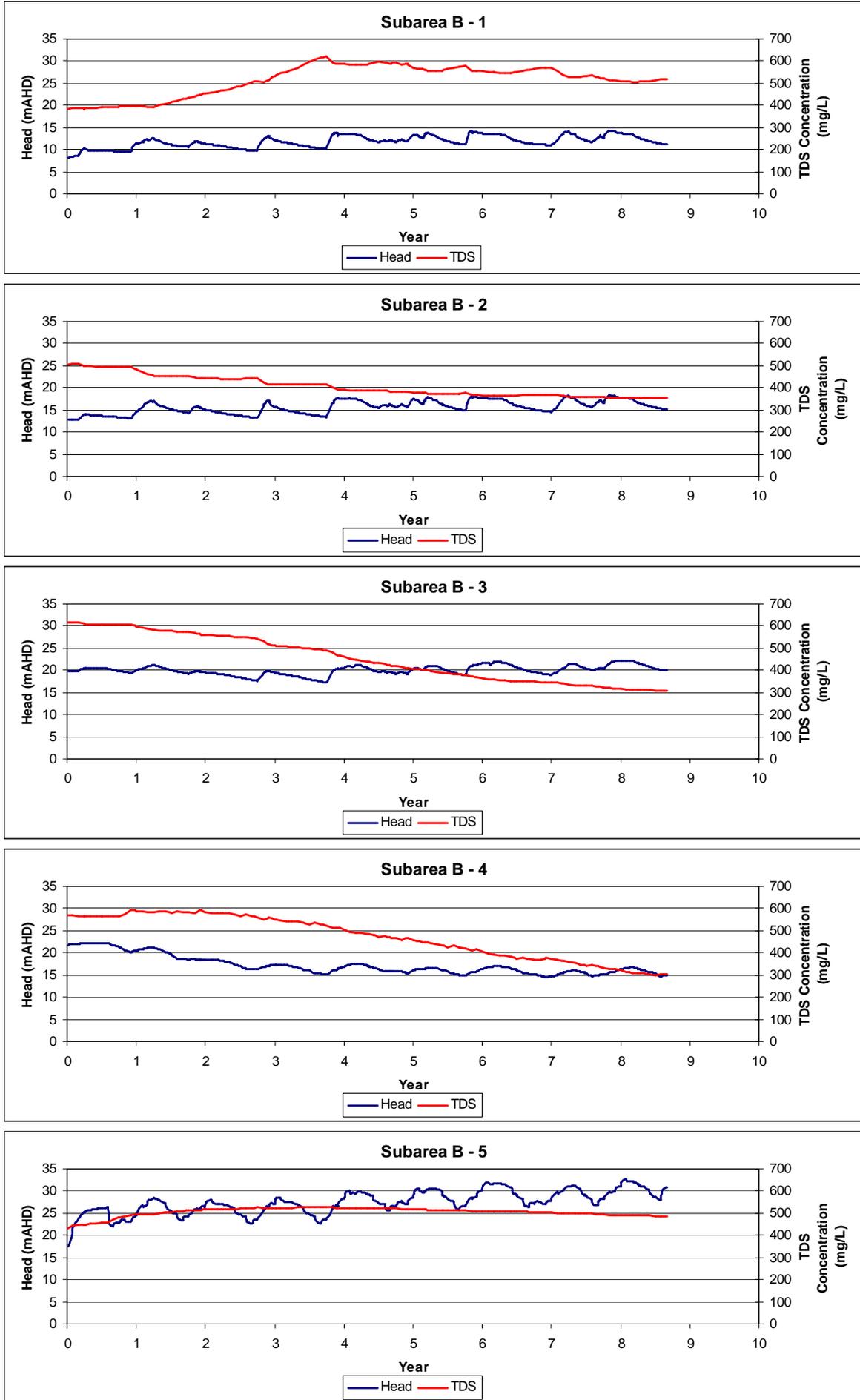
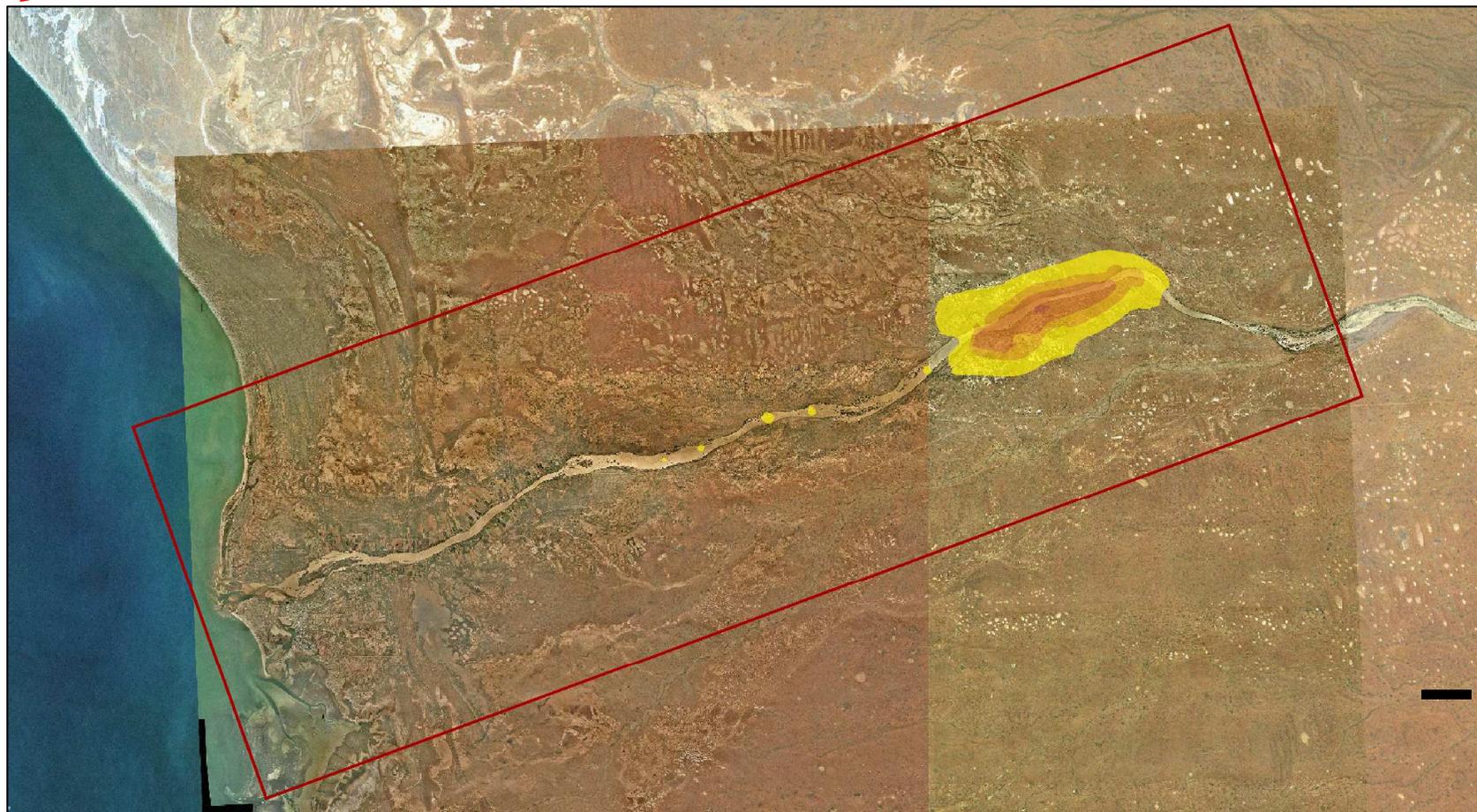


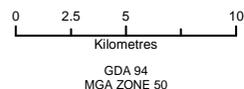
Figure 20: Head- and Solute-Time Curves – Scenario 3



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- SKM
- Department of Water

SCALE 1:275000



Legend

Study Area	0.25 - 1
Scenario 3 Head Impact	-0.25 - 0.25
Head Change (m)	-1 - -0.25
> 5	-2 - -1
2 - 5	-5 - -2
1 - 2	< -5

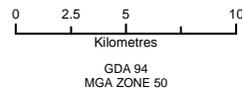
Figure 21: Scenario 3 Water Level Impact, Year 8.6



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SCALE 1:275000



Legend

Study Area	100 - 200
Scenario 3 TDS Impact	-100 - 100
TDS Change (mg/L)	-200 - -100
> 1000	-500 - -200
500 - 1000	-1000 - -500
200 - 500	< -1000

Figure 22: Scenario 3 TDS Impact, Year 8.6

3.1.4 Scenario 4 – Low Frequency Recharge Best Case

Scenario 4 is designated as the Low Frequency Recharge Best Case and represents the maximum sustainable yield that can be abstracted under low frequency recharge river flow conditions. In this case sustainable yield is defined as the volume of water that can be abstracted during a two-year no-flow period without exceeding water quality criteria.

To simulate increased abstraction, an additional 4 GL/annum (from the infill bores, Figure 6) of allocation was added to Subareas B-L to provide a basis on which to assess increased well deliverability and water quality under increased abstraction from the subarea. The MNW package was allowed to manage these bores to maximise abstraction with respect to well and aquifer hydraulics, subject to water level changes due to low frequency recharge and river flows. The solute transport model results are reviewed to confirm that the water quality criteria are met by bores in Subareas B-L. The abstraction in Subarea A is also managed by the MNW package and is set at a maximum of 5.8 GL/year, depending on low frequency recharge conditions.

Review of the water balances from the simulation are summarised in Tables 7 and 8. Table 7 shows that over the course of the 10 year simulation, the average abstraction was 25.2 GL/annum, of which 5.6 GL/annum was from Subarea A and 19.6 GL/annum from Subareas B-L, or about 1.6 GL/annum greater than the 2004 Management Plan allocation limit during periods of drought of 18 GL, and 3.8 GL/annum more than the low frequency recharge base case. The addition of 4 GL/annum of capacity to Subareas B-L, along the Gascoyne River, resulted in 3.6 GL/annum increase compared to Scenario 1. Table 8 shows the abstraction for the 2001 to 2003 no-flow period, and indicates that for the two year no-flow period 20.4 GL/annum was abstracted from Subareas B-L. This suggests that Subareas B-L suffers from declining abstraction after the initial no-flow period and that in the short term Subareas B-L can produce 2.4 GL/annum above present allocations. However, under low frequency recharge conditions the abstraction of 19.6 GL/annum is considered higher than the long term sustainable yield.

The results suggest that total allocation for Subarea A and Subareas B-L could be sustained at higher levels up to 25 GL/annum under low frequency recharge conditions. It is likely that additional water can be obtained from Subareas B-L, by judicious location of new production bores that take advantage of more transmissive sections of the RBS/OAA, subject to further investigation. The only criterion for locating the eight additional bores (each producing 1,400 kL/day) was to locate the bores in the RBS between existing bores. The simulated location of these bores does not imply that they are necessarily in viable or optimum locations.

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.01	11.80	0.00	-6.30	0.00
2	2.61	2.01	0.00	-7.29	0.61
3	-0.16	18.60	0.00	-7.37	0.01
4	-1.85	11.20	0.00	-1.12	0.06
5	0.23	0.00	-5.63	0.00	1.18
6	-0.66	0.00	-19.60	0.00	-0.01
Subarea A Total	2.83	13.81	-5.63	-13.59	1.79
Subareas B-L Total	-2.67	29.80	-19.60	-8.49	0.06

Table 7: Scenario 4 Water Balance Summary – Simulation

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	4.43	0.48	0.00	-2.51	0.00
2	3.51	0.08	0.00	-3.46	0.62
3	8.90	3.96	0.00	-3.07	0.02
4	8.93	0.40	0.00	-0.40	0.06
5	0.39	0.00	-5.50	0.00	1.20
6	0.47	0.00	-20.40	0.00	-0.01
Subarea A Total	8.33	0.56	-5.50	-5.97	1.82
Subareas B-L Total	18.30	4.36	-20.40	-3.47	0.07

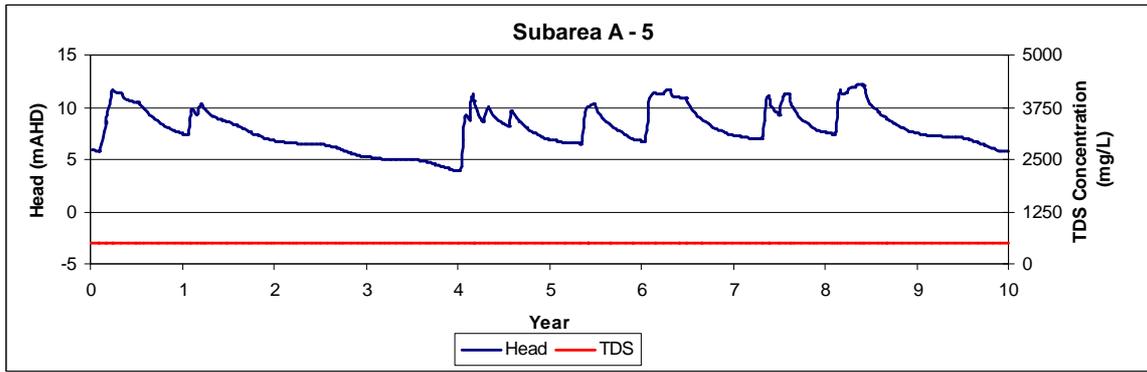
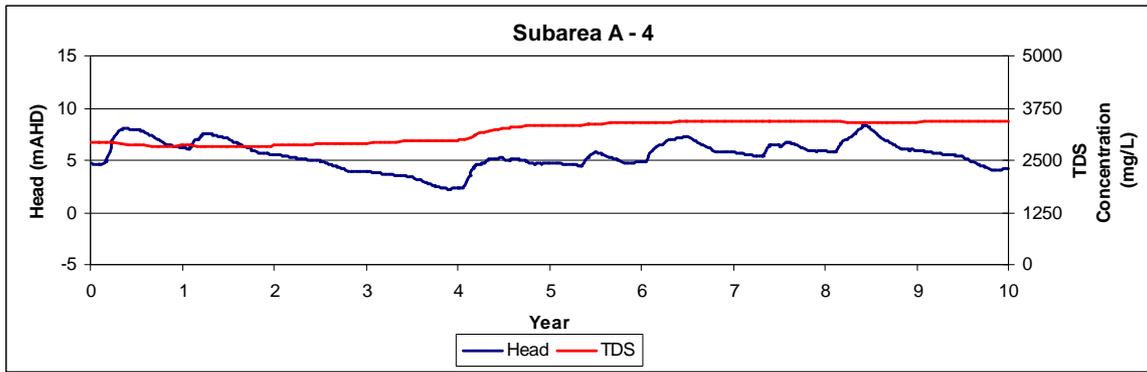
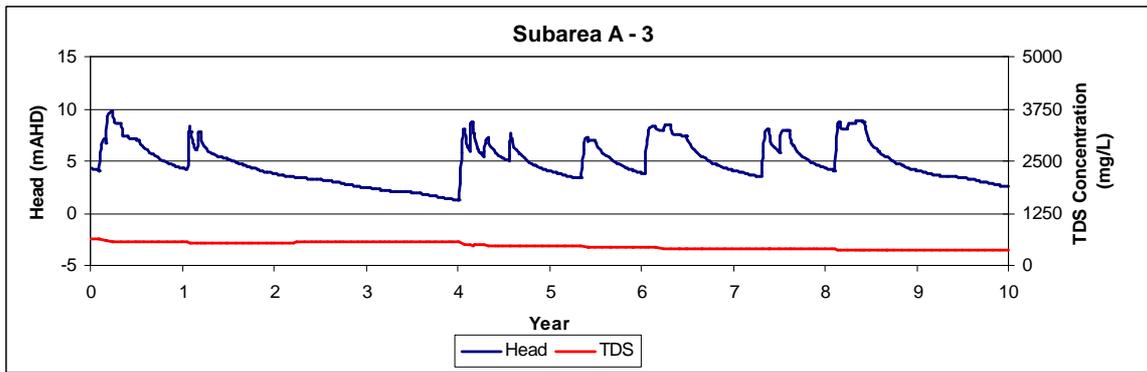
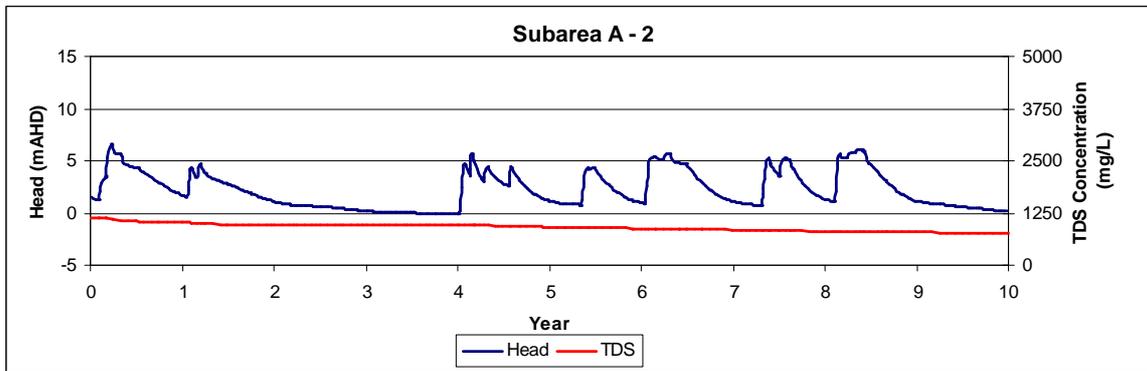
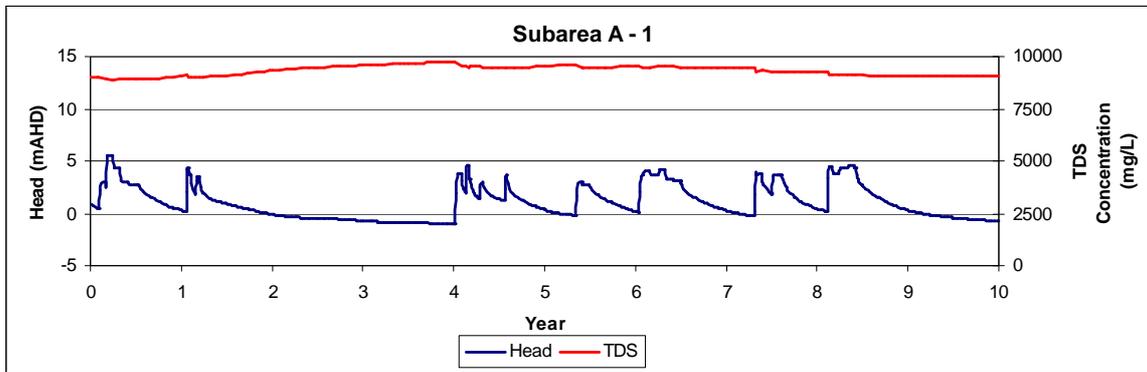
Table 8: Scenario 4 Water Balance Summary – No-Flow Period

Figure 24 shows the impact of abstraction from Subareas B-L versus the Low Frequency Recharge Base Case (Figure 16). The impact due to pumping from the additional 8 Subareas B-L bores occurs on both sides of the Gascoyne River, and is typically less than 1 metre. Unlike in the moderate frequency recharge flow case where river recharge acts to maintain aquifer water levels, under low frequency recharge conditions the RBS water levels decline and do not rebound over the course of the simulation indicating depletion of the aquifer. This is consistent with the observed loss of well specific capacity in later years of the simulation. The loss of storage is also the result of ending the simulation during a no-flow period, and highlights the importance of managing the system to account for potential

droughts.

Figure 26 shows the impact of abstraction from Subareas B-L versus the Low Frequency Recharge Base Case at the end of the 2001 to 2003 no-flow (Figure 18). The impact due to pumping from the additional 8 Subareas B-L bores occurs on both side of the Gascoyne River, and is typically less than 1 metre. Unlike in the moderate frequency recharge flow case where river recharge acts to maintain aquifer water levels, under low frequency recharge conditions the RBS water levels decline and do not rebound due to the absence of recharge. Water levels in Subarea A decline by 2-5 metres at the end of the low frequency recharge period, indicating that abstraction can be sustained at allocated levels of 5.6 GL/annum, but with some risk of reduced water quality. Indicated TDS changes in the vicinity of the river are on the order of an increase of 100-200 mg/L.

Similarly, Figure 25 and 27 shows water quality changes compared to the Low Frequency Recharge Base Case (Figures 17 and 19). Results indicate that water quality has a reduced TDS by up to 200 mg/L after 10 years of pumping and at the end of the low frequency recharge period, indicating some freshening of groundwater in Subarea A. In Subareas B-L water quality tends to improve with declining TDS at most observation bores. These results are consistent with the river recharge model, in which fresher river waters recharge the RDS/OAA, where higher TDS water has been abstracted.



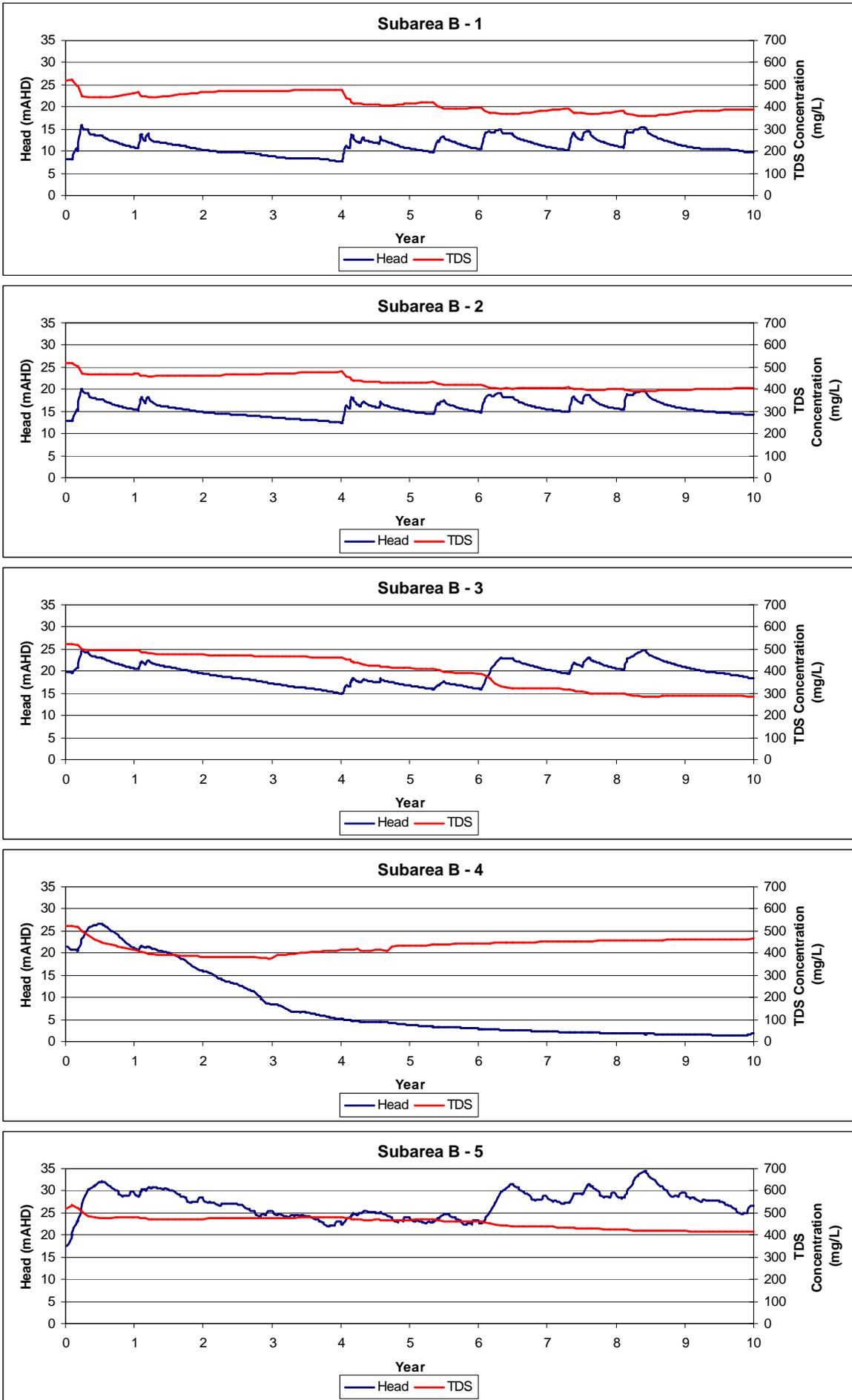
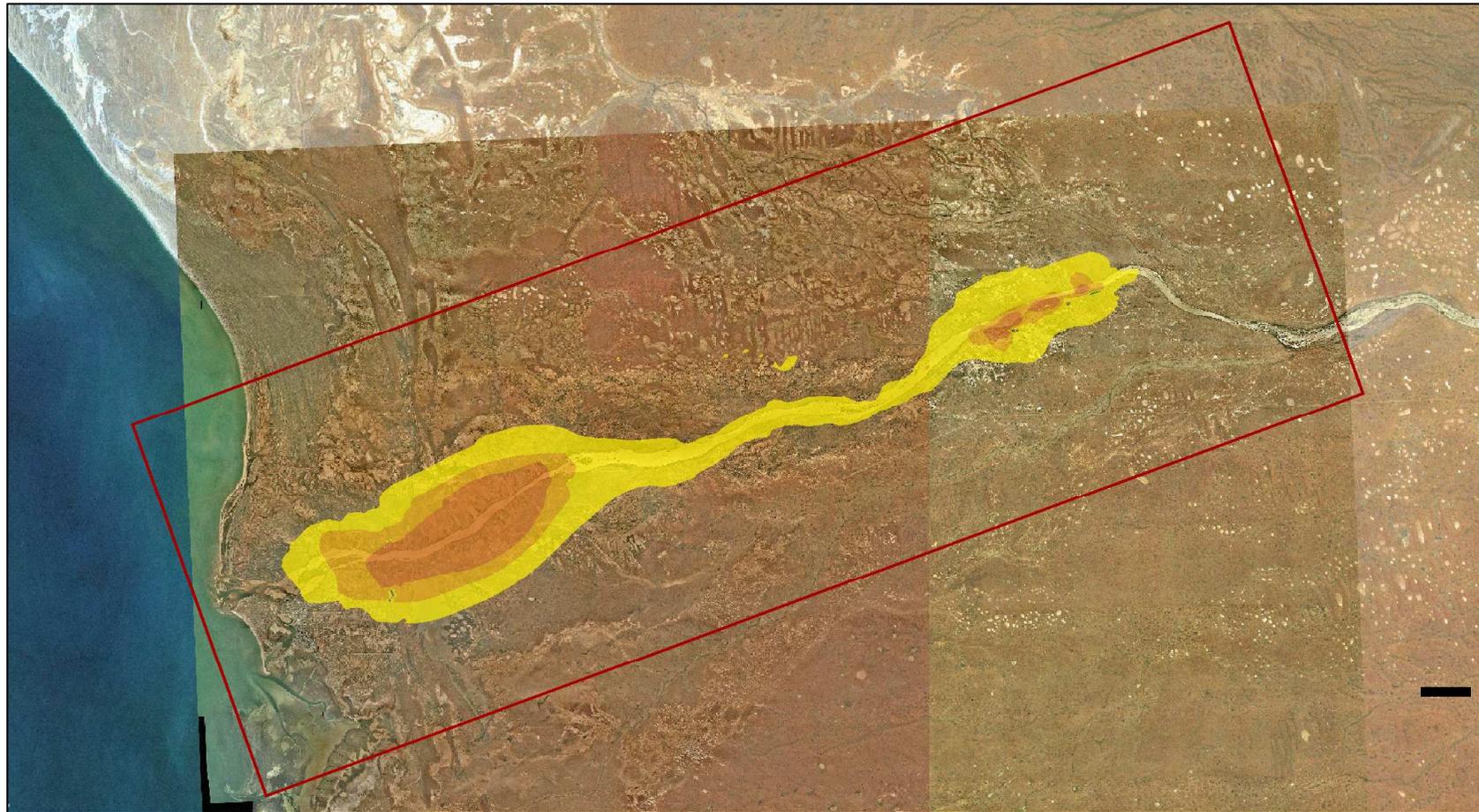


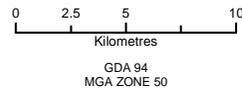
Figure 23: Head- and Solute-Time Curves – Scenario 4



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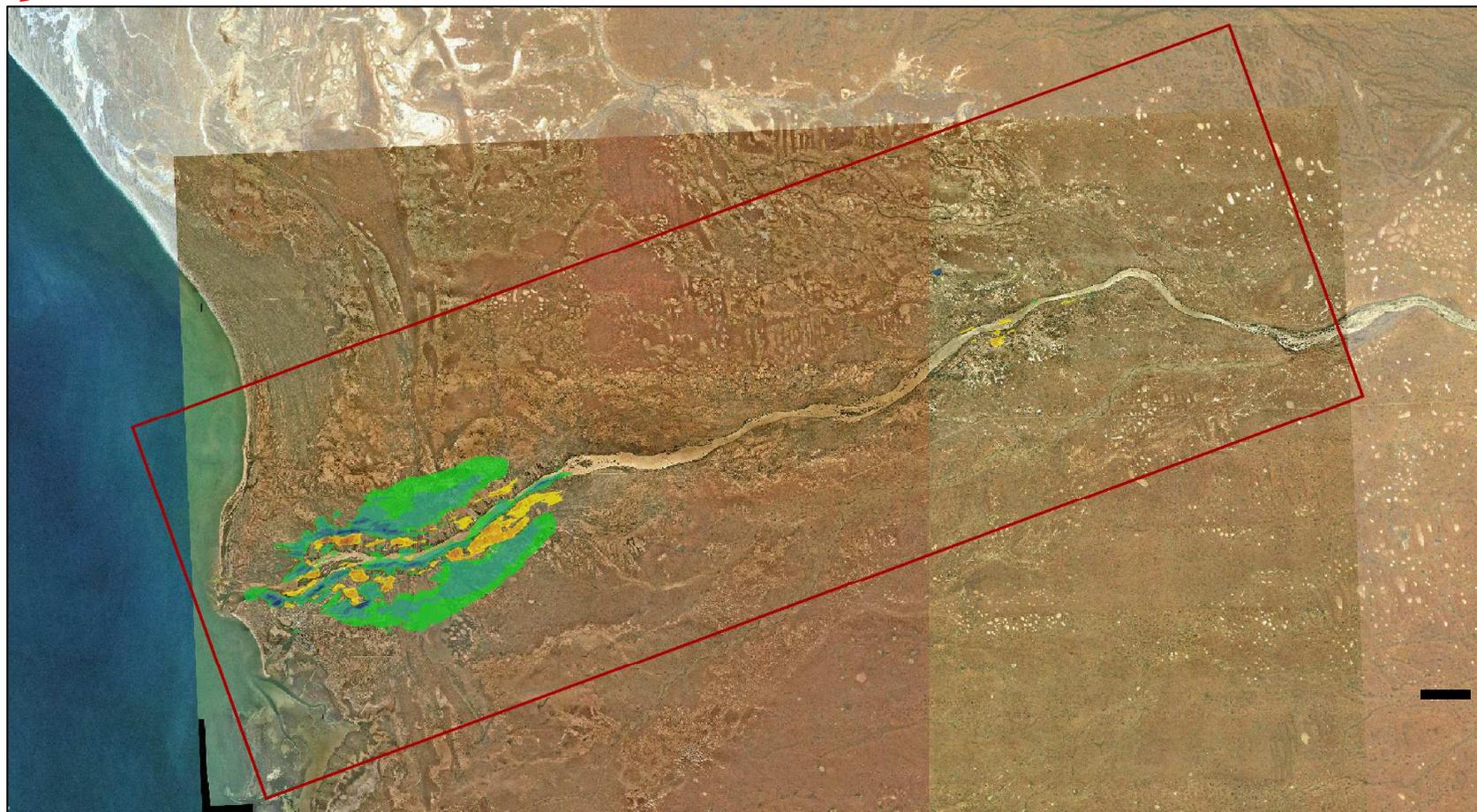
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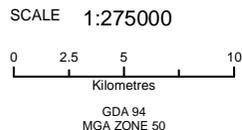
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Scenario 4 Head Impact	-0.25 - 0.25
Head Change (m)	-1 - -0.25
> 5	-2 - -1
2 - 5	-5 - -2
1 - 2	< -5

Figure 24: Scenario 4 Water Level Impact, Year 10



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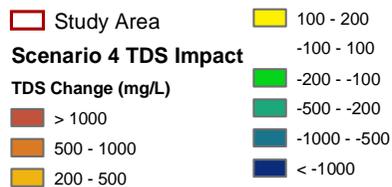
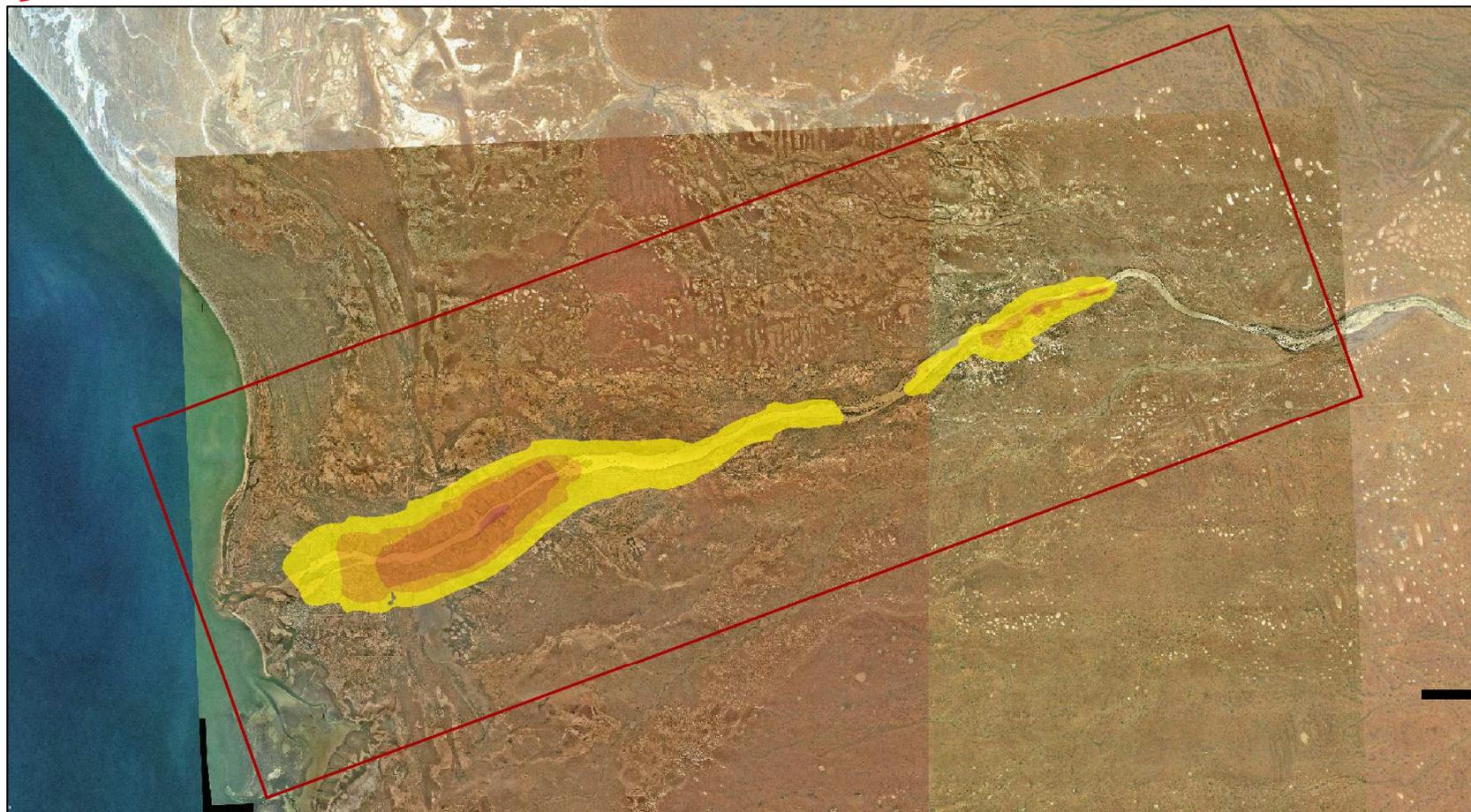


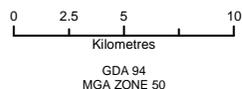
Figure 25: Scenario 4 TDS Impact, Year 10



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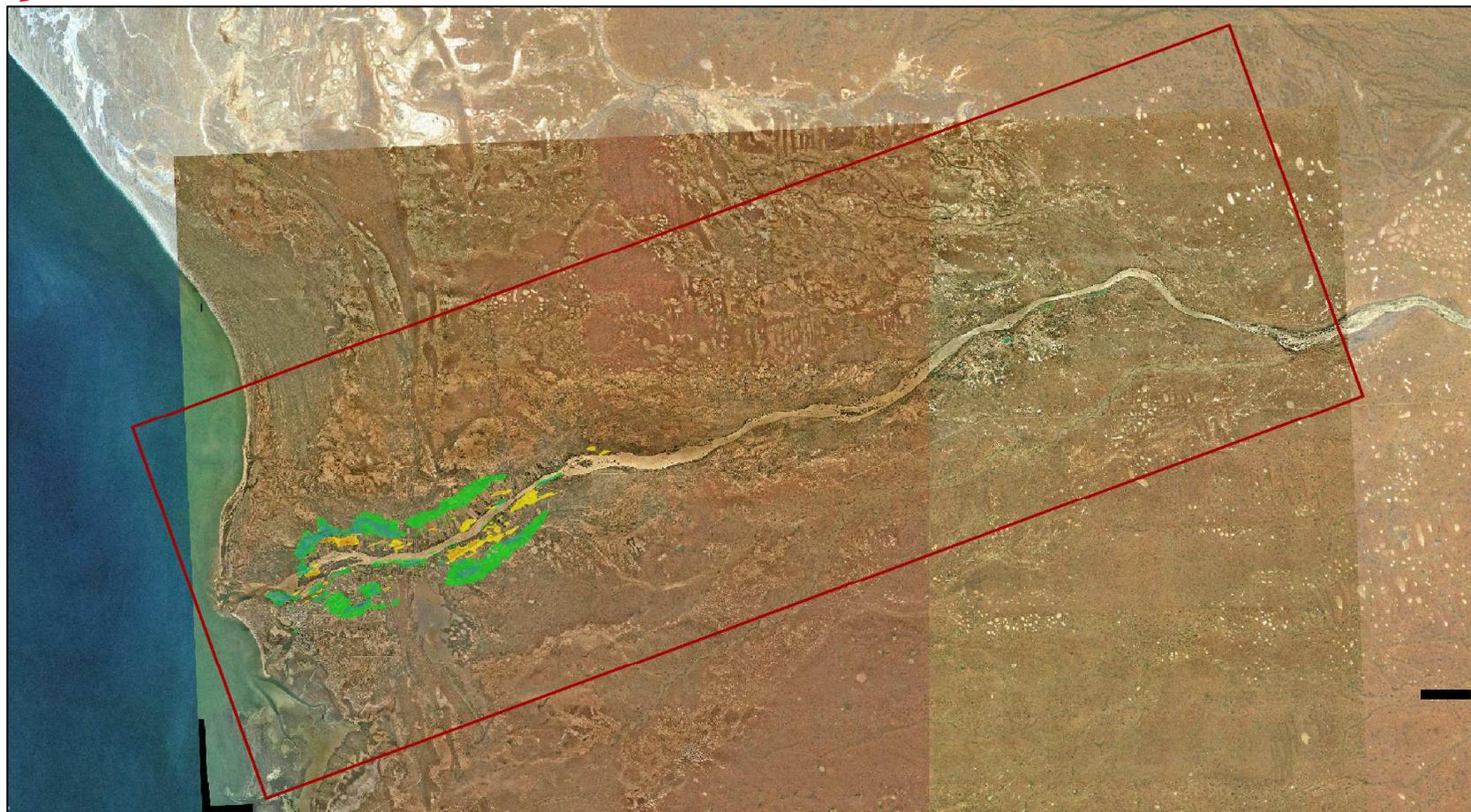
Study Area

Scenario 4 Head Impact, Dry Sequence

Head Change (m)

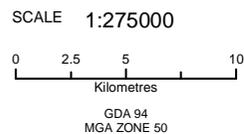
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Figure 26: Scenario 4 Water Level Impact, Year 4



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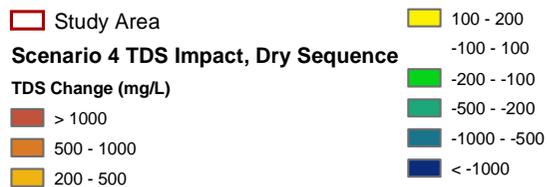


Figure 27: Scenario 4 TDS Impact, Year 4

3.1.5 Scenario 5 – Moderate Frequency Recharge Best Case with Brickhouse Pumping

Scenario 5 is designated as the Moderate Frequency Recharge Best Case (Scenario 3) with the addition of 27 bores in the Brickhouse area, and represents an expansion of the Subareas B-L allocation from 12.2 GL/annum to 20.2 GL/annum. This scenario quantifies whether an additional 4 GL/annum can be abstracted north of the Gascoyne River, in addition to a 4 GL/annum increase from the existing borefield in Subareas B-L. The maximum sustainable yield that can be abstracted under moderate frequency recharge rainfall conditions is defined as the maximum volume of water that can be abstracted during a 10 year moderate frequency recharge flow sequence without exceeding water quality criteria.

The 27 bores in the Brickhouse area are designed to each abstract 407 m³/day, approximately 2km north of the north bank of the Gascoyne River, Figure 7. To model the scenario, 27 bores were added to the model, completed in layers 2 through 6. The MNW package was allowed to manage the Brickhouse bores to maximise abstraction with respect to well and aquifer hydraulics, subject to water level changes due to variation in river flows. The solute transport model results are reviewed to confirm that the water quality criteria are met by bores in Subareas B-L as well as in the Brickhouse area. The 5.8 GL/annum of abstraction in Subarea A is also managed by the MNW package.

The water balance from the simulation is summarised in Table 9. Table 9 shows that over the course of the 8.6 year simulation, the average abstraction was 22.8 GL/annum, or about 4.8 GL/annum greater than the 2009 allocation. The majority of this water is production from Subareas B-L, with 3.3 GL/annum from the Brickhouse area. The addition of 4 GL/annum of capacity from the Brickhouse borefield resulted in a 3.3 GL/annum increase compared to Scenario 3. This suggests that pumping less than 22.8 GL/annum from the RBS/OAA is viable given sufficient river recharge. The results suggest that total allocation for Subarea A and Subareas B-L could be sustained at higher levels, up to 22.8 GL/annum, which includes 5.6 GL/annum from Subarea A, and 17.2 GL from Subareas B-L of which 13.9 GL from the Water Corporation bores and 3.3 GL from the proposed Brickhouse bores.

Based on the results of Scenarios 3 and 5, it may be possible that a similar volume of additional water can be obtained directly from Subareas B-L, by the judicious location of new production bores that take advantage of higher transmissivity sections of the RBS/OAA. As all of the groundwater being pumped from the Brickhouse borefield is sourced as river recharge, there is limited hydrogeological advantage in developing bores farther away from the river. The disadvantages of moving bores farther north are:

- The greater the distance from the river, the less likely the area will receive timely river recharge;
- The risk of compromising the water quality of the borefield by drawing in higher salinity groundwater is increased;
- A greater number of low-yield bores will be needed, increasing the capital cost of extracting the 3.3 GL/annum of water; and
- The bores do not exploit a new or independent source of water, but take advantage of excess river flow to induce additional recharge, which can be more efficiently done by bores closer to the river.

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.12	9.24	-1.70	-4.24	0.00
2	2.81	1.25	-1.75	-6.09	0.57
3	0.16	16.20	-5.19	-2.44	0.01
4	1.30	1.74	-3.46	-0.24	0.05
5	0.26	0.00	-2.13	0.00	1.09
6	-0.05	0.00	-8.56	0.00	0.36
Subarea A Total	3.19	10.49	-5.58	-10.33	1.66
Subareas B-L Total	1.41	17.94	-17.21	-2.68	0.42

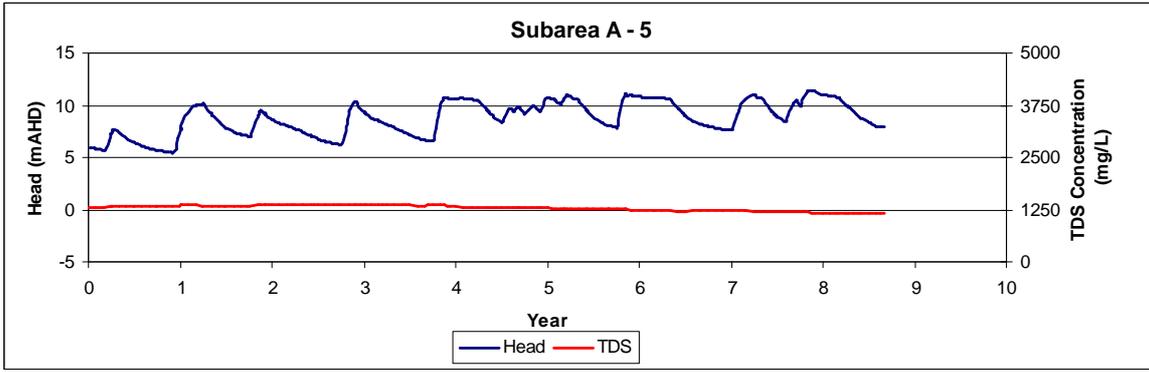
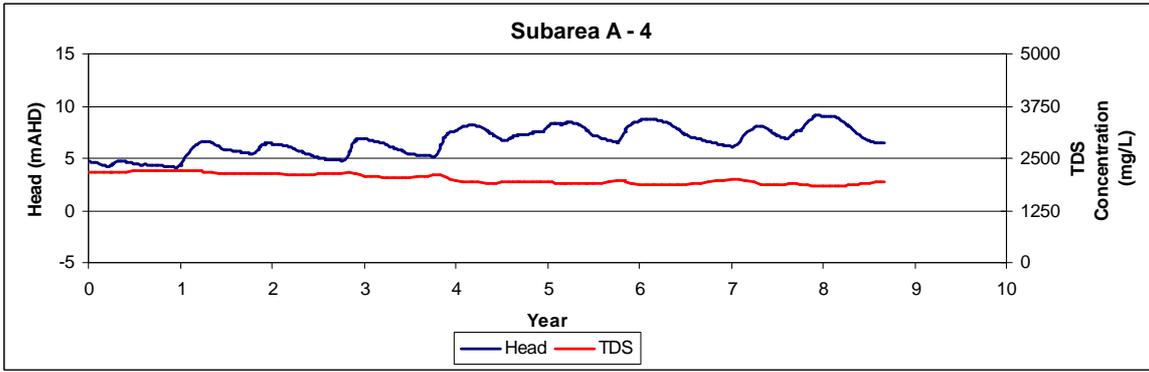
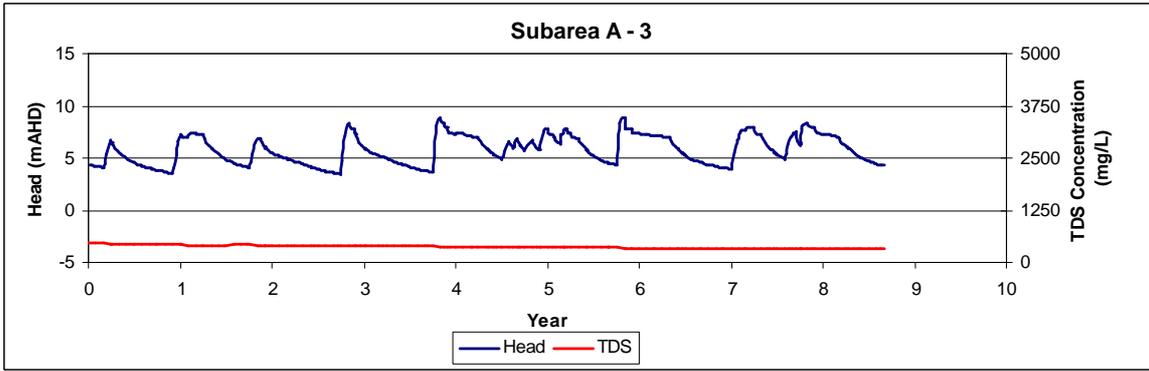
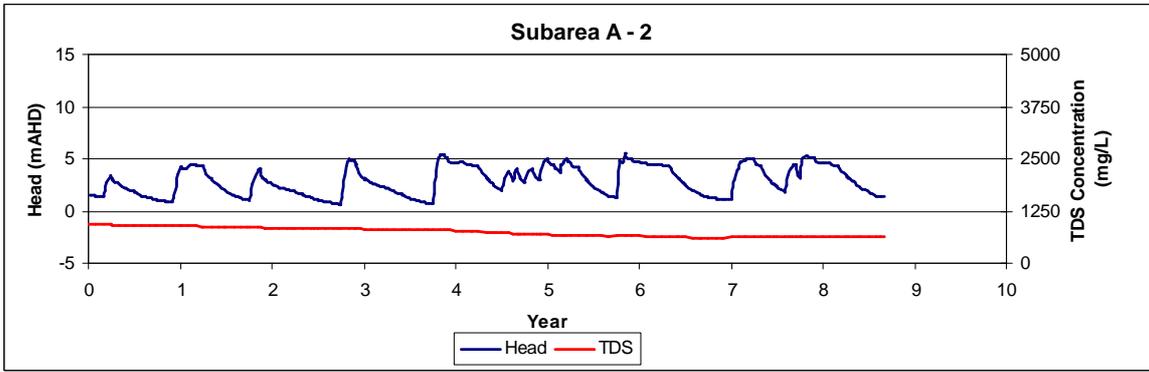
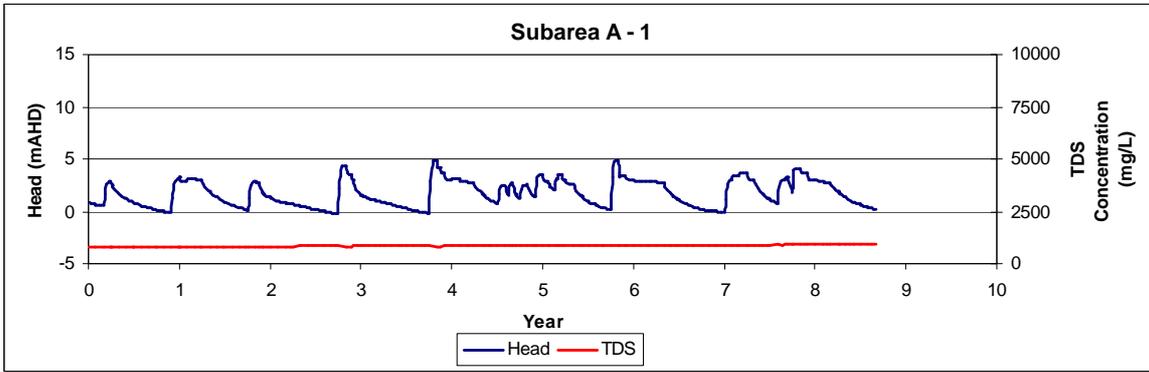
Table 9: Scenario 5 Water Balance Summary

A review of the simulated hydrographs, Figure 28, shows water levels continue to rise over the simulation period, even with the increase in abstraction to 22.8 GL/annum. This demonstrates that there is still sufficient river recharge to replenish the aquifer under increased abstraction. The actual change in water level over the period is small, with water levels at the end of the model at or near the same level as at the beginning, due to the effective recharge of the aquifer after successive river flows.

In terms of water quality, TDS generally declined over the period, as increased abstraction removed groundwater, and lowered water levels, thereby allowing increased recharge by fresher river flow water, and reduced evapotranspiration. It is important to recognise that this condition applies only if river recharge has low TDS, i.e. 55 mg/L. If river recharge has higher TDS the effect of recharge may not result in the same degree of improving groundwater quality.

Figure 29 shows the impact of abstraction from Subareas B-L versus the Moderate Frequency Recharge Base Case (Figure 13). The impact due to pumping from the Brickhouse borefield and the additional 8 Subareas B-L bores occurs on both side of the Gascoyne River, and is about 2 metres. However, in the RBS, water levels are unchanged as river recharge acts to maintain aquifer water levels, indicating the efficacy of recharge to the RBS.

Similarly, Figure 30 shows water quality changes compared to the Moderate Frequency Recharge Base Case (Figure 14) of less than 200 mg/L after 10 years of pumping indicating some freshening of groundwater, though primarily in Subarea A and unconnected with pumping in Subareas B-L. At Brickhouse production locations water quality has declined or remained unchanged (TDS increase of 100-200 mg/L) at most of the bores. This suggests there is some risk of exceeding the water quality criteria at some of the Brickhouse bores under sustained pumping.



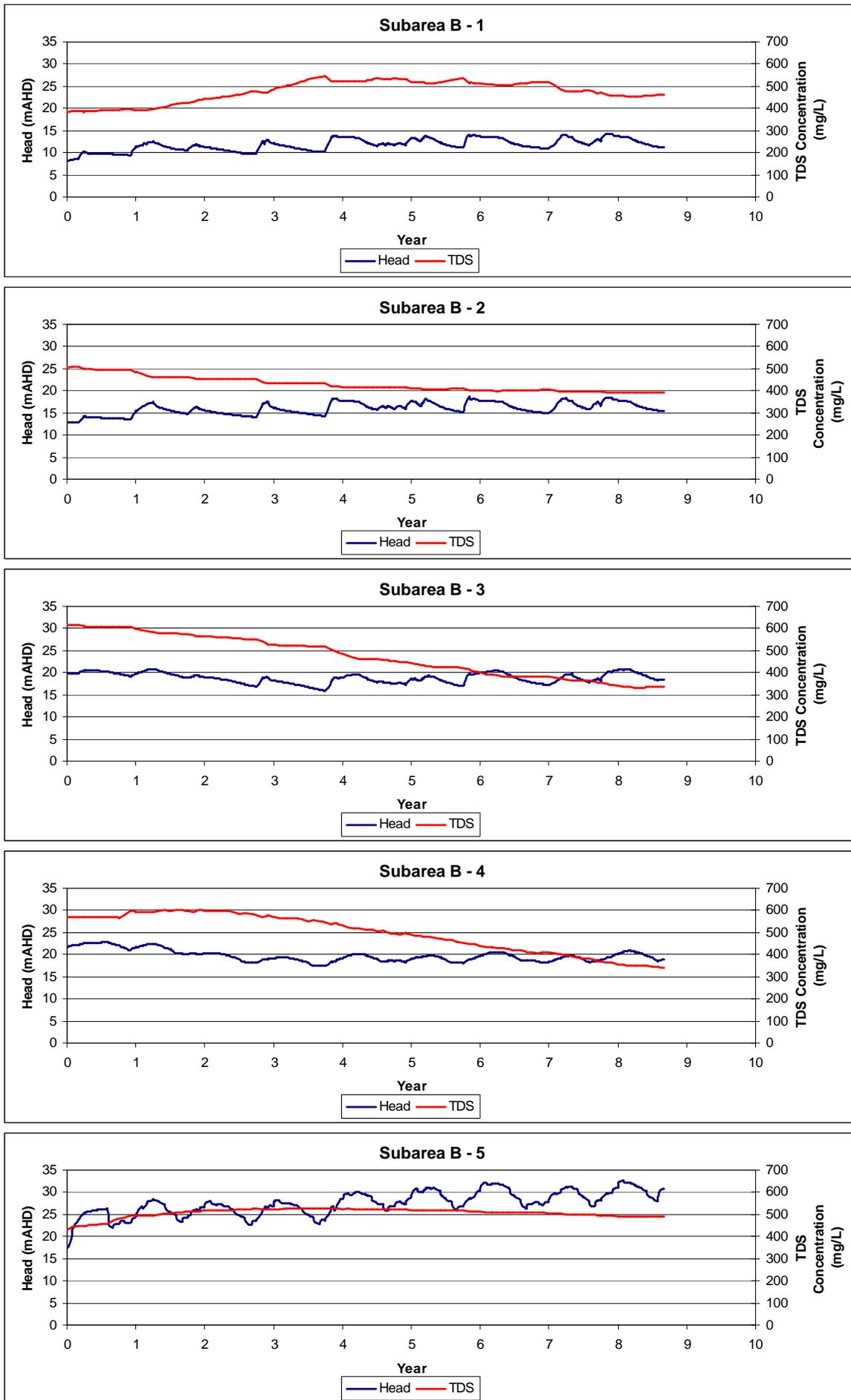
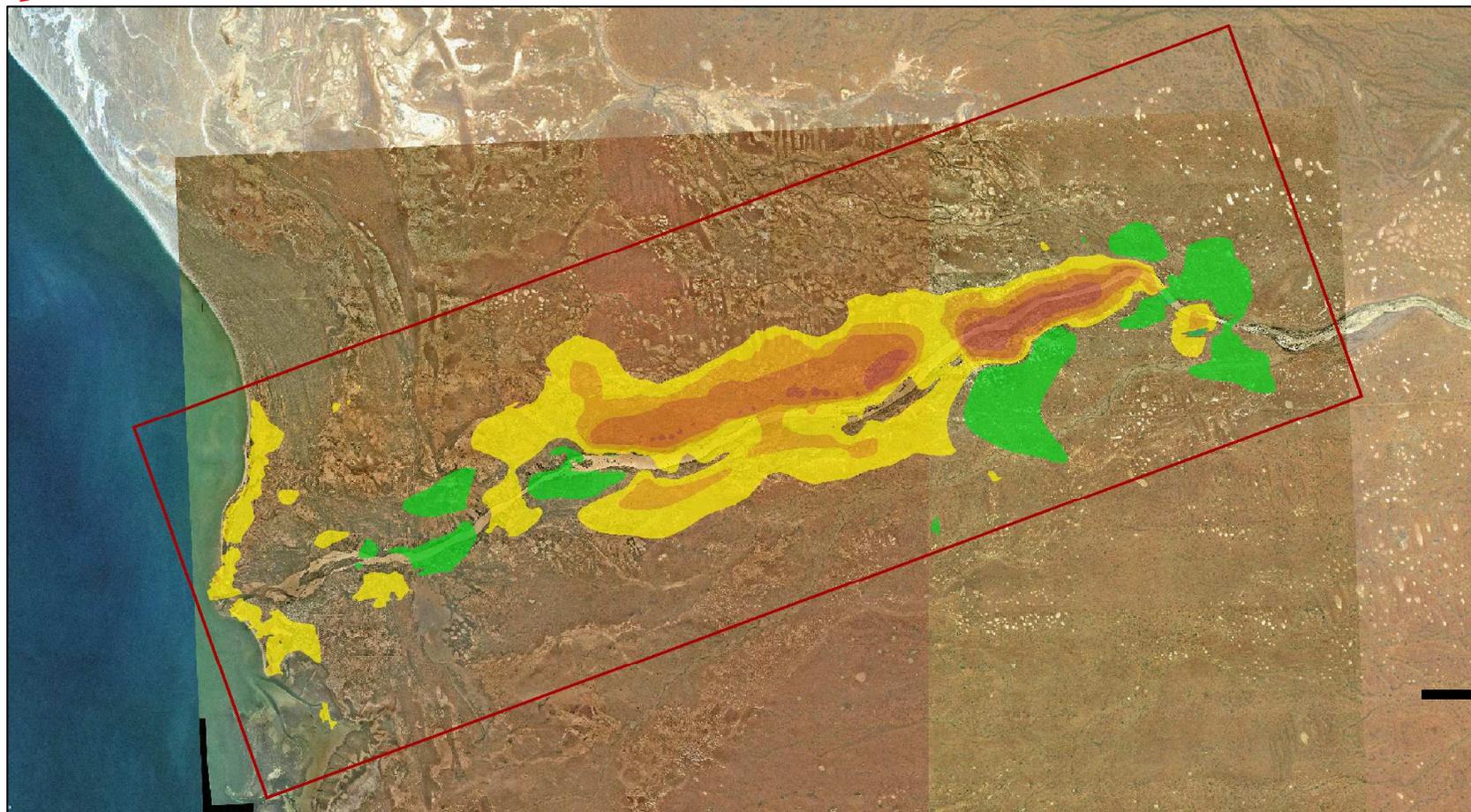


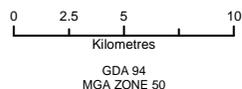
Figure 28: Head- and Solute-Time Curves – Scenario 5



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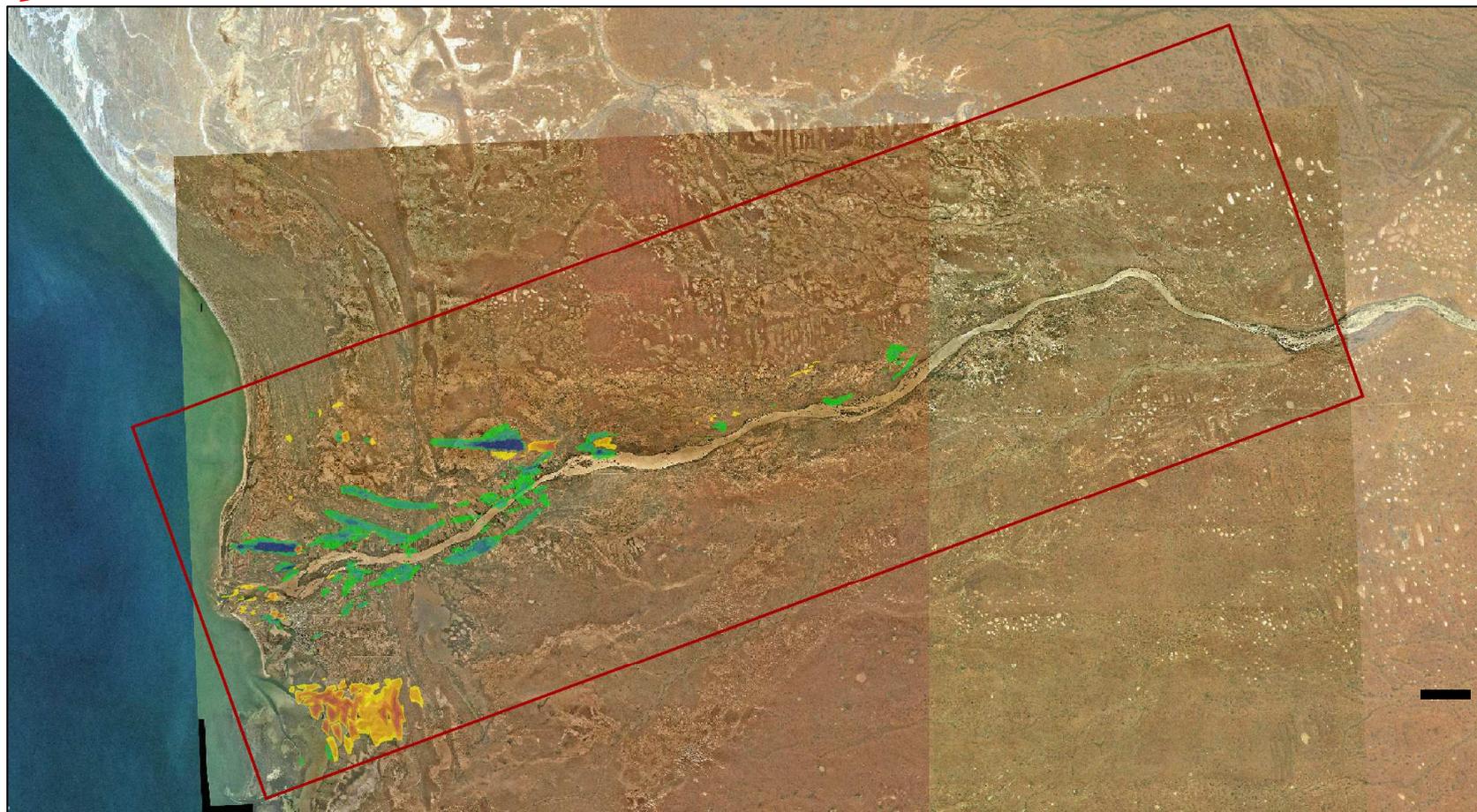
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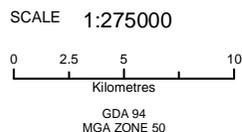
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Scenario 5 Head Impact	 -0.25 - 0.25
Head Change (m)	 -1 - -0.25
 > 5	 -2 - -1
 2 - 5	 -5 - -2
 1 - 2	 < -5

Figure 29: Scenario 5 Water Level Impact, Year 8.6



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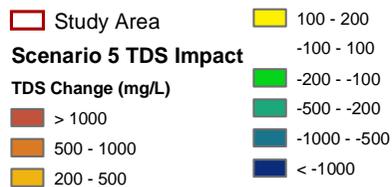


Figure 30: Scenario 5 TDS Impact, Year 8.6

3.1.6 Scenario 6 – Low Frequency Recharge Best Case with Brickhouse Pumping

Scenario 6 is similar to Scenario 5, except the simulation uses the low frequency recharge sequence for river recharge. This scenario is designated the Low Frequency Recharge Best Case with an additional 27 bores in the Brickhouse area, and represents an expansion of the Subareas B-L low frequency recharge allocation from 19.6 GL/annum, as calculated in Scenario 4, to 23.6 GL/annum. This scenario quantifies whether an additional 4 GL/annum can be abstracted north of the Gascoyne River, in addition to a 4 GL/annum increase from the existing borefield in Subareas B-L under low frequency recharge conditions. The maximum sustainable yield that can be abstracted under no-flow conditions is defined as the maximum volume of water that can be abstracted during a two-year no-flow sequence with out exceeding water quality criteria.

The 27 bores in the Brickhouse area are designed to each abstract 407 m³/day each, and are located approximately 2km north of the north bank of the Gascoyne River, Figure 7. To model the scenario, 27 bores were added to the model, all being completed in layers 2 through 6. The MNW package was used to simulate all abstraction, and was allowed to manage the bores to maximise abstraction with respect to well and aquifer hydraulics, subject to water level changes due to low frequency recharge and flows. The solute transport model results are reviewed to confirm that the water quality criterion is meant by bores in Subareas B-L as well as in the Brickhouse area. The 5.8 GL/annum of abstraction in Subarea A is also managed by the MNW package and will vary over the simulation in response to low frequency recharge and flow conditions.

The water balance from the simulation is summarised in Tables 10 and 11. Table 10 shows that over the course of the 10 year simulation, the average abstraction was 5.6 GL/annum from Subarea A, and 22.8 GL/annum from Subareas B-L and the Brickhouse borefield. In Subareas B-L the increase in abstraction is 4.8 GL/annum greater than the current allocation. The majority of this water is production from Subareas B-L, 19.6 GL/year, with 3.2 GL/annum from the Brickhouse area. The addition of 4 GL/annum of capacity from the Brickhouse borefield resulted in 3.2 GL/annum increase compared to Scenario 4. This suggests that pumping less than 28.4 GL/annum from the RBS/OAA under low frequency recharge conditions is viable given sufficient river recharge. The results suggest that total allocation for Subarea A and Subareas B-L could be sustained at higher levels, up to 28.4 GL/annum. Note that some loss of deliverability occurred over the ten year period, suggesting the estimated annual abstraction is not sustainable beyond two years of no-flow.

Based on the results of Scenario 4 and 6, it is likely that a similar volume of additional water can be obtained directly from Subareas B-L, by judicious location of new production bores that take advantage of higher transmissivity sections of the RBS/OAA. As all of the water being pumped from the Brickhouse borefield is sourced as river recharge, there is limited hydrogeological advantage in develop production bores farther away from the river. The disadvantages of moving bores farther north are:

- The greater the distance from the river, the less likely the area will receive timely river recharge;
- The risk of compromising the water quality of the borefield by drawing in higher salinity groundwater is increased;
- A larger number of low-yield bores will be needed to abstract the 4 GL/annum, increasing the capital cost of extracting the 4 GL/annum of water; and
- The bores do not exploit a new or independent source of water, but take advantage of excess river flow to induce additional recharge, which can be more efficiently done by bores closer to the river.

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.03	11.80	0.00	-6.11	0.00
2	2.71	2.02	0.00	-7.21	0.61
3	0.07	19.00	0.00	-6.63	0.01
4	-0.57	12.40	0.00	-1.00	0.06
5	0.24	0.00	-5.60	0.00	1.18
6	-0.32	0.00	-22.80	0.00	-0.01
Subarea A Total	2.98	13.82	-5.60	-13.32	1.79
Subareas B-L Total	-0.82	31.40	-22.80	-7.63	0.06

Table 10: Scenario 6 Water Balance Summary - Simulation

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	4.54	0.47	0.00	-2.42	0.00
2	3.70	0.08	0.00	-3.42	0.62
3	9.92	3.80	0.00	-2.70	0.02
4	11.80	0.40	0.00	-0.35	0.06
5	0.41	0.00	-5.44	0.00	1.20
6	1.01	0.00	-23.80	0.00	-0.01
Subarea A Total	8.65	0.55	-5.44	-5.84	1.82
Subareas B-L Total	22.73	4.20	-23.80	-3.05	0.07

Table 11: Scenario 6 Water Balance Summary – No-Flow Period

A review of the simulated hydrographs, Figure 31, shows water levels fall during the two year no-flow and do not fully recover after flowing of the river. This suggests that under low frequency recharge conditions there may be long term depletion of storage with abstraction levels of 22.8 GL/annum from Subareas B-L. Similar declines in Subarea A are also observed, suggesting that abstraction on the order of 5.6 GL/annum during low frequency recharge is not sustainable.

In terms of water quality, TDS generally declined over the period, as increased abstraction removed groundwater, and lowered water levels, thereby allowing increased recharge by fresher flow waters, and reduced evapotranspiration. It is important to recognise that this condition applies only if river recharge has low TDS, i.e. 55 mg/L. If river recharge has higher

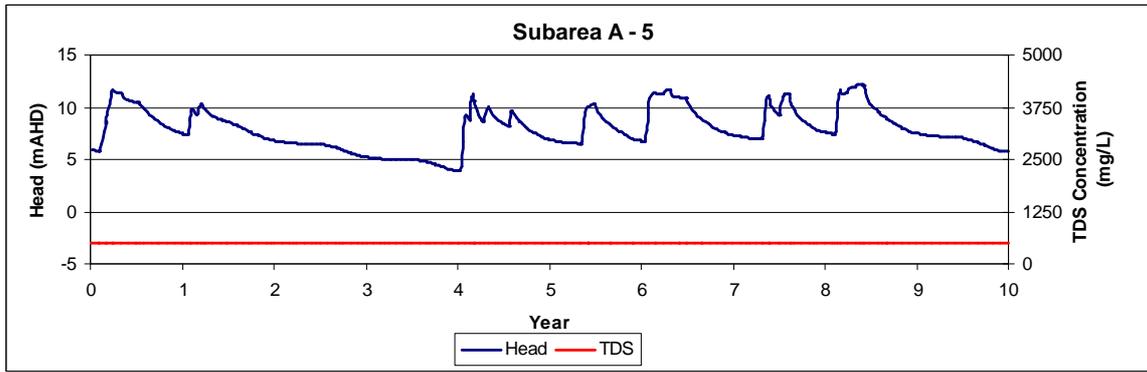
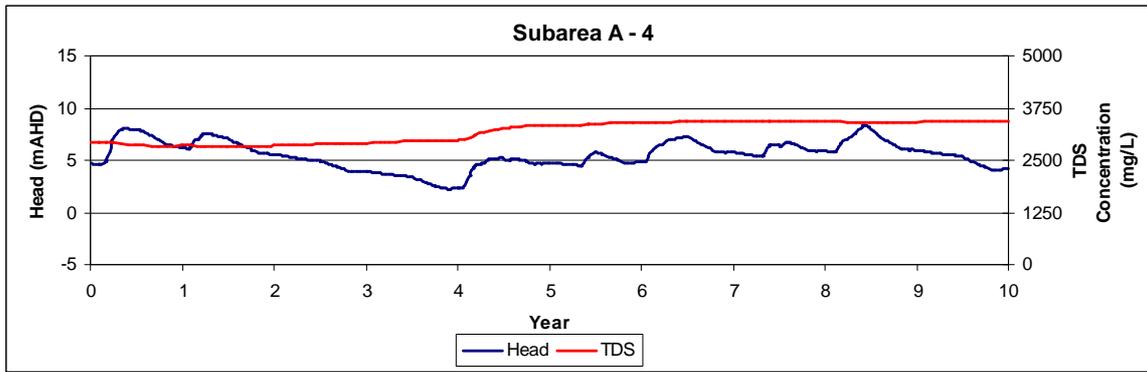
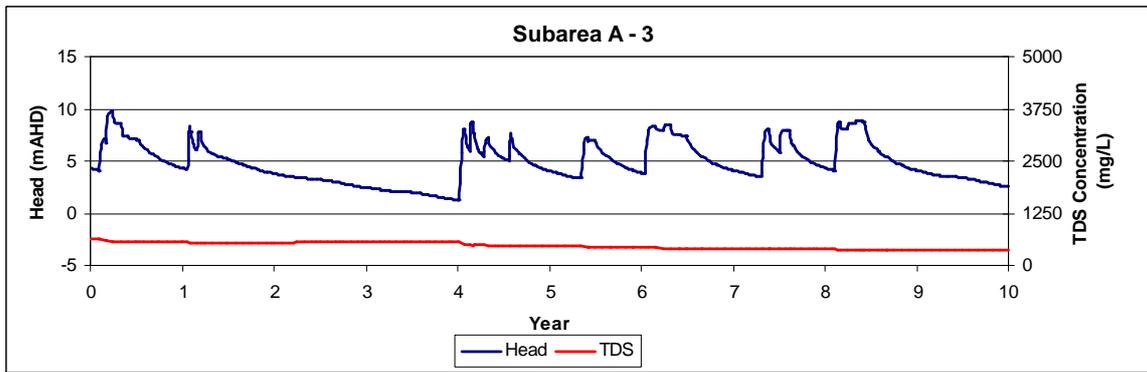
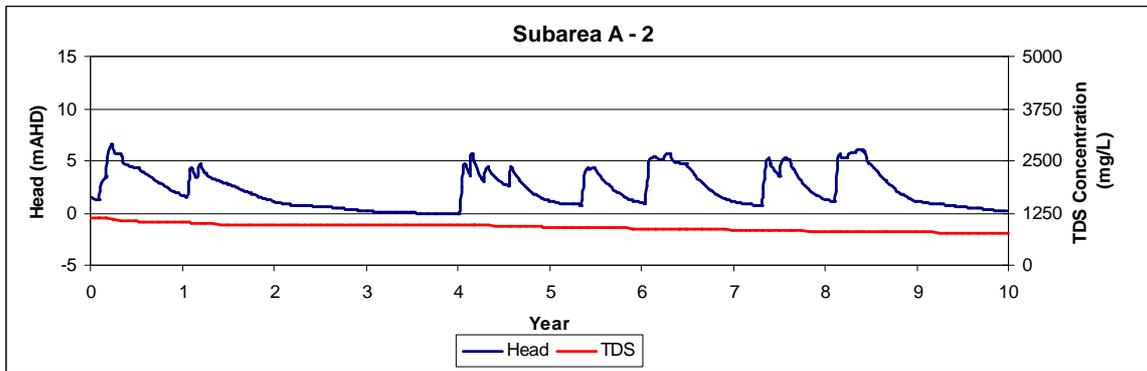
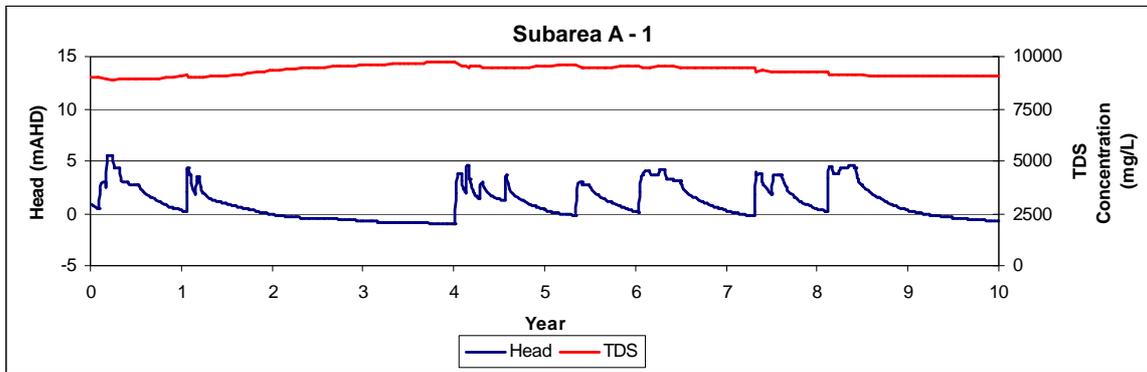
TDS the effect of recharge may not result in improving groundwater quality.

Figure 32 shows the water level impact of abstraction from Subareas B-L versus the Low Recharge Frequency Base Case (Figure 16). The impact due to pumping from the Brickhouse borefield and the additional eight Subareas B-L bores occurs on both side of the Gascoyne River, and is about 2 metres. Unlike in the moderate frequency recharge flow case where river recharge acts to maintain water levels in RBS, under low frequency recharge conditions the RBS water levels decline by about 2 metres.

Similarly, Figure 33 shows water quality changes compared to the Low Recharge Frequency Base Case (Figure 17) are mostly of less than 200 mg/L after 10 years of pumping, indicating some freshening of groundwater, though primarily in Subarea A and unconnected with pumping in Subareas B-L. At the Brickhouse production locations water quality has declined with TDS increasing by up to 500 mg/L at some bores. This suggests that under low frequency recharge conditions there is some risk of increasing salinity due to abstraction and demonstrates that abstraction of 3.2 GL/annum from the area is not likely to be sustainable beyond 10 years of low frequency recharge conditions.

Figure 34 shows the impact of abstraction from Subareas B-L versus the Low Recharge Frequency Base Case at the end of the first no-flow period (Figure 18). The impact due to pumping from the Brickhouse borefield and the additional eight Subareas B-L bores occurs on both side of the Gascoyne River, and is about 2 metres. Unlike in the moderate frequency recharge flow case where river recharge acts to maintain aquifer water levels, under low frequency recharge conditions the RBS water levels decline by about 2 metres.

Similarly, Figure 35 shows water quality changes compared to the Low Recharge Frequency Base Case (Figure 19) are mostly of less than 200 mg/L after 4 years of pumping, indicating some freshening of groundwater, though primarily in Subarea A and unconnected with pumping in Subareas B-L. At the Brickhouse production locations water quality has declined with TDS increasing by up to 500 mg/L. This suggests that under low frequency recharge conditions there is some risk of increasing salinity due to abstraction.



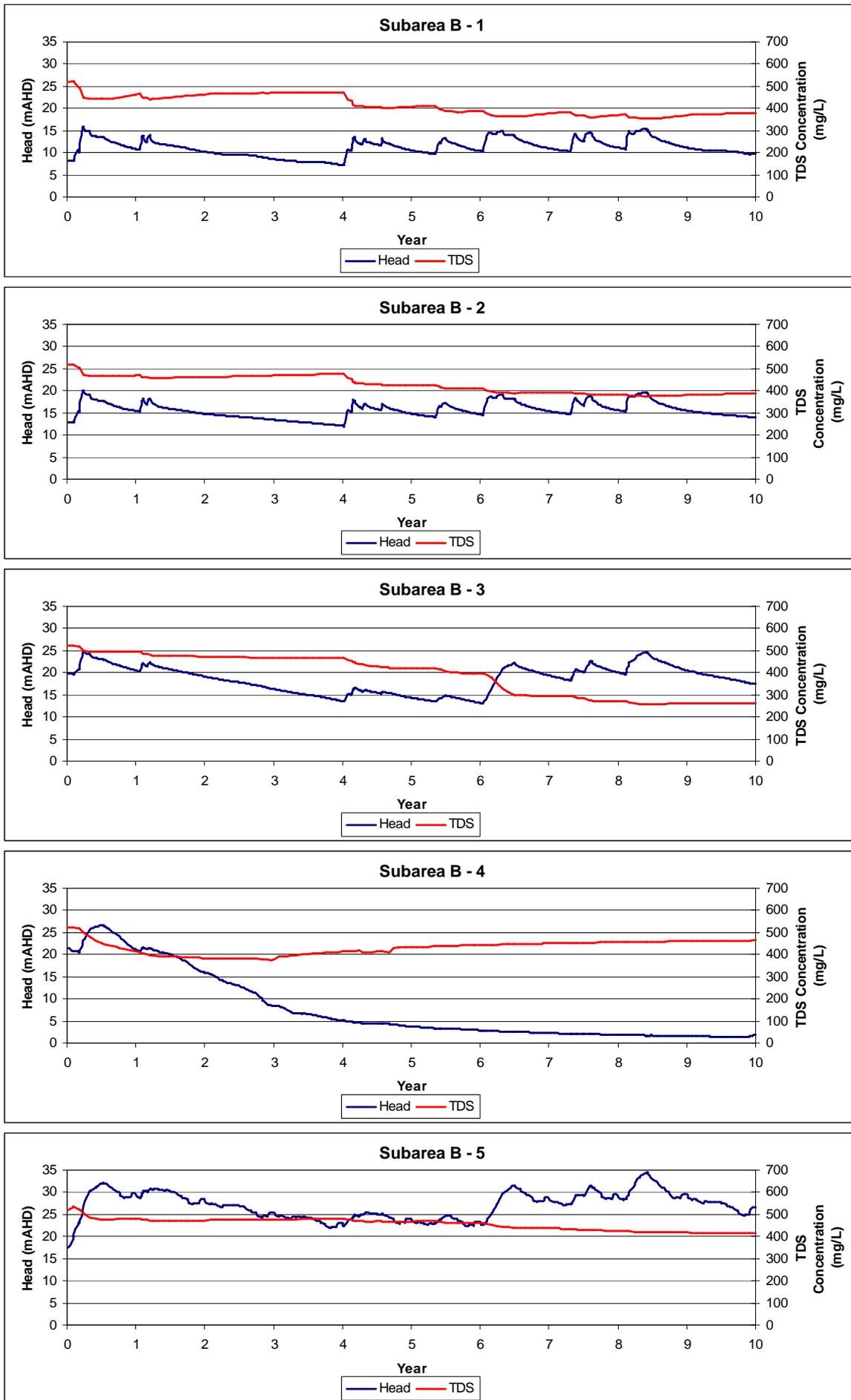
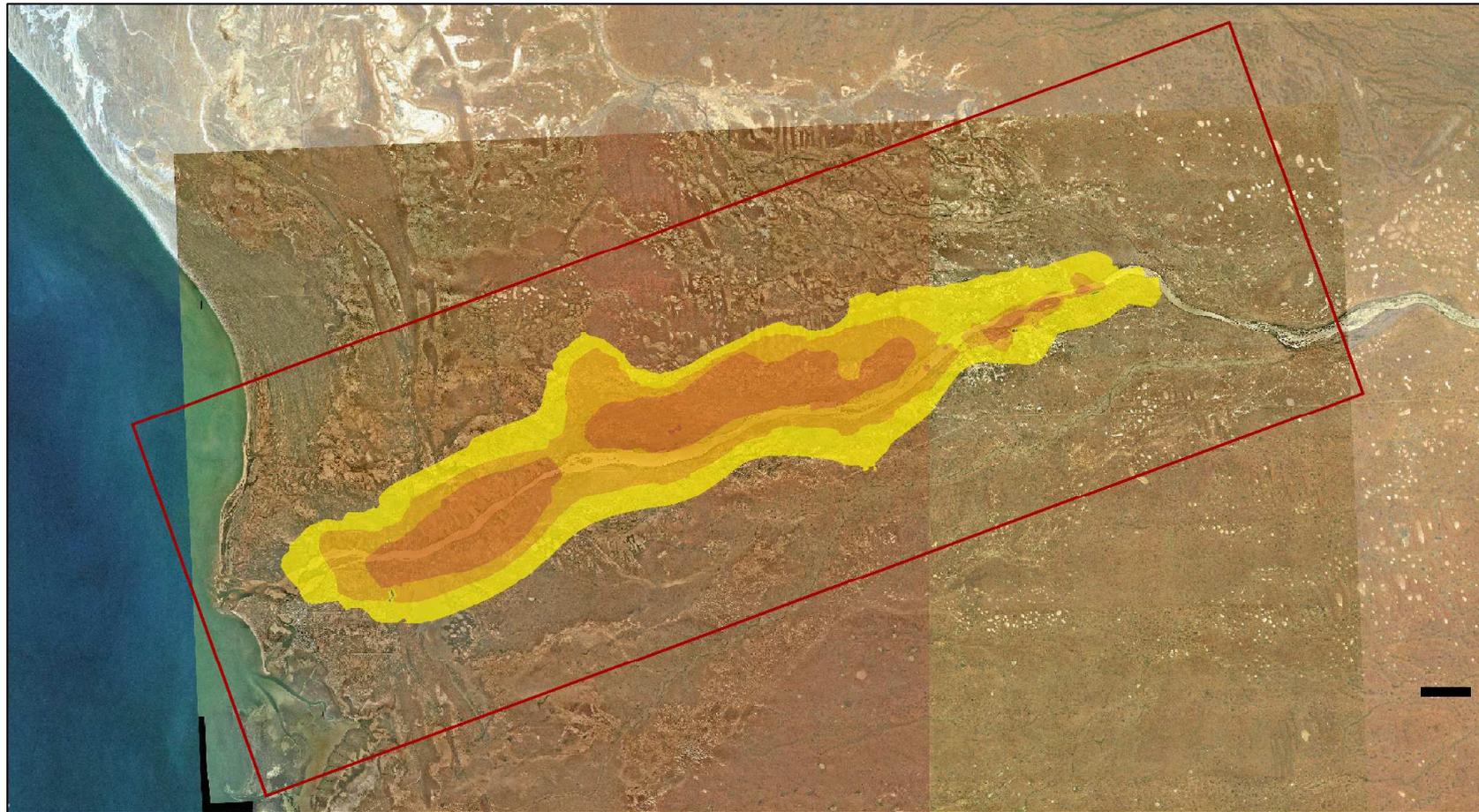


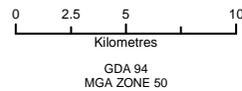
Figure 31: Head- and Solute-Time Curves – Scenario 6



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ACKNOWLEDGEMENT DATA SOURCES
- Geoscience Australia
- SKM
- Department of Water

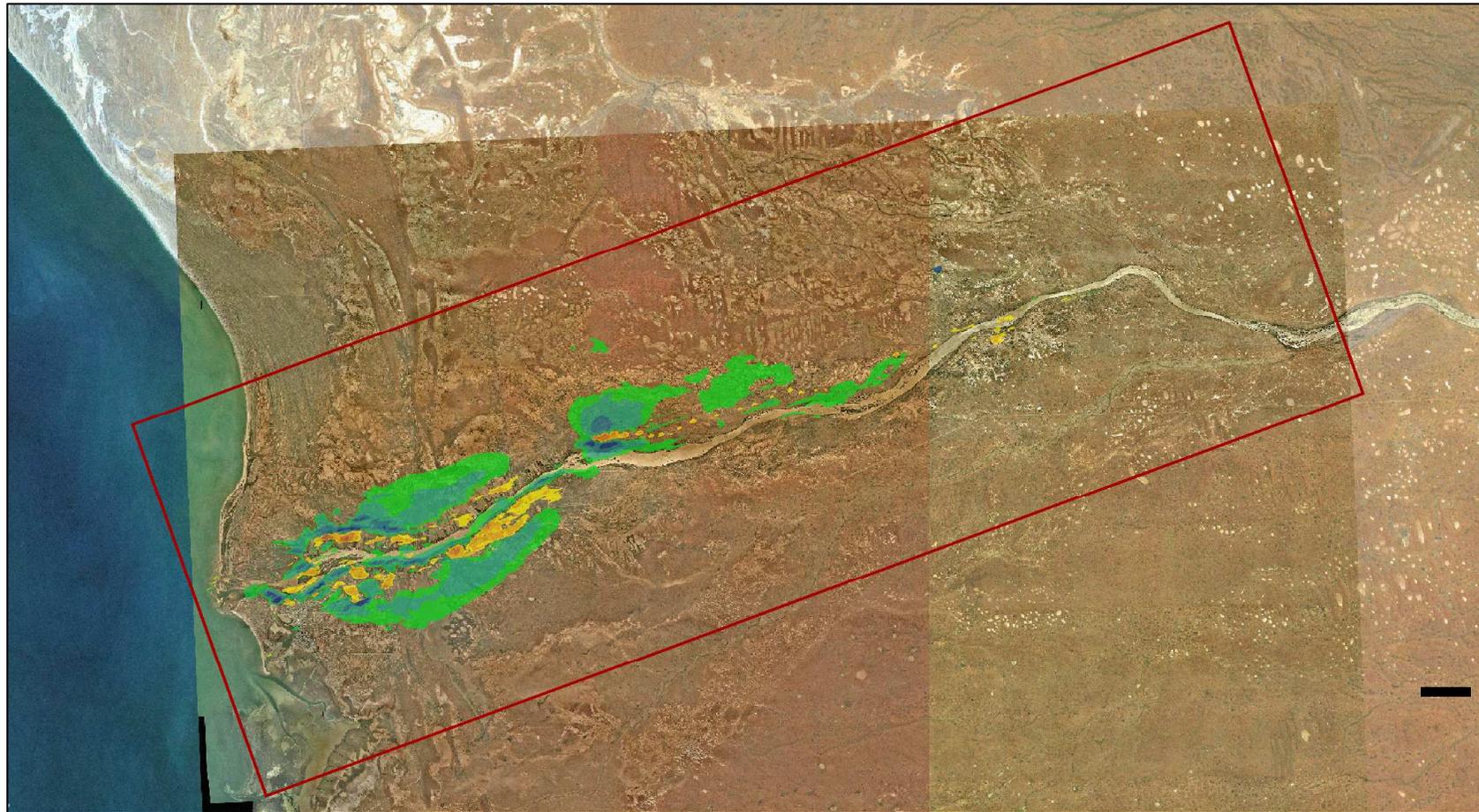
SCALE 1:275000



Legend

Study Area	0.25 - 1
Scenario 6 Head Impact	-0.25 - 0.25
Head Change (m)	-1 - -0.25
> 5	-2 - -1
2 - 5	-5 - -2
1 - 2	< -5

Figure 32: Scenario 6 Water Level Impact, Year 10



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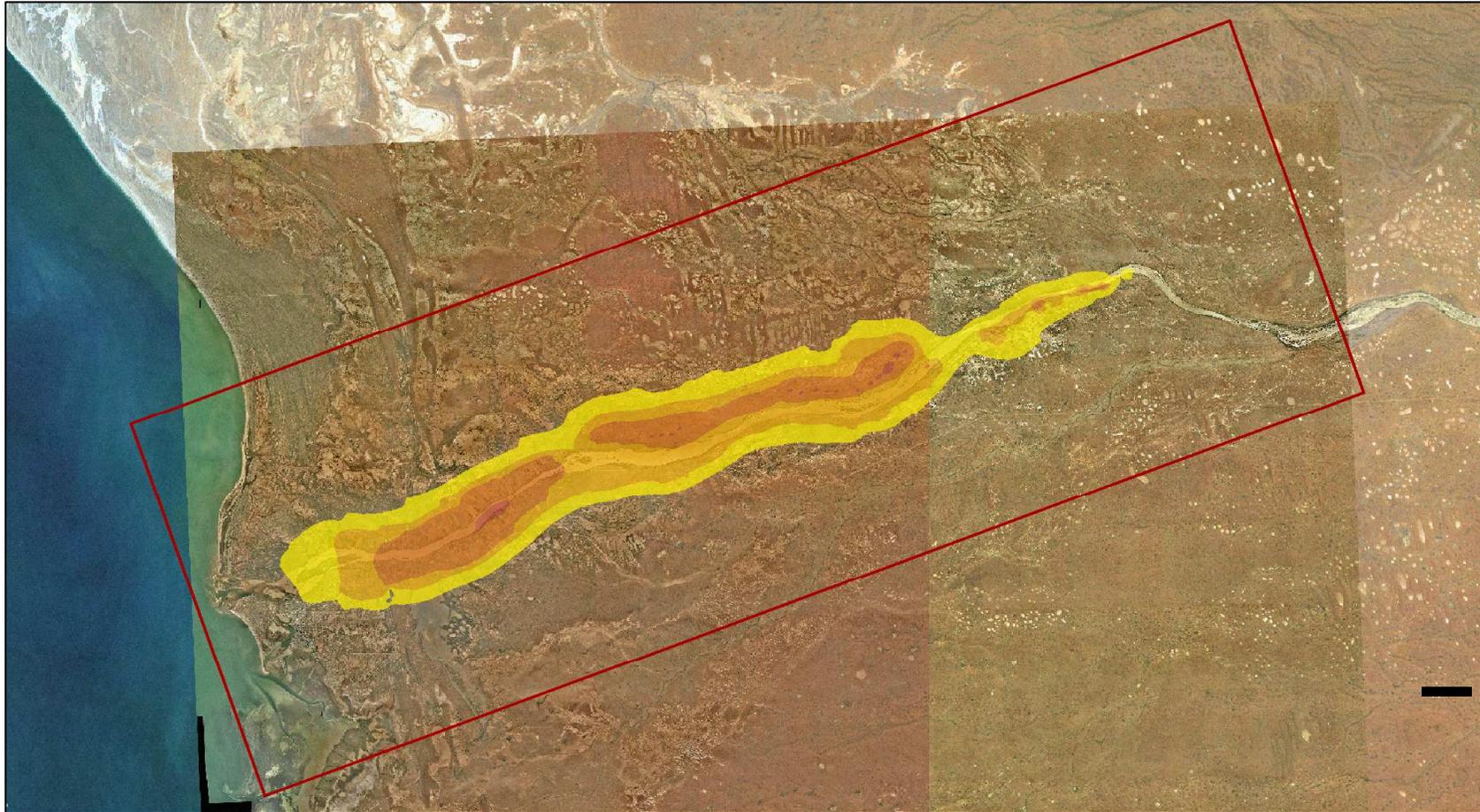
ACKNOWLEDGEMENT
DATA SOURCES
- Geoscience Australia
- SKM
- Department of Water

SCALE 1:275000
0 2.5 5 10
Kilometres
GDA 94
MGA ZONE 50

Legend

- Study Area
- Scenario 6 TDS Impact**
- TDS Change (mg/L)**
- > 1000
- 500 - 1000
- 200 - 500
- 100 - 200
- 100 - 100
- 200 - -100
- 500 - -200
- 1000 - -500
- < -1000

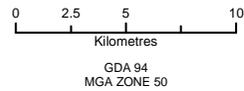
Figure 33: Scenario 6 TDS Impact, Year 10



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ACKNOWLEDGEMENT
DATA SOURCES
- Geoscience Australia
- SKM
- Department of Water

SCALE 1:275000



Legend

Study Area

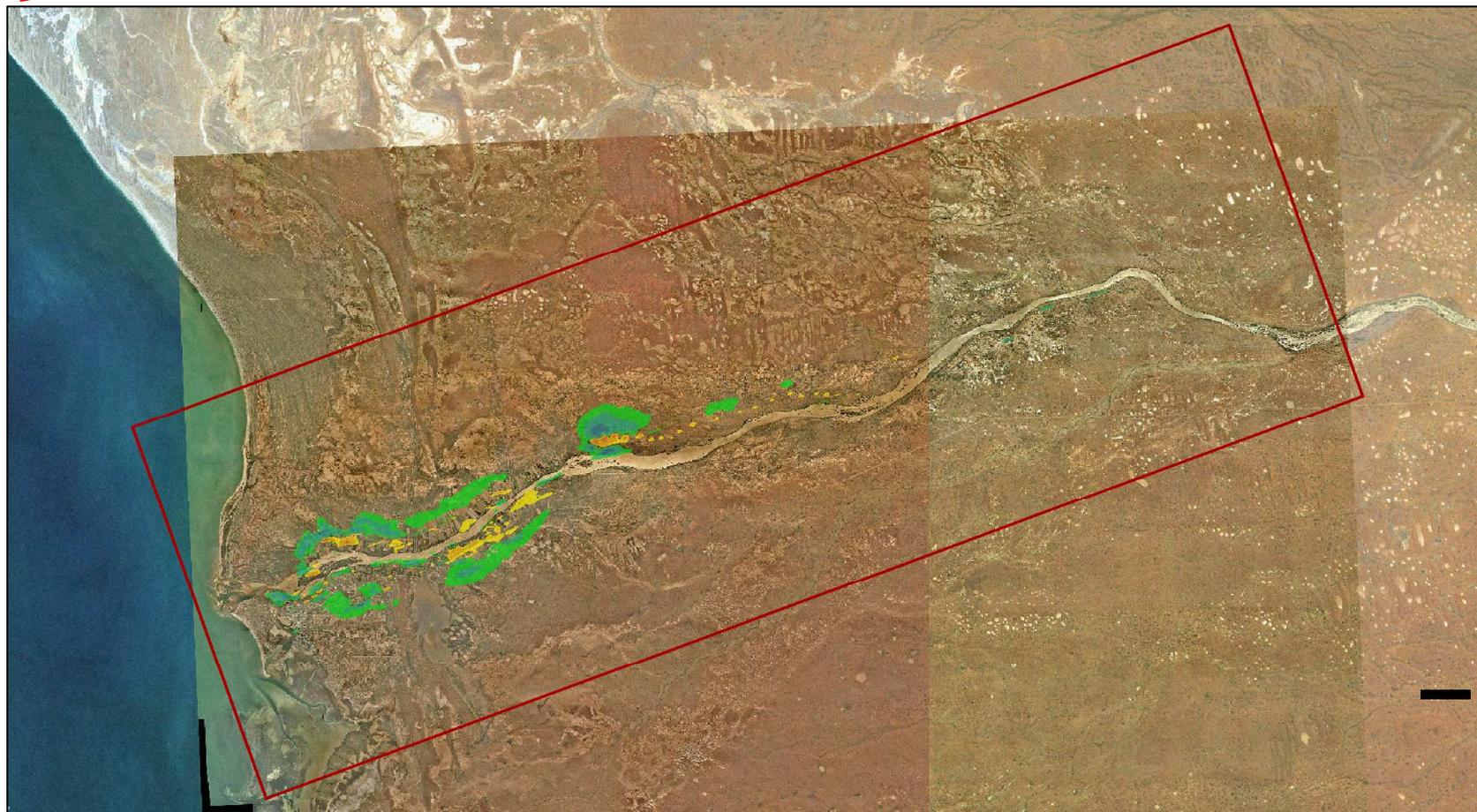
Scenario 6 Head Impact, Dry Sequence

Head Change (m)

- > 5
- 2 - 5
- 1 - 2

- 0.25 - 1
- 0.25 - 0.25
- 1 - -0.25
- 2 - -1
- 5 - -2
- < -5

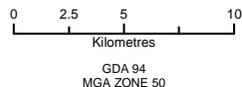
Figure 34: Scenario 6 Water Level Impact, Year 4



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ACKNOWLEDGEMENT
DATA SOURCES
- Geoscience Australia
- SKM
- Department of Water

SCALE 1:275000



Legend

- Study Area
- Scenario 6 TDS Impact, Dry Sequence**
- TDS Change (mg/L)**
- > 1000
- 500 - 1000
- 200 - 500
- 100 - 200
- 100 - 100
- 200 - -100
- 500 - -200
- 1000 - -500
- < -1000

Figure 35: Scenario 6 TDS Impact, Year 4

Table 12 summarizes the results of the six scenarios simulated using GASFAMS V1.

Scenario	Description	Recharge Sequence	Allocation Component Simulation Results		
			Subarea A (GL/annum)	Subareas B-L (GL/annum)	Total (GL/annum)
1	Base case	Moderate Frequency Recharge (1991-1999)	5.6	10.4	16.0
2	Low Frequency Recharge	Low Frequency Recharge, (2000-2008) Salinity Subarea A > 1000 mg/L	0.0	15.8	15.8
3	Subarea A & Subareas B-L Best case	Moderate Frequency Recharge	5.6	13.9	19.5
4	Subarea A & Subareas B-L Best case	Low Frequency Recharge, (2000-2008) Salinity Subarea A > 1000 mg/L	5.6	19.6	25.2
5	Brickhouse Borefield 4GL/annum	Moderate Frequency Recharge	5.6	17.2	22.8

Table 12: Scenarios 1 – 6 Flow Results Summary

3.2 Solute Transport Scenarios 1 – 6

Scenarios 1 through 6 were also simulated using water quality criteria using GASFAMS 1.1. The flow scenarios were run using MT3DMS to assess abstraction against water quality criteria, outputting abstraction water quality for each bore, using the MNW package.

A water quality simulations for Scenarios 1 through 6 indicates that:

- in all cases the amount of fresh water available in Subarea A is less than 5.8 GL/annum;
- The optimized cases for Scenarios 3 and 4 do not significantly change the available water in Subarea A, as draw-point distribution is the limiting factor in extracting water from Subarea A;
- The results for Subareas B-L show that results for low frequency recharge conditions produce significantly more fresh water than the moderate frequency recharge case. These differences are due to both the recharge sequence used, and as well as actual

production bores in use and the pumping schedule used. Significant optimization of the borefields in Subareas B-L occurred after 2000 which is reflected in the results for the low frequency recharge period.

Table 13 summarizes the results for Scenarios 1 through 6, which shows the annual averages for abstraction meeting and exceeding water quality criteria in Subarea A and Subareas B-L. Abstraction from Subareas B-L in Scenario 5 is constrained by infrastructure, suggesting that the allocation used in the simulation cannot be met.

Table 13 results indicate:

- The total volume of abstracted water from Subarea A is constrained both by the number of bores (i.e. available infrastructure), but also by the water quality produced from those bores, with the estimated minimum fresh water abstraction of 4.1 GL/annum on average.
- The available resources in Subareas B-L are sufficient to meet the maximum allocation of 26 GL/annum, without significant water quality issues.
- The location of bores and operating strategy in Subareas B-L has a significant effect on the total fresh water available, as reflected in the different fresh water resources under moderate frequency recharge and low frequency recharge conditions.
- The average TDS of abstracted brackish water in Subarea A provides an opportunity for co-mingling production from selected bores to obtain additional resources meeting the 1000 TDS criterion.
- Abstraction from the Brickhouse borefield is not materially impacted over the 10 year abstraction period by changes in water quality.

Scenario	Subarea A						Subareas B – L					
	Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)			Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)		
	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS Concentration (mg/L)
1	4.3	74	483	1.6	28	2500	9.0	73	455	2.2	18	1085
2	0.0	0	0	0.0	0	0	18.0	100	473	0.0	0	0
3	4.3	74	490	1.6	28	2571	11.9	73	435	3.5	22	1141
4	4.1	71	447	1.7	29	2881	21.8	99	465	0.0	0	0
5	4.3	74	483	1.6	28	2585	9.3	36	428	6.0	23	1650
6	4.1	71	442	1.7	29	2887	25.5	98	500	0.3	1	1004

Table 13: Scenarios 1 – 6 TDS Results Summary

3.3 Scenarios 7 and 8 – Subarea A Abstraction of 8.6 GL

Scenarios 7 and 8 simulate the existing allocations under moderate frequency recharge and low frequency recharge conditions, respectively, with the following modifications:

- Subarea A allocations are increased to a total of 8.6 GL/annum;
- This increased abstraction is accommodated by duplicating all production bores in Subarea A, and offsetting the duplicated bores by 50 metres north and south from the original bore, with the original bore removed from the model.
- Abstraction from Subareas B-L remains the same as in the existing management plan, that is, 12.2 GL/annum in the moderate frequency recharge sequence and 18 GL/annum in the low frequency recharge sequence.

These scenarios quantify whether Subarea A can sustain higher allocations under moderate frequency recharge and low frequency recharge conditions in terms of both quantity and quality, assuming new infrastructure. They are similar to Scenarios 3 and 4, which however do not include new infrastructure.

The water and mass balances for abstraction in Scenarios 7 and 8 are summarised in Tables 14, 15 and 16. Table 14 shows that over the course of the 8.6 years in the moderate frequency recharge simulation, the average abstraction of fresh water from Subarea A is 6.4 GL/annum, and 2.2 GL/annum of brackish water. Total abstraction from Subarea A is 8.6 GL/annum indicating that with duplicate bores, it is likely the area would be able to produce 8.6 GL/annum.

If all bores are produced, a total of 8.6 GL/annum would be abstracted from Subarea A at an average water quality of 1020 mg/L. This exceeds the TDS criterion by only 20 mg/L and suggests that there may be opportunities for increasing total abstraction above 6.4 GL/annum if blending of water could be undertaken at the subarea or sub-subarea scale.

Table 14 shows that over the course of the 10 years in the low frequency recharge simulation, the average abstraction of fresh water from Subarea A is 5.8 GL/annum, and 2.6 GL/annum of brackish water. Total abstraction from Subarea A is 8.4 GL/annum indicating that with duplicate bores, it is likely the area would be able to produce 8.6 GL/annum.

If all bores are produced, a total of 8.4 GL/annum would be abstracted from Subarea A at an average water quality of 1200 mg/L. This exceeds the TDS criterion by 200 mg/L and suggests that there may be limited opportunities for increasing total abstraction above 5.8 GL/annum if blending of water could be undertaken at the subarea or sub-subarea scale.

Based on the results of these scenarios, it may be possible to increase the monthly allocation for those bores that have good water quality to a total of 6.4 GL/annum. However, additional sampling and water level monitoring should be undertaken to confirm the modelling results.

Scenario	Subarea A						Subareas B – L					
	Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)			Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)		
	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS Concentration (mg/L)
7	6.4	74	464	2.2	26	2644	9.0	73	428	2.2	18	1630
8	5.8	67	420	2.6	30	2926	17.9	99	480	0.0	0	0

Table 14: Summary of Scenarios 7 and 8

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.14	19.31	-3.21	-9.29	0.00
2	2.00	1.16	-3.13	-7.70	0.61
3	0.16	19.70	-2.73	-6.15	0.01
4	0.29	0.24	-4.95	-0.12	0.05
5	0.16	0.00	-2.20	0.00	2.29
6	-0.46	0.00	-6.36	0.00	0.40
Subarea A Total	2.02	20.47	-8.54	-16.99	2.90
Subareas B-L Total	-0.01	19.94	-14.04	-6.27	0.46

Table 15: Scenario 7 Water Balance Summary

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.07	15.46	-2.87	-7.19	0.00
2	2.28	0.93	-2.45	-7.04	0.63
3	0.51	20.80	-5.97	-6.09	0.01
4	0.97	0.31	-3.56	-0.14	0.05
5	0.25	0.00	-2.54	0.00	2.37
6	1.46	0.00	-8.21	0.00	0.11
Subarea A Total	2.46	16.39	-7.86	-14.23	3.00
Subareas B-L Total	2.94	21.11	-17.74	-6.23	0.17

Table 16: Scenario 8 Water Balance Summary

3.4 Scenarios 9 and 10 - Subarea A Abstraction of 11 GL

Scenarios 9 and 10 simulate the existing allocations under moderate frequency recharge and low frequency recharge conditions, respectively, with the following modifications:

- Subarea A allocations are increased to a total of 11 GL/annum;
- This increased abstraction is accommodated by duplicating all production bores in Subarea A, and offsetting the duplicated bores by 50 metres north and south, with the original bore removed from the model.
- Abstraction from Subareas B-L remains the same as in the existing management plan.

These scenarios quantify whether Subarea A can sustain higher allocations under moderate frequency recharge and low frequency recharge conditions in terms of both quantity and quality.

The water and mass balances for abstraction from scenarios 9 and 10 are summarised in Tables 17, 18 and 19. Table 17 shows that over the course of the 8.6 year moderate frequency recharge simulation, the average abstraction of fresh water from Subarea A is 8.1 GL/annum, and 2.9 GL/annum of brackish water. Total abstraction is 11.0 GL/annum indicating that with duplicate bores, it is possible the area could produce 11 GL/annum. The 8.1 GL/annum abstracted is more than the volume produced in Scenario 7, indicating that additional bores or optimization of abstraction may allow an increase in abstraction volumes above 8 GL/annum of fresh water from Subarea A.

If all bores are produced, a total of 11 GL/annum would be abstracted from Subarea A at an average water quality of 1020 mg/L. This exceeds the TDS criterion by 20 mg/L and suggests that there may be opportunities for increasing total abstraction above 8.0 GL/annum from Subarea A if blending of water could be undertaken at the subarea or sub-subarea scale.

Table 17 also summarizes the abstracting of 11 GL/annum from Subarea A over the course of the 10 year low frequency recharge simulation. The average abstraction of fresh water is 7.4 GL/annum and 3.3 GL/annum of brackish water. The total abstraction from the Subarea A is 10.7 GL/annum, indicating that even with duplicate bores, Subarea A will have difficulty producing 11 GL/annum. The 7.4 GL/annum abstracted is 1.6 GL/annum more than Scenario 8, indicating that additional bores or optimization of abstraction may increase total abstraction volumes above 7 GL/annum of fresh water.

If all bores are produced, a total of 10.7 GL/annum would be abstracted from Subarea A at an average water quality of 1210 mg/L. This exceeds the TDS criteria by 210 mg/L and suggests that during low frequency recharge it will be more difficult to increase total abstraction above 7.0 GL/annum using the blending of water.

Based on the results of these scenarios, it may be possible to increase the monthly allocation for those bores that have good water quality to 7.0 GL/annum. However, additional sampling and water level monitoring should be undertaken to confirm the modelling results.

In addition, the simulation results suggest that the co-mingling of water from selected bores in Subarea A could result in an increase in fresh resources from 7.0 GL/annum to 10.7 GL/annum. However, this would require additional infrastructure.

Scenario	Subarea A						Subareas B – L					
	Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)			Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)		
	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS Concentration (mg/L)
9	8.1	74	433	2.9	26	2667	11.5	64	411	3.7	21	1145
10	7.4	67	420	3.3	30	2976	17.9	99	320	0.0	0	0

Table 17: Summary of Scenarios 9 and 10

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.02	20.39	-3.99	-8.78	0.00
2	2.22	1.19	-3.52	-7.60	0.61
3	0.48	19.30	-5.63	-5.08	0.01
4	0.08	0.22	-4.74	-0.11	0.05
5	0.19	0.00	-3.20	0.00	2.29
6	-0.77	0.00	-4.04	0.00	0.40
Subarea A Total	2.43	21.58	-10.71	-16.38	2.90
Subareas B-L Total	-0.21	19.52	-14.41	-5.19	0.46

Table 18: Scenario 9 Water Balance Summary

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.54	15.48	-3.39	-6.85	0.00
2	2.61	0.90	-2.74	-6.96	0.63
3	0.89	20.40	-5.96	-6.08	0.01
4	1.00	0.30	-3.55	-0.14	0.05
5	0.31	0.00	-3.15	0.00	2.37
6	1.45	0.00	-8.19	0.00	0.11
Subarea A Total	3.46	16.38	-9.28	-13.81	3.00
Subareas B-L Total	3.34	20.70	-17.70	-6.22	0.17

Table 19: Scenario 10 Water Balance Summary

3.5 Scenario 11 – Modified Low Frequency Recharge Sequence

Scenario 11 simulates the existing allocations under moderate frequency recharge and low frequency recharge conditions with the following modifications:

- Subarea A allocations are set to a total of 5.8 GL/annum;
- Abstraction from Subareas B-L is 12.2 GL/annum in the moderate frequency recharge sequence.

This scenario quantifies how sensitive Subareas A and B-L are to a modified recharge sequence.

The water and mass balance for abstraction from Scenario 11 is summarised in Tables 20 and 21. Table 20 shows that over the course of the 10 year modified recharge simulation, the average abstraction of fresh water from Subarea A is 4.1 GL/annum, and 1.8 GL/annum of brackish water. Total abstraction is 5.8 GL/annum. These results suggest that Subarea A has limited sensitivity to the recharge sequence used in the simulations, as the results are similar to Scenarios 1 and 3.

In the case of Subareas B-L, the simulation shows that over the course of the 10 year modified recharge simulation, the average abstraction of fresh water from Subareas B-L is 7.1 GL/annum of fresh water and 2.5 GL/annum of brackish water. Total abstraction is 9.6 GL/annum. These results indicate a significant reduction in fresh water abstraction compared to Scenario 1, 2 and 3. This suggests that Subareas B-L has some sensitivity to the recharge sequence used in the simulations.

Based on the results of these scenarios, it suggests that Subareas B-L is sensitive to the occurrence of large floods, which is consistent with the conceptual model of recharge in this area.

Scenario	Subarea A						Subareas B – L					
	Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)			Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)		
	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS Concentration (mg/L)
11	4.1	71	482	1.8	31	2500	7.1	58	435	2.5	20	1080

Table 20: Summary of Abstraction for Scenario 11

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.19	18.91	-2.50	-10.46	0.00
2	1.95	1.16	-2.68	-7.92	0.62
3	-0.12	20.50	-2.90	-7.95	0.01
4	-0.71	0.26	-4.99	-0.15	0.05
5	0.17	0.00	-1.88	0.00	2.33
6	-1.17	0.00	-3.07	0.00	0.40
Subarea A Total	2.31	20.07	-7.06	-18.38	2.95
Subareas B-L Total	-2.00	20.76	-10.96	-8.10	0.46

Table 21: Scenario 11 Water Balance Summary

3.6 Scenarios 12 and 13 – Increased Monthly Limit Allocation on Selected Bores

Scenarios 12 and 13 simulate the existing allocations under moderate frequency recharge and low frequency recharge conditions, respectively, with the following modifications:

- Large users are allowed to abstract 15,000 kL/month, 5,000 kL more than is presently allowed;
- The increased monthly abstraction is in addition to the existing allocation, resulting in Subarea A allocation increasing to 7.1 GL/annum.
- Abstraction from Subareas B-L remains the same as in the existing management plan.

These scenarios quantify whether the additional monthly abstraction results in decreasing water quality.

The water balance for the abstraction bores in scenario 12 and 13 are summarised in Tables 22, 23 and 24. Table 22 shows that over the course of the 8.6 year moderate frequency recharge simulation, the average abstraction from Subarea A is 4.9 GL/annum of fresh water, and 2.3 GL/annum of brackish water. Compared to the results of Scenario 3, the results do not show any significant difference in the total volume water abstracted meeting water quality criteria. This result suggests that increased monthly abstraction from large users should not result in a significant increase in TDS in abstracted water.

Table 22 also shows that over the course of the 10 year low frequency recharge simulation, the average abstraction from Subarea A is 4.7 GL/annum of fresh water and 2.5 GL/annum of brackish water. Compared to the results of Scenario 4, the results do not show any significant difference in the total volume water abstracted meeting water quality criteria. This result suggests that increased monthly abstraction from large users, even under no-flow conditions, should not result in a significant increase in TDS in abstracted water.

Based on the results of these scenarios, it may be possible to increase the monthly allocation for those bores that have good water quality to 15,000 kL/month. However, additional sampling and water level monitoring should be undertaken to confirm the modelling results.

Scenario	Subarea A						Subareas B – L					
	Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)			Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)		
	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS Concentration (mg/L)
12	4.9	69	480	2.3	33	2500	8.4	69	435	2.9	24	1075
13	4.7	66	433	2.5	35	2948	17.8	99	473	0.0	0	0

Table 22: Summary of Abstraction for Scenario 12 and 13

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.22	20.74	-2.39	-12.18	0.00
2	2.03	1.34	-2.57	-8.44	0.68
3	-0.23	20.60	-2.76	-8.55	0.01
4	-0.55	0.24	-4.84	-0.13	0.05
5	0.15	0.00	-1.86	0.00	2.59
6	-1.10	0.00	-3.02	0.00	0.40
Subarea A Total	1.96	22.08	-6.82	-20.62	3.27
Subareas B-L Total	-1.88	20.84	-10.62	-8.68	0.46

Table 23: Scenario 12 Water Balance Summary

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	0.25	14.29	-2.31	-7.46	0.00
2	2.26	0.91	-2.17	-7.10	0.63
3	0.35	20.80	-3.39	-7.31	0.01
4	0.48	0.34	-4.08	-0.17	0.05
5	0.23	0.00	-2.12	0.00	2.37
6	0.55	0.00	-7.58	0.00	0.11
Subarea A Total	2.74	15.20	-6.60	-14.56	3.00
Subareas B-L Total	1.38	21.14	-15.05	-7.48	0.17

Table 24: Scenario 13 Water Balance Summary

3.7 Scenarios 14, 15 and 16 – Stochastic Climate Sequences

Scenarios 14, 15 and 16 are 20-year simulations that model the potential volume able to be abstracted under dry, median and wet climate conditions, respectively, with the following modifications:

- Subarea A allocations are increased to a total of 11 GL/annum;
- This increased abstraction is accommodated by duplicating all production bores in Subarea, and offsetting the duplicated bores by 50 metres north and south, with the original bore removed from the model.
- Groundwater abstraction may only occur while the river is not flowing, with all water being drawn from river flow;
- Abstraction from Subareas B-L is maximized to 26 GL/annum as described above.
-

The dry, median and wet climate sequences were constructed as follows:

- Daily river stage height data for the years 1959 to 2010 were collated;
- A statistic was defined to describe the amount of recharge that is to be expected for a given calendar year (i.e. a year's recharge potential), defined as the sum of the daily average flowing river stage height days for that year, with units metre-days (m*d, or md);
- 1,000 20-year climate sequence replicants were created by randomly selecting 20 of the years from 1959 to 2010, and concatenating them in a random order;
- The total recharge potential of a replicant was calculated as the sum of the recharge potentials of each of the years that make up the replicant;
- The 1000 sequences were then ranked on their recharge potentials, and the 50th, 500th and 950th were chosen, representative of the 5th, 50th and 95th climate percentiles as definitions of dry, median and wet sequences respectively.

The river stage height (metres) and flowing duration (days) are the variables incorporated into the recharge potential statistic, which is assumed to correctly reflect the likely recharge to aquifer for that year. However further study should be undertaken to confirm the validity of using these variables to rank recharge versus using other variables such as daily river discharge volumes, or a combination of variables.

The 5th percentile climate replicant represents a 20-year climate sequence that is drier than 19 out of any 20 random climate sequences that can be constructed from the data of the last 50 years. Similarly, the 95th percentile climate replicant represents a 20-year climate sequence that is wetter than 19 out of any 20 random climate sequences that can be constructed from the data of the last 50 years. The 50th percentile climate replicant is representative of an average 20-year climate sequence.

Each model was run for 20 years, from January 2012 to December 2031. The dry, median and wet sequences' stage heights are shown in Figures 36, 37 and 38 below, respectively.

The 11 GL/annum Subarea A abstraction sequences used for Scenarios 14, 15 and 16 were constructed as follows:

- For the period 1991 to 2000, the average pumping rate for each bore for each month of the year was calculated, under conditions when the river is not flowing;
- Each bore in each month of the 20 year sequence was assigned the corresponding pumping value, if the river was not flowing in that month; otherwise pumping was set to zero.
- Total abstraction in Subarea A was then calculated on a yearly basis, and scaling factors for each year were calculated in order to bring abstraction for each year up to 11

GL/annum.

The use of the above algorithm ensures that modelled abstraction will be up to 11 GL/annum in Subarea A, and that groundwater is only abstracted when the river is not flowing.

Subareas B-L abstraction remained identical to that used for Scenarios 5 and 6, i.e. 26 GL/annum, including Brickhouse abstraction.

The water balance for the abstraction bores in Scenarios 14, 15 and 16 are summarised in Tables 25, 26, 27 and 28. Table 25 shows that over the course of the 20 year dry simulation, the average abstraction from Subarea A is 3.6 GL/annum of fresh water, and 1.6 GL/annum of brackish water. Compared to the results of Scenario 9, the results show a significant reduction in the total volume of water abstracted by pumping. When combined with the results of scenarios 1, 2 and 3, the results suggest that 5% percentile is between 3.6 and 4.1 GL/annum. This result suggests that there is a 5% chance of not being able to meet 3.6 GL/annum of abstraction, i.e. 19 out of every 20 years' abstraction will be greater than 4.1 GL of fresh water.

Table 25 also shows that over the course of the 20 year average simulation, the average abstraction from Subarea A is 8 GL/annum of fresh water and 2.8 GL/annum of brackish water. Compared to the results of Scenario 9, the results do not show any significant difference in the total volume water abstracted meeting water quality criteria. This result suggests that there is a 50% confidence that 8 GL/annum of fresh water can be abstracted from Subarea A in any given year.

Table 25 also shows that over the course of the 20 year wet simulation, the average abstraction from Subarea A is 7.8 GL/annum of fresh water and 3 GL/annum of brackish water. Compared to the results of Scenario 9, the results do not show any significant difference in the total volume water abstracted meeting water quality criteria. This result, coupled with the result from Scenario 15, suggests that abstraction from Subarea that 8 GL/annum of fresh water represents the likely upper limit of abstraction attainable from Subarea A.

Based on the results of these scenarios, there is a 95% chance of surpassing 3.6 GL/annum abstraction in any given year, and a 50% chance of abstracting 8 GL/annum in any given year. The 95% percentile of 11.2 GL/annum, which is inferred based on the moderate frequency recharge distribution may be a good estimate of total accessible fresh water storage in the system and represents the limit that Subarea A will be able to deliver.

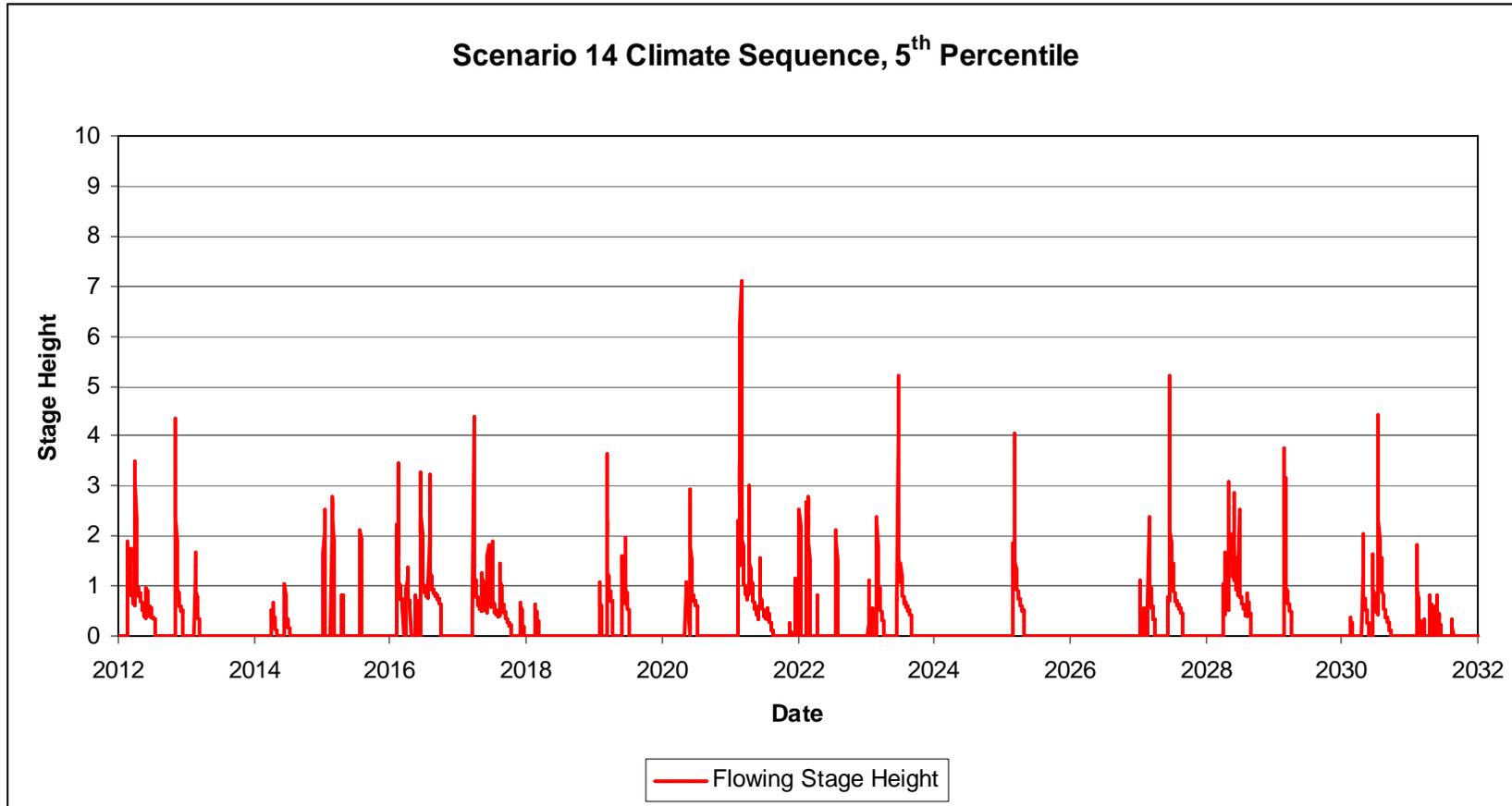


Figure 36: Scenario 14 Dry Climate Sequence, 5th Percentile

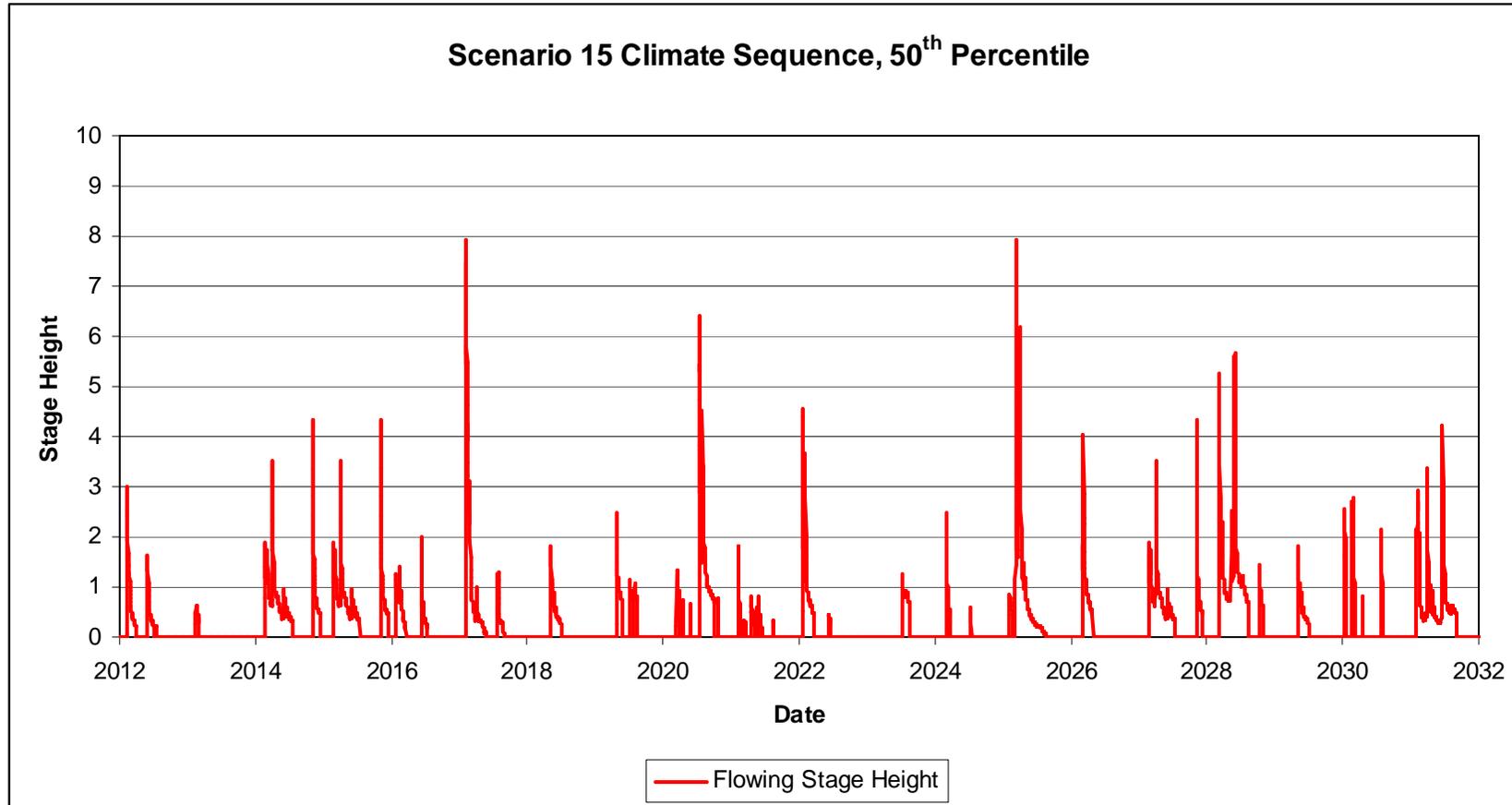


Figure 37: Scenario 15 Average Climate Sequence, 50th Percentile

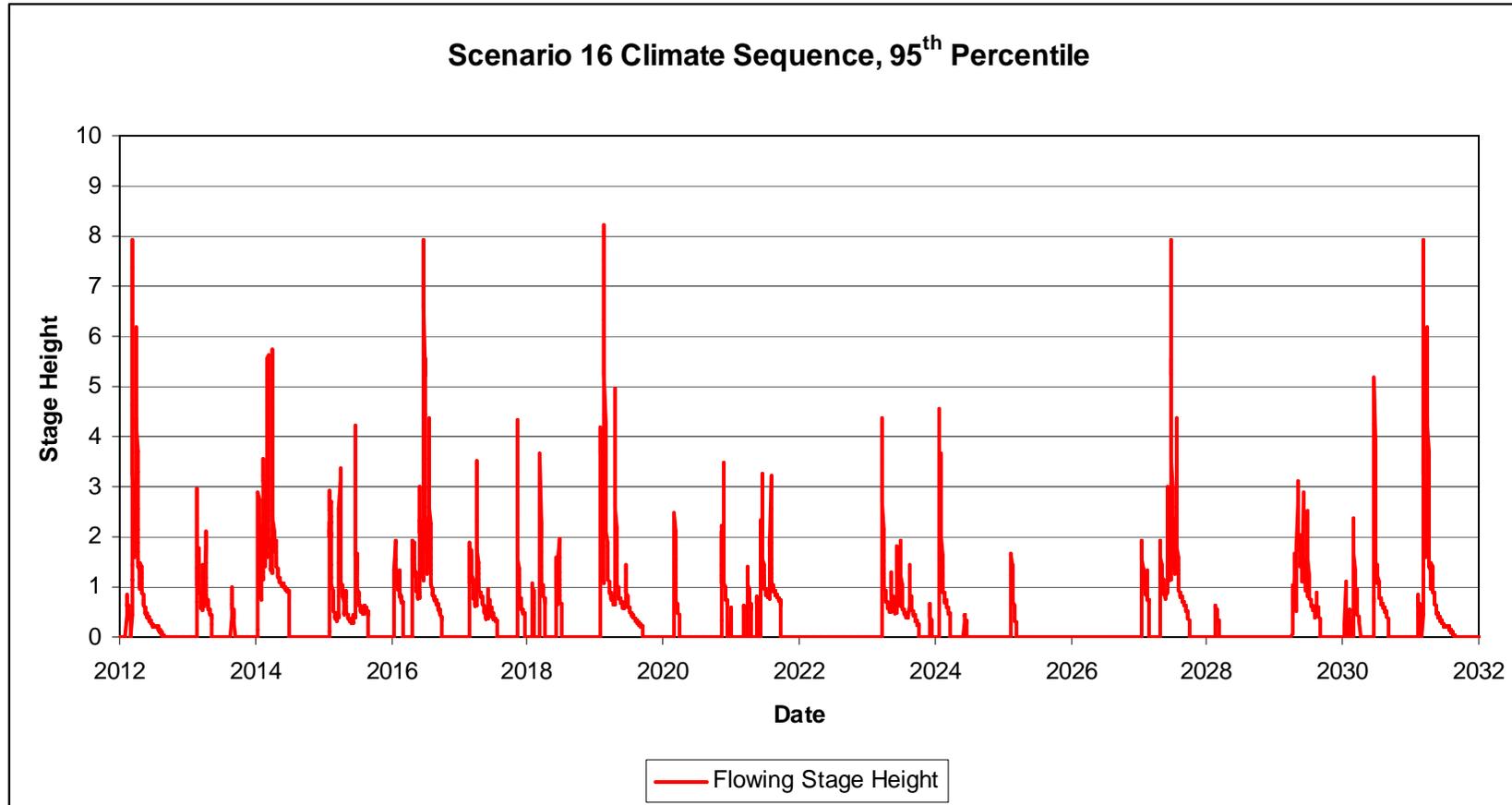


Figure 38: Scenario 16 Wet Climate Sequence, 95th Percentile

Scenario	Subarea A						Subareas B – L					
	Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)			Fresh (< 1000 mg/L)			Saline (> 1000 mg/L)		
	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS (mg/L)	Abstraction (GL/a)	% of Expected	Average TDS Concentration (mg/L)
14	3.6	33	614	1.6	14	2535	20.5	79	495	5.8	22	2133
15	8.0	73	431	2.8	26	2723	20.5	79	488	5.5	21	2134
16	7.8	71	461	3.0	28	2694	20.9	80	471	5.2	20	2179

Table 25: Summary of Abstraction for Scenario 12 and 13

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.71	16.69	-1.67	-11.29	0.00
2	0.80	1.10	-1.35	-6.76	0.68
3	-0.53	25.9	-5.65	-8.27	0.01
4	0.73	0.43	-3.69	-0.13	0.05
5	0.03	0.00	-1.42	0.00	2.60
6	2.20	0.00	-11.45	0.00	0.16
Total	2.53	44.1	-25.23	-26.5	3.50

Table 26: Scenario 14 Water Balance Summary

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.92	21.31	-3.71	-9.56	0.00
2	0.87	1.27	-3.02	-6.44	0.68
3	-0.65	27.9	-5.65	-9.48	0.01
4	0.62	0.48	-3.83	-0.16	0.05
5	0.03	0.00	-3.37	0.00	2.60
6	2.15	0.00	-11.32	0.00	0.17
Total	2.09	50.9	-30.90	-25.6	3.50

Table 27: Scenario 15 Water Balance Summary

Zone	Storage (GL/annum)	Recharge (GL/annum)	Wells (GL/annum)	Evaporation (GL/annum)	Inflows (GL/annum)
1	-0.25	21.49	-3.92	-10.68	0.00
2	1.20	1.42	-3.08	-6.88	0.68
3	-0.56	35.9	-5.92	-14.81	0.01
4	0.49	0.83	-5.57	-0.30	0.05
5	0.09	0.00	-2.96	0.00	2.60
6	1.14	0.00	-11.11	0.00	0.16
Total	2.11	59.6	-32.57	-32.7	3.50

Table 28: Scenario 16 Water Balance Summary

4 ESTIMATED YIELD RANGE

The yield is defined as the level of water extraction from a particular system that, if exceeded, would compromise environmental assets, or ecosystem functions and the result in other economic loss.

Due to the highly variable nature of the aquifer system, yield is presented as a statistical range rather than a specific value for the Gascoyne aquifers. This approach accounts for the variation in the level of aquifer storage due to the sequence of recharge events in previous years and the statistical nature of river flow. The stochastic climate sequences modelled in Scenarios 14, 15 and 16 allow for the random combinations of aquifer storage levels with recharge events thereby providing a statistical estimate of yield under a variety of conditions.

Based on the results of the sixteen modelled scenarios, aquifer yield ranges were constructed by assessing the 5th percentile annual abstraction and median annual abstraction, for both Subarea A and Subareas B-L, and using these values to construct normally distributed yield ranges. Note that the use of a normal distribution is an assumption and hence may not necessarily reflect the actual probability of the model aquifer outcomes.

The 5th percentile annual abstraction is defined as the abstraction that can be realised in 19 out of every 20 years, i.e. there is a 95% chance of meeting this abstraction in any given year. The median annual abstraction (50th percentile) is similarly defined as the abstraction that can be realised in 1 out of every 2 years.

For Subarea A, the freshwater abstraction for Scenarios 11/14 and 15 represent the 5th and 50th percentiles, respectively, of the Subarea A yield range, as shown in Table 29 below. Due to the uncertainty with regards to yield in Subareas B-L, and the insensitivity of yield in Subareas B-L to differing climates, as shown by Scenarios 14, 15 and 16, the 5th and 50th percentiles were defined as the freshwater abstraction realised by Scenario 5 and Scenario 15, respectively, as shown in Table 29 below.

Based on the 5th and 50th percentiles for each subarea, normally distributed yield ranges were computed. The probability distribution functions and cumulative distribution functions for the calculated yield ranges are shown in Figures 39 and 40 below for Subarea A and Subareas B-L, respectively.

Subarea	95% Probability of Realisation (GL/annum)	50% Probability of Realisation (GL/annum)	Standard Deviation
A	4.1	8.0	2.37
B-L	10.7	20.5	5.95

Table 29: Subarea A and Subareas B-L Yield Range Parameters

Figure 39 shows that there is a 95% probability that 4.1 GL of fresh water can be pumped from Subarea A on an annual basis, and that an average of 8.0 GL of fresh water may be pumped from Subarea A in the long term. The statistics are based upon the implementation of optimised infrastructure to more efficiently recover the water resource in Subarea A. Though the estimated yield range indicates that there is a 5% probability that 11.9 GL of fresh water may be pumped out of Subarea A in a given year, this may be limited by aquifer storage and recharge rates and there may be some difficulty experienced in realising this amount of abstraction, even under the most favourable conditions.

Figure 40 shows that there is a 95% probability that 10.7 GL of fresh water can be pumped from Subareas B-L on an annual basis, and that a median of 20.5 GL of fresh water may be pumped from Subareas B-L. Though the estimated yield range indicates that there is a 5% probability that 30.3 GL of fresh water may be pumped out of Subareas B-L in a given year, this may be limited by aquifer storage and recharge rates and there may be some difficulty experienced in realising this amount of abstraction, even under the most favourable conditions.

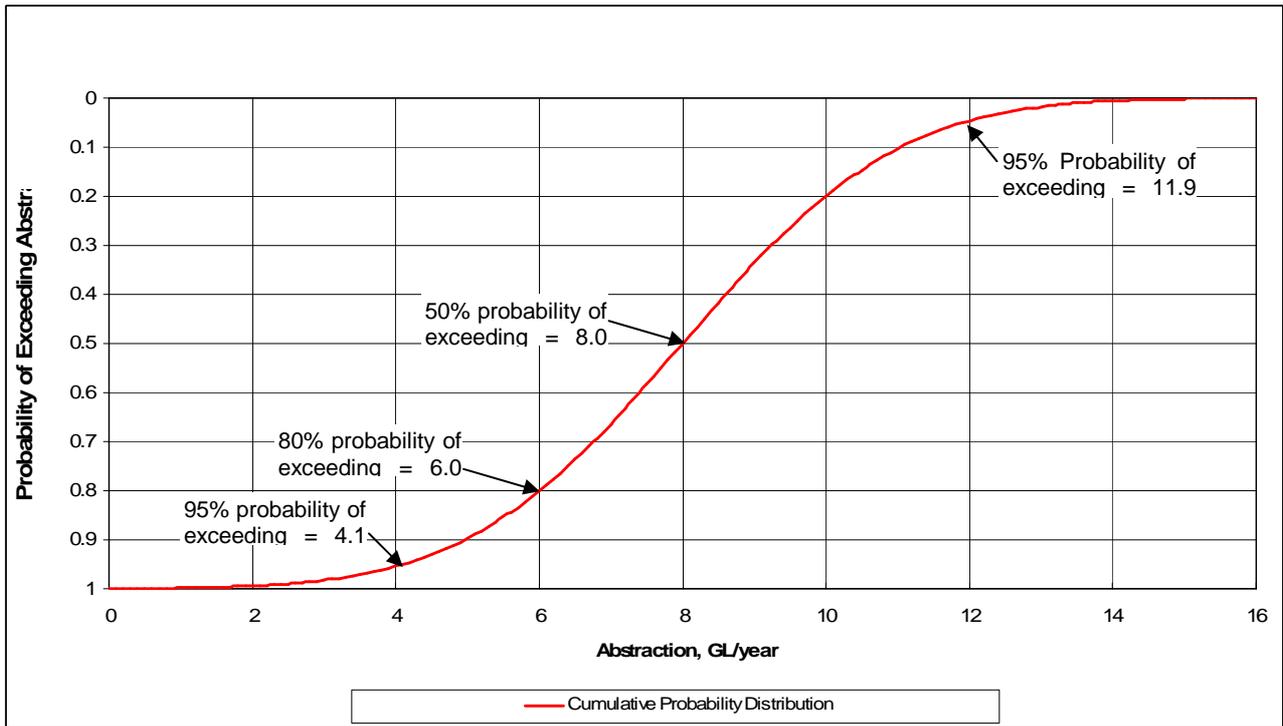


Figure 39: Subarea A Yield Range

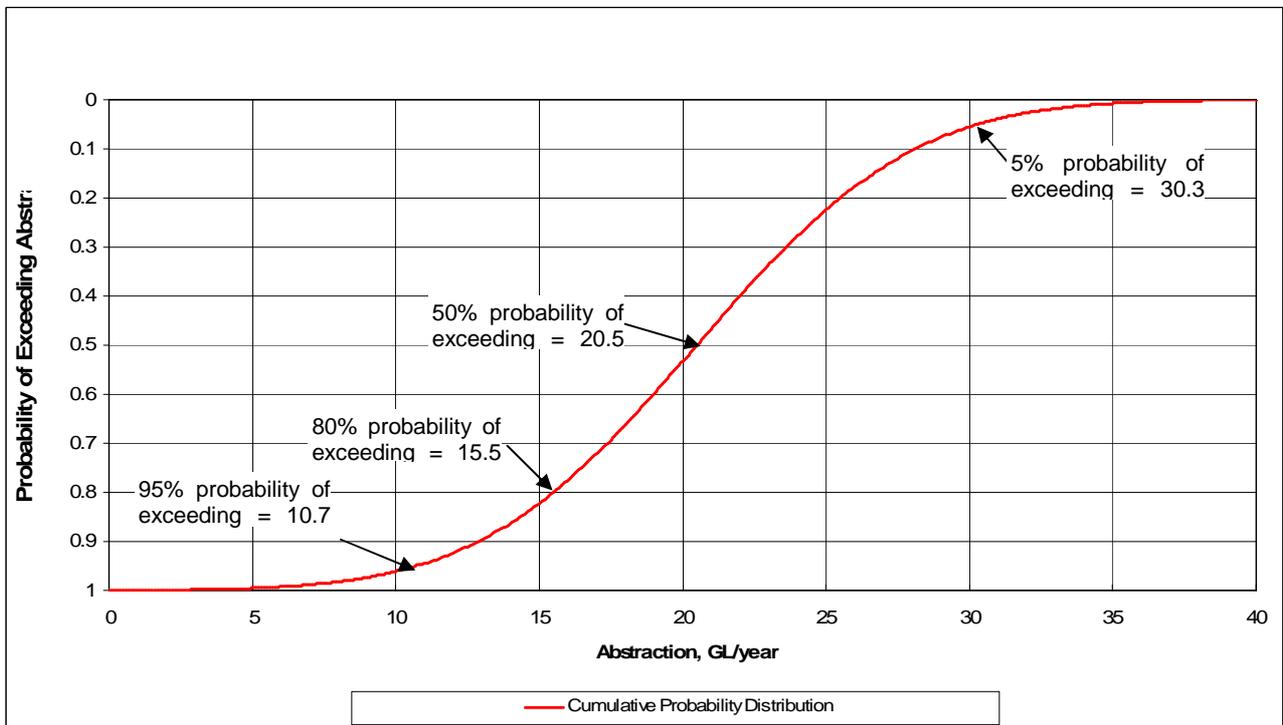


Figure 40: Subareas B-L Yield Range

5 CONCLUSIONS

The GASFAMS V1.1 was used to simulate sixteen abstraction scenarios.

Results for Scenarios 1 through 6 indicate:

- The total volume of abstracted water from Subarea A is constrained both by the number of bores (i.e. available infrastructure), but also by the water quality produced from those bores, with the estimated maximum fresh water abstraction of 4.1 GL/annum on average.
- The available resources in Subareas B-L are sufficient to meet the maximum allocation of 26 GL/annum, without significant water quality issues.
- The location of bores and operating strategy in Subareas B-L has a significant effect on the total fresh water available, as reflected in the different fresh water resources under moderate frequency recharge and low frequency recharge conditions.
- The average TDS of abstracted brackish water in Subarea A provides an opportunity for co-mingling production from selected bores to obtain additional resources meeting the 1000 TDS criterion.
- Abstraction from the Brickhouse borefield is not materially impacted over the 10 year abstraction period by changes in water quality.

Results for Scenarios 7 and 8 indicate:

- The average abstraction of fresh water from Subarea A is 6.4 GL/annum, and 2.2 GL/annum of brackish water;
- Total abstraction from Subarea A is 8.6 GL/annum indicating that with duplicate bores, it is likely the area would be able to produce 8.6 GL/annum under moderate frequency recharge conditions.
- If all bores are produced, a total of 8.6 GL/annum would be abstracted at an average water quality of 1020 mg/L.
- Over the course of the 10 years in the low frequency recharge simulation, the average abstraction of fresh water from Subarea A is 5.8 GL/annum, and 2.6 GL/annum of brackish water.
- Total abstraction from Subarea A is 8.4 GL/annum indicating that with duplicate bores, it is likely the area would be able to produce 8.6 GL/annum under low frequency recharge conditions.
- If all bores are produced, a total of 8.4 GL/annum would be abstracted at an average water quality of 1200 mg/L.
- Based on the results of these scenarios, it may be possible to increase the monthly allocation for those bores that have good water quality to a total of 6.4 GL/annum. However, additional sampling and water level monitoring should be undertaken to confirm the modelling results.
- Given the average water quality there may be opportunities for increasing total abstraction above 6.4 GL/annum if blending of water could be undertaken at the subarea or sub subarea scale.

Results for Scenarios 9 and 10 indicate:

- That over the course of the 8.6 year moderate frequency recharge simulation, the average abstraction of fresh water from Subarea A is 8.1 GL/annum, and 2.9 GL/annum of brackish water.
- Total abstraction is 11.0 GL/annum indicating that with duplicate bores, it is possible the area could produce 11 GL/annum under moderate frequency recharge conditions.
- If all bores are produced, a total of 11 GL/annum would be abstracted at an average water quality of 1020 mg/L.
- Over the course of the 10 year low frequency recharge simulation the average abstraction of fresh water is 7.4 GL/annum and 3.3 GL/annum of brackish water. The total abstraction from Subarea A is 10.7 GL/annum, indicating that even with duplicate bores, Subarea A will have difficulty producing 11 GL/annum under low frequency recharge conditions.
- If all bores are produced, a total of 10.7 GL/annum would be abstracted at an average water quality of 1210 mg/L. This exceeds the TDS criteria by 210 mg/L and suggests that during low frequency recharge it will be more difficult to increase total abstraction above 7 GL/annum using the blending of water.
- It may be possible to increase the monthly allocation for those bores that have good water quality to about 7 GL/annum. However, additional sampling and water level monitoring should be undertaken to confirm the modelling results.

Results for Scenario 11 indicate:

- That over the course of the 10 year modified recharge simulation; the average abstraction of fresh water from Subarea A is 4.1 GL/annum, and 1.81 GL/annum of brackish water. Total abstraction is 5.8 GL/annum.
- These results suggest that Subarea A has limited sensitivity to the recharge sequence used in the simulations, as the results are similar to Scenarios 3 and 4.
- For Subareas B-L, the average abstraction of fresh water from Subareas B-L is 7.1 GL/annum and 2.5 GL/annum of brackish water. Total abstraction is 9.6 GL/annum.
- These results show a significant reduction in fresh water abstraction compared to the Scenarios 1, 2 and 3.

This suggests that Subareas B-L has some sensitivity to the recharge sequence used in the simulations. Based on the results of these scenarios, it suggests that Subareas B-L is sensitive to the occurrence of large floods, which is consistent with the conceptual model of recharge in this area.

Results for Scenarios 12 and 13 indicate:

- That over the course of the 8.6 year moderate frequency recharge simulation, the average abstraction from Subarea A is 4.9 GL/annum of fresh water, and 2.3 GL/annum of brackish water.
- Compared to the results of Scenario 3, the results do not show any significant difference in the total volume water abstracted meeting water quality criteria.
- For the low frequency recharge scenario the average abstraction from Subarea A is 4.7 of fresh water, and 2.5 GL/annum of brackish water.
- Compared to the results of Scenario 4, the results do not show any significant difference in the total volume water abstracted meeting water quality criteria.
- These results suggest that increased monthly abstraction from large users, even under no-flow conditions, should not result in a significant increase in TDS in abstracted water.

Results for Scenarios 14, 15 and 16 indicate:

- Under a 5th percentile 20-year dry sequence, the average abstraction from Subarea A is 3.6 GL/annum of fresh water, and 1.6 GL/annum of brackish water.
- Under long term average climate conditions, the average abstraction from Subarea A is 8.0 GL/annum of fresh water, and 2.8 GL/annum of brackish water.
- Under the 95th percentile 20-year wet sequence, the average abstraction from Subarea A is 7.8 GL/annum of fresh water, and 3.0 GL/annum of brackish water.
- Under a 5th percentile 20-year dry sequence, the average abstraction from Subareas B-L is 20.5 GL/annum of fresh water, and 5.8 GL/annum of brackish water.
- Under long term average climate conditions, the average abstraction from Subareas B-L is 20.5 GL/annum of fresh water, and 5.5 GL/annum of brackish water.
- Under the 95th percentile 20-year wet sequence, the average abstraction from Subareas B-L is 20.9 GL/annum of fresh water, and 5.2 GL/annum of brackish water.
- Compared to the results of Scenarios 9, the results of Scenarios 15 and 16 do not show any significant difference in the total volume water abstracted meeting water quality criteria.
- Under prolonged low frequency recharge conditions, there is a significant reduction in aquifer deliverability and abstracted water quality.

The aquifer yield estimates for Subarea A and Subareas B-L suggest that:

- there is a 95% probability that 4.1 GL of fresh water can be pumped from Subarea A on an annual basis;
- there is a 50% probability that 8.0 GL of fresh water can be pumped from Subarea A on an annual basis;
- Though the estimated yield range indicates that there is a 5% probability that 11.9 GL of fresh water may be pumped out of Subarea A in a given year, this may be limited by aquifer storage and recharge rates and there may be some difficulty experienced in realising this amount of abstraction, even under the most favourable conditions.
- there is a 95% probability that 10.7 GL of fresh water can be pumped from Subareas B-L on an annual basis;
- there is a 50% probability that 20.5 GL of fresh water can be pumped from Subareas B-L on an annual basis;
- Though the estimated yield range indicates that there is a 5% probability that 30.3 GL of fresh water may be pumped out of Subareas B-L in a given year, this may be limited by aquifer storage and recharge rates and there may be some difficulty experienced in realising this amount of abstraction, even under the most favourable conditions.

6 REFERENCES

- ALLEN, A.D. 1971a. Gascoyne River investigation. GSWA Hydrogeology Rep. 873
- ALLEN, A.D. 1971b, Cretaceous–Holocene stratigraphy and structure, Lower Gascoyne River, Carnarvon Basin, W.A. GSWA Hydrol. Rep. 901
- ALLEN, A.D. 1971c, Groundwater resources along the Lower Gascoyne River – a summary. GSWA Hydrol. Rep. 902
- ALLEN A.D. 1972, Results of Investigation into Groundwater Resources along Lower Gascoyne River for Carnarvon Irrigation and Town Water Supplies. GSWA Record 1972/9.
- Aquaterra Consulting Pty Ltd, 2000, Murray-Darling Basin Commission Groundwater Flow Modelling Guideline, November 2000
- CyMod Systems, 2009, The Development of the Gascoyne River Floodplain Aquifers Modelling System, GASFAMS V1, July 2009
- DODSON, WJ, 2000. *Gascoyne River Floodplain Aquifer Model*. HR172.
- DODSON, W.J. 2001, Basin A water quality review, Lower Gascoyne River. WRC file 15040 Hydrogeol. Rep. 192
- DODSON, WJ, 2002. *Estimating Recharge from Ephemeral Rivers In Arid Environments*. A case study and numerical model of the Gascoyne River, Western Australia
- DODSON, WJ, May 2002. *Groundwater Recharge from the Gascoyne River, Western Australia*. HR204
- FIRTH, K. 1998. Carnarvon Artesian Basin Infrastructure Survey. DoW Reference Call No. 556.51 (941.29) FIR
- GLOBAL GROUNDWATER, 2006, Brickhouse Drilling Bore Completion Report, Department of Agriculture.
- GSWA, 1985, Kennedy Range, 1:250,000 Geological Map Sheet SG 50-1, Geological Survey of Western Australia, Second Edition, 1985.
- HOCKING, RM, MOORS, HT and VAN DE GRAAFF, JE, 1987, Geology of the Carnarvon Basin, WA. WA Geological Survey Bulletin 133.
- MARTIN, MW, 1990a, *Carnarvon Irrigation Scheme Recharge and Salinity Investigation Well Completion Report*, Western Australia Geological Survey, Hydrogeology Report No. 1990/10 (unpublished).
- MARTIN, MW, 1990b, *Groundwater Resources of the Older Alluvium, Gascoyne River, Carnarvon, Western Australia*: Western Australia Geological Survey, Hydrogeology Report No 1990/21 (unpublished).
- MARTIN, MW, 1992, *Carnarvon Irrigation Scheme Well Field Drilling Investigation, 1992*, Western Australia Geological Survey, Hydrogeology Report No. 1992/45 (unpublished).
- MARTIN, MW, 1993, *Carnarvon Irrigation Scheme, Basin F Pumping Trial*: Western Australia Geological Survey, Hydrogeology Report No. 1993/40 (unpublished).
- MIDDLEMIS, H., 2001, Groundwater Flow Modelling Guideline, Report for Murray-Darling Basin Commission.
- SINCLAIR KNIGHT MERZ (SKM), 2002, Lower Gascoyne River, Carnarvon Flood Plain Management Study, Water and Rivers Commission (now Department of Water, WA), Shire of Carnarvon, Volumes 1 and 2, October 2002.
- SKIDMORE, D.J.P., 1997, Carnarvon Irrigation Scheme, Review of Monitoring Requirements: Water and Rivers Commission, Western Australia, Hydrogeology Report No. 91 (unpublished).
- SMEC Australia 2001. Ecological Water Requirements for the Lower Gascoyne River, Carnarvon, WA. Marcam Environmental, Marshall, JK in SMEC, 2001.
- USGS, 1998, *A Modular Three-dimensional Finite-Difference Groundwater Flow Model*, United States Geological Survey.
- USGS, 1996, User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, U.S. GEOLOGICAL SURVEY, Open-File Report 96-485

- USGS, 2000, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model— User Guide To The Observation, Sensitivity, And Parameter-Estimation Processes And Three Post-Processing Programs Open-File Report 00-184.
- USGS, 2002, User's Guide for the Limited Drawdown Multi-Node Well Package for the U.S. Geological Survey's Modular Finite-Difference Ground-Water Flow Model, Versions MODFLOW96 and MODFLOW-2000, Open-File Report 02-293
- VOGWILL, R.I.J., 1971, Aquifer testing at the Gascoyne River. GSWA Hydrogeol. Rep. 896
- VOGWILL, R.I.J., 1972, Aquifer testing at the Gascoyne River. GSWA Hydrogeol. Rep.HR1076.
- Water Corporation, 1999a. Carnarvon water source plan: Infrastructure Planning Branch
- Water Corporation 1999b. Carnarvon source review: Performance assessment of the Gascoyne River borefield; Infrastructure Planning Branch