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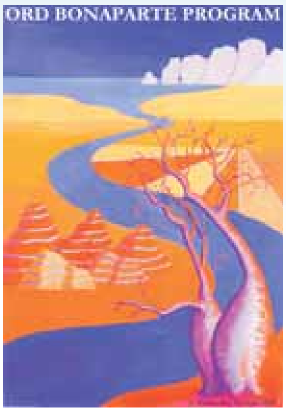
Water Levels and Water Quality Trends in the Ord River Irrigation Area (ORIA) for the Period September 2001 - March 2003

Daniel W. Pollock, Ramsis B. Salama and Neil R. Viney



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AUSTRALIAN CENTRE FOR INTERNATIONAL AGRICULTURAL RESEARCH

CSIRO Land and Water, Perth
Technical Report 40/03, June 2003

CSIRO LAND and WATER

WATER LEVELS AND WATER QUALITY TRENDS IN THE ORD RIVER IRRIGATION AREA (ORIA) FOR THE PERIOD SEPTEMBER 2001 – MARCH 2003

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ABSTRACT

The water level data from September 2001 to March 2003 reveal variable water level trends across the irrigation area, and within transects. This indicates a response to localised events (e.g. irrigation), and may be related to the distance between the bores and nearby channels. There is also a significant response in water levels across the irrigation area to a major rainfall event in February 2002, where 110 mm of rain fell in one day, with over 200 mm falling in five days (remnants of Cyclone Steve). Over the monitoring period, the maximum water level variation at one site was in the order of 2 m (i.e. range from minimum to maximum). The water level response in the Packsaddle Plain was more uniform than in the Ivanhoe Plain. In the Packsaddle Plain, water levels tended to rise in the wet season of 2001-2002, and fell for the remainder of the monitoring period. Water levels in the Ivanhoe Plain show non-uniform responses, possibly as a result of local irrigation events.

The monthly average total mass solute export coefficient from the Ivanhoe Plain is about 4900 kg/ km^2/month of solutes which is very high compared to the monthly average total mass export coefficient from the overall Ord River catchment of 800 kg/km^2/month of solutes.

Although the Ivanhoe Plain irrigation area drains contribute less than 15% of the total solutes in the Ord River at Tarrara Bar, this is a relatively high contribution compared to the volumes discharging from the drains to the total volume flowing in the Ord. This rather high solute load is mainly due to the excessive leaching of salts from soils and other chemicals used in the irrigation area.

BACKGROUND

Location

The Ord River Irrigation Area (ORIA) is located in the East Kimberley region of Western Australia and the Northern Territory. The OBP Regional Irrigation study encompasses the Packsaddle and Ivanhoe Plains, which cover a total area of approximately 15,000 ha. Irrigated agriculture commenced in 1963, leading to significant changes in the hydrologic budget of the aquifers underlying the plains.

Hydrogeology

The Ivanhoe Plain contains superficial sediments resting on a palaeo-topographic surface of basalt, sandstone and limestone. The geological sequence is comprised of a superficial sequence consisting of river gravels, sandy, poorly cemented sands or sandstones, silty clays and clays, and show extreme variation in lateral and vertical distribution (McGowan, 1983). This reflects deposition in a complex sedimentary environment involving two braided river systems. McGowan (1983) classified the sediments regionally in terms of two predominant lithotypes: gravels and clays. Very coarse sand sequences show local association with the gravels. Other sands as well as cemented sands and silts occur within the clay sequences and are interpreted as thin interbeds or poorly sorted strata. Two major gravel units have been identified and represent two palaeo-river systems. The upper unit is less than 10 m thick with an average thickness of 2 m. The thickness of the lower unit varies between 5–20 m. Both units are present over a considerable area of the Ivanhoe Plain (McGowan, 1983).

Groundwater exists mainly in the superficial and alluvial deposits within palaeochannels and depressions of the Ivanhoe and Packsaddle Plains. Due to the nature and thickness of the gravel and very coarse sand strata, transmissivities of the superficial sediments are locally very high ($>1000\ m^2d^{-1}$) and generally high ($>100\ m^2d^{-1}$) where the lower gravel unit is greater than 5 m thick. The areas in which the upper gravel unit is thickest usually correspond to areas with the highest transmissivities and good interconnectivity between the upper and lower gravels (McGowan, 1983). On the other hand, the calculated mean sand and gravel aquifer transmissivity from aquifer tests in the Ivanhoe Plain is about 2400 m^2d^{-1} and a hydraulic conductivity of 400 md^{-1}, assuming a 6 m thick aquifer (O'Boy, 1997; 1998). The mean transmissivity of the deep gravel aquifer at Packsaddle is about 2000 m^2d^{-1}, which gives a hydraulic conductivity of 333 md^{-1}, assuming a 6 m-thick aquifer (O'Boy, 1997).

HYDROLOGICAL ZONES IN THE ORD RIVER IRRIGATION AREA (ORIA)

Prior to the construction of the Diversion Dam and the associated irrigation and drainage system, two main processes controlled the depth to groundwater and groundwater flow in the ORIA: the recharge and discharge patterns of the Ord River and the recharge from rainfall during the wet season. Water levels were deep and the main direction of flow was from the eastern high grounds towards the Ord River and northeast towards Cave Spring Gap. After the construction of the Diversion Dam and the M1 channel, several hydrological compartments were created which changed and controlled groundwater flow and depth to water in the Packsaddle and the Ivanhoe Plains. Based on this new hydrological regime, the following hydrological zones (compartments) were created (Figure 1).

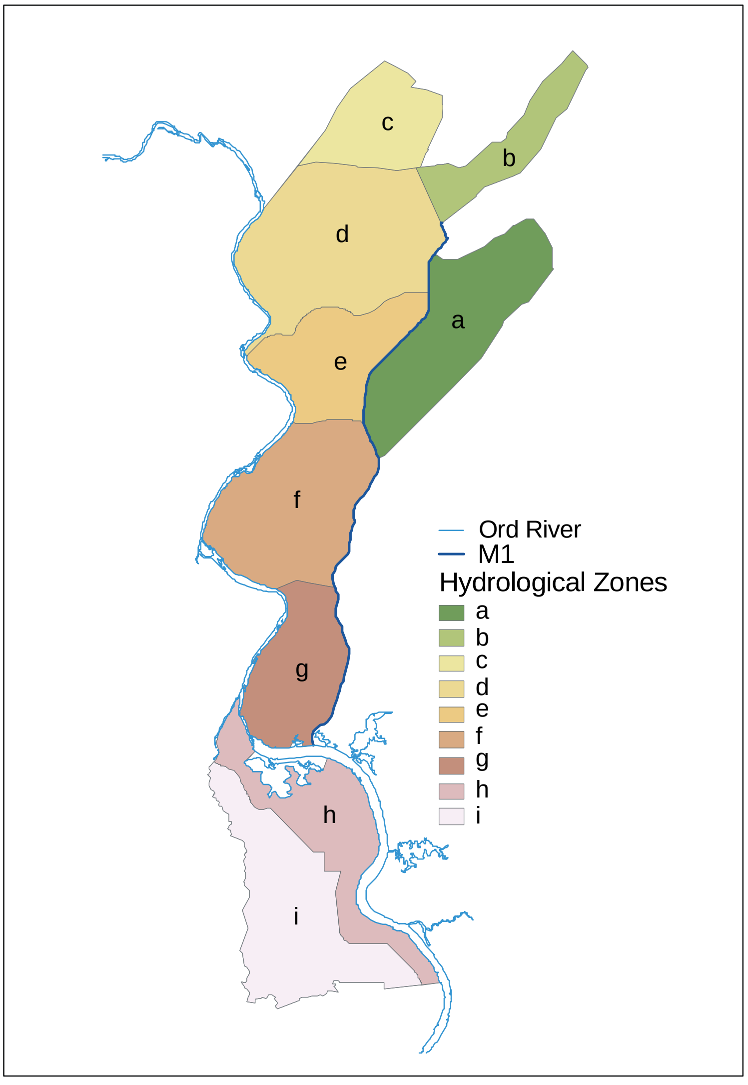

Figure 1: Hydrological Zones of the Ord

Hydrological zones in Ivanhoe Plain:

The filling of the Diversion Dam, M1, and associated irrigation channels created several hydrological zones in the Ivanhoe Plain (Salama *et al*., 2002a): The Southern Zone (G) of the Ivanhoe Plain is defined by Kununurra Lake to the south, the M1 to the east, the Ord River to the west, and supply channel S2 and the northeast bend of the Ord River to the north. The Middle Zone (F) is controlled by the M1 to the east, the Ord River to the west, the S2 channel to the south and the S3 channel to the north. The Kimberley Research Station Zone (E) is defined by the M1 to the east, the Ord River to the west and Dumas Lookout to the north. Dumas Lookout Zone (D) is defined by the basalt outcrop at Dumas Lookout to the south, M1 to the east, D7 to the north, and the Ord River to the west.

Green Location Zone (C) covers the northern part of the irrigation area, north of D7. Martins Location Zone (A) is the only zone east of the M1; the flooding of the M1 and rising groundwater levels along the M1 create a subsurface dam, which constricts the flow out of Martins Zone. Cave Spring Gap Zone (B) is the most northern zone and covers the narrow gap, surrounded to the southeast and northwest by outcropping bedrock, which forms a bottleneck.

Hydrological zones in Packsaddle Plain:

The construction of the Diversion Dam and the filling of Lake Kununurra created a backwater effect on Packsaddle Plain. The rising water levels in the lake caused similar rises in groundwater levels in the north and west of Packsaddle Plain. The hydrological boundary formed by Packsaddle Creek in the west and the backwater effects of Lake Kununurra created a semi-closed basin (Packsaddle Basin). The basin is divided into two hydrological zones: (a) Lake Kununurra Zone (H) between the lake in the east and north and the irrigation channels Sp and Sp1 in the central part of the Plain; and (b) Packsaddle Creek Zone (I) west of the irrigation channels and east of Packsaddle Creek in the west.

METHODS

Groundwater and surface water monitoring system

The hydrological response unit map was used to design a surface and groundwater monitoring system that extended the pre-existing WRC/Agriculture WA networks. The new network focussed on the M1, areas between the Ord River and the irrigation area (upstream and downstream of the KDD), and irrigation canals and drains. During a field trip in September 2001, 78 new bores were drilled and field instruments were deployed (Figure 2). The bores are grouped into 23 transects to allow assessment of the interaction between the shallow and deep aquifers and vertical and lateral seepage effects. Field instrumentation includes:

Water Loggers;

Ultrasound Doppler Instruments (UDI);

Stage height loggers;

EC Probes; and

a Weather Station.

A total of 185 baseline water samples were taken at this stage for water quality and isotopic analysis (115 from bores, 66 from drains and 4 from other surface water sites such as Lake Argyle and the KDD).

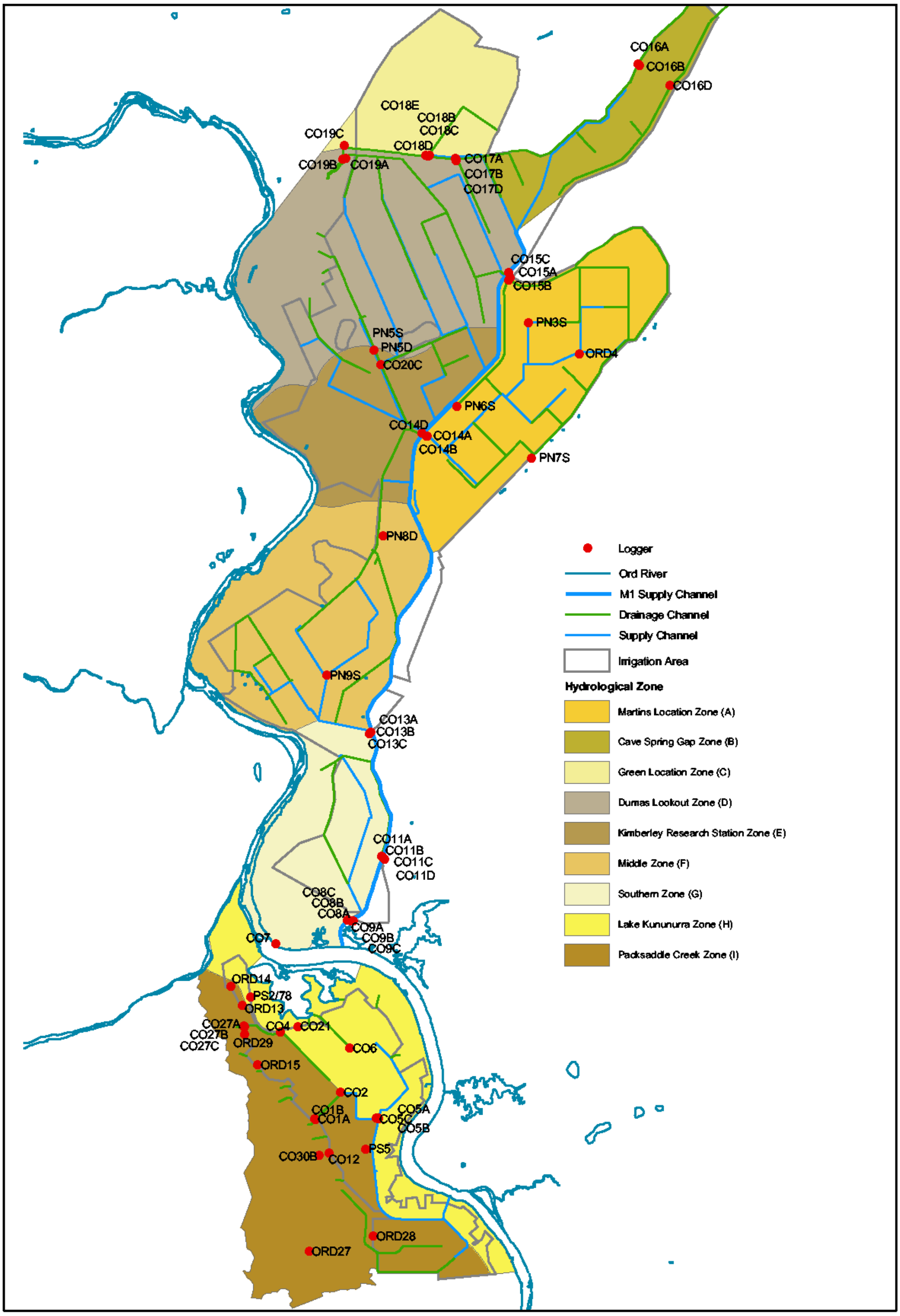

Figure 2: Location of monitoring wells installed with automatic loggers

Like most field monitoring programs, some modifications have occurred over the course of the project to accommodate improvements and adapt to physical and operational changes in the environment. An additional three stage height recorders have been installed in the surface water monitoring system. Now almost all sites with EC probes have a dedicated stage height recorder. Tables 1 & 2 provide details of installations and the current status of the monitoring network.

This report will only present a preliminary analysis of the 18 month data; detailed analysis of the data will be carried out at the end of the second stage when 3 years continuous data will be collected. In this report, solute is used as a synonym for 'total soluble salts'.

Table 1: Status of Monitoring Network across ORIA after initial fieldtrip in September 2001

Instrument	Number deployed	Monitoring measure	Monitoring interval
Loggers: in 49 CSIRO and 27 WRC Bores	76	Groundwater levels	2 hourly
EC Probes	11	Water quality	½ hourly
Ultra Sound Doppler Instrument (UDI)	4	Surface water flows	½ hourly
Stage Height Loggers	4	Surface water elevation	2 hourly
Weather Station	1	Weather data: 7 parameters (temp, humidity; barometric pressure; wind speed; wind direction; pluviometer (rain gauge)	Irregularly (average 3 monthly)

Table 2: Status of Monitoring Network across ORIA in June 2003

Instrument	Number Deployed	Monitoring Interval
Loggers	110	2 hourly
EC Probes	11	2 hourly
Ultra Sound Doppler Instrument (UDI)	3	½ hourly
Stage Height Loggers	7	2 hourly
Weather Station	1	Irregularly (Average 3 monthly)

2001/2003 GENERAL WATER LEVEL TRENDS IN THE ORD IRRIGATION AREA (APPENDIX 1)

The water level data from September 2001 to March 2003 reveal variable water level trends across the irrigation area, and within transects. This indicates a response to localised events (e.g. irrigation), and may be related to the distance between the bores and nearby channels. There is also a significant response in water levels across the irrigation area to a major rainfall event in February 2002, where 110 mm of rain fell in one day, with over 200 mm falling in five days (remnants of Cyclone Steve). Over the monitoring period, the maximum water level variation at one site was in the order of 2 m (i.e. range from minimum to maximum). The water level response in the Packsaddle Plain was more uniform than in the Ivanhoe Plain. In the Packsaddle Plain, water levels tended to rise in the wet season of 2001-2002, and fell for the remainder of the monitoring period. Water levels in the Ivanhoe Plain show non-uniform responses, possibly as a result of local irrigation events.

Packsaddle Plain

In Packsaddle Creek (Zone I) water levels were rising since November 2001 with a sharp rise of 1 m in the middle of February. The rise continued to the first week of March; thereafter the water levels started falling and the downward trend continued to February 2003. In the central Packsaddle area where there is a thick layer of clays, the water level rise was less pronounced (<0.5 m), while the areas near the main supply channel showed a rapid rise to the event in February 2001. The corresponding rise to the event in the north eastern corner of Packsaddle was in the order of 0.8 m but the fall to February 2002 was 1.5 m.

Ivanhoe Plain

Groundwater in the southern zone (G) directly downstream of Lake Kununarra showed a sharp rise of 1.2 m to the event for a short period followed by a rapid fall. Thereafter the water level fluctuated in direct response to the levels in Lake Kununurra. Near the M1 the rise was gradual with a sharp rise on 10 February 2002 which peaked on 20 February 2002 (0.8 m) in the eastern side. Further downstream (Section 11) the water levels started rising two weeks later (2 March 2002) and peaked (0.7 m) on 10 April 2002.

Downstream at site 13 the rise started much later than the event on 06 March 2002, and continued rising near the M1 with a slight fall in the eastern side. Further downstream (site 14), the trends are different with water levels falling since September 2002 and rising from 20 February 2002. The rise continued to 16 April 2002. The rise in the shallow and deep aquifer in the Middle Zone (F) was more gradual and peaked in the middle of April 2002 in the deep aquifer and in June 2002 in the shallow aquifer (lower hydraulic connection). In the Kimberley (Zone E) in the western side of the Ivanhoe, the rise started on 14 February 2002 and peaked on 4 March 2002 (0.5 m); the rise was sustained for 2 months before falling. In Martins Location (Zone A) in the area adjacent to D4 which receives catchment water, there was a rapid response to the event, while the other areas showed a minor response. Water levels in the area near the junction of the D4 and D7 showed a rapid rise and fall near the D4 and a slower rise near the D7 (but with a sharper fall).

2001/2003 WATER QUALITY AND SOLUTE LOADS IN THE DRAINS (APPENDIX 2)

Table 3: Minimum and maximum monitored drain Water quality

Drain	Minimum water quality (mg/l)	Maximum water quality (mg/l)
DP3D	50	400
DP8U	50	400
DP8D	50	360
D4U	300	600
D4D	360	600
D7U	300	480
D7E	100	360
D7D	200	300
D3U	600	600

Water Quality

The continuous monitoring of EC levels in selected drains in Packsaddle and Ivanhoe Plains (Figure 2) as well as measurement of discharge made it possible to prepare preliminary estimates of solute loads. The EC measurements were converted to mg/l using a relationship developed for the area from 63 surface water samples collected from the drains (Figure 3) (Salama *et al.*, 2002b).

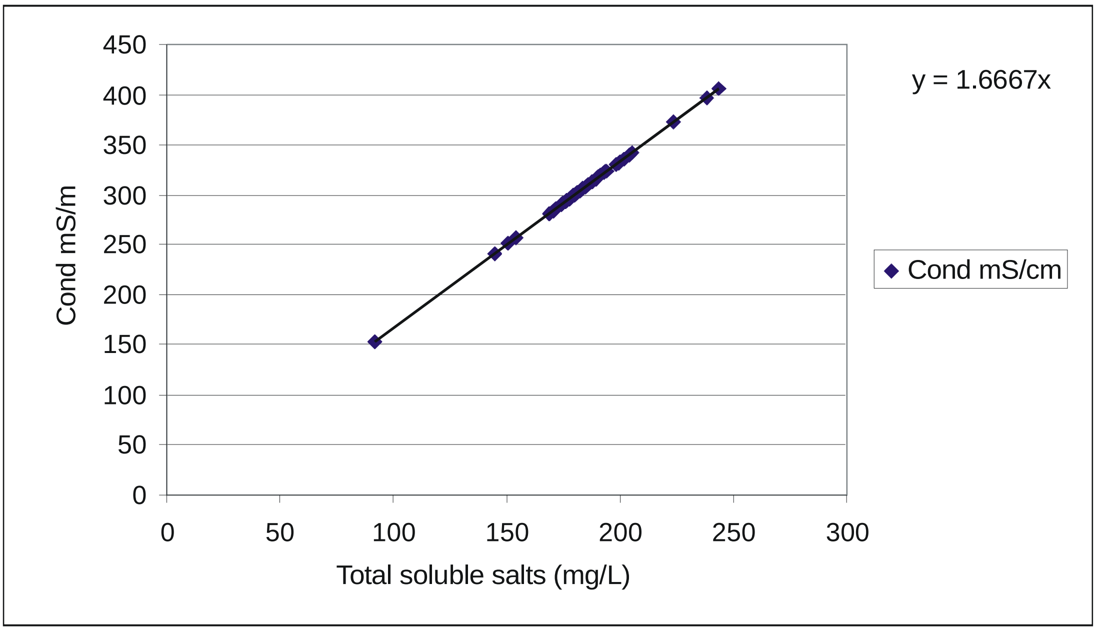

Figure 3: Relationship between EC and total solute

Nearly all the surface water in the drains is of very good quality (low total soluble salts), ranging from 50 – 100 mg/l. In low runoff periods the total dissolved solids increase to medium levels ranging from 300 – 600 mg/l (Table 3).

Solute Load

Table 4: Drains solute load

Drain	Minimum Solute load Tons/month	Average Solute Load Tons/month	Maximum Solute Load Tons/month
DP3D	20	20	20
DP8U	20	20	20
DP8D	50	75	120
D3U	20	50	100
D3D	40	100	530
D7U	50	100	700
D7ED	100	100	350
D7	100	150	200
D4	800	2000	8000
Ord River (Tarrara Bar)	30000	40000	100000

Solute load was calculated monthly, using daily concentration calculated from the continuous EC readings and drain discharge calculated from the stage heights:

Solute Load = c q t

where c = concentration (kg/m^3)

q = drain flow (m^3/day)

t = time interval (month)

Solute load of the Packsaddle Plain drains is usually not more than 20 tons per month except for the DP8D which averages about 75 tons per month and rarely reaches a maximum of 120 tons per month (Table 4).

The solute load from the Ivanhoe drains ranges from 40 to 530 tons per month in the minor drains. In the D7, at the junction of the D7 and D4, solute loads range from a minimum of 100 to a maximum of 200 tons per month. On the other hand, the D4 at the same location ranges from a minimum of 800 to a maximum of 8000 tons per month. These loads are small compared to the load in the Ord River recorded at Tarrara Bar where it ranges from 30000 to 100000 tons per month (Table 4). The maximum load for the Ord of 100000 tons was recorded for the month of February 2002, which was an exceptionally high flow.

Modelling of water flows from the ORIA (Viney, 2003) indicates that the five distinct drains in Table 4 (DP3, DP8, D3, D7 and D4) combine to produce 43 % of the total discharge from the irrigation area to the Ord River. If they can be assumed to also contribute 43 % of the solute discharge, then from Table 4, the average monthly discharge of solutes from the ORIA may be estimated as 5400 tons. This represents less than 15 % of the monthly solute load at Tarrara Bar.

Total Mass Export Coefficient

The ***total mass export coefficient*** or ***unit area load*** is the estimate of the amount of solutes lost per hectare or square kilometre of watershed. Export coefficients are calculated by dividing the total mass load of a substance by the watershed area (actual or effective drainage area) upstream of the sampling station for a given period of time (e.g. year).

Mass Export is defined as:

$$\text{Mass Export} = \frac{\text{Mass Load (kg)}}{\text{Catchmend Area}\left(\text{km}^2\right)}$$

The calculation of mass export coefficients (as kg km^{-2} $month^{-1}$) allows for general comparisons of pollutant export from watersheds with differing sizes. However, export coefficients are strongly influenced by runoff volume due to climatic and cropping factors, and pollutant delivery of different water quality parameters may behave differently depending on watershed size or scale. Thus, comparisons between watershed export coefficients may be more qualitative than quantitative.

The monthly average total mass export coefficient from the Ivanhoe Plain is about 4900 kg/km^2/month of solutes which is very high compared to the monthly average total mass export coefficient from the overall Ord River catchment of 800 kg/km^2/month of solutes.

Although the Ivanhoe Plain irrigation area drains contribute less than 15% of the total solutes in the Ord River at Tarrara Bar, this is a relatively high contribution compared to the volumes discharging from the drains to the total volume flowing in the Ord. This rather high solute load is mainly due to the excessive amounts of solutes leaching from the soils and of fertilisers and other chemicals used in the irrigation area.

ACKNOWLEDGEMENTS

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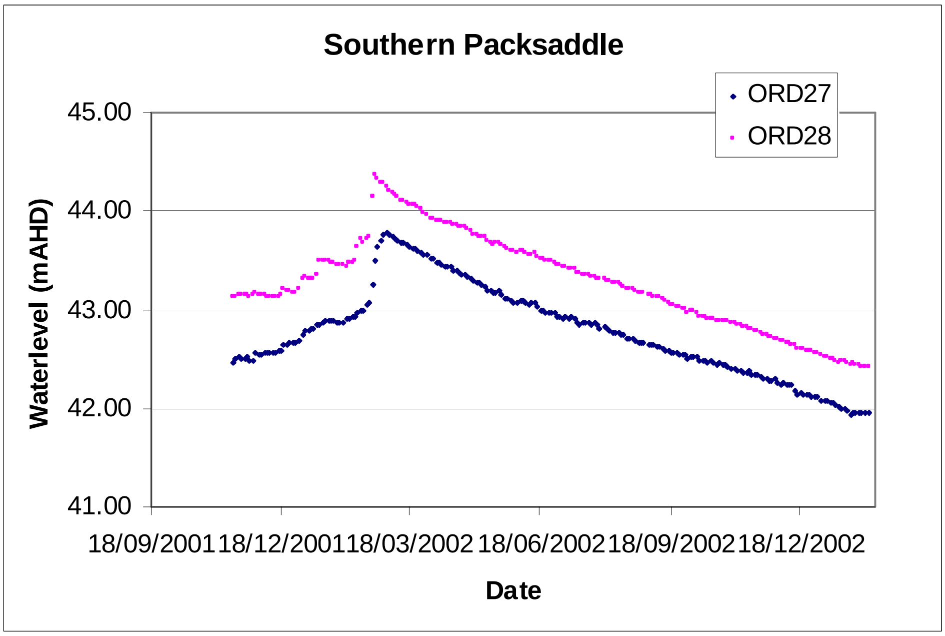
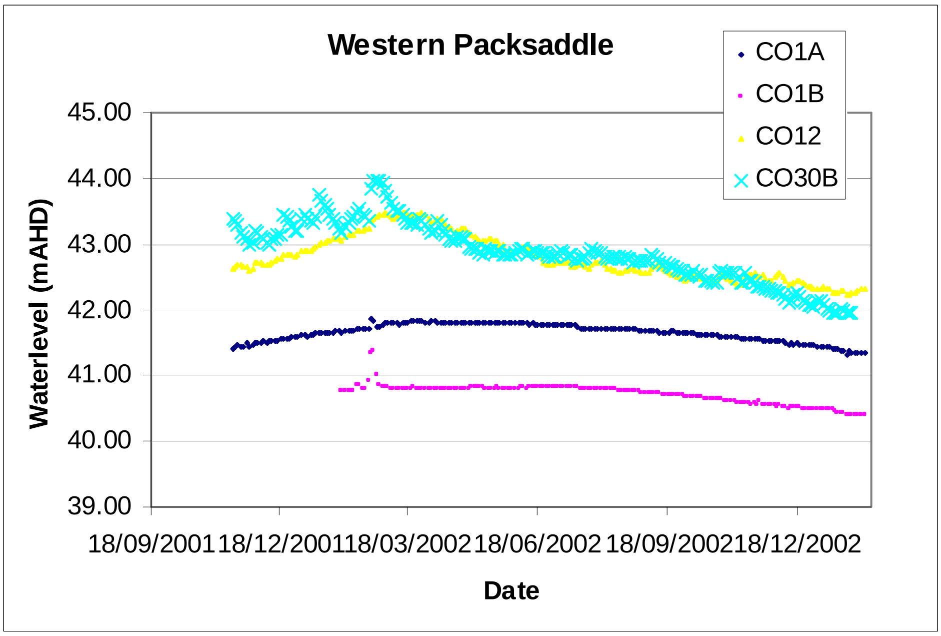
APPENDIX 1


Southern Packsaddle
ORD27
ORD28
Waterlevel (mAHD)
45.00
44.00
43.00
42.00
41.00
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date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CO1B
CO12
CO30B
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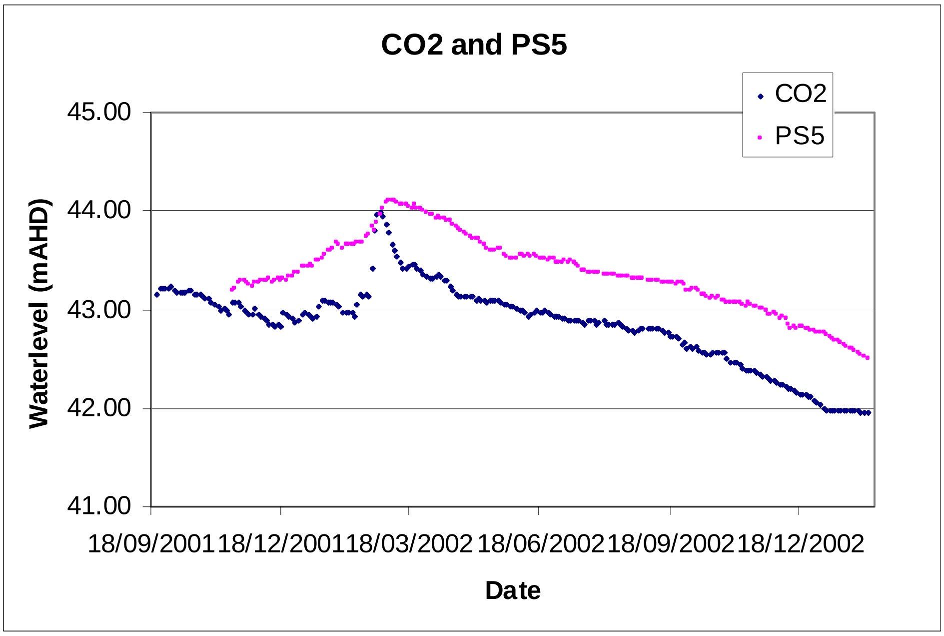
18/09/2002
18/12/2002
Date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PS5
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44.00
43.00
42.00
41.00
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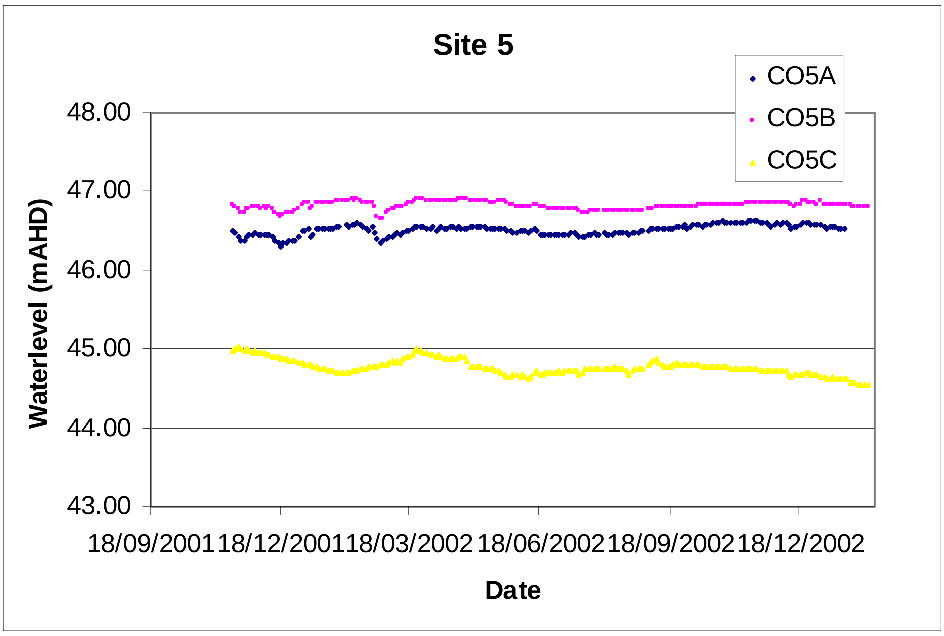
18/09/2002
18/12/2002
Date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CO5C
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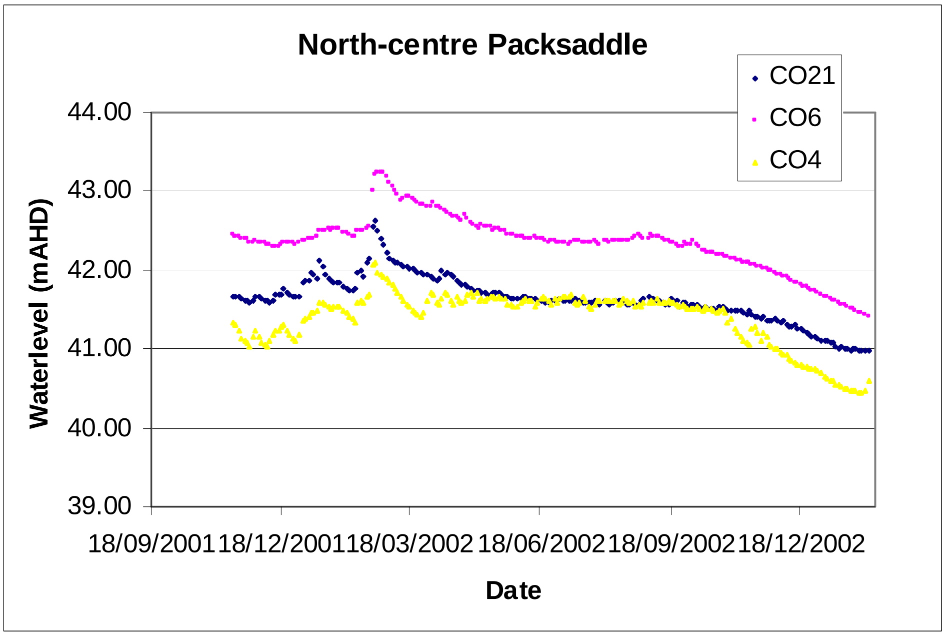
18/12/2002
Date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18/03/2002
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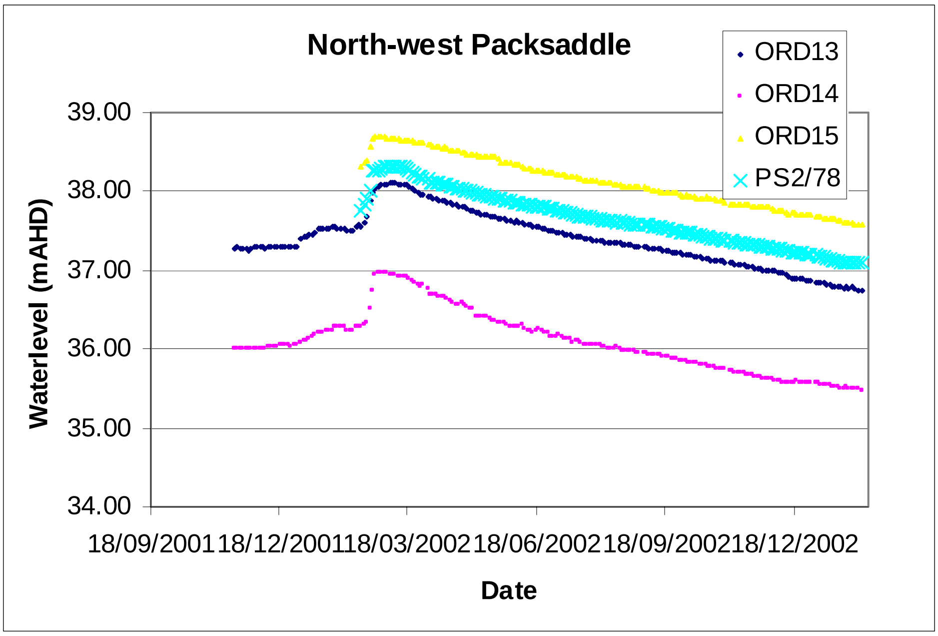
18/12/2002
Date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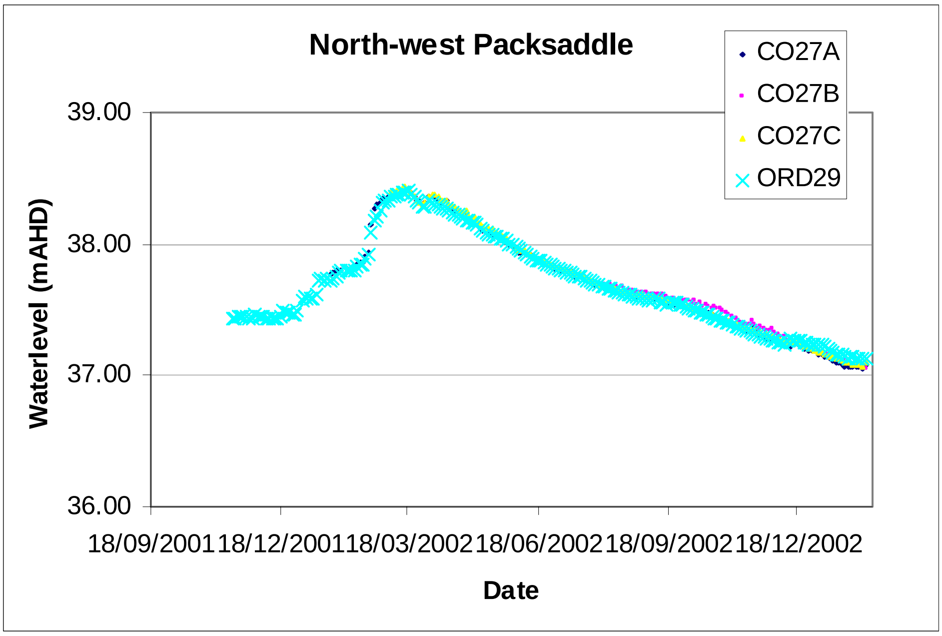
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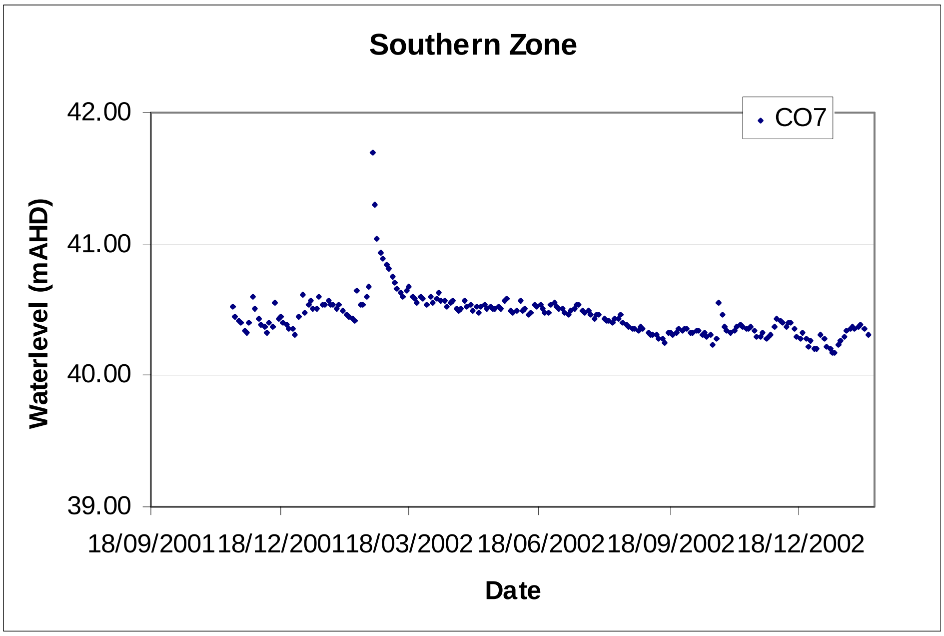
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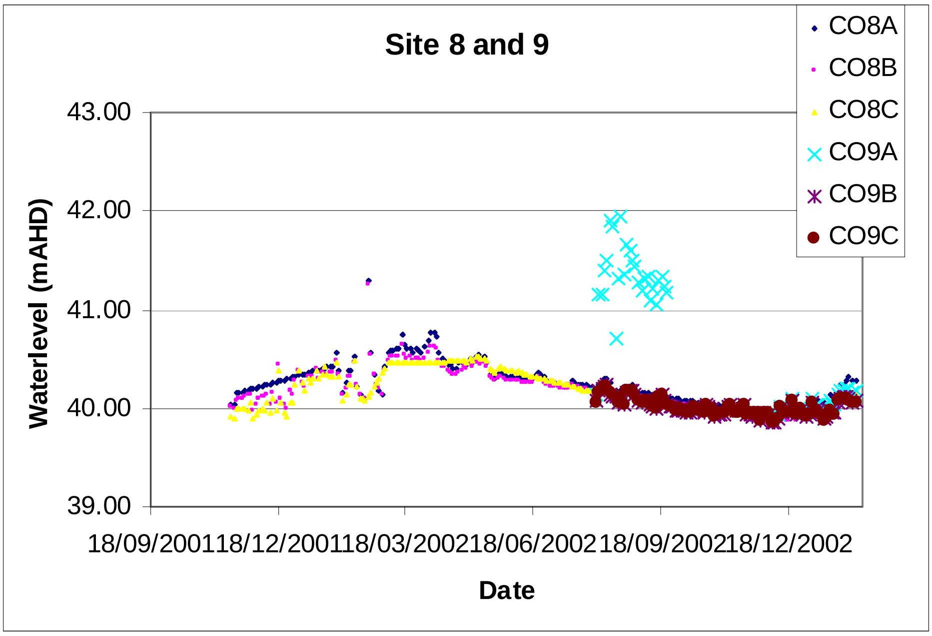
18/09/2002
18/12/2002
Date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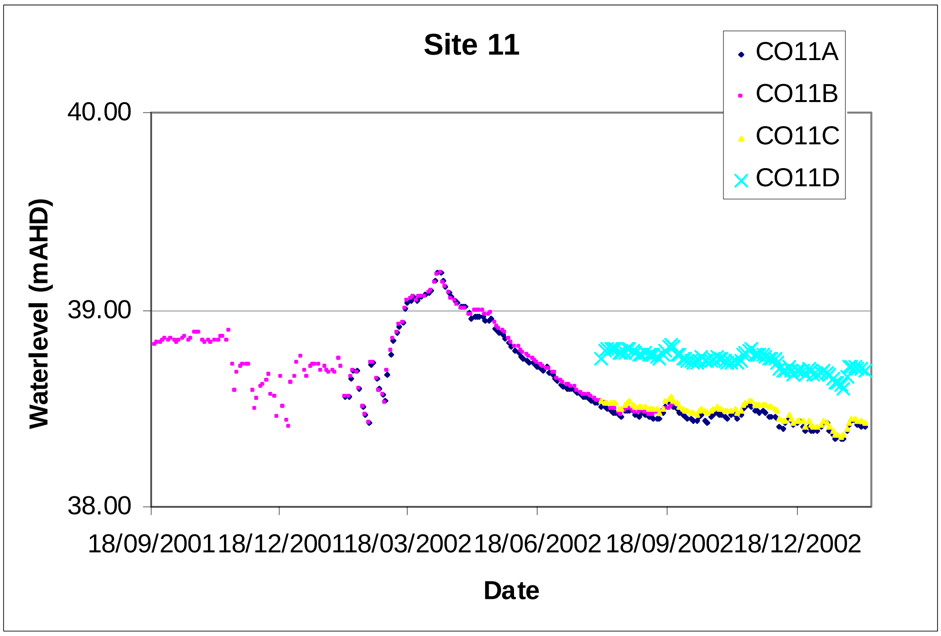
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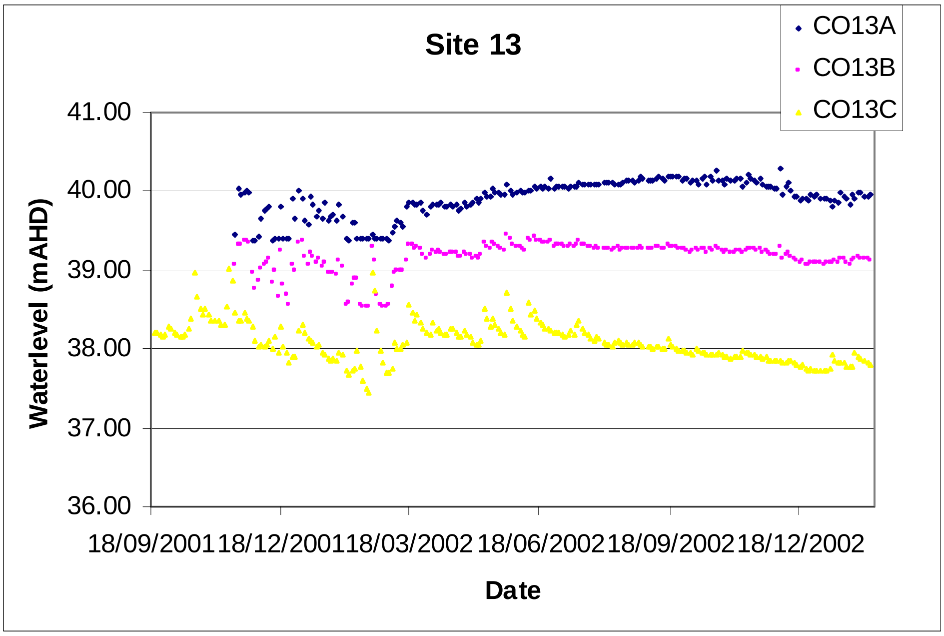
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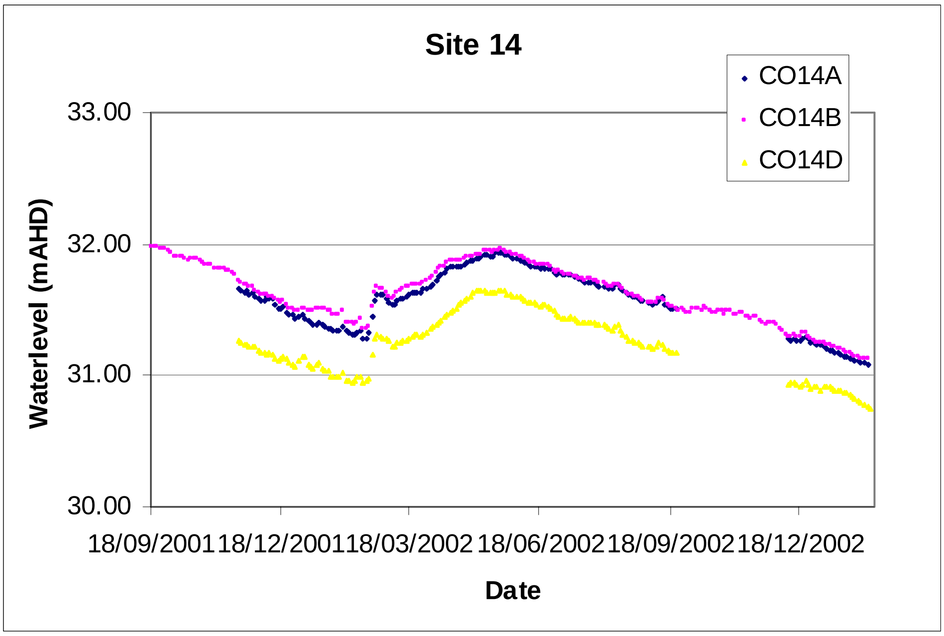
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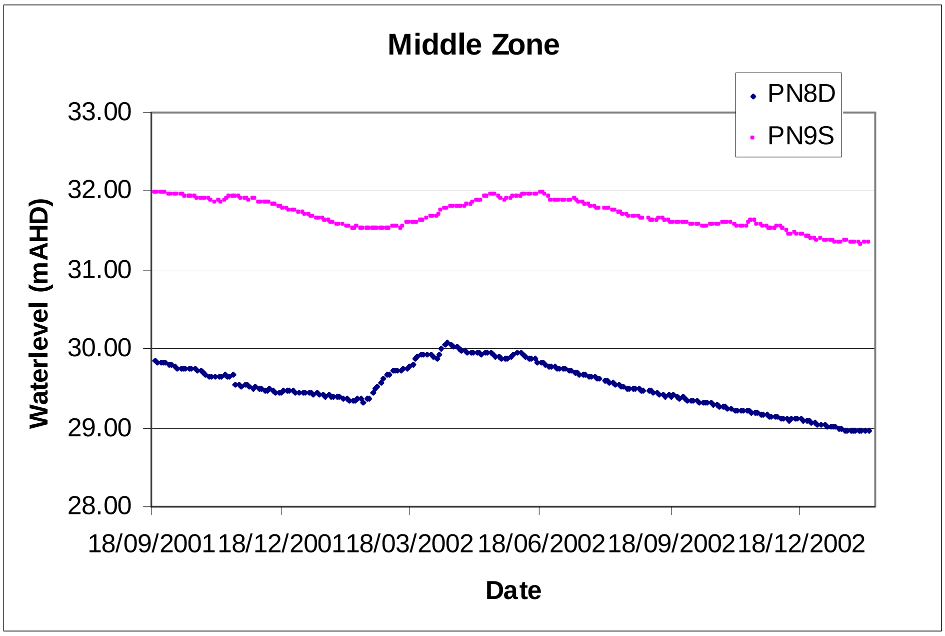
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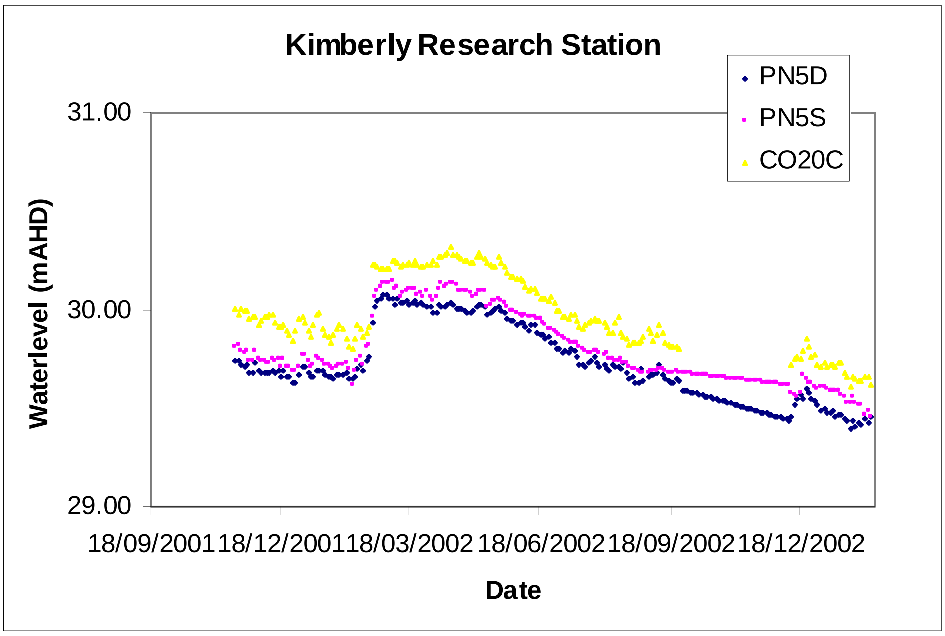
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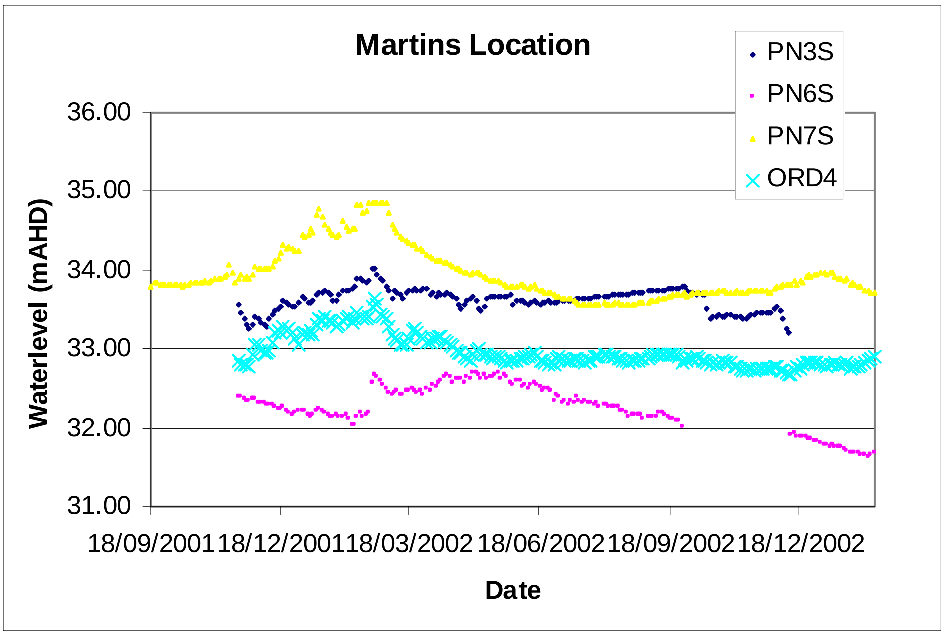
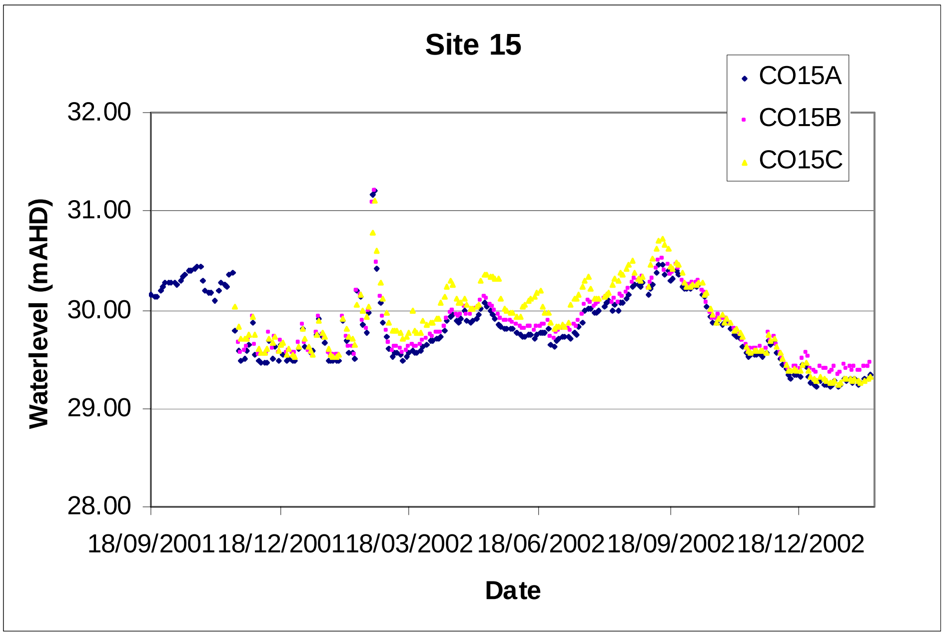
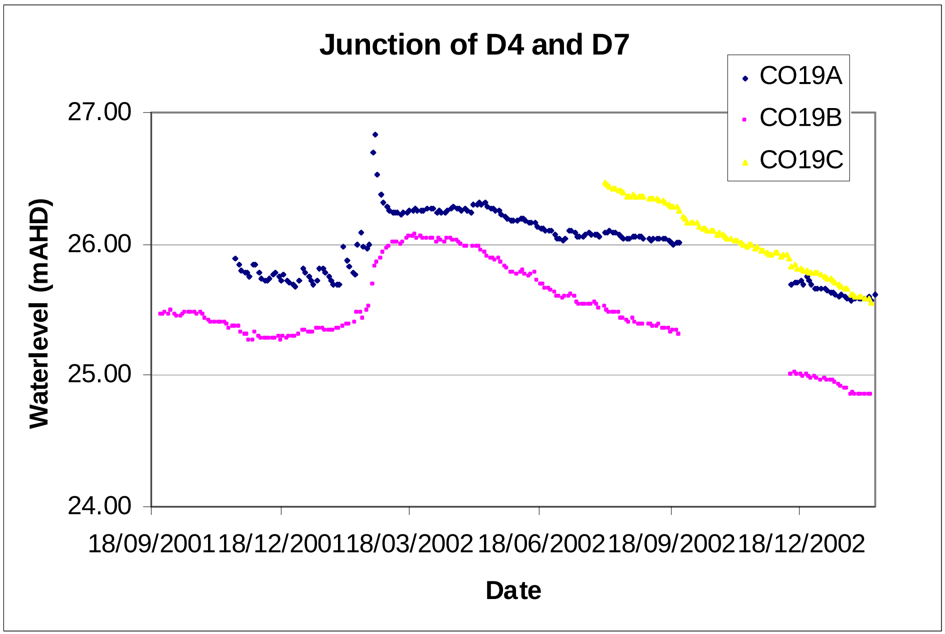
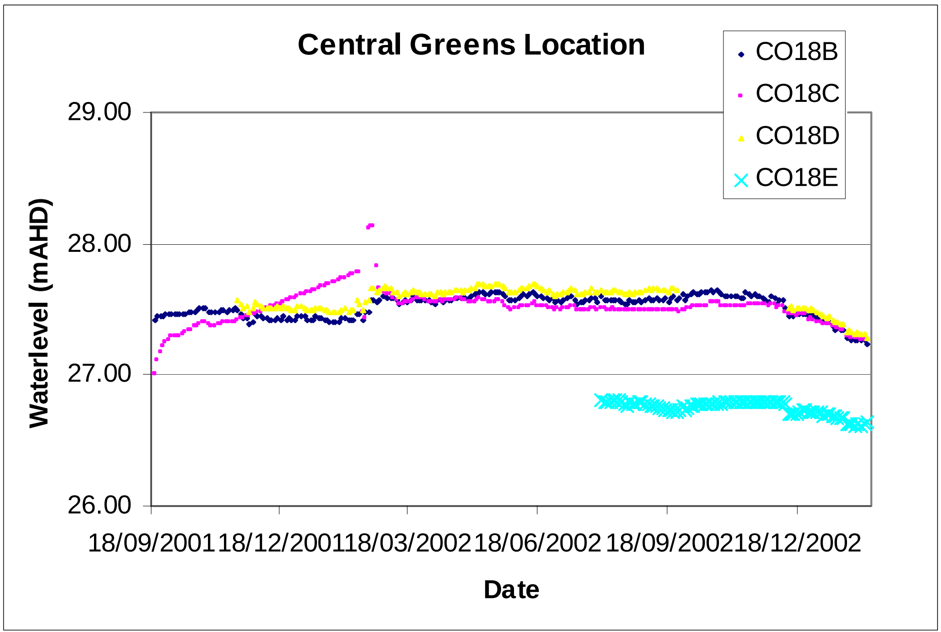
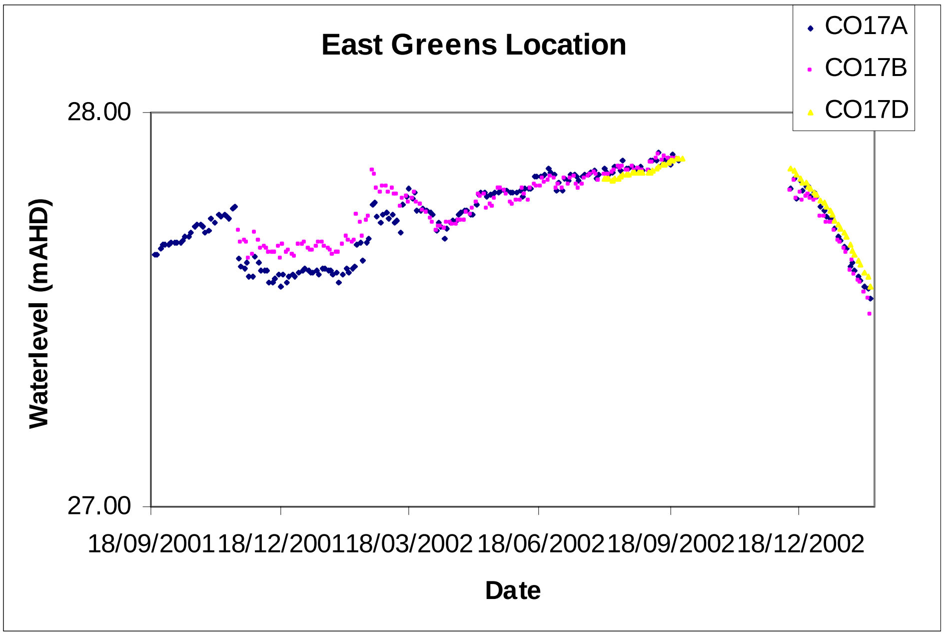
18/12/2002
Date

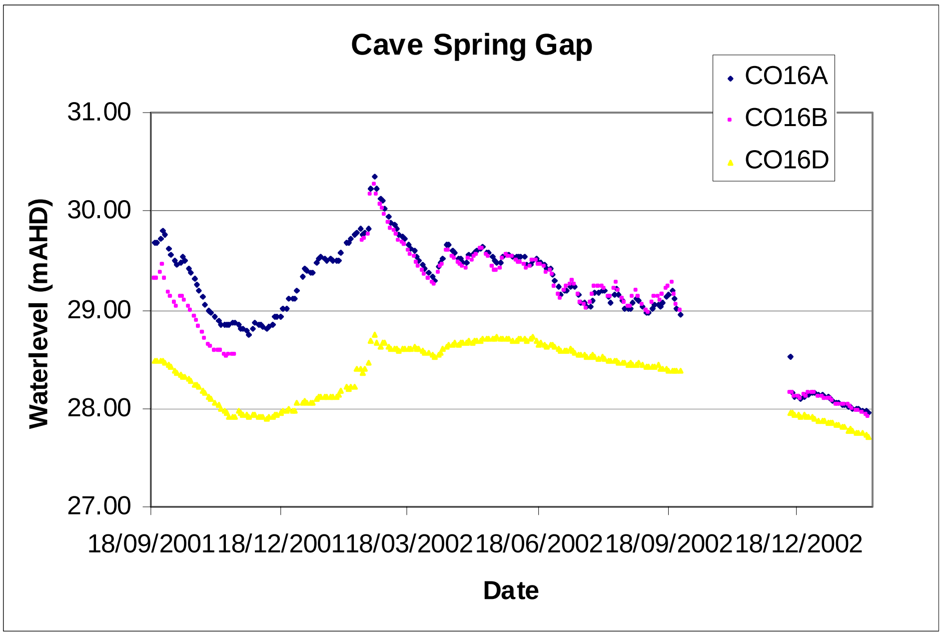

Martins Location
PN3S
PN6S
PN7S
ORD4
Waterlevel (mAHD)
36.00
35.00
34.00
33.00
32.00
31.00
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date


Site 15
CO15A
CO15B
CO15C
Waterlevel (mAHD)
32.00
31.00
30.00
29.00
28.00
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date

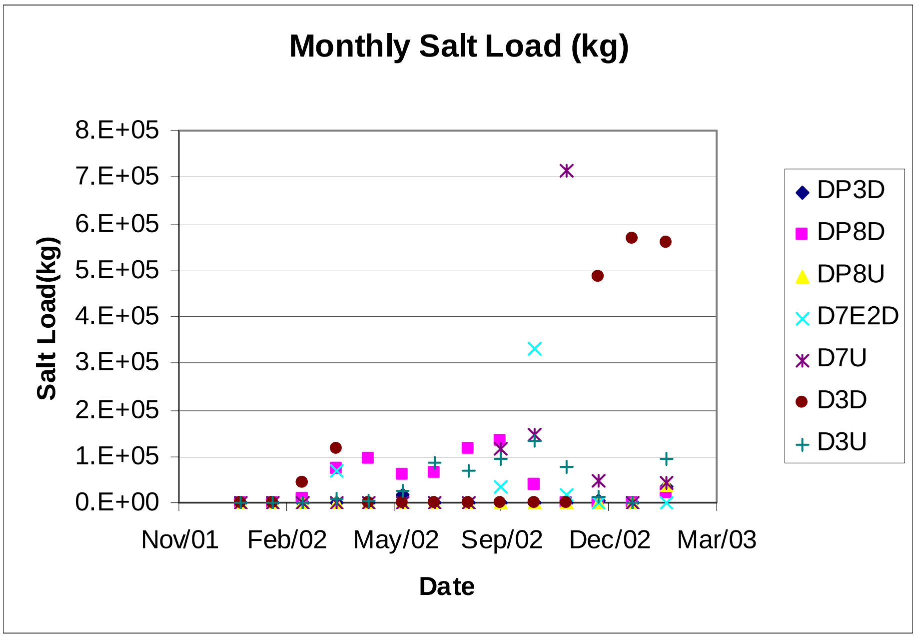

Junction of D4 and D7
CO19A
CO19B
CO19C
27.00
26.00
25.00
24.00
Waterlevel (mAHD)
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date


Central Greens Location
CO18B
CO18C
CO18D
CO18E
29.00
28.00
27.00
26.00
Waterlevel (mAHD)
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date

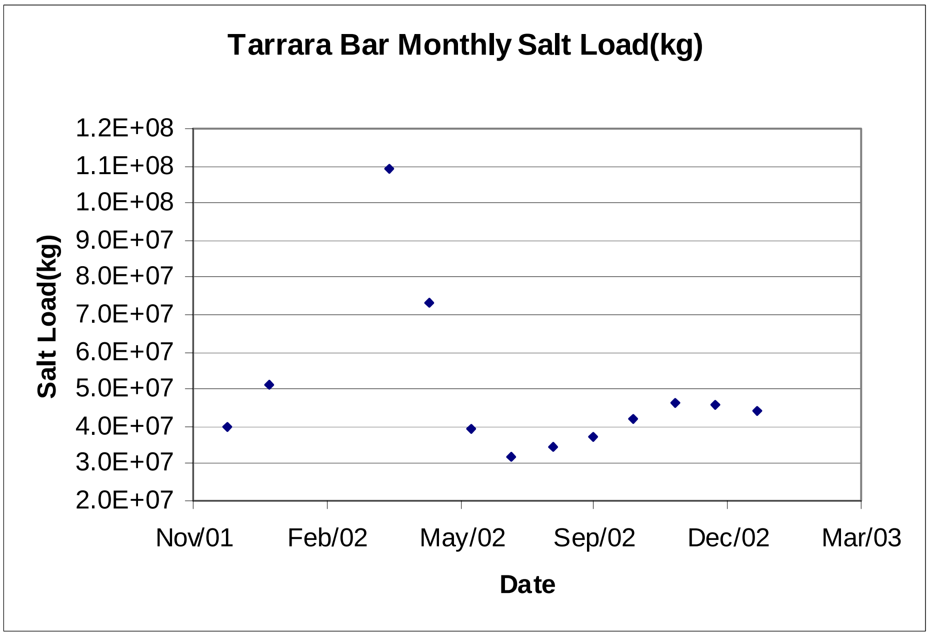

East Greens Location
CO17A
CO17B
CO17D
28.00
27.00
Waterlevel (mAHD)
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date


Cave Spring Gap
CO16A
CO16B
CO16D
31.00
30.00
29.00
28.00
27.00
Waterlevel (mAHD)
18/09/2001
18/12/2001
18/03/2002
18/06/2002
18/09/2002
18/12/2002
Date

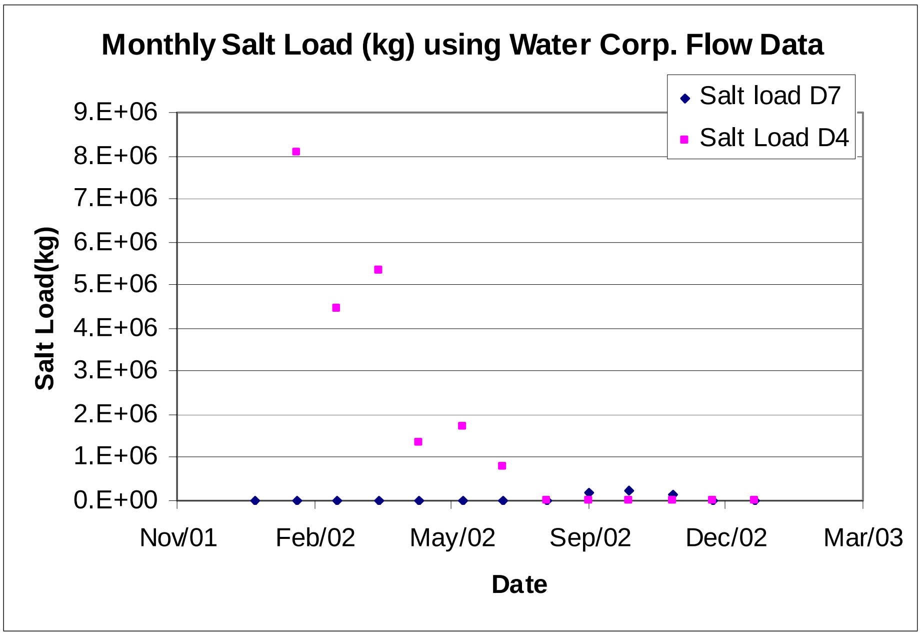
APPENDIX 2



Monthly Salt Load (kg)
Salt Load(kg)
8.E+05
7.E+05
6.E+05
5.E+05
4.E+05
3.E+05
2.E+05
1.E+05
0.E+00
Nov/01
Feb/02
May/02
Sep/02
Dec/02
Mar/03
Date
DP3D
DP8D
DP8U
D7E2D
D7U
D3D
D3U



Tarrara Bar Monthly Salt Load(kg)
Salt Load(kg)
1.2E+08
1.1E+08
1.0E+08
9.0E+07
8.0E+07
7.0E+07
6.0E+07
5.0E+07
4.0E+07
3.0E+07
2.0E+07
Nov/01
Feb/02
May/02
Sep/02
Dec/02
Mar/03
Date


Monthly Salt Load (kg) using Water Corp. Flow Data
Salt load D7
Salt Load D4
9.E+06
8.E+06
7.E+06
6.E+06
5.E+06
4.E+06
3.E+06
2.E+06
1.E+06
0.E+00
Salt Load(kg)
Nov/01
Feb/02
May/02
Sep/02
Dec/02
Mar/03
Date