THE UNIVERSITY OF NEW SOUTH WALES

water
research
laboratory

Manly Vale N.S.W. Australia

HAWKESBURY NEPEAN RIVER SALINE DYNAMICS
LONG TERM MODEL SIMULATIONS

by

D R Cox and W L Peirson

Technical Report 2003/10
October 2003

THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
WATER RESEARCH LABORATORY

HAWKESBURY NEPEAN ESTUARY
SALINE DYNAMICS
LONG TERM MODEL SIMULATIONS

WRL Technical Report 2003/10 October 2003

by

D R Cox and W L Peirson

https://doi.org/10.4225/53/58d49f903df84

Water Research Laboratory
School of Civil and Environmental Engineering
University of New South Wales ABN 57 195 873 179
King Street
Manly Vale NSW 2093 Australia

Telephone: +61 (2) 9949 4488
Facsimile: +61 (2) 9949 4188

Technical Report No	2003/10
Report Status	Final
Date of Issue	October 2003
WRL Project No.	02107
Project Manager	D R Cox

Title	Hawkesbury Nepean River Saline Dynamics – Long Term Model Simulations
Author(s)	D R Cox and W L Peirson
Client Name	Hawkesbury Nepean River Management Forum
Client Address	PO Box 556, Windsor NSW 2756
Client Contact	Brian Walters
Client Reference	

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Study Scope and Purpose

The University of New South Wales, Water Research Laboratory (WRL) was commissioned by the Hawkesbury Nepean River Management Forum to undertake a detailed numerical assessment of the long term impacts of different flow management regimes on the salinity distribution in the Hawkesbury Nepean estuary.

The Hawkesbury Nepean estuary (Figure 1) is an example of a tide-dominated, drowned valley estuary (Roy et al., 2001). The river is approximately 300 km long and supplies 98% of Sydney's potable water supply. As with many estuaries in Australia, the rainfall within the catchment may be highly variable, resulting in a high degree of natural variability in estuarine salinity. During periods of high rainfall, salt water is flushed from the estuary by the increased freshwater flow, while during periods of low rainfall, saline water from the estuary mouth is able to penetrate further up the estuary, either as a density current or through tidal mixing (Dyer, 1997). In the Hawkesbury Nepean, the limit of saline intrusion (> 0.5 ppt) is usually in the vicinity of the Colo River junction but has been observed to move as far upstream as Sackville (SPCC, 1983).

Since the 1860s, the freshwater flow and hydraulic characteristics of the Hawkesbury Nepean have been progressively modified by the construction of dams, weirs and other water supply structures in the upper parts of the catchment, and to a lesser extent, the extraction of water for irrigation and returns to the river from sewage treatment plants. Significant shoaling of the river has also been observed by local fishermen during the past 25 years between the Colo confluence and Wisemans Ferry (Wyllie, 2003).

These human activities all have consequences for estuarine salinity and hence the ecology of the river system. Reduced freshwater inflows due to extraction for human usage allows salinity to penetrate further upstream than under natural conditions. The term "Environmental Flows" has in recent years been used to describe freshwater flow to a river or estuary that is maintained solely for environmental reasons, to maintain the health and biodiversity of the water body (Peirson et al., 2001, 2002). Freshwater inflows to the estuary from sewage treatment plants, although much smaller, have the potential to reduce salinity in localised parts of the estuary from the high natural levels experienced during periods of drought.

As described in this report, the salinity distribution in the Hawkesbury Nepean estuary was simulated over an 87 year period (1909-1995) for five flow management regimes. Simulations were undertaken using a salinity model previously shown to be capable of reproducing the longitudinal salinity distribution in the estuary (Cox et al., 2003). Synthetic freshwater inflows were provided from the results of catchment modelling using the HSPF model, which were undertaken by SMEC. The freshwater inputs to the estuary included contributions from catchment runoff, dam releases, sewage treatment plant discharges as well as extractions for irrigation purposes.

The five flow regimes which are compared in this report (see Table 1 for details) were:

- natural condition;
- current condition; and
- three environmental flow options involving different management strategies for upstream dams (Options 3, 5 and 6).

In each case, the long-term modelling results were analysed for differences in the predicted salinity structure of the estuary and potential impacts on the aquatic ecosystem.

2. NUMERICAL MODELLING

2.1 General

The model and its calibration against measured tide levels, tidal discharges and longitudinal salinity structure in the estuary are described in detail in a previous report (Cox et al., 2003). A summary of this work is given in Sections 2.2-2.4 below. The long term simulations of the Hawkesbury Nepean salinity, which are the focus of the present phase of the study, are described in Section 2.5.

2.2 Estuary Model Description

The hydrodynamics and salinity distribution in the Hawkesbury Nepean estuary have been simulated using RMA-2 and RMA-11, components of the RMA finite element modelling suite. The 1D mesh (Figure 2) extends from West Head upstream to the tidal limit at Yarramundi, and includes the tidal sections of the major tributaries of the Hawkesbury River downstream of this point. The model includes a total length of 144.9 km and area of 6714.6 Ha.

2.3 Hydrodynamic Model

Tidal currents and freshwater inflows to the Hawkesbury Nepean estuary have been simulated using the hydrodynamic model RMA-2 (King, 1998). An ocean tidal boundary condition was applied at the downstream end of the model.

The hydrodynamic model was calibrated against tide level and tidal flow data obtained by MHL (1988) during four one-day gauging exercises on the Hawkesbury River between April and August 1981. For the model calibration, streamflow data and results from an HSPF catchment model by SMEC were used to define the freshwater inflow at the upstream limits of the model.

2.4 Salinity Model

The longitudinal salinity distribution in the Hawkesbury Nepean estuary has been simulated using the water quality model RMA-11 (King, 1997). Output from the hydrodynamic model is used to provide the water levels and flow within the estuary for input to the salinity model. The salinity of tidal inflows at the downstream (ocean) boundary of the model is assumed to be 35 ppt. A varying diffusion coefficient is used to account for the effect of variations in river geometry and tidal mixing with distance from the estuary mouth. The model has been calibrated against salinity surveys of the Hawkesbury Nepean obtained by the Electricity Commission during 1977-78.

2.5 Long Term Simulations

2.5.1 Flow Regimes

Long term simulations of the salinity in the Hawkesbury Nepean estuary were undertaken for the period from 1909-1995, for a number of different flow regimes. Daily runoff volumes from an HSPF catchment model incorporating rainfall runoff, dam releases and irrigation extractions were provided by SMEC during 2003. Details of the flow regimes simulated are given in Table 1 below.

Table 1
Flow Regimes for Long Term Simulations

	Dam Behavior	Catchment Characteristics	Irrigation Extractions	STP discharges
Natural	No Dams	Natural conditions, based on rainfall record from 1909 to 1995	None	None
Current	95th percentile transparent flows	Natural conditions, based on rainfall record from 1909 to 1995	Records based on land usage and irrigator pumping capacity.	A constant discharge based on current STP dry weather flows.
Option 3	95th percentile transparent flows with 10% translucency	Natural conditions, based on rainfall record from 1909 to 1995	Records based on land usage and irrigator pumping capacity	A constant discharge based on current STP dry weather flows.
Option 5	95th percentile transparent flows with 20% translucency	Natural conditions, based on rainfall record from 1909 to 1995	Records based on land usage and irrigator pumping capacity	A constant discharge based on current STP dry weather flows.
Option 6	80th percentile transparent flows with 20% translucency	Natural conditions, based on rainfall record from 1909 to 1995	Records based on land usage and irrigator pumping capacity	A constant discharge based on current STP dry weather flows.

Source: J. Martin, SMEC

In all cases, natural catchment conditions were assumed. Depending on the catchment size, some changes in the runoff characteristics of the more urbanized catchments may have been

expected between the natural and modified catchment conditions, but these were not included in the HSPF catchment modelling undertaken by SMEC.
Thus the management of outflows from dams is the main difference between the current condition and the three environmental flow options modelled in this study. Dam inflow/outflow behavior may be described in terms of "transparent" and "translucent" flows. In transparent flows, the same volume entering the dam is also leaving the dam at any given time. Translucent flows occur when the volume of water leaving a dam is less than the volume entering it. A dam with 95%ile transparent flow with 10% translucency will allow low flows (exceeded 95% of the time) to pass through the dam, while allowing only 10% of the volume of higher inflows to pass through.

The HSPF inflows to the estuary are shown in Figure 3 for the natural condition from 1909-1995, for the Nepean at Yarramundi, Grose River, Colo River and Macdonald River. Exceedance curves for the HSPF inflow to the Nepean River at Yarramundi are compared in Figure 4 for the natural, current and three environmental flow options.

An exceedance curve based on gauged river flows at Penrith for the period 1914-1996 is also shown in Figure 4 for comparative purposes. It is noted that the HSPF model natural condition upstream flow data provided shows less variability at low flows than is observed in the measured river flow data. Thus the salinity model may underestimate the estuarine salinity during relatively dry periods, and may underpredict the overall variability in long term salinity as a result.

2.5.2 Model Configuration

Long term simulations were undertaken for the 87 years of available data from the HSPF model using an hourly time step. An hourly time step was shown in the model calibration report (Cox et al., 2003) to provide sufficient resolution for long term salinity modelling. A predicted tidal elevation boundary condition was applied at the downstream end of the model.

3. SALINITY SIMULATION RESULTS

3.1 Longitudinal Salinity Distributions

The modelled Hawkesbury Nepean salinity distributions for the natural condition, current condition and the three environmental flow options are presented in Figures 5 to 9 as time series of the daily average locations of the 1, 5, 10 and 20 ppt isohalines over the 87 years of simulation. The natural condition clearly allows less saline intrusion in the upper reaches of the estuary than either the current condition or the three environmental flow options.

3.2 Analysis of Habitat

The long-term modelling results (for the natural and current conditions, and the three environmental flow options) were analysed for differences in the predicted salinity structure of the estuary and potential impacts on the aquatic ecosystem. The following aspects of the modelled salinity structure of the Hawkesbury Nepean estuary were examined in detail:

- the amount of habitat available for different ecosystem facets, based on salinity threshold criteria;
- the variability in salinity along the length of the estuary; and
- the distribution of salinity in the area of greatest biological change, near Wisemans Ferry.

3.2.1 Habitat Quantity for Indicative Salinity Thresholds

Following a review of the components of the aquatic ecosystem, a list of nine ecosystem facets and indicative salinity thresholds were provided by Dr. Keith Bishop, as listed in Table 2.

The long term salinity simulation results were analysed for the quantity of available habitat within the indicative salinity thresholds for the 99th, 95th, 90th, 80th and 50th percentile inflow conditions. The results are presented in Tables 3 to 12 and Figures 10 to 14.

The current condition and Options 3, 5 and 6 all show significant reductions in the available habitat compared with the natural condition. The reduction in habitat is more severe for regions of lower salinity which are more sensitive to the differences in lower inflows between the different flow regimes. Of the three environmental flow options, Option 6 shows the least reduction in habitat from the natural condition.

Table 2
Indicative Salinity Thresholds

Ecosystem Facet	Salinity	Biological Significance	Quantity Measure
1	<0.5ppt	• upper limit for platypus (indirect impacts) • very high salt sensitive freshwater-associated algae	Estuary length and area
2	<1.0ppt	• the maintenance of freshwater ecosystems • maximum biomass of *Egeria densa* • high salt sensitive freshwater-associated macrophytes • high salt sensitive freshwater-associated algae • lowest (recorded) limit for school prawns	Estuary area
3	<2.5ppt	• approx. one third biomass of *Egeria densa* • high-moderate salt sensitive freshwater-associated macrophytes • approx. lower limit (3 ppt) for juv. king prawns	Estuary area
4	<5.0ppt	• upper limit for adult Australian bass outside of the spawning season • absolute upper limit for *Egeria densa* • moderate salt sensitive freshwater-associated macrophytes • moderate salt sensitive freshwater-associated algae	Estuary area
5	<7.5ppt	• low-moderate salt sensitive freshwater-associated macrophytes • approx. lower limit (7 ppt) for adult king prawns	Estuary area
6	>8.0ppt	• lower limit for adult Australian bass during the spawning season	Estuary area
7	<10ppt	• low salt sensitive freshwater-associated macrophytes • low salt sensitive freshwater-associated algae	Estuary area
8	<13ppt	• upper limit for adult Australian bass during the spawning season	Estuary area
9	<20ppt	• Sydney rock oyster - winter mortality • Sydney rock oyster - marine fouling of substrates	Estuary length

Table 3
Statistics of Available Habitat Length Natural Condition, 1909-1995

Upper Salinity Threshold (ppt)	Length of Available Habitat (km)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	88.1	70.5	60.5	53.9	43.9
1.0	90.8	74.7	66.7	59.4	49.7
2.5	95.0	81.6	74.7	69.6	58.3
5.0	98.4	87.6	81.7	76.9	68.3
7.5	100.4	91.4	86.2	82.2	74.6
8.0	100.8	92.0	87.1	83.0	75.5
10.0	102.5	94.1	89.8	86.2	79.6
13.0	105.1	97.0	93.2	90.2	84.2
20.0	114.6	102.2	99.3	97.3	93.5

Table 4
Statistics of Available Habitat Length Current Condition, 1909-1995

Upper Salinity Threshold (ppt)	Length of Available Habitat (km)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	75.9	48.5	37.3	31.4	22.5
1.0	79.5	54.0	43.4	36.3	26.9
2.5	85.6	64.7	53.7	45.8	33.9
5.0	90.9	73.6	64.9	57.0	41.9
7.5	94.1	79.3	72.1	65.5	50.1
8.0	94.7	80.3	73.1	67.0	51.4
10.0	96.8	83.7	77.0	71.9	56.7
13.0	99.1	88.3	82.5	77.5	66.1
20.0	10.5	96.4	92.6	89.2	81.7

Table 5
Statistics of Available Habitat Length Option 3, 1909-1995

Upper Salinity Threshold (ppt)	Length of Available Habitat (km)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	76.4	50.6	39.4	32.7	24.2
1.0	80.7	56.2	45.4	37.7	28.8
2.5	86.7	66.9	55.8	48.9	35.7
5.0	91.8	74.9	66.9	59.1	43.9
7.5	94.9	80.6	73.4	67.6	51.8
8.0	95.5	81.5	74.4	69.1	52.9
10.0	97.4	84.9	78.5	73.3	58.4
13.0	99.7	89.2	83.7	79.1	68.0
20.0	105.9	97.0	93.3	90.1	82.8

Table 6
Statistics of Available Habitat Length: Option 5, 1909-1995

Upper Salinity Threshold (ppt)	Length of Available Habitat (km)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	77.9	52.4	41.6	34.4	25.3
1.0	81.9	58.4	48.4	39.6	30.2
2.5	87.9	69.0	57.9	50.5	36.9
5.0	92.6	76.3	69.0	61.1	45.6
7.5	95.7	81.8	74.7	69.2	53.3
8.0	96.2	82.7	75.7	70.3	54.8
10.0	98.0	86.0	79.9	74.4	60.5
13.0	100.2	90.1	84.8	80.3	69.5
20.0	106.9	97.6	94.0	90.9	83.7

Table 7
Statistics of Available Habitat Length: Option 6, 1909-1995

Upper Salinity Threshold (ppt)	Length of Available Habitat (km)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	80.3	59.4	51.0	43.3	31.9
1.0	83.9	65.9	56.4	49.6	37.0
2.5	89.4	74.1	66.6	58.8	46.2
5.0	93.8	81.2	74.8	69.3	55.9
7.5	96.8	86.0	80.5	75.0	63.8
8.0	97.3	86.8	81.3	76.0	65.4
10.0	99.0	89.6	84.6	80.2	70.6
13.0	101.0	93.1	88.9	84.9	76.4
20.0	108.2	99.4	96.6	93.9	88.4

Table 8
Statistics of Available Habitat Area: Natural Condition, 1909-1995

Upper Salinity Threshold (ppt)	Area of Available Habitat (Ha)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	1664	1113	884	757	582
1.0	1810	1213	1020	865	688
2.5	1978	1429	1212	1095	842
5.0	2101	1641	1433	1260	1065
7.5	2173	1837	1579	1453	1211
8.0	2185	1863	1613	1473	1231
10.0	2256	1947	1755	1577	1344
13.0	2358	2044	1910	1776	1509
20.0	2825	2241	2130	2060	1922

Table 9
Statistics of Available Habitat Area: Current Condition, 1909-1995

Upper Salinity Threshold (ppt)	Area of Available Habitat (Ha)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	1219	665	479	389	278
1.0	1342	759	575	463	334
2.5	1556	965	753	614	423
5.0	1812	1189	968	812	549
7.5	1948	1337	1152	986	695
8.0	1970	1376	1178	1028	715
10.0	2034	1492	1263	1145	807
13.0	2126	1679	1459	1278	1001
20.0	2351	2019	1886	1731	1433

Table 10
Statistics of Available Habitat Area: Option 3, 1909-1995

Upper Salinity Threshold (ppt)	Area of Available Habitat (Ha)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	1248	702	511	407	299
1.0	1391	796	606	486	357
2.5	1598	1024	789	671	453
5.0	1856	1218	1025	860	583
7.5	1976	1386	1185	1044	721
8.0	1993	1423	1208	1082	740
10.0	2063	1531	1308	1183	845
13.0	2143	1729	1491	1329	1056
20.0	2386	2044	1913	1769	1465

Table 11
Statistics of Available Habitat Area: Option 5, 1909-1995

Upper Salinity Threshold (ppt)	Area of Available Habitat (Ha)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	1289	731	544	432	314
1.0	1442	843	663	514	374
2.5	1654	1080	833	701	472
5.0	1884	1247	1080	897	609
7.5	1999	1439	1213	1087	746
8.0	2013	1463	1235	1110	772
10.0	2088	1569	1359	1208	885
13.0	2162	1767	1528	1373	1093
20.0	2436	2073	1942	1812	1493

Table 12
Statistics of Available Habitat Area: Option 6, 1909-1995

Upper Salinity Threshold (ppt)	Area of Available Habitat (Ha)				
	50%ile	80%ile	90%ile	95%ile	99%ile
0.5	1375	865	709	572	395
1.0	1498	997	799	686	474
2.5	1739	1202	1017	853	622
5.0	1935	1414	1215	1089	791
7.5	2037	1569	1381	1220	949
8.0	2060	1602	1416	1240	983
10.0	2120	1747	1523	1369	1115
13.0	2191	1904	1720	1530	1249
20.0	2517	2134	2027	1939	1686

3.2.2 Longitudinal Variability in Salinity

The standard deviation of salinity was calculated along the length of the estuary for the natural and current conditions, and the three environmental flow options. The results are shown graphically in Figure 15, along with the corresponding average salinities along the estuary. Standard deviations measured at 10 km intervals downstream from the tidal limit are also listed in Table 13.

Table 13
Longitudinal Salinity Standard Deviation, 1909-1995

Distance Downstream of Tidal Limit (km)	Standard Deviation of Salinity (ppt)				
	Natural	Current	Option 3	Option 5	Option 6
0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0
20	0.0	0.1	0.1	0.1	0.0
30	0.0	0.3	0.2	0.2	0.1
40	0.0	0.8	0.7	0.6	0.3
50	0.0	1.4	1.2	1.1	0.6
60	0.6	2.2	2.0	1.9	1.2
70	1.1	3.3	3.0	2.8	2.0
80	2.2	4.9	4.7	4.4	3.4
90	4.4	7.2	7.0	6.8	5.7
100	8.1	9.9	9.7	9.6	8.9
110	9.6	10.2	10.2	10.1	9.8
120	9.3	9.3	9.3	9.2	9.1
130	7.8	7.5	7.5	7.5	7.4
140	4.2	3.9	3.8	3.9	3.9

The natural condition showed only small variations in salinity (standard deviation <0.1 ppt) in the upstream parts of the estuary less than 50 km downstream of Yarramundi. The variability in salinity is increased in these upper reaches for the current condition and the three environmental flow options. The maximum variability in salinity occurred about 35 km from the downstream end of the model, just upstream of Spencer. Downstream of this point there was little variability in salinity between the five flow options modelled.

3.2.3 Salinity Distribution Within the Area of Greatest Biological Change

Salinity exceedances were calculated for 1909-1995 at three locations in the area of greatest biological change, near Wisemans Ferry, for the five flow regimes. Figures 16 to 20 show the results for locations 5 km downstream of Wisemans Ferry, at Wisemans Ferry, and at 5 km upstream of Wisemans Ferry for the natural and current conditions, and the three environmental flow options.

The current condition and Options 3, 5 and 6 all show significant increases in the salinity exceeded for a given percentage of the time, compared with the natural condition. At Wisemans Ferry, a salinity of 5 ppt is exceeded approximately 12% of the time under the natural condition, while the same salinity is exceeded approximately 35% of the time under the current condition.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Salinity Simulation Results and Ecosystem Impacts

A calibrated model has been utilised for long term simulations of the salinity structure of the Hawkesbury Nepean estuary under tides and with synthetic freshwater inflows provided by SMEC for the 87 year period from 1909 to 1995. The model results were analysed for impacts on the aquatic ecosystems of the estuary.

The current condition and Options 3, 5 and 6 all showed significant reductions in the available habitat length and area for specific salinity thresholds compared with the natural condition. The reduction in habitat was more severe for regions of lower salinity which are more sensitive to changes in the frequency and volume of lower inflows between the different flow regimes. Of the three environmental flow options, Option 6 showed the greatest improvement in habitat length and area compared with the current condition.

In the upper parts of the estuary, less than 50 km downstream of Yarramundi, the current condition and the environmental flow options showed increased variability in salinity compared with the natural condition. Of the three flow options, Option 6 showed the greatest reduction in variability over the current condition. The maximum variability in salinity occurred about 35 km from the downstream end of the model, just upstream of Spencer. Downstream of this point there was little change in the salinity variability between the five flow options modelled.

In the area of greatest biological change, near Wisemans Ferry, the current condition and Options 3, 5 and 6 all show significant increases in the salinity exceeded for a given percentage of the time, with Option 6 showing the least change from the natural condition.

4.2 The Study in an Adaptive Management Context

Some concerns have been noted in Section 2.5.1 of this report regarding the freshwater flow data which was supplied for this study. In particular, the synthetic natural condition upstream flow data provided from the HSPF modelling showed less variability at low flows than has been observed in measured river flow data. The variability in the modelled salinities may have been underpredicted as a result. In spite of these concerns, it was necessary to complete this study within the timeframe available.

As part of an adaptive management process, it is therefore recommended that the salinity modelling described in this report should be repeated once the disparity between the predicted and recorded freshwater inflows is resolved.

5. REFERENCES

Cox, D.R., Peirson, W.L. and Davies, J.L. (2003) "Hawkesbury Nepean Estuary Saline Dynamics – Model Calibration", *Water Research Laboratory Technical Report 2003/01.*

Dyer, K.B. (1997) "Estuaries: A Physical Introduction", 2nd Edition, John Wiley & Sons.

King, I.P. (1997) "RMA-11 – A Three Dimensional Finite Element Model for Water Quality in Estuaries and Streams, Version 2.5", *Department of Civil Engineering, University of California, Davis.*

King, I.P. (1998) "RMA-2 – A Two Dimensional Finite Element Model for Flow in Estuaries and Streams, Version 6.5", *Department of Civil Engineering, University of California, Davis.*

MHL (1988) "Hawkesbury River Tidal Data 1981", *NSW Public Works Department, Manly Hydraulics Laboratory, Report No 369 (Volumes 1 and 2), PWD Report No 88002.*

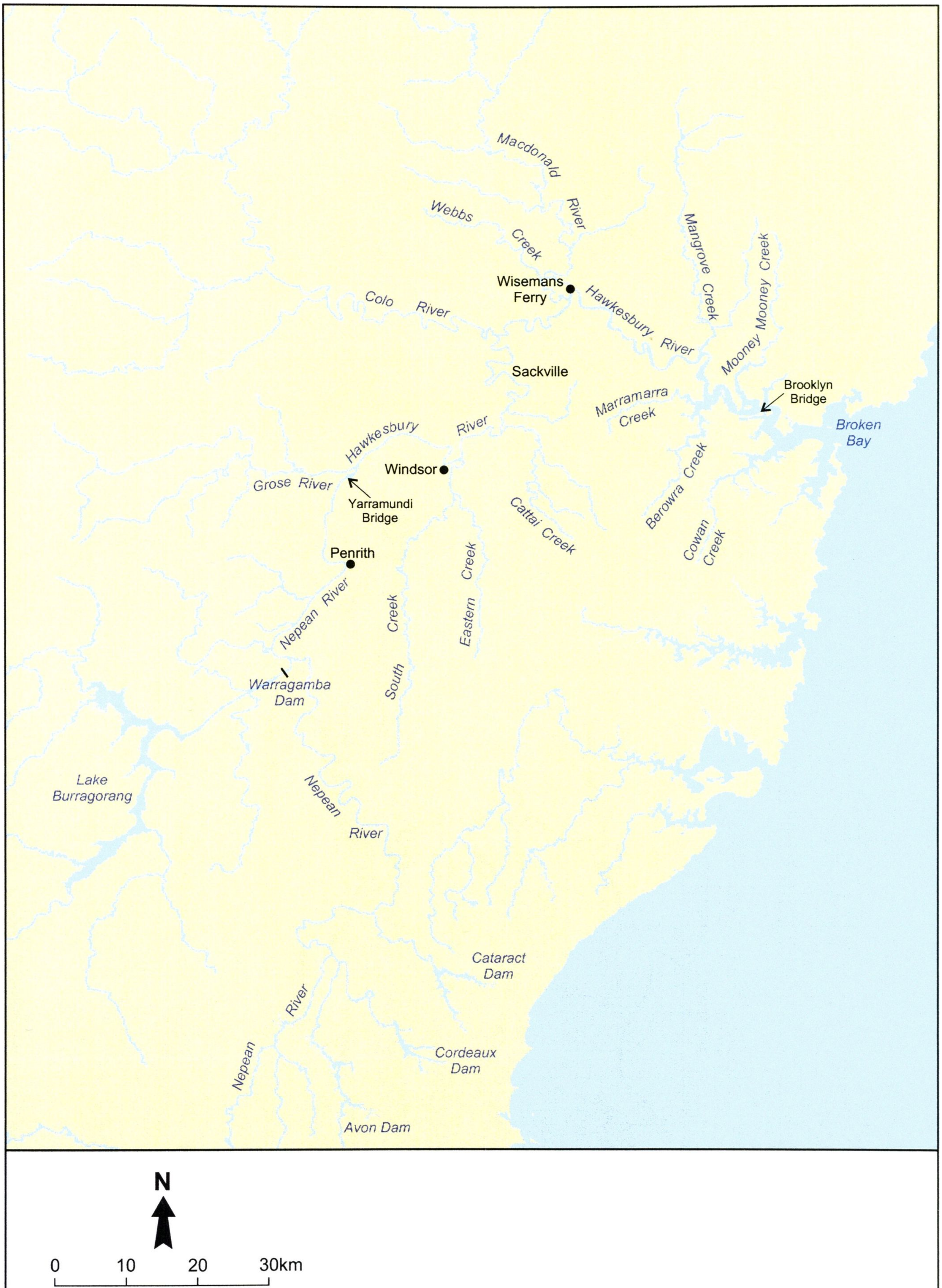
Peirson, W.L., Nittim, R., Chadwick, M.J., Bishop, K.A. and Horton, P.R. (2001) "Assessment of changes to saltwater/freshwater habitat from reductions in flow to the Richmond River estuary, Australia", *Water Science & Technology, 43(9), 89-97.*

Peirson, WL., Bishop, K., Van Senden, D., Horton, PR. and Adamantidis, CA. (2002) "Environmental Water Requirements to Maintain Estuarine Processes", *Water Research Laboratory, University of NSW, Technical Report No. 00/11*, also published as Environmental Flows Initiative Technical Report Number 3, Commonwealth of Australia, Canberra.

Roy, P.S., Williams, R.J., Jones, A.R., Yassini, I., Gibbs, P.J., Coates, B., West, R.J., Scanes, P.R., Hudson, J.P. and Nichol, S. (2001) "Structure and function of south-east Australian estuaries", *Estuarine, Coastal and Shelf Science, 53, 351-384.*

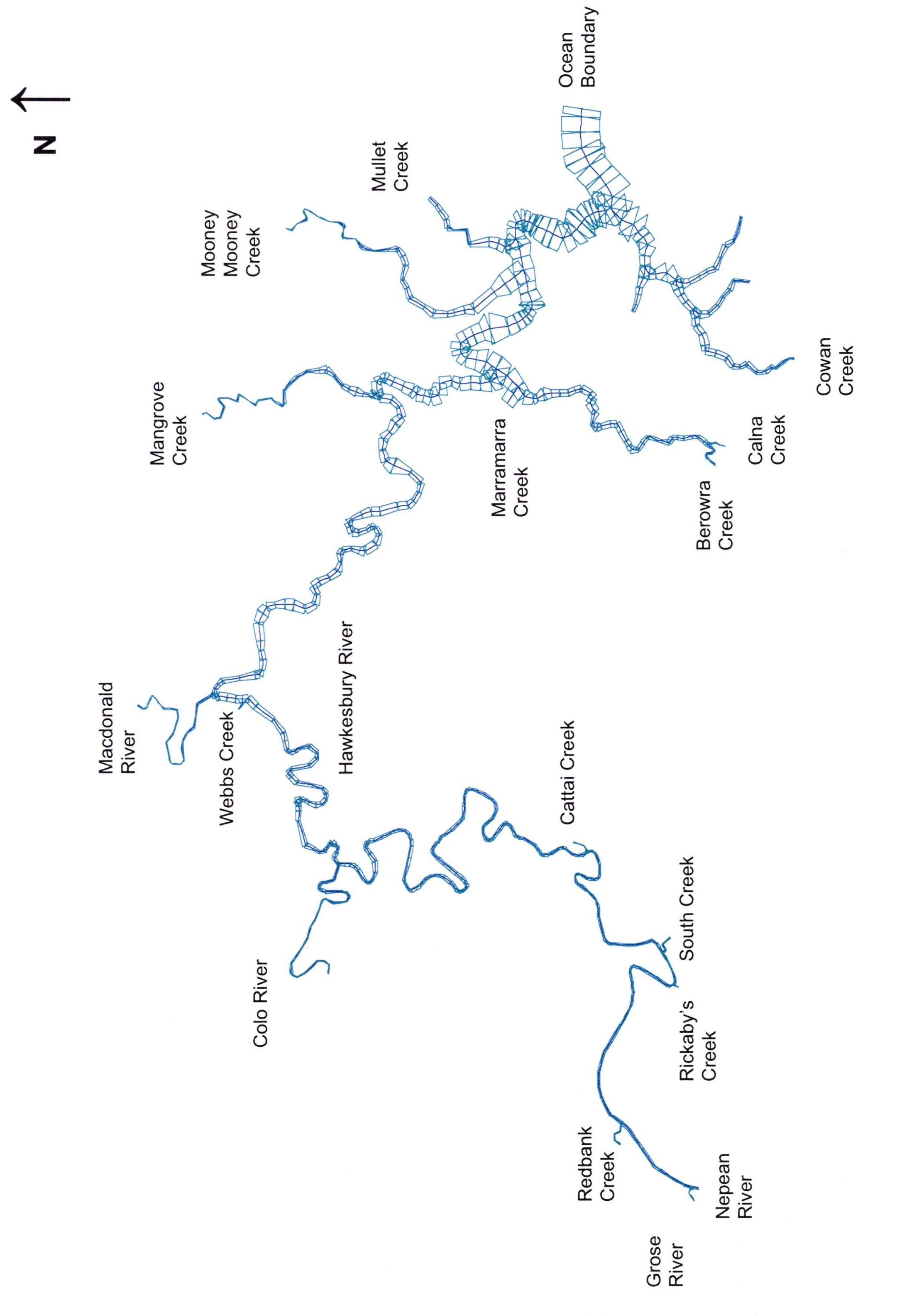
SPCC (1983) "Water Quality in the Hawkesbury-Nepean River: A Study and Recommendations", State Pollution Control Commission Report, September 1983.

Wyllie, S.J. (2003) "Hawkesbury Shoaling as Reported by the Prawn Fishermen", WRL letter report to Hawkesbury-Nepean River Forum, 11 February 2003.

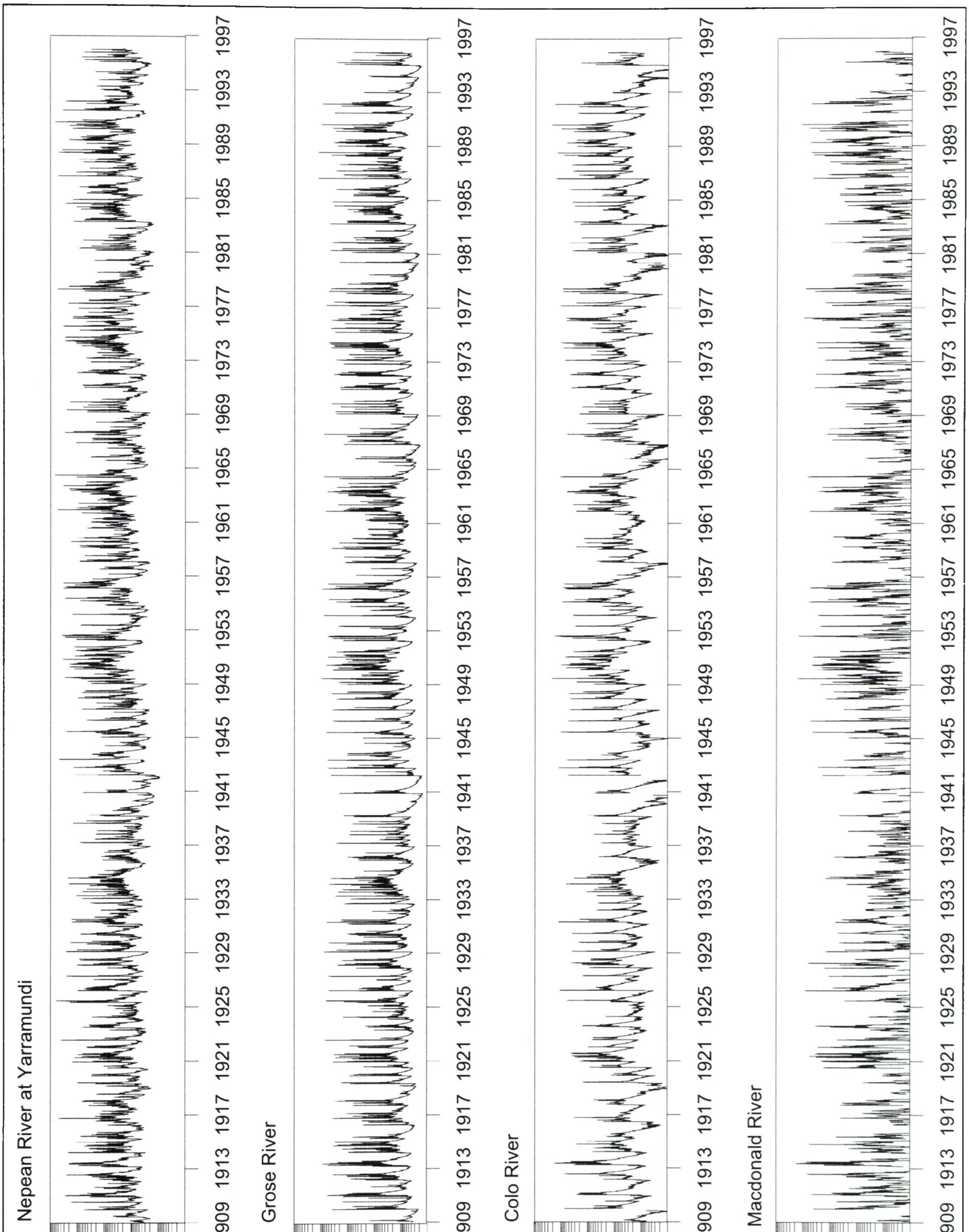


WRL Report No. 2003/10	HAWKESBURY NEPEAN RIVER SYSTEM	Figure 1

02107-01.cdr

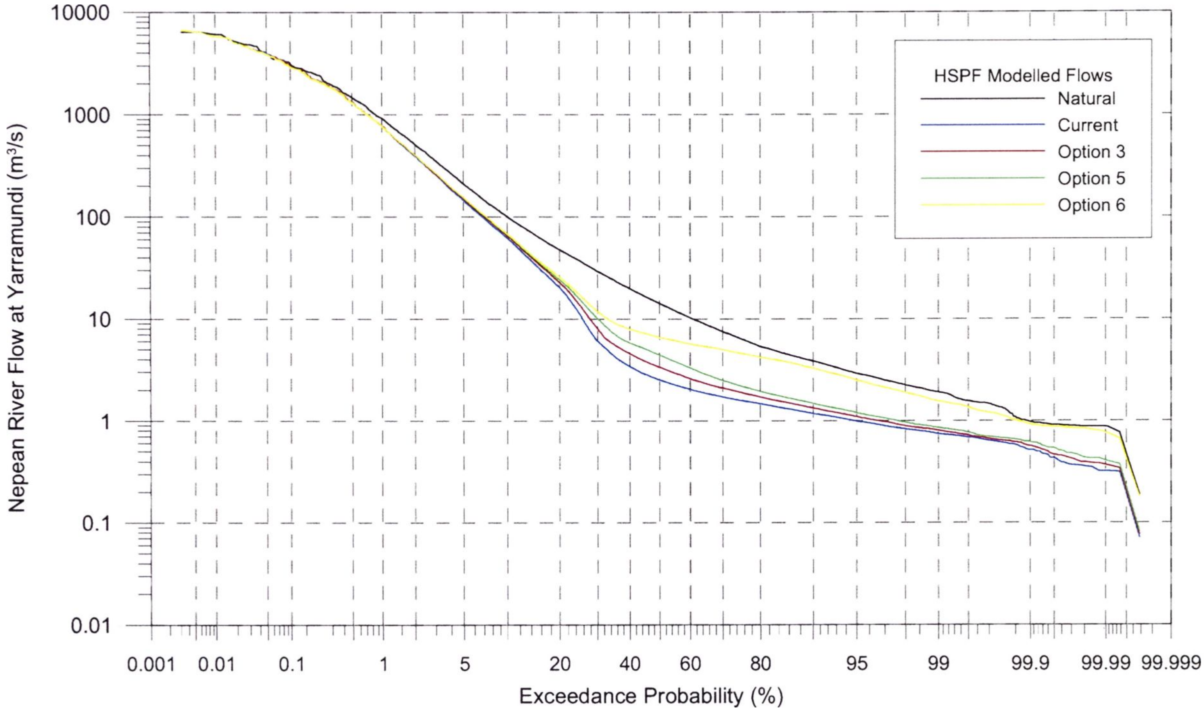


WRL Report No. 2003/10	HAWKESBURY NEPEAN ESTUARY MODEL MESH	Figure 2 fig2.doc

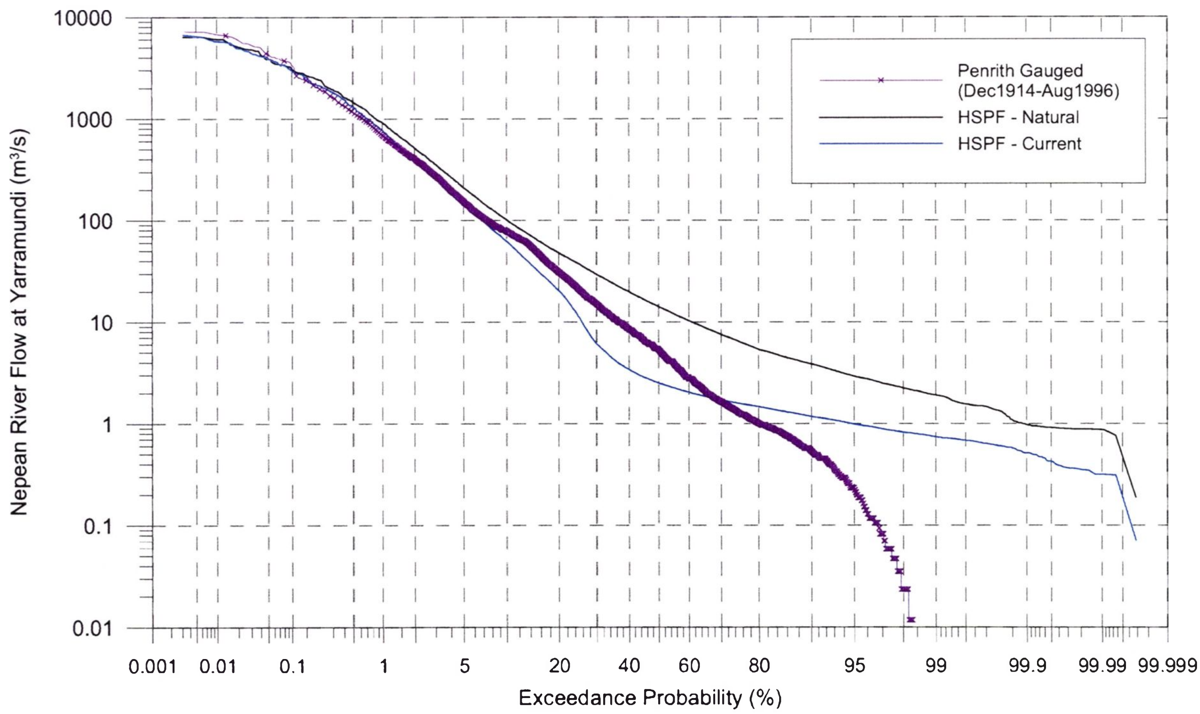


WRL Report No. 2003/10	MAJOR RIVER INFLOWS TO HAWKESBURY NEPEAN 1909-1995 NATURAL CONDITION	Figure 3

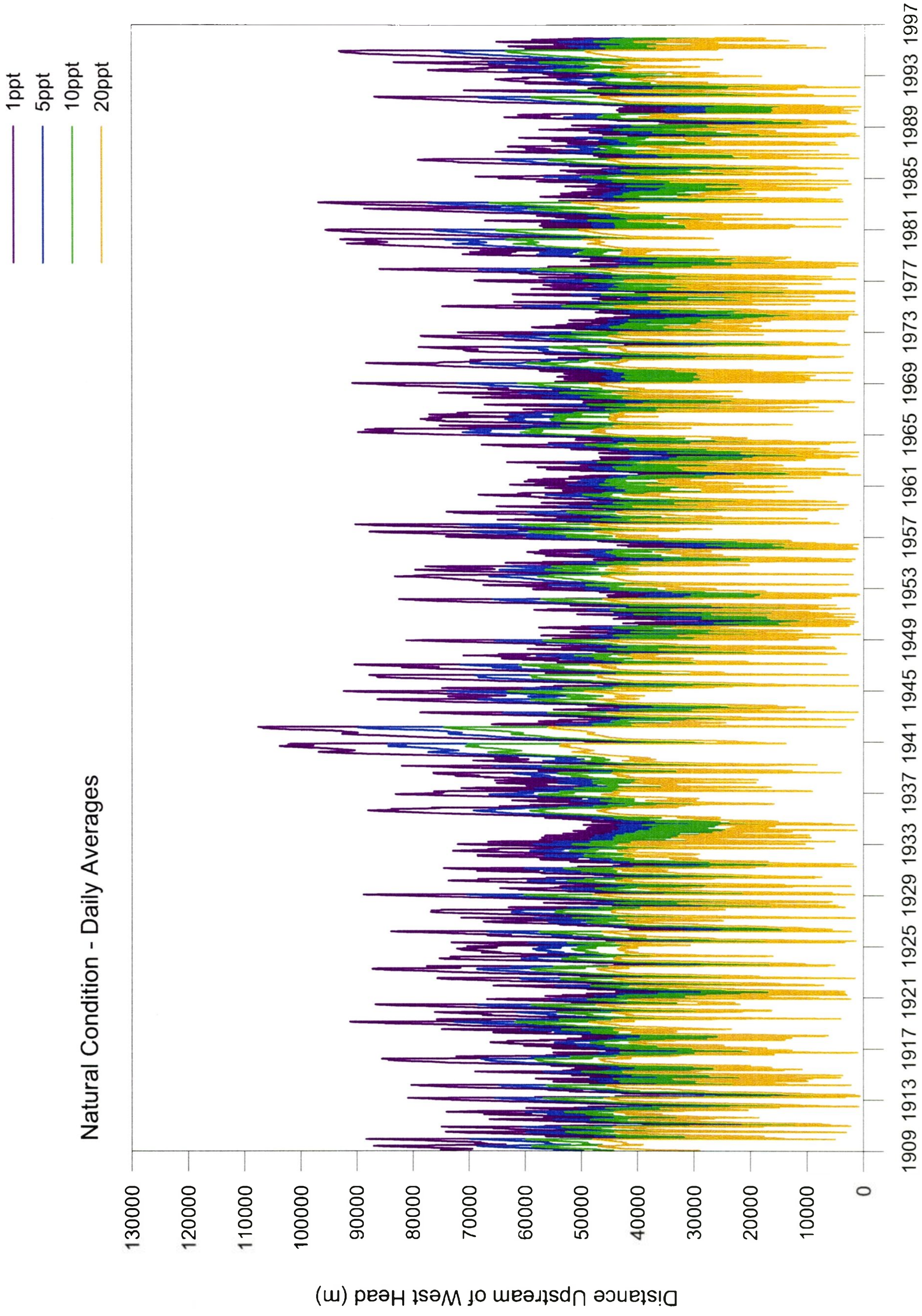
a) HSPF Model at Yarramundi (1909-1995)



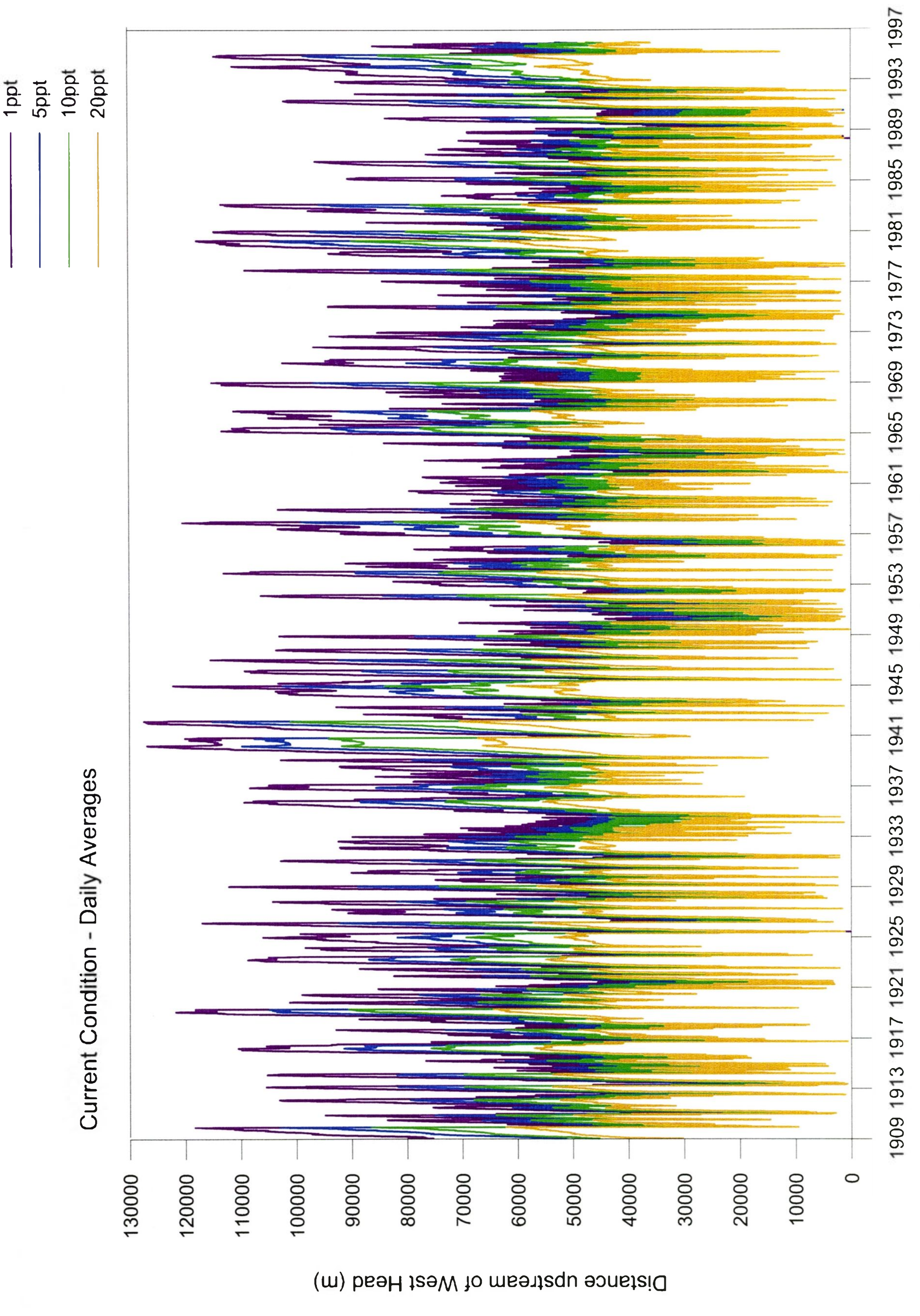
b) Penrith Gauged (1914-1996) compared with HSPF



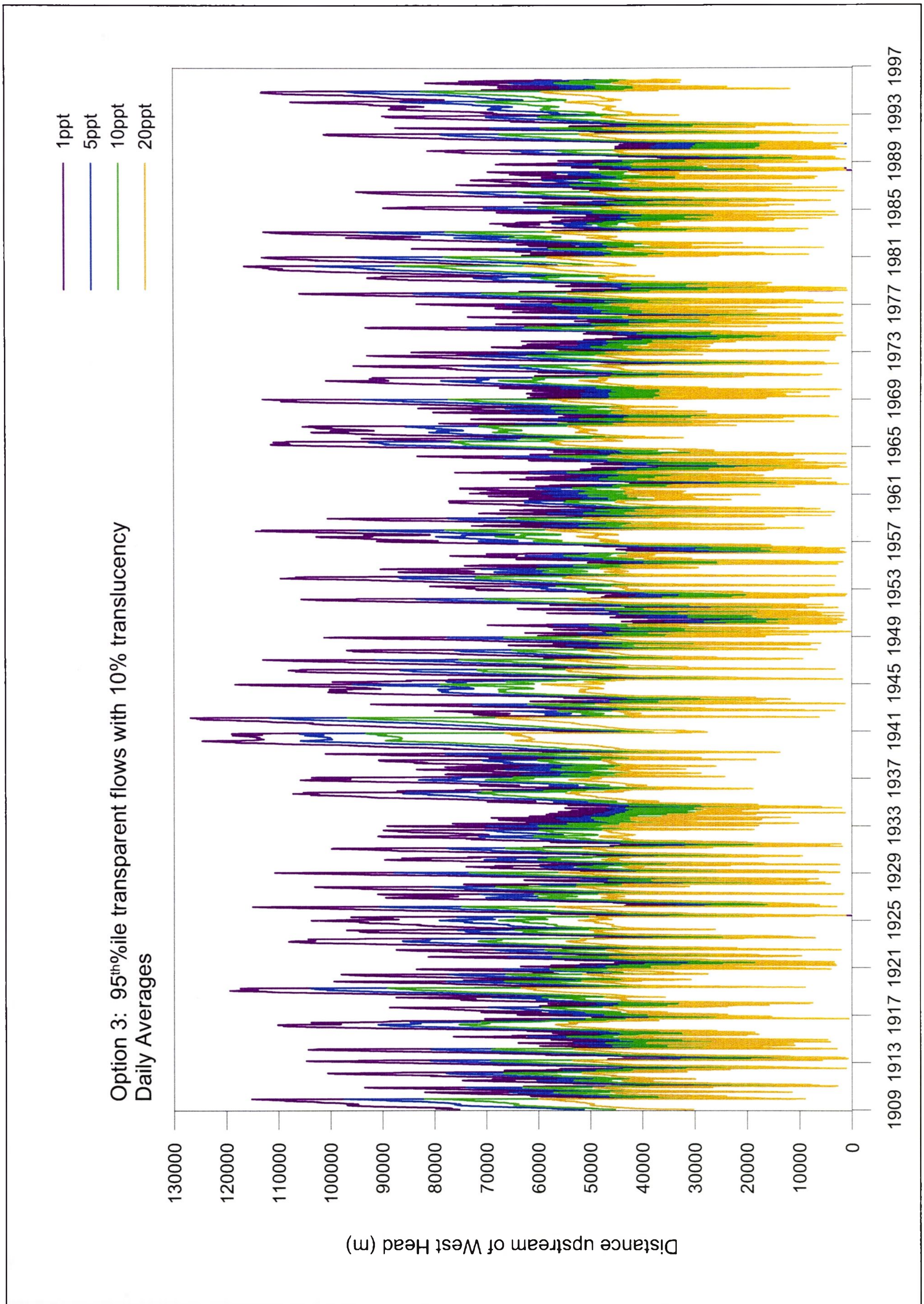
WRL Report No. 2003/10	PROBABILITY DISTRIBUTIONS OF NEPEAN RIVER FLOW AT YARRAMUNDI (HSPF MODEL) AND PENRITH (GAUGED)	Figure 4 fig4.doc



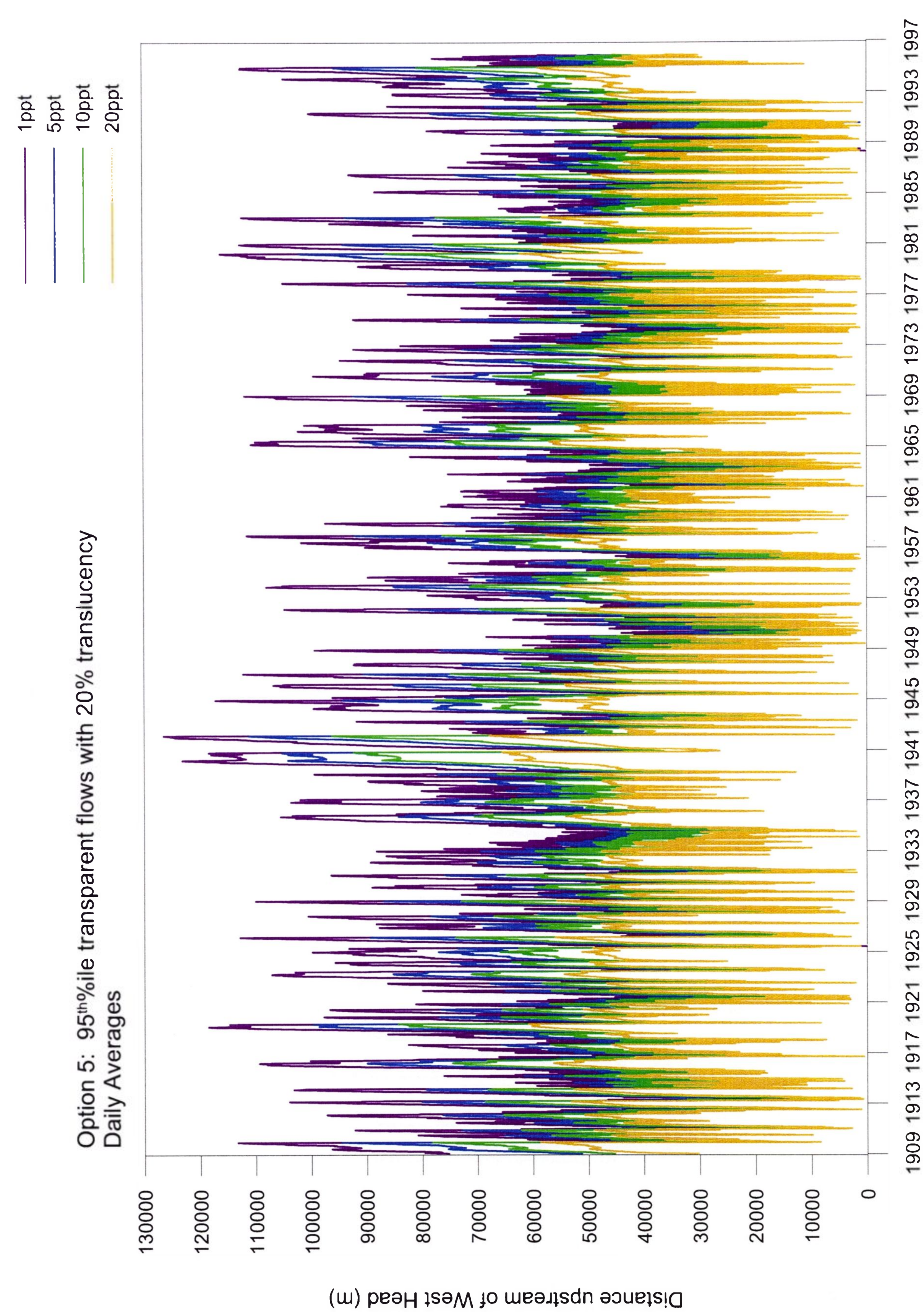
WRL Report No. 2003/10	MODELLED SALINTY DISTRIBUTION IN THE HAWKESBURY RIVER, 1909-1995 NATURAL CONDITION	Figure 5



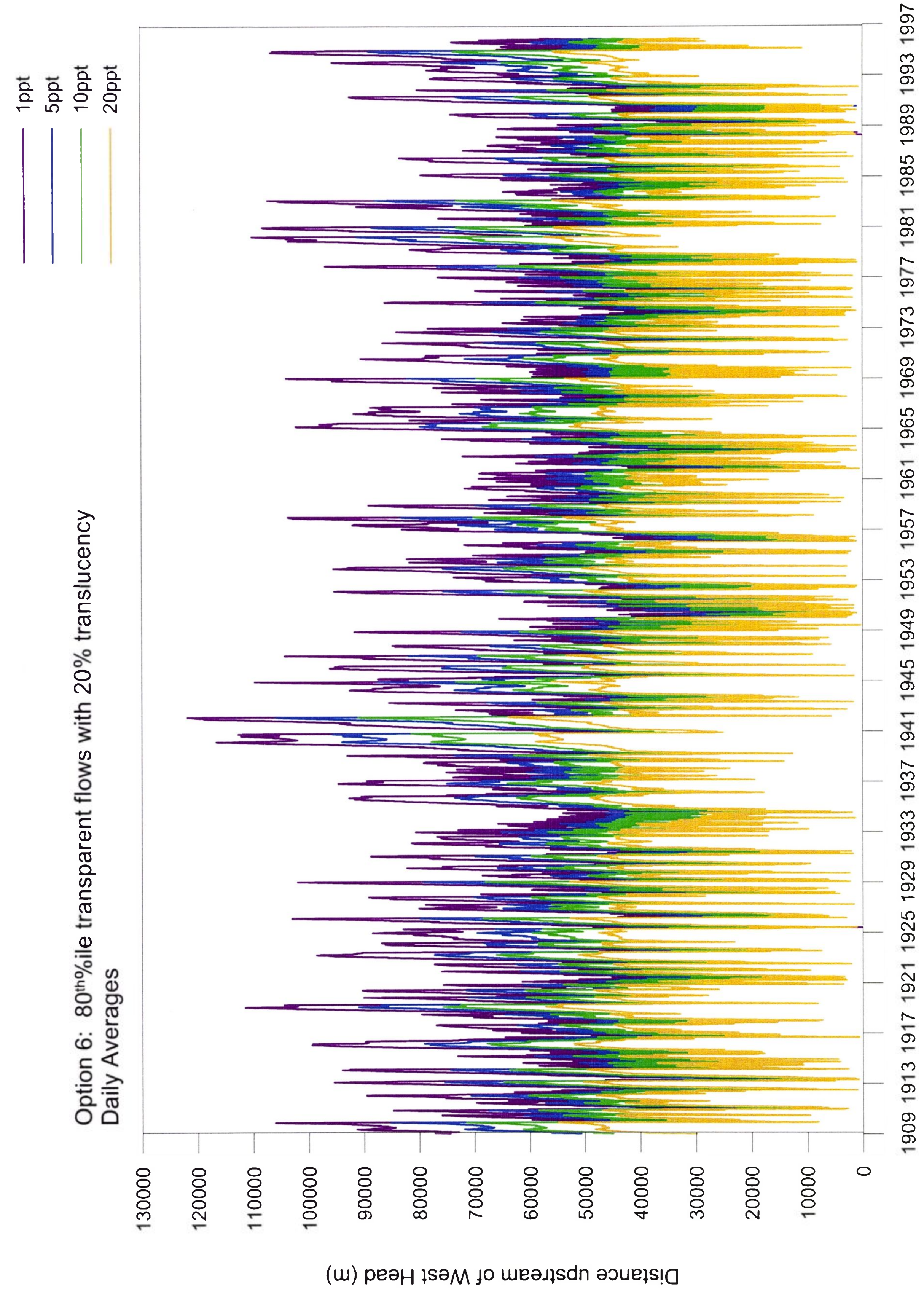
WRL Report No. 2003/10	MODELLED SALINTY DISTRIBUTION IN THE HAWKESBURY RIVER, 1909-1995 CURRENT CONDITION	Figure 6



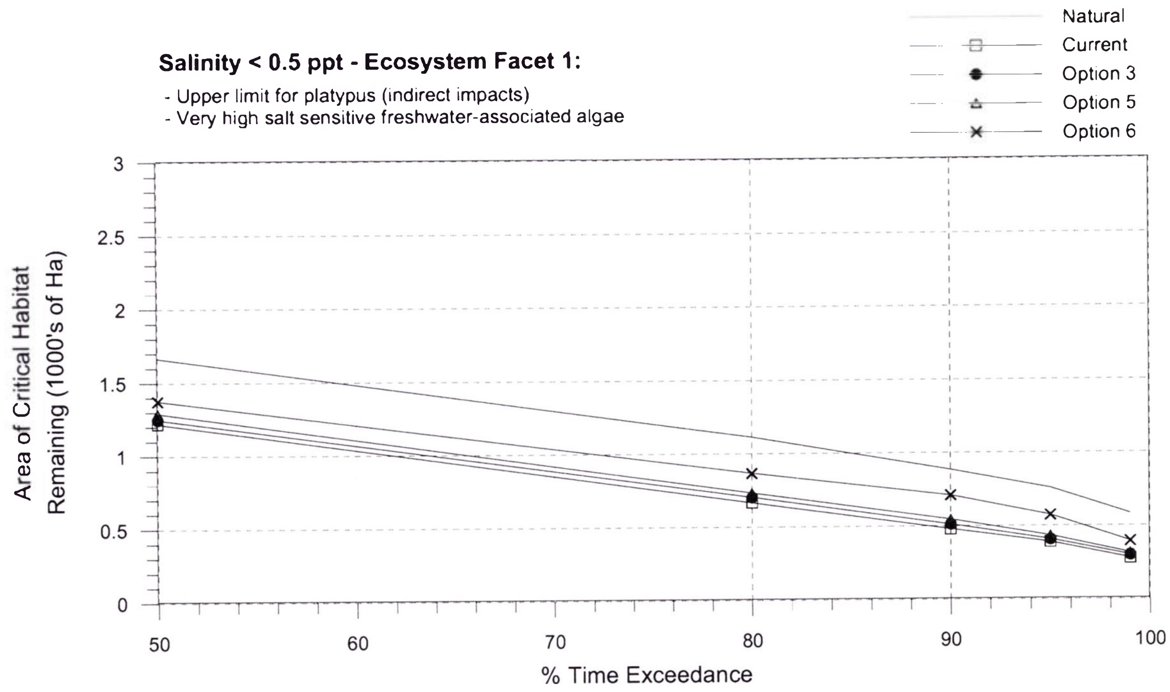
WRL Report No. 2003/10	MODELLED SALINTY DISTRIBUTION IN THE HAWKESBURY RIVER, 1909-1995 OPTION 3	Figure 7

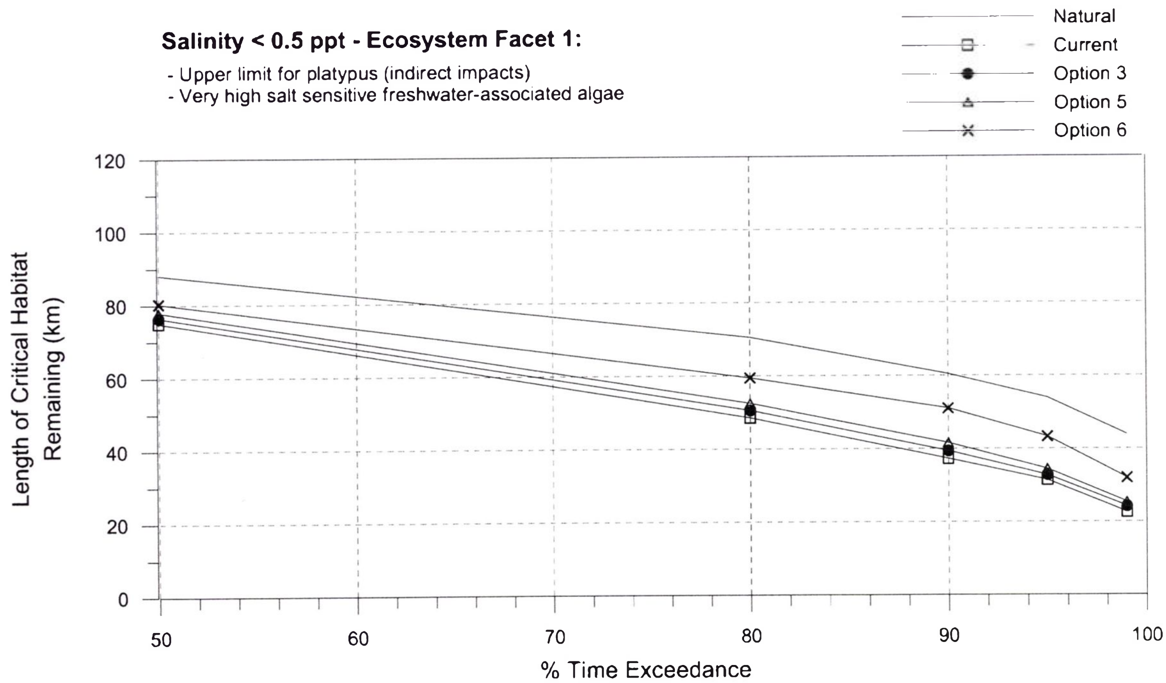


WRL Report No. 2003/10	MODELLED SALINTY DISTRIBUTION IN THE HAWKESBURY RIVER, 1909-1995 OPTION 5	Figure 8

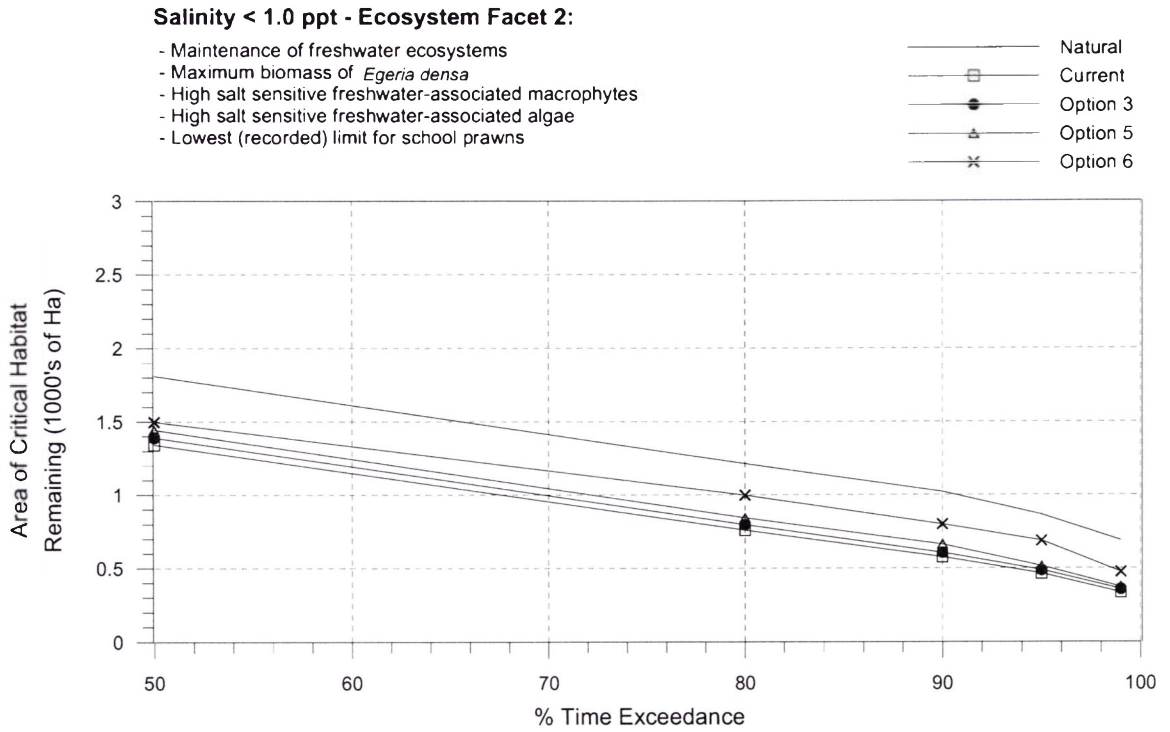


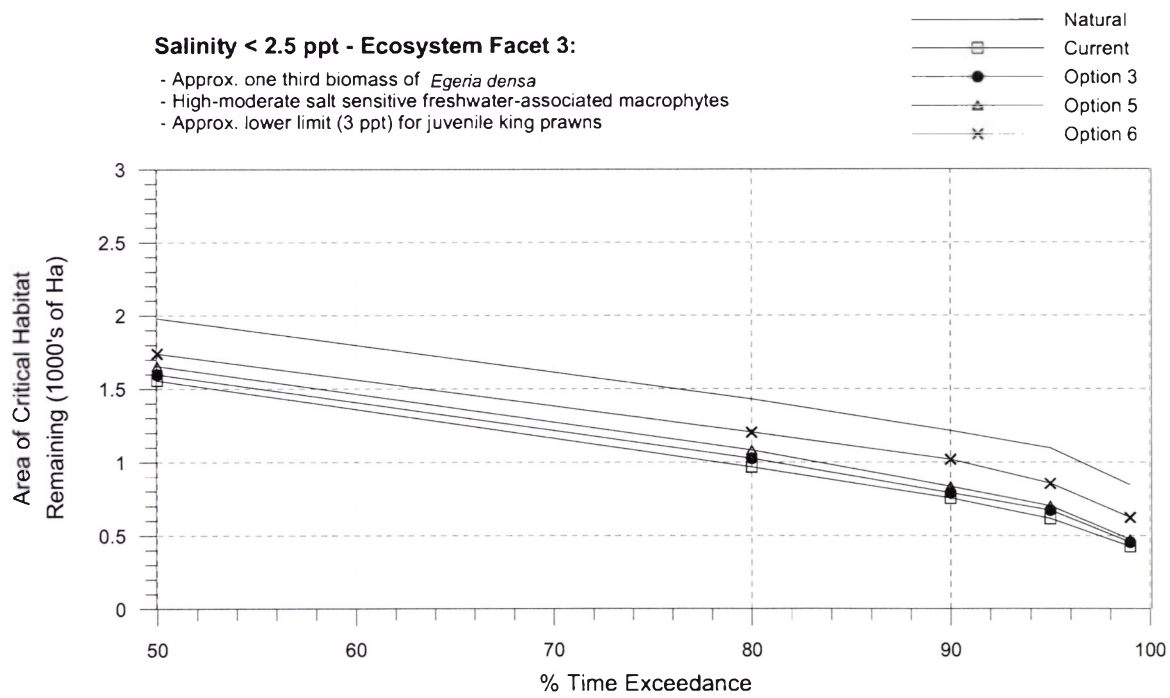
WRL Report No. 2003/10	MODELLED SALINTY DISTRIBUTION IN THE HAWKESBURY RIVER, 1909-1995 OPTION 6	Figure 9



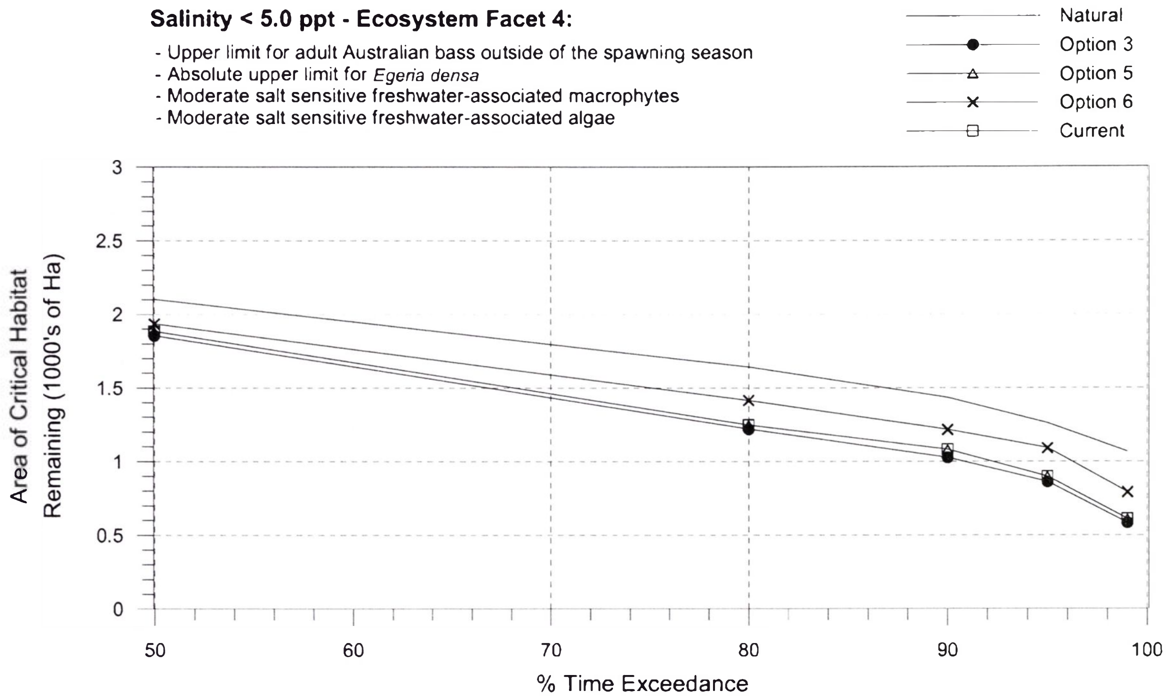


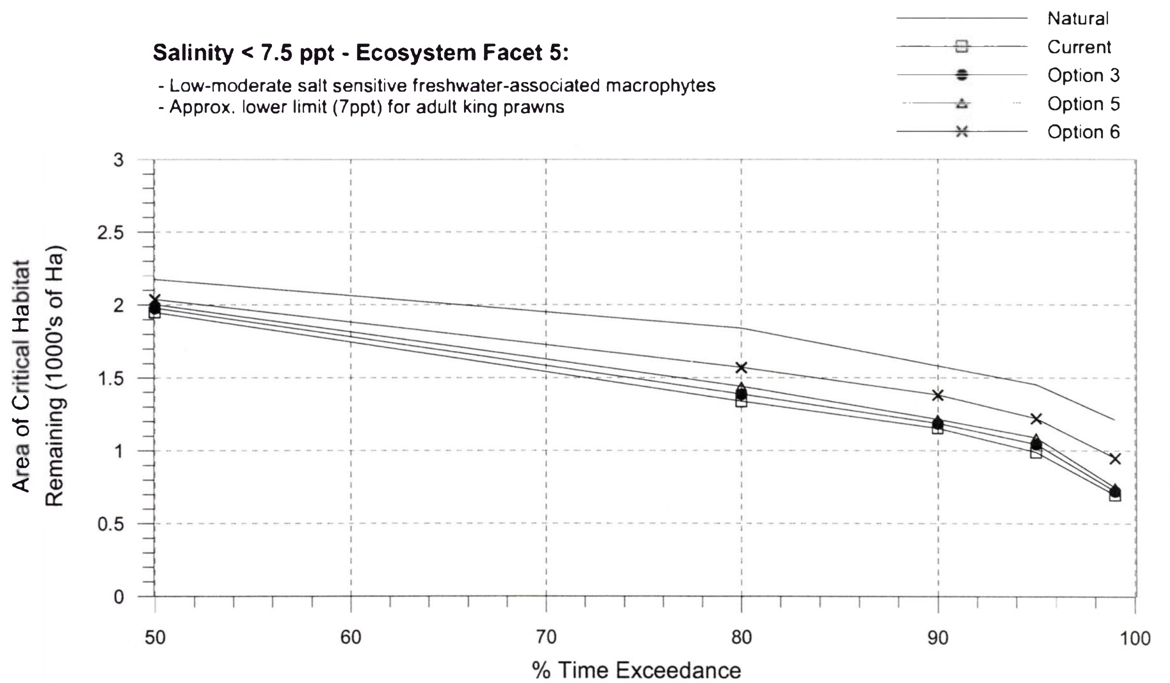
WRL	AVAILABLE HABITAT ECOSYSTEM FACET 1	Figure 10
Report No. 2003/10		fig10.doc



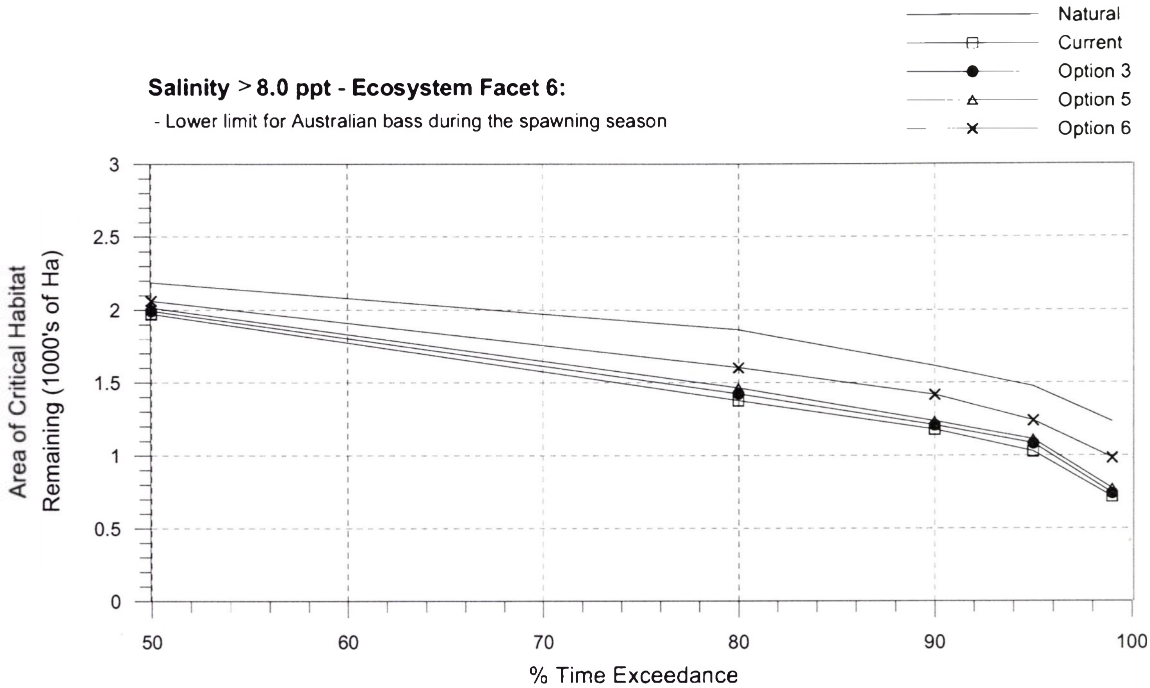


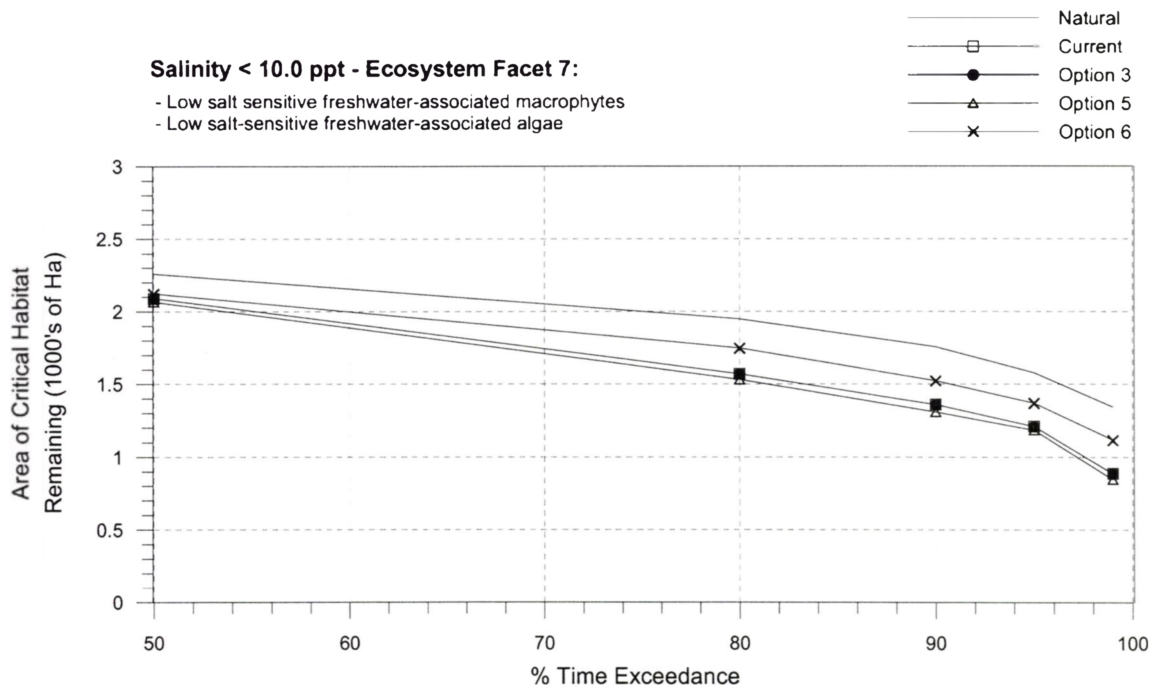
WRL Report No. 2003/10	AVAILABLE HABITAT ECOSYSTEM FACETS 2 AND 3	Figure 11 fig11.doc



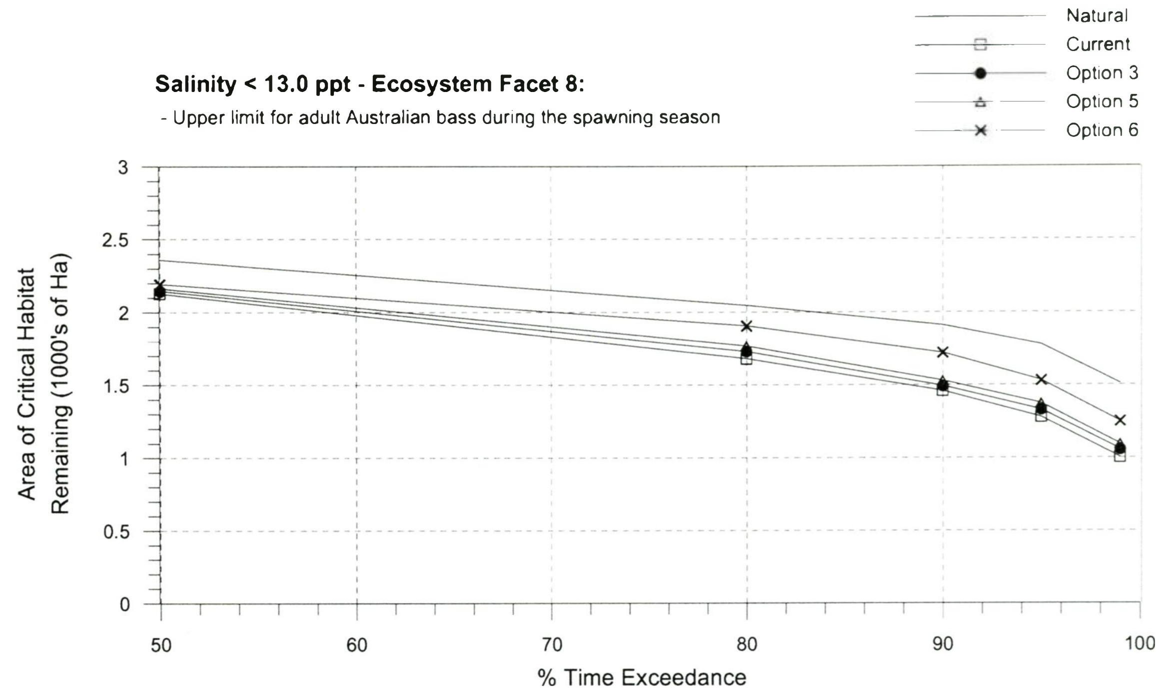


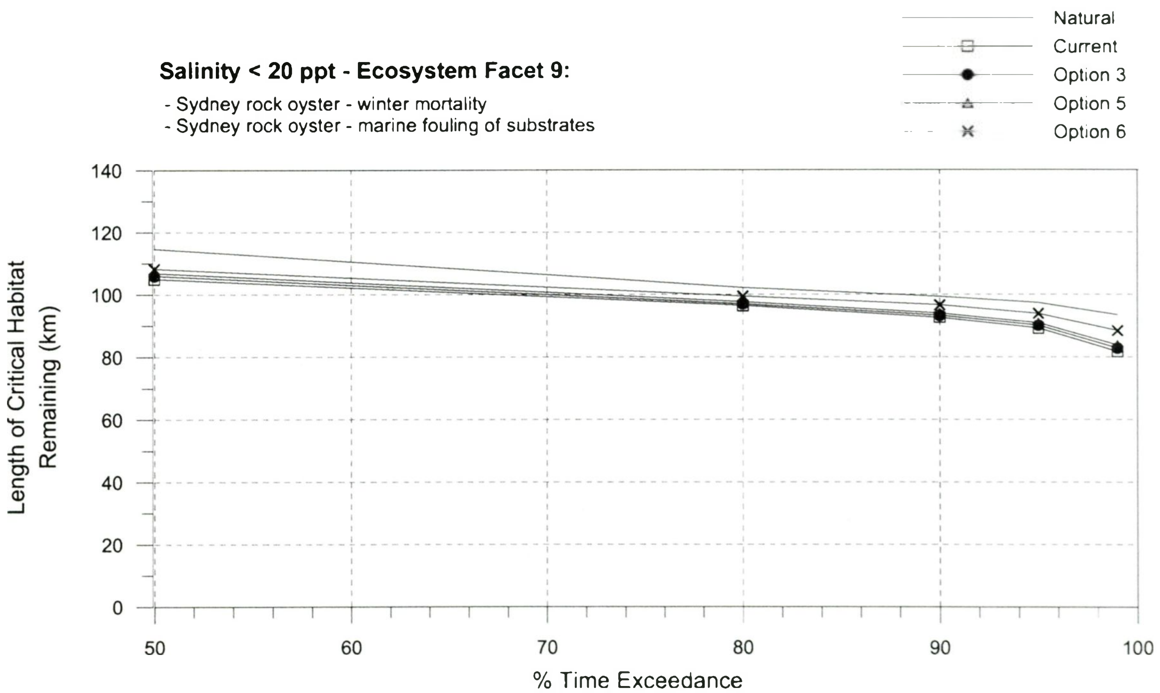
WRL Report No. 2003/10	AVAILABLE HABITAT ECOSYSTEM FACETS 4 AND 5	Figure 12 fig12.doc



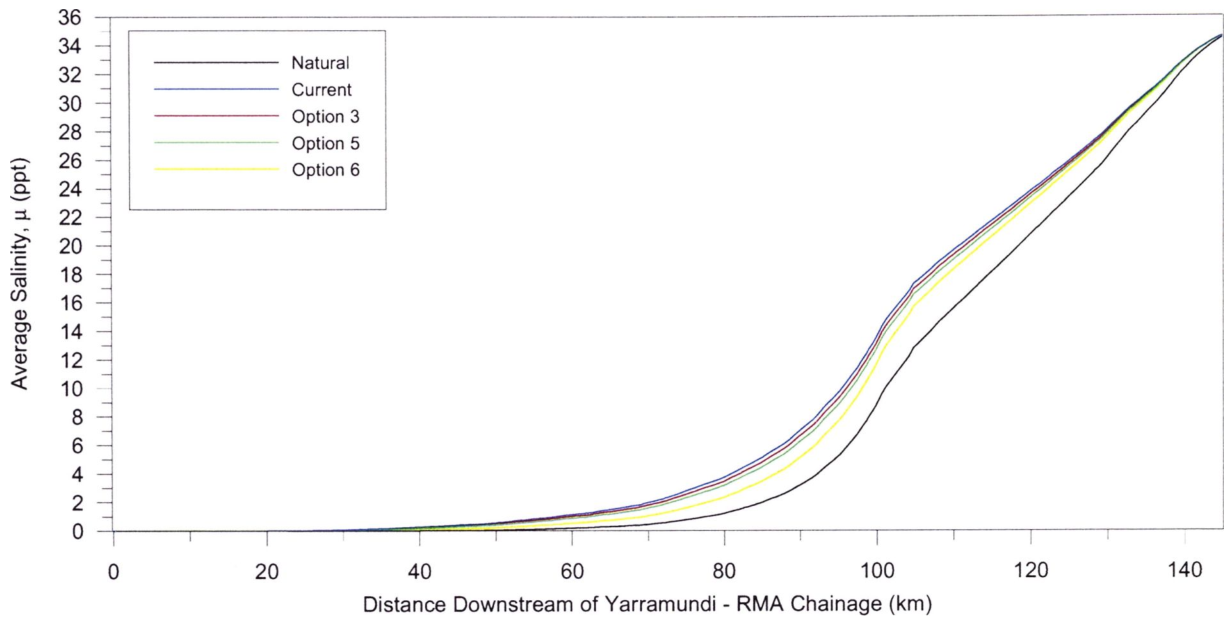


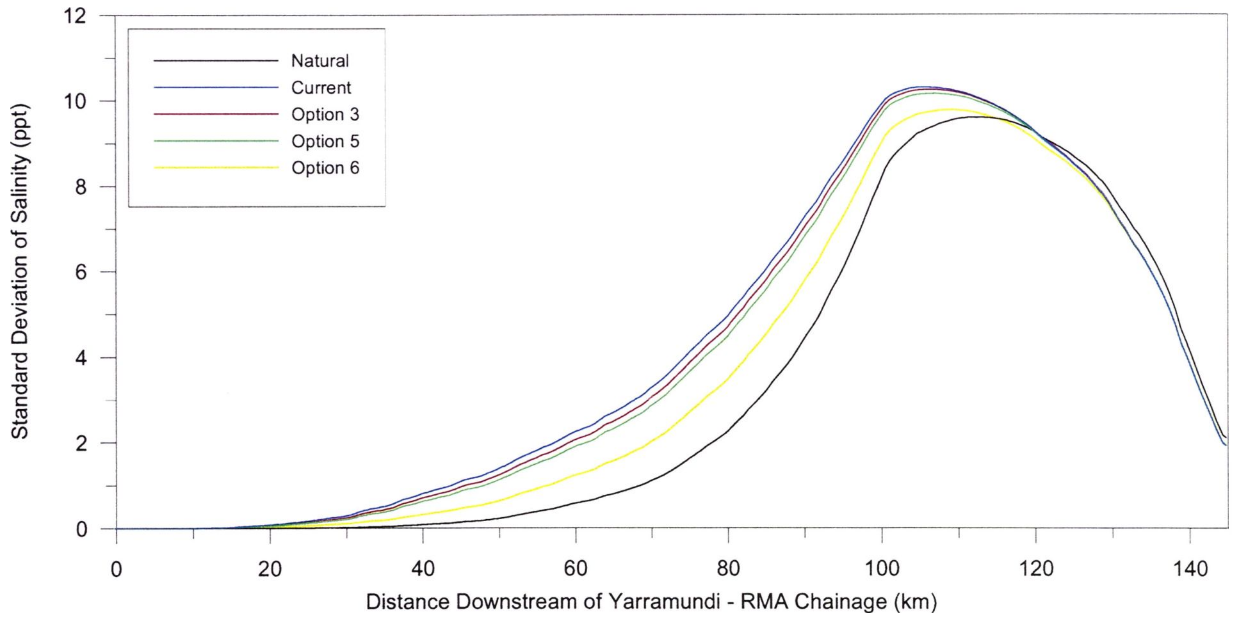
WRL Report No. 2003/10	AVAILABLE HABITAT ECOSYSTEM FACETS 6 AND 7	Figure 13 fig13.doc



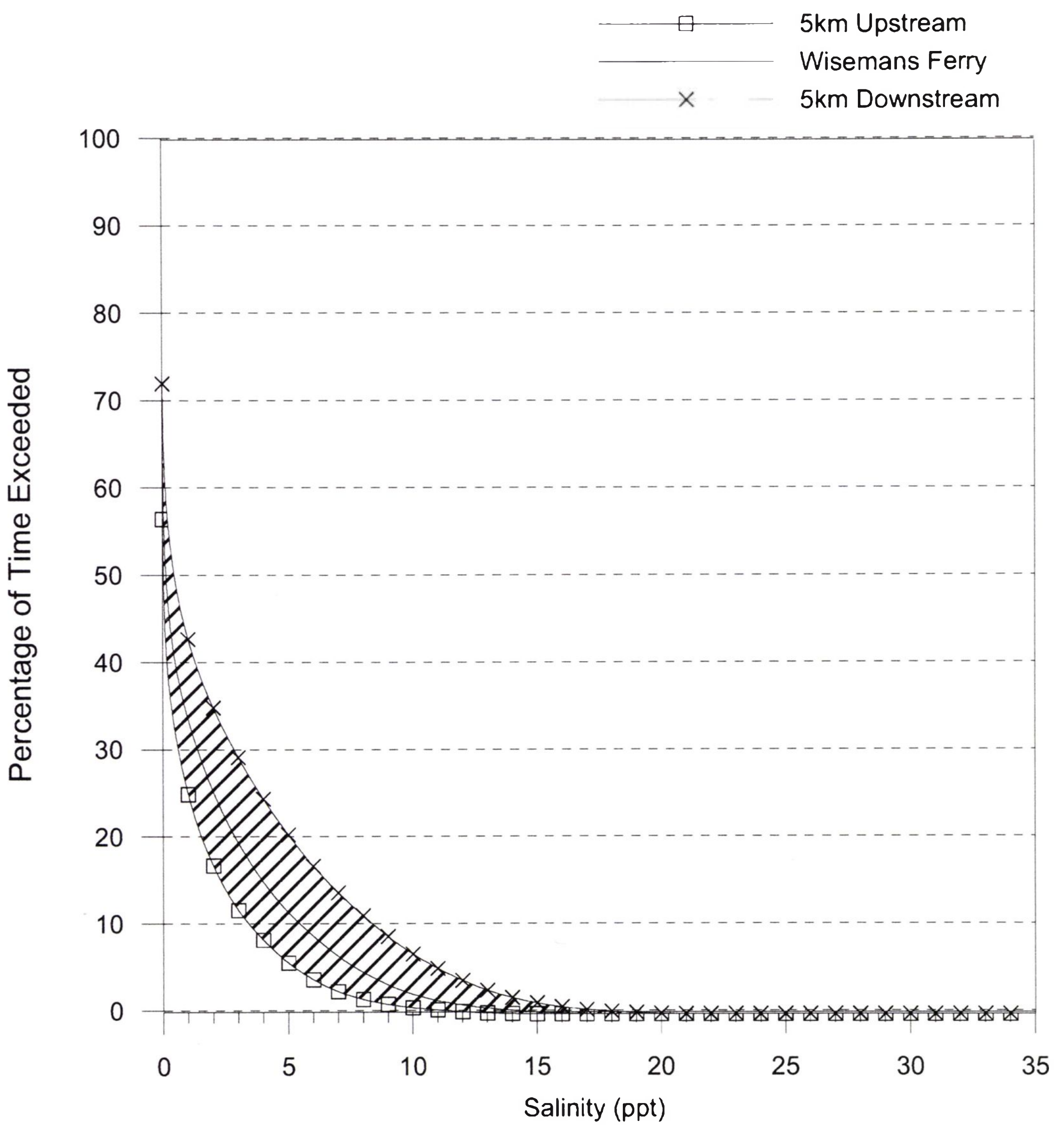


WRL Report No. 2003/10	AVAILABLE HABITAT ECOSYSTEM FACETS 8 AND 9	Figure 14 fig14.doc

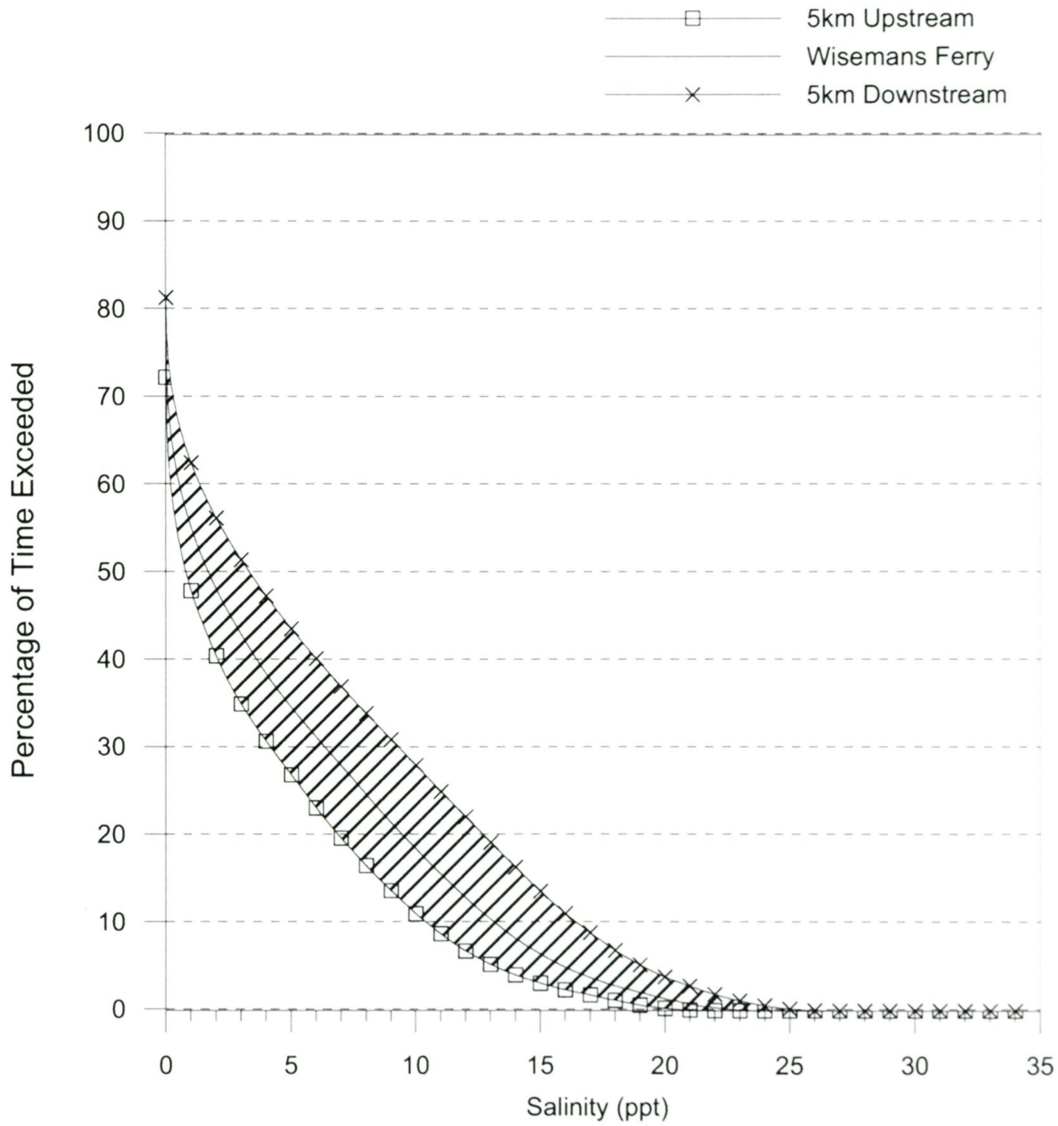




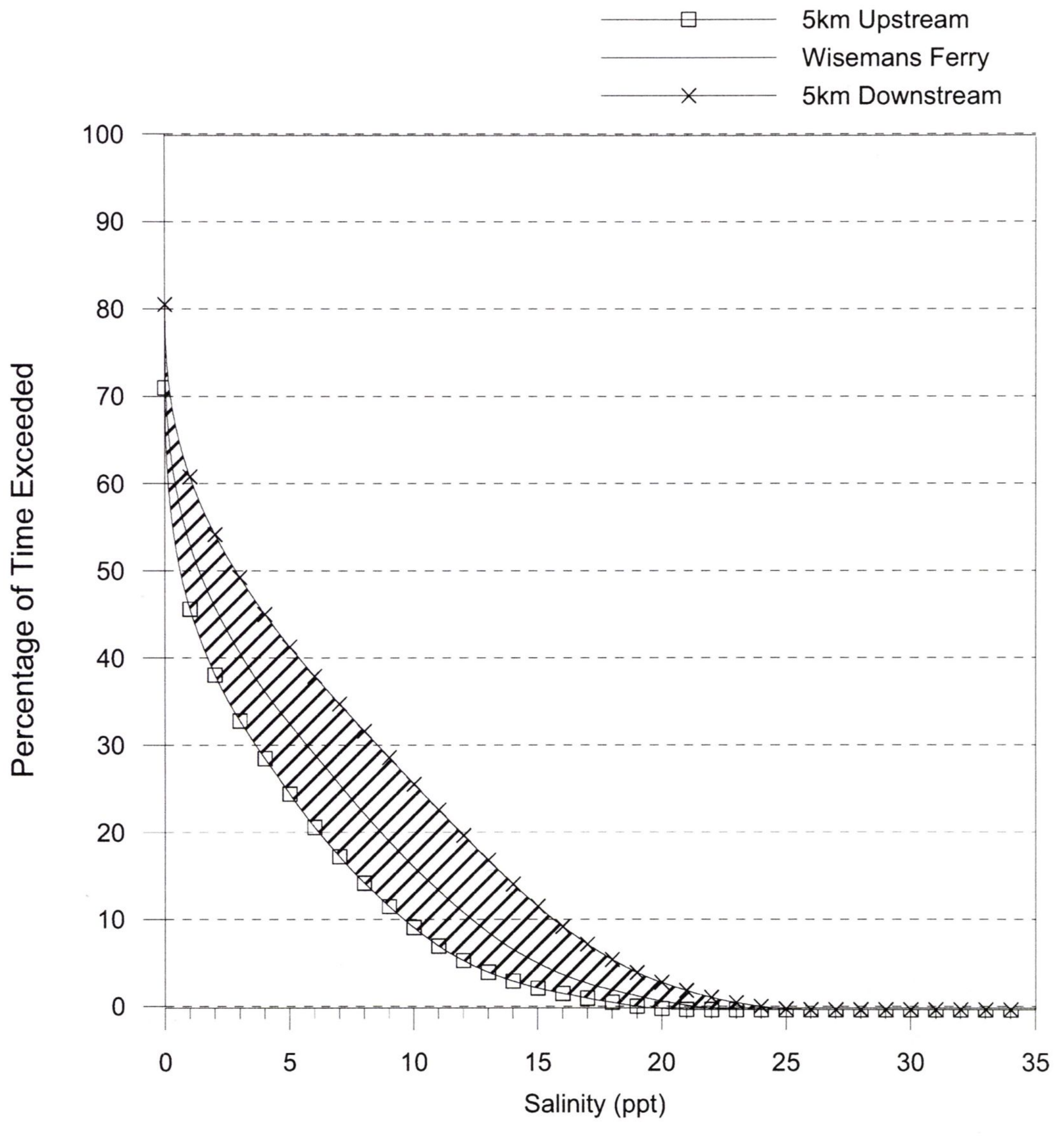
WRL Report No. 2003/10	MODELLED SALINITY MEAN AND STANDARD DEVIATION	Figure 15 fig15.doc



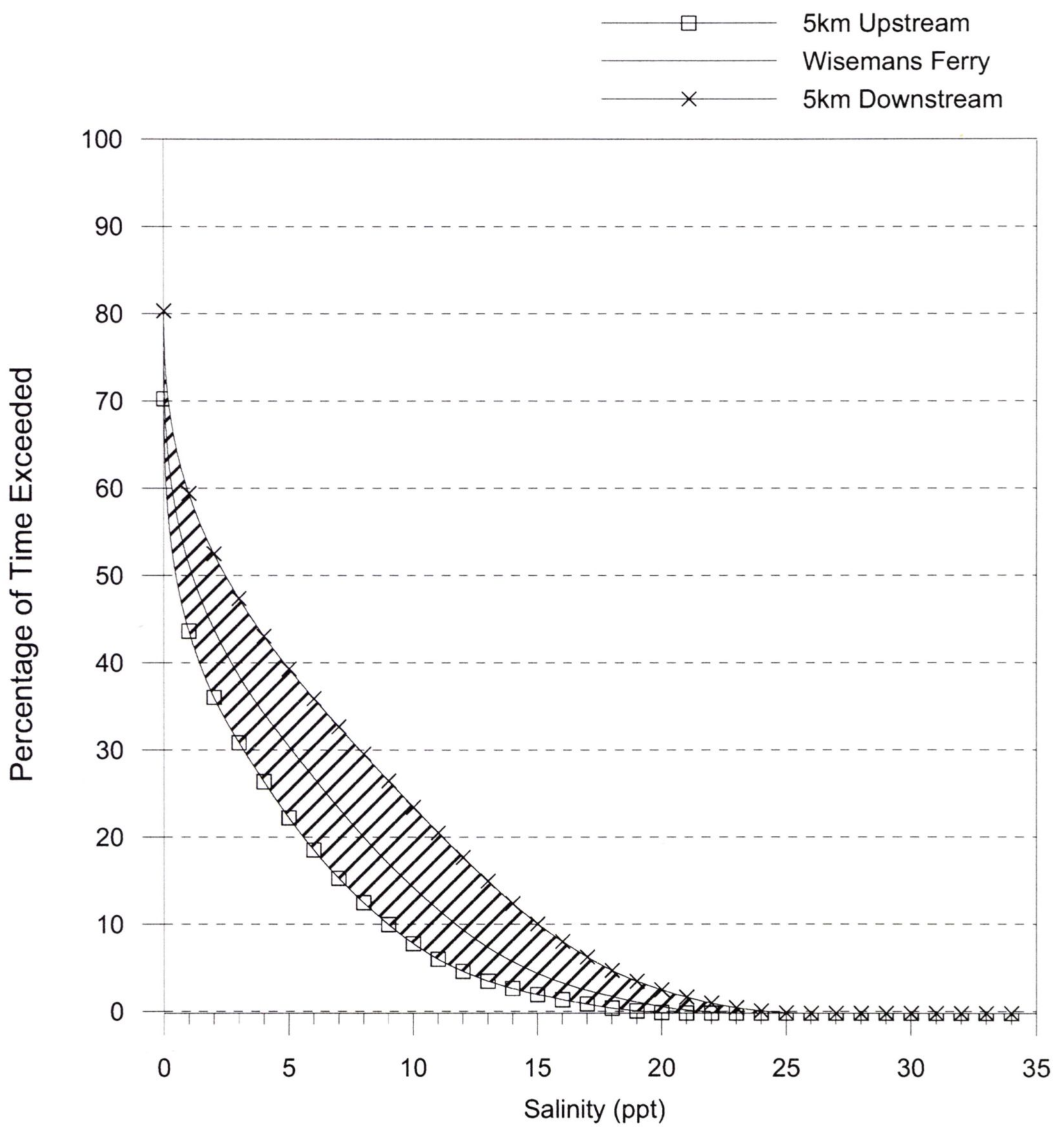
WRL Report No. 2003/10	SALINTY EXPOSURE NEAR WISEMANS FERRY NATURAL CONDITION	Figure 16 fig16.doc



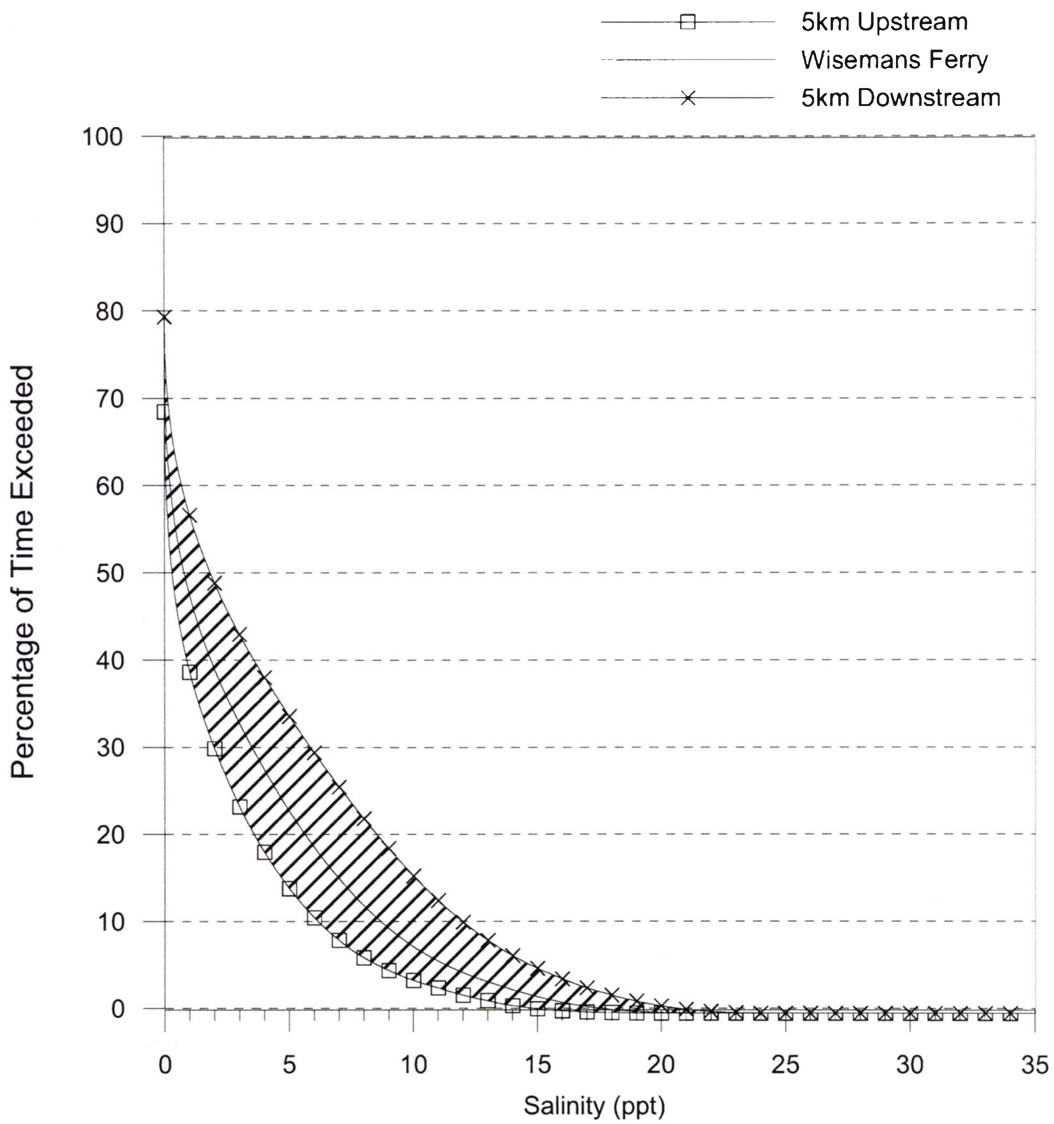
WRL Report No. 2003/10	SALINTY EXPOSURE NEAR WISEMANS FERRY CURRENT CONDITION	Figure 17 fig17.doc



WRL Report No. 2003/10	SALINTY EXPOSURE NEAR WISEMANS FERRY OPTION 3	Figure 18 fig18.doc



WRL Report No. 2003/10	SALINTY EXPOSURE NEAR WISEMANS FERRY OPTION 5	Figure 19 fig19.doc



WRL Report No. 2003/10	SALINTY EXPOSURE NEAR WISEMANS FERRY OPTION 6	Figure 20 fig20.doc