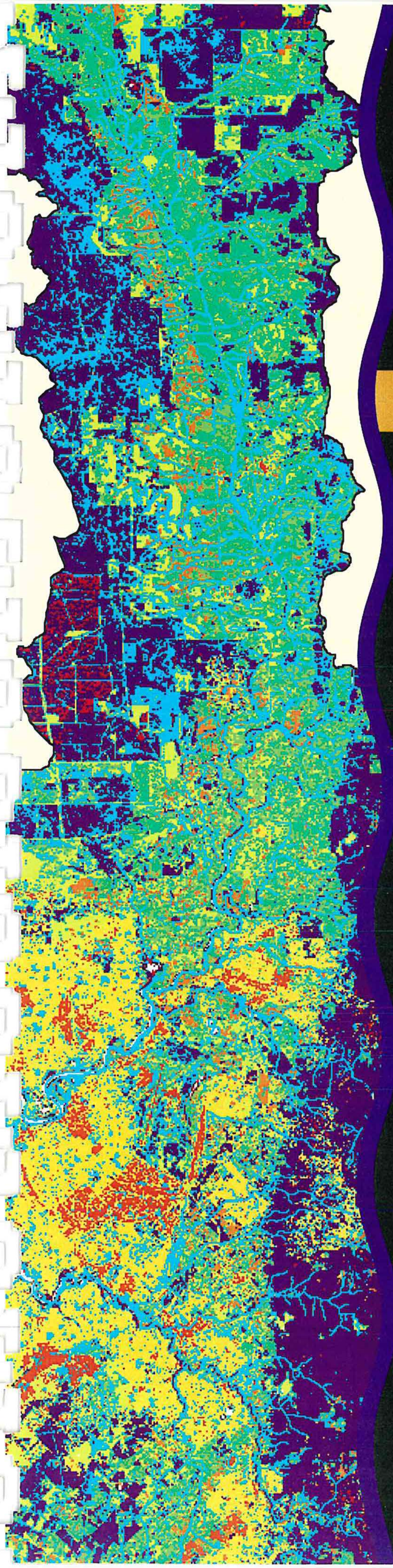
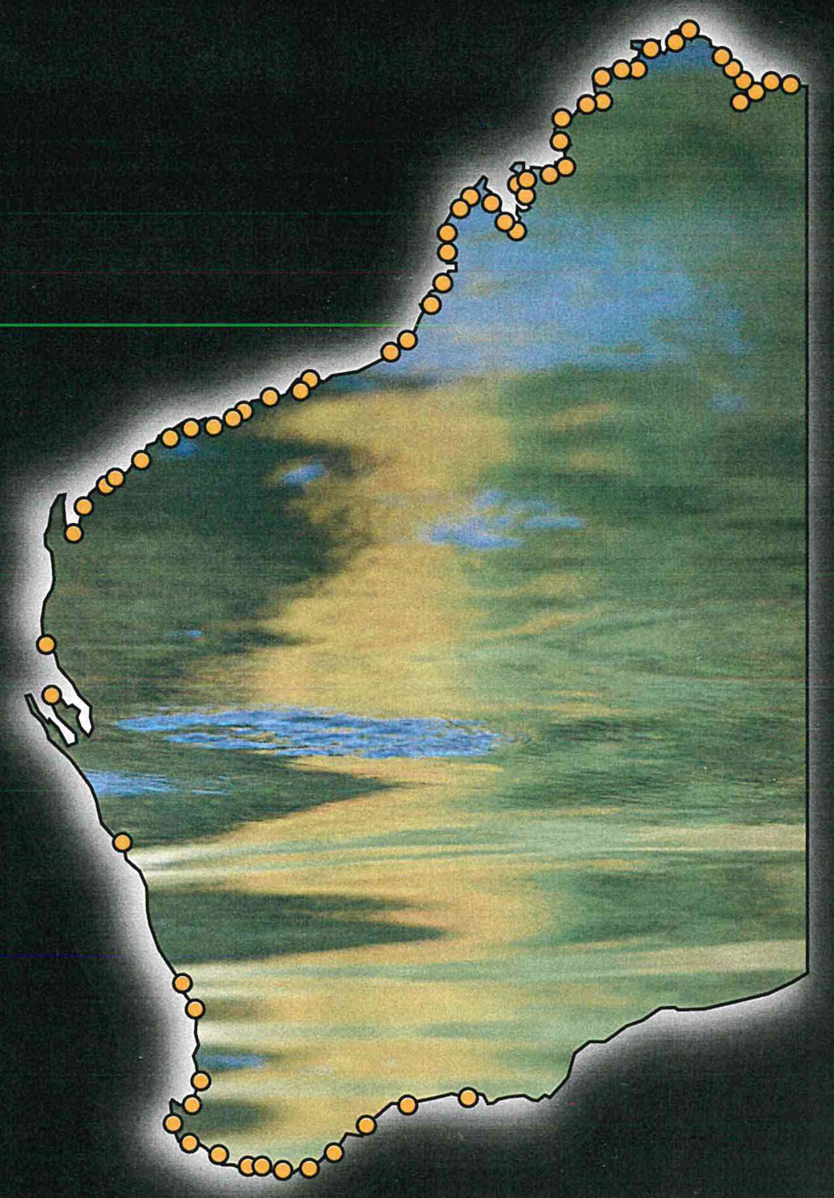


ESTUARIES

OF WESTERN AUSTRALIA

An Inventory and Risk Assessment



Department of Environmental Protection

WATER AND RIVERS COMMISSION

DECEMBER 1999

Kevin

estuaries in western australia

contents

1 Introduction & Summary

There are over 145 estuaries in Western Australia. They span a wide environmental range from the Kimberleys to Esperance, and have a great variety of forms. Many WA estuaries have been included or recommended to be part the State Conservation Estate. Much is known about a few of our estuaries, but little is known about the majority of them.

Landcover and the pattern of rainfall, both govern the quality of water moving through the landscape. The timing and nature of river flow and stormwater runoff, and marine exchange are factors which control the physical, chemical and biological nature of all our estuaries.

Estuaries in Western Australia support thriving commercial and recreational fisheries, and are prized by local communities for all forms of direct contact and passive recreation. Unfortunately, some estuaries in the southwest have been exhibiting limited periods of very poor water quality, following extended nutrient enrichment.

Observed increases in the frequency of potentially harmful phytoplankton blooms, and nuisance macroalgal accumulations, have also been accompanied by less obvious, but problematic reductions in biological diversity. There is usually a move to smaller, less desirable organisms better able to tolerate low dissolved oxygen concentrations and higher levels of organic and nutrient pollution.

Much can be determined about the nature and susceptibility of Western Australian estuaries from an integrative analysis of available spatial and temporal data. These data include aerial photography, satellite images, landform and soils maps and bottom-end water quality data.

This project, proposed and supported by State Natural Resource Management Agencies, the National Landcare Program and Murdoch University will combine best-available information describing landform and soils, and a landuse classification scheme derived from satellite coverages, with runoff data from regional catchments.

Relationships derived from the integration of these data sets will be incorporated into simple GIS models to describe regional runoff quality for catchments where no monitoring data are available. This analysis will provide best possible estimates of runoff volume timing and quality for both average and extreme years.

For some regional rivers, information on biological community structure is available from the National Monitoring River Health program. Macro-invertebrate and phytoplankton data have been used to describe the health of streams and rivers. These data may also be used to help define the nature of runoff inputs to receiving estuaries.

Output from the spatial models and the biological and chemical data will be combined with information on tidal exchange to estimate the annual water and nutrient flux to estuaries. The ecological health, and susceptibility of Western Australian estuaries to eutrophication and sedimentation will be derived.

Successful completion of the estuarine status and risk assessment at the end of 1999, will be an important step in helping the community and waterway managers identify priority catchments and to flag areas requiring improved management. Information generated through the project will also form a solid basis for future state-of-the-environment reporting of estuarine health.

this document

This document has been prepared in-house to provide stakeholders with an update of the objectives and outcomes of the "Estuarine Inventory and Risk Assessment" project.

This mock-up also provides a preview of the final inventory atlas to be completed at the end of December 1999.

As laid out in this mock-up, the first three sections will summarise physical, chemical and biological information by region, through a status and risk assessment.

Section 4 will provide an inventory of information for each of the more than 145 estuaries in the state. Examples for the Swan Estuary and Oyster Harbour have been provided to show the range of information that will be contained in the final inventory. The project has been jointly proposed by the Water and Rivers Commission, the Department of Environmental Protection and Murdoch University, with funding provided by WRC, DEP and the National Landcare Program. Funding details are summarised in the final page.

2.1 Rainfall & Runoff

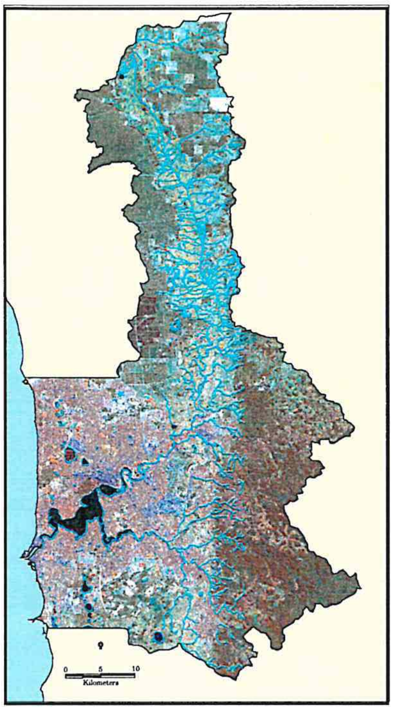
A comprehensive network of stream gauging stations established in the 1970s, has yielded considerable information on the nature of rainfall and runoff throughout regional Western Australia. The Water and Rivers Commission has prepared regional summaries of this information as part of the water resource assessment programme.

Using Geographical Information Systems (GIS) to estimate runoff from rainfall, slope, soil and landuse information

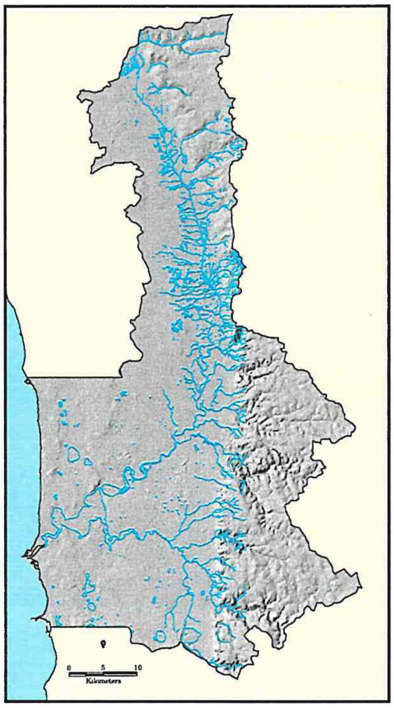
Although coverage of the gauging network has been appropriate for water resource assessment, significant areas of the State have not been monitored from the perspective of bottom-end assessment of runoff quality to estuaries.

Summaries of regional rainfall and runoff which have been prepared by the WRC, will be extended through a probabilistic analysis of average and extreme conditions. Relationships between rainfall, landform, landcover and runoff will be established where gauging information is available and will be extended to ungauged catchments.

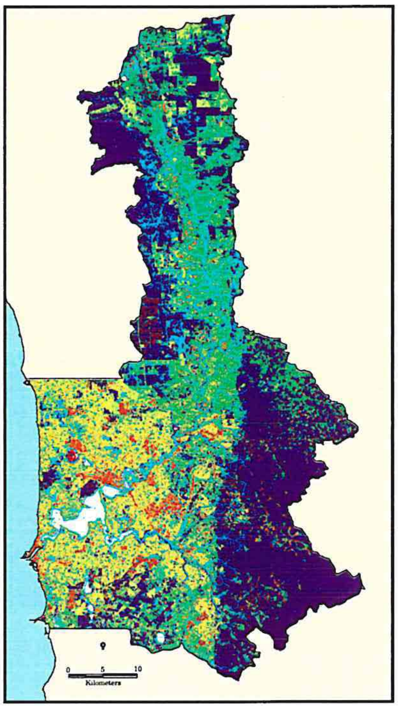
Satellite coverages are available for estuarine catchments where monitoring information is not available, and these will be used to develop a landcover classification scheme which will form the basis of the runoff estimation procedure.



This figure shows a false colour LandsatTM image of the Swan coastal catchment. Urban areas are pink, forest is red and pasture is pale green. Image analysis was used to classify landuse into 12 classes.



This figure shows a digital elevation model of the Swan coastal catchment. Contours were used to generate the DEM, which was used to derive slope classification, for runoff estimation.



This figure shows estimated annual runoff from the Swan coastal catchment. Blue represents least runoff, and red the greatest. Runoff was estimated as a function of rainfall, slope class and land use.

project outcomes - rainfall and runoff

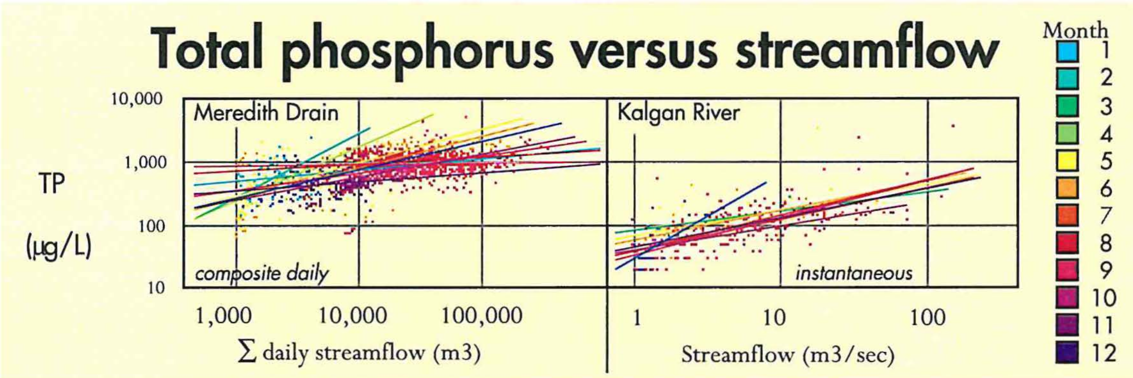
Best available information will be used to compile a spatial database for all estuarine catchments of: streamlines, catchment boundaries, soils and landform information. To prepare a landcover classification using existing State-owned satellite coverages. To compile raster-based models estimating the spatial distribution of annual runoff under average and extreme rainfall years. Models will be developed using PC ArcView, with workstations using ArcInfo and Erdas Imagine. PC Microstation and MapInfo will be used to facilitate data translation and output. ArcView models and all input and output coverages will be available through the WALIS Land Information Directory on project completion.

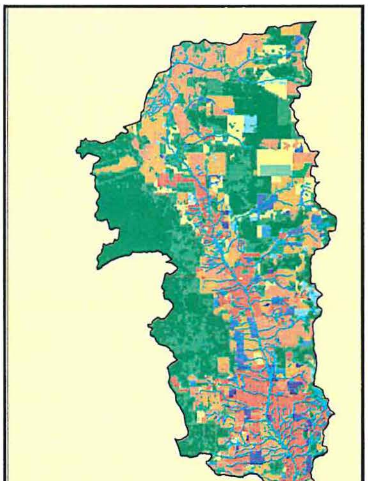
2.2 Nutrient loads

The nutrient content of runoff has been monitored continuously for a limited number of streams in Western Australia. The two graphs below show a very sandy coastal catchment (Meredith Drain), and an inland catchment (Kalgan River), with finer textured soils. These catchments show different relationships between runoff volume and TP.

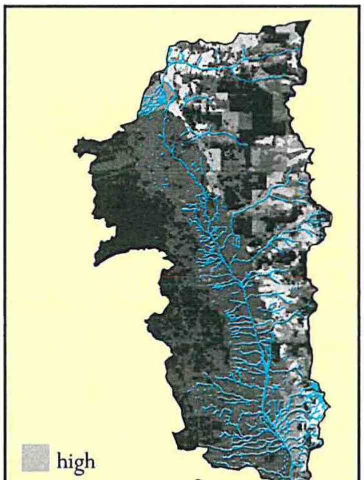
Meredith Drain shows little change in TP concentrations in July and August when flows are greatest. The Kalgan River has much lower TP concentrations, which increase with increasing flow rate throughout the year. Relationships of this sort will be used to model TP losses from catchments where no monitoring information is available.

Estimating catchment nutrient availability and runoff concentrations. Modelling runoff nutrient loads for average and extreme conditions.

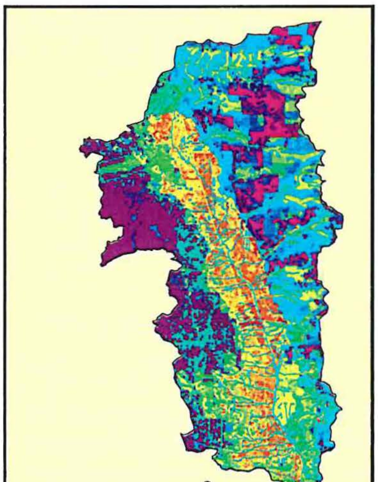




This figure shows clearing history for the Ellenbrook catchment. Uncleared bush is shown in green and land cleared more than fifty years ago is red. Paler shades show land cleared in recent years.



This figure shows an estimate of the available (bicarbonate extractable), soil phosphorus in the Ellenbrook catchment. A strong relationship exists between available soil P and runoff P.



This figure shows estimated annual phosphorus loss from Ellenbrook. Blue and purple show low P loss, and red the greatest. Phosphorus loss was estimated as a function of soil P, landcover and runoff.

project outcomes - nutrient losses

To use best available information to compile a spatial database for all estuarine catchments of: clearing and fertilizer history, soil P retention ability, and erosion risk. To compile raster-based models estimating the spatial distribution of annual sediment and nutrient loss under average and extreme rainfall years for all estuarine catchments in WA.

2.4 Biological communities

The nature of phytoplankton communities in estuaries gives an indication of the prevailing water quality conditions. The diversity, species richness and proportion of potentially harmful species, all provide information on the environmental condition of the waterway.

The nature of the sediments and their associated biota provide information on the role of sediments as a source or sink for nutrients and organic matter. Nutrient enrichment of estuaries usually results in an increase in the organic content of sediments and a decrease in species diversity of benthic animals.

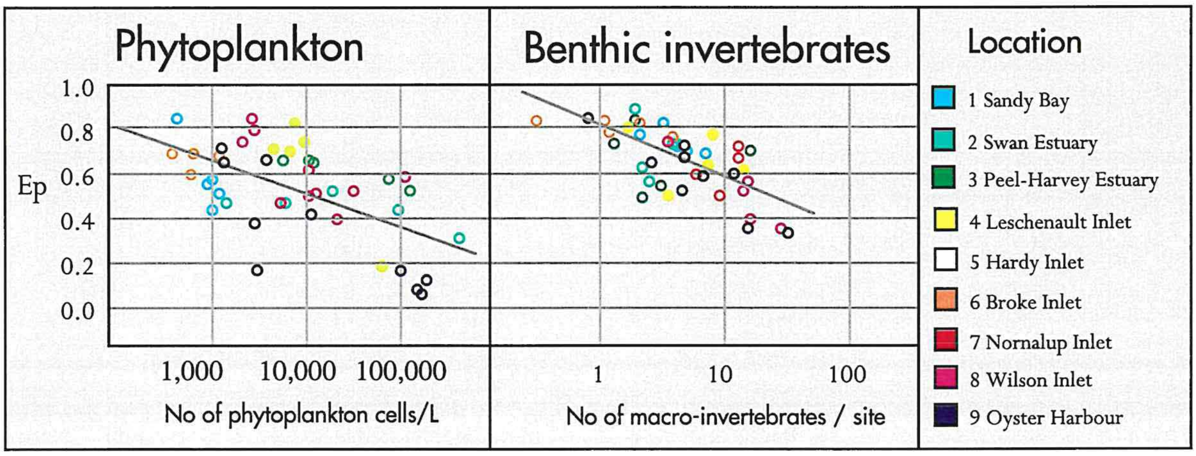
The distribution of phytoplankton and benthic macro-invertebrates in estuaries is highly variable in both space and time. Intensive surveys over a number of seasons would be required to appropriately quantify biological communities.

In the absence of resources required to undertake quantitative monitoring in Western Australian estuaries, much can be gained from a strategic snapshot of lower trophic groups in selected regional estuaries during key index periods. Snapshots should be accompanied by a limited assessment of prevailing physical and chemical conditions.

Screening for harmful phytoplankton and assessing the nature of phytoplankton and benthic macroinvertebrate communities

A limited number of field trips will be required to selected regional estuaries and their catchments to ground-truth the landuse classification scheme and estuarine mapping.

These field trips to selected remote estuaries will also be used to characterize the physical and chemical nature of the water column and the sediments, and to undertake a preliminary assessment of the nature of the phytoplankton and benthic macro-invertebrate communities.



This figure shows Pielou's evenness (Ep) plotted versus the number of phytoplankton cells per litre of estuarine water. Phytoplankton distribution is variable in space and time, and even though the data plotted above are from simple snap-shots of estuaries of the southwest of Western Australia, notable trends have emerged. Pristine areas like Broke Inlet had very high diversity (Ep), with lower total cell numbers. Oyster Harbour had a small phytoplankton bloom at the time. These data show a reduction in diversity as productivity increased.

This figure shows Pielou's evenness (Ep) plotted versus the number of benthic macro-invertebrates recorded in four cores collected from each estuarine site. Sites in Wilson Inlet and upstream Oyster Harbour, had very high macro-invertebrate numbers but with reduced diversity. This indicates organic enrichment. Less organically-enriched sites in estuaries had lower biomass but higher diversity. This type of information will help managers make decisions about the trade-off between increasing productivity and the loss of diversity accompanying eutrophication.

project outcomes - rainfall and runoff

To establish a limited number of sampling sites in selected regional estuaries where little or no quantitative information has been collected previously. To investigate water and sediment nutrient content and physical characteristics, together with snap-shots of phytoplankton and benthic macro-invertebrate communities. To screen for the presence of potentially harmful phytoplankton.

3 Estuarine status and susceptablity

In Western Australian estuaries, nutrient supply is one of the main factors limiting the growth of phytoplankton and aquatic macrophytes.

The capacity of an estuary to dilute and assimilate nutrients from runoff depends on the degree of marine flushing, estuarine volume to runoff ratios, mixing and oxygen status of deeper waters and the nature of the sediments and biological communities.

Reliable determination of all of these factors for all Western Australian estuaries would be well beyond available resources, although ball-park estimation of marine flushing and runoff inputs are less difficult (see previous pages).

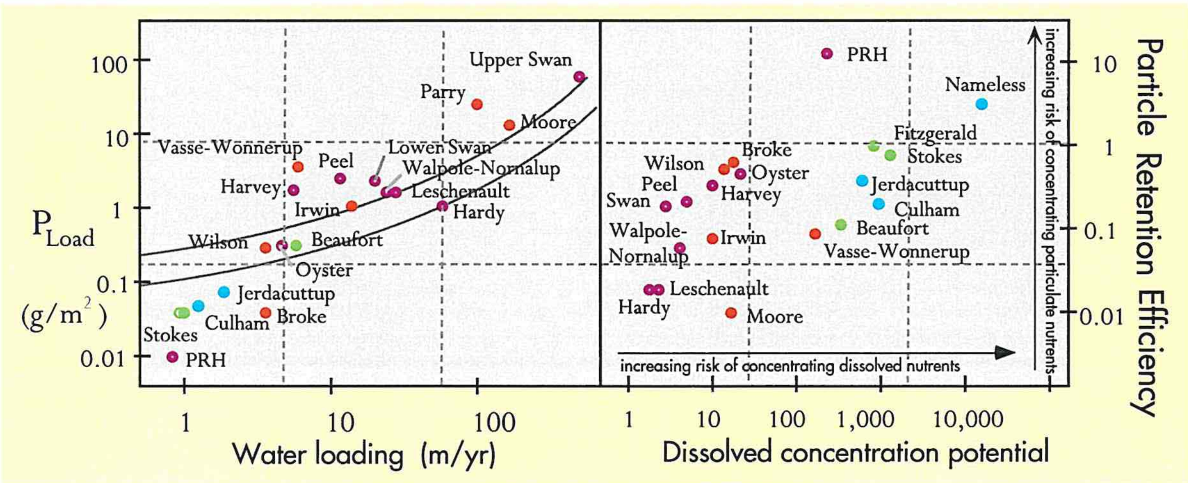
Using estimates of estuarine volume, marine flushing and runoff fluxes to classify eutrophication status and susceptability

Estimates of estuarine volumes, marine flushing, runoff volume and nutrient content have been used elsewhere to flag systems, at risk of eutrophication.

The Vollenweider eutrophication model assumes P limitation, and steady state conditions. This model has been successfully used by the DEP to define management requirements in the Peel-Harvey, and Vasse Wonnerup estuaries even though the operating assumptions may have been violated in these situations.

The US EPA/NOAA currently uses estuarine volume to runoff ratios (PRE), and the freshwater fraction method (DCP), to determine marine flushing and thereby classify eutrophication status and susceptability.

This project will apply both of these models to all Western Australian estuaries to asses their utility in terms of classifying eutrophication status and risk. The figures below show preliminary application of these models to a limited number of southwest estuaries.



This figure shows preliminary application of the Vollenweider model to a number of southwest estuaries. Estuaries above the upper line are considered to be eutrophic, while estuaries below the lower line are not considered to be enriched. The model results are in broad agreement with current understanding of eutrophication status in these waterways. Predictions of chlorophyll-a using this model are also in broad agreement with field observations.

This figure shows preliminary application of the US EPA/NOAA risk assessment model for estuarine eutrophication. It is based on the ratio of estuarine volume to annual runoff (PRE), and flushing time (DCP). Estuaries to the left of the diagram have a lower risk of concentrating dissolved nutrients, while those to the right are more at risk. Estuaries at the top of the diagram are at risk of accumulating particulate-bound pollution, while those at the bottom are less so.

project outcomes - estuarine status and susceptability

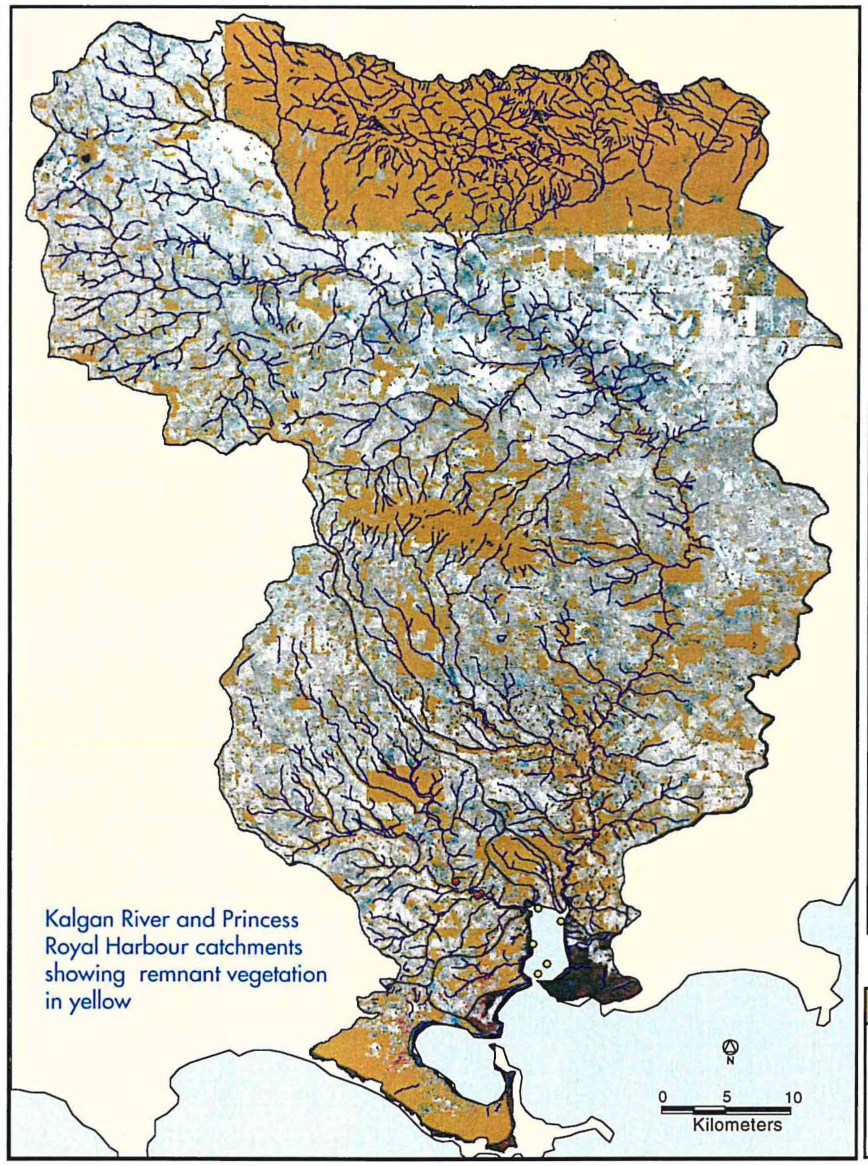
To integrate runoff quality information from catchments with physical, chemical and biological information from estuaries. To identify eutrophication status and risk for all 145 Western Australian estuaries. Both models of eutrophication status and risk mentioned above, are currently in use by European and US waterway managers, and both will be evaluated and fine-tuned for local applicability.

Physical and Hydrologic Characteristics

Catchment area		Discharge volumes - Nutrient sediment load				
		Period of record	1955-	1989-	1989-	1993-
	km²	Quality of load data 2- 3	10^3 M^3	Nitrogen load t	Phosphorus load t	Sediment load t
Urban area	5	Urban drainage	1	1	0	50
Forest	3,042	Forest drainage	420	28	2	239
Rural	2,190	Rural drainage	20,000	60	12	945
Total drainage inputs	5,237	Total drainage inputs	24,200	89	14	1234
Tidal data		**Seasonal inputs**				
Prevailing tide	Semidiurnal	Spring	295	1	0	3
Tidal prism 10^3 M^3	3,000	Summer	135	11	0	2
Phase range of tide		Winter	20,820	580	11	961
Map key	Range (m)	Autumn	4,265	112	13	180
A	.7	7-day, 10-Year Low flow	1	1	0	0
B	.5	50-Year flood	50,000	95	34	184
C	.4	100-Year flood	84,000	306	30	5072
D	.2					
E	.1					

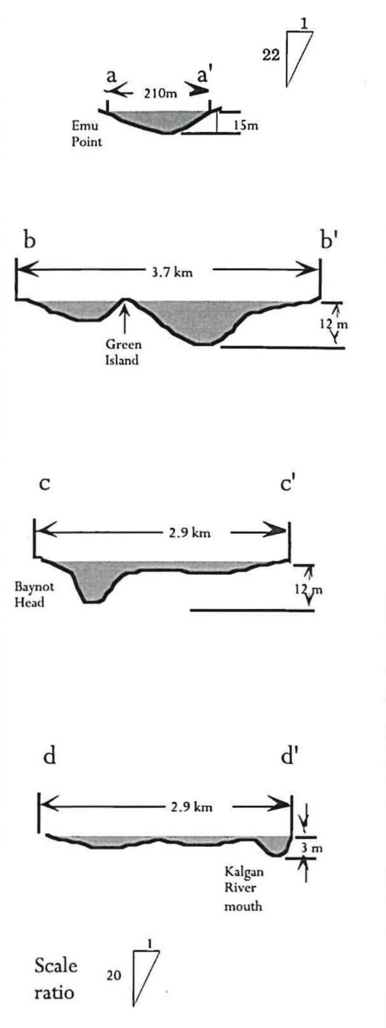
Estuarine Dimensions				Stratification Class	
	Mean depth - width ratio	Surface area km²	mean depth m	3 Month high flow	3 Month low flow
Oyster Harbour	5	13.4	6.5	MS	VH
Kalgan River tidal	28	2.7	2.1	VS	VH

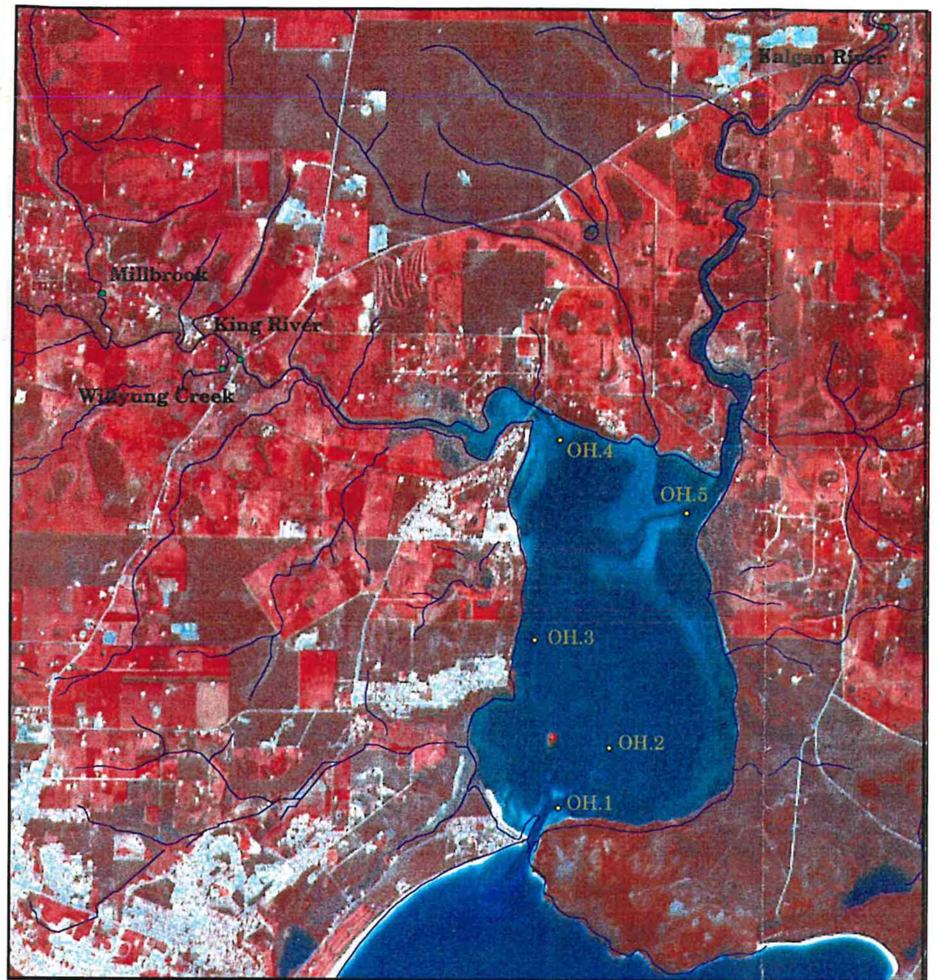
Abbreviations: Vertically homogeneous VH, Moderately stratified MS, Highly stratified HS.



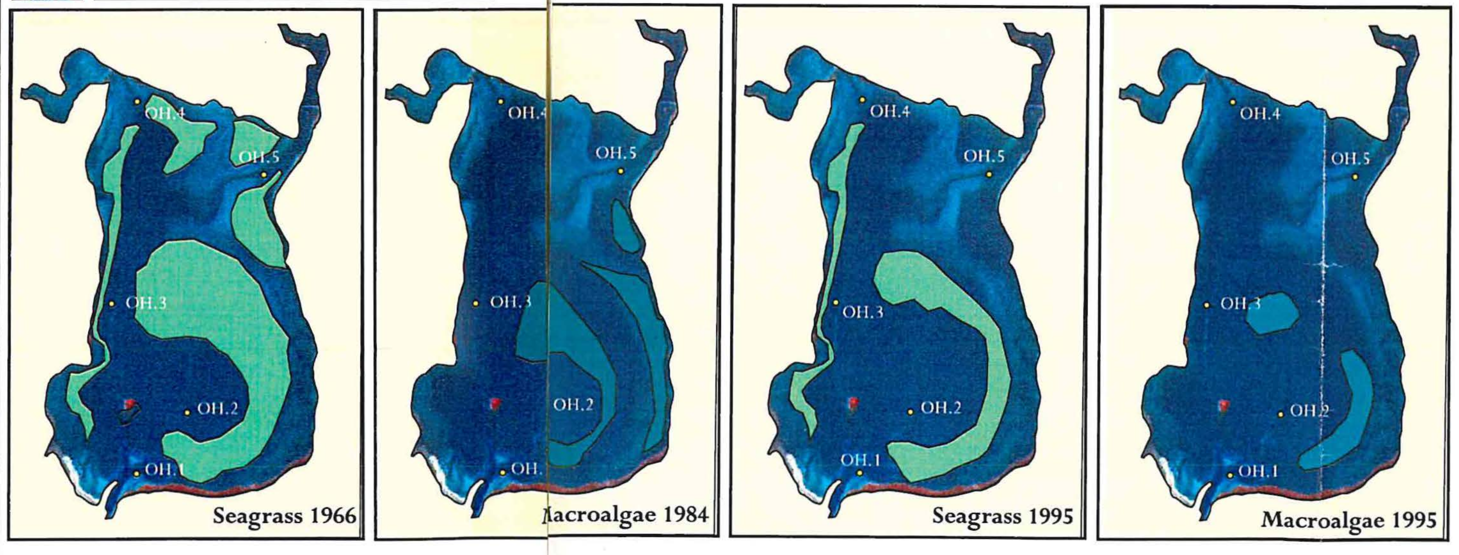
Kalgan River and Princess Royal Harbour catchments showing remnant vegetation in yellow

Profiles





NOTE: THE INFORMATION IN THIS MOCKUP IS ILLUSTRATIVE ONLY AND NOT INTENDED TO BE CORRECT.



Key to nutrient loading estimates

Quality	Error	Data availability
1 Excellent	± 10%	Good
2 Good	± 20-50%	Good to moderate
3 Fair	± 50-100%	Limited
4 Poor	± 100%	Limited to none

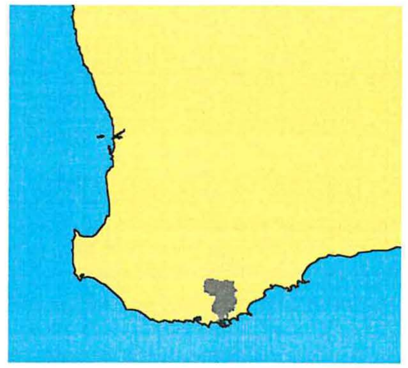
Key to seagrass maps

Quality	Data availability
1 Excellent	Surveyed transects
2 Good	Video transects
3 Fair	Manta tow
4 Poor	Spot snorkeling

Map sources

1:100,000 topographic series,	DOLA
1:50,000 streamlines	WRC
1:10,000 Estuarine charts	WRC
1:25,000 nautical charts,	DOT
JPEG satelite images	RSAC
Aerial photographs	DOLA

Oyster Harbour



Legend

- Tide gauge
- Flow gauge
- Estuarine inventory site
- Head of tide
- Urban drainage area
- Tidal fresh area
- Mixing zone
- Seawater zone
- Salinity boundary - Low variability
- Salinity boundary - High variability

interpretation

The main basin of Oyster Harbour has a moderate ability to concentrate dissolved substances. The basin has a low particle retention efficiency because of the level of marine flushing and the magnitude of bouyant fresh plumes in large runoff events (D'Adamo et al 1993).

The estuary currently has a moderate level of phytoplankton activity and anoxia of bottom waters is rare.

Seagrass loss and macroalgal nuisance in the mid 1980's has lessened, and the harbour ecosystem appears to be improving.

Without catchment restoration, the very large particulate and dissolved loads delivered in the 1982 floods may occur in the future, threatening the ecosystem and seagrass recovery.

Oyster Harbour has a rating of 3 and would need a 30% reduction in current loads to become a class 2 waterway.

Water and Rivers Commission

Western Australian Rivers & Estuaries Program

Department of Environmental Protection

NOTE: THE INFORMATION IN THIS MOCKUP IS ILLUSTRATIVE ONLY AND NOT INTENDED TO BE CORRECT.

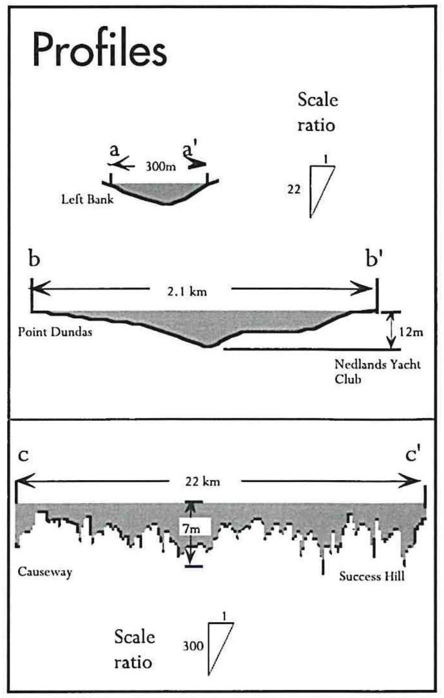
Swan Canning Estuary

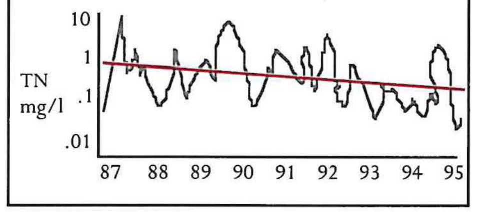
Physical and Hydrologic Characteristics

Catchment area		Discharge volumes - Nutrient sediment load				
		Period of record	1965-	1987-	1987-	1995-
	km²	Quality of load data 2- 3	10^3 M^3	Nitrogen load t	Phosphorus load t	Sediment load t
Urban area	2,000	Urban drainage	138000	57	6	500
Coastal plain rural	6,000	Coastal plain drainage	69000	280	52	2369
Avon River	119,000	Avon River drainage	362000	407	14	9465
Total catchment area	127,000	Total drainage inputs	569000	744	72	12334
Tidal data		**Seasonal inputs**				
Prevailing tide	Semidiurnal	Spring	31295	41	4	678
Tidal prism 10^3 M^3	26,000	Summer	8535	11	1	185
Phase range of tide		Winter	443820	580	56	9621
Map key	Range (m)	Autumn	85350	112	11	1850
A	1.1	7-day, 10-Year Low flow	2.6	0	0	0
B	.5	50-Year flood	50,000	65	6	1084
C	.25	100-Year flood	234,000	306	30	5072
D	.2					
E	.1					

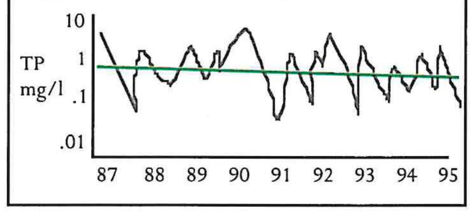
Estuarine Dimensions				Stratification Class	
	Mean depth - width ratio	Surface area km²	mean depth m	3 Month high flow	3 Month low flow
Fremantle to Pt Walter	5	3.4	10.5	MS	VH
Melville water	28	15.7	2.1	MS	VH
Perth water	12	12.4	1.2	VH	VH
Upstream of Causeway	9	3.8	1.1	VH	HS

Abbreviations: Vertically homogeneous VH, Moderately stratified MS, Highly stratified HS.

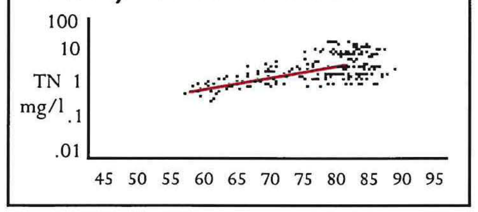




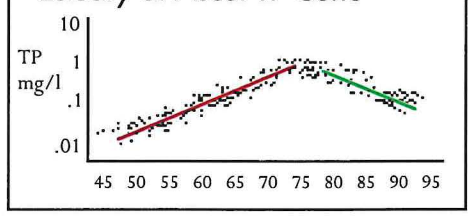
Ellenbrook TN Concentrations



Ellenbrook TP Concentrations

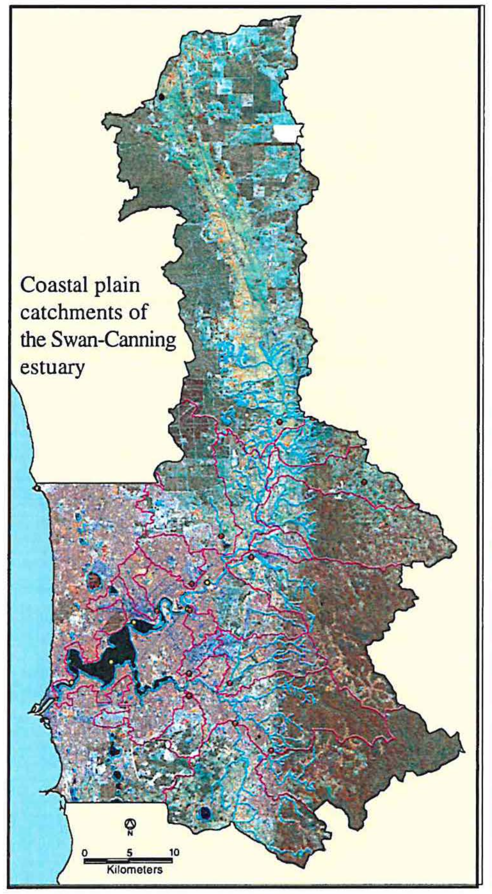


Estuary at Ascot TN Conc

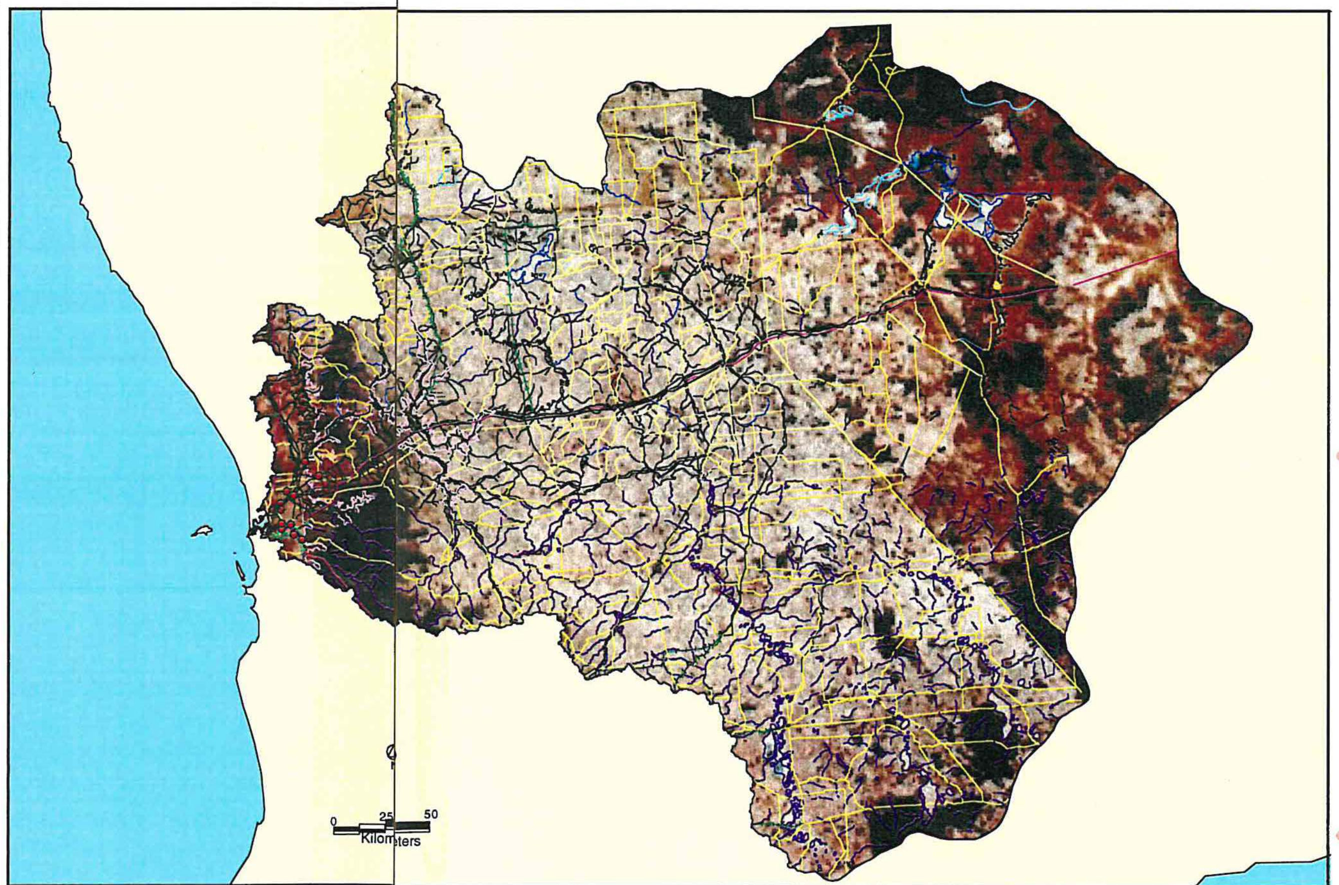


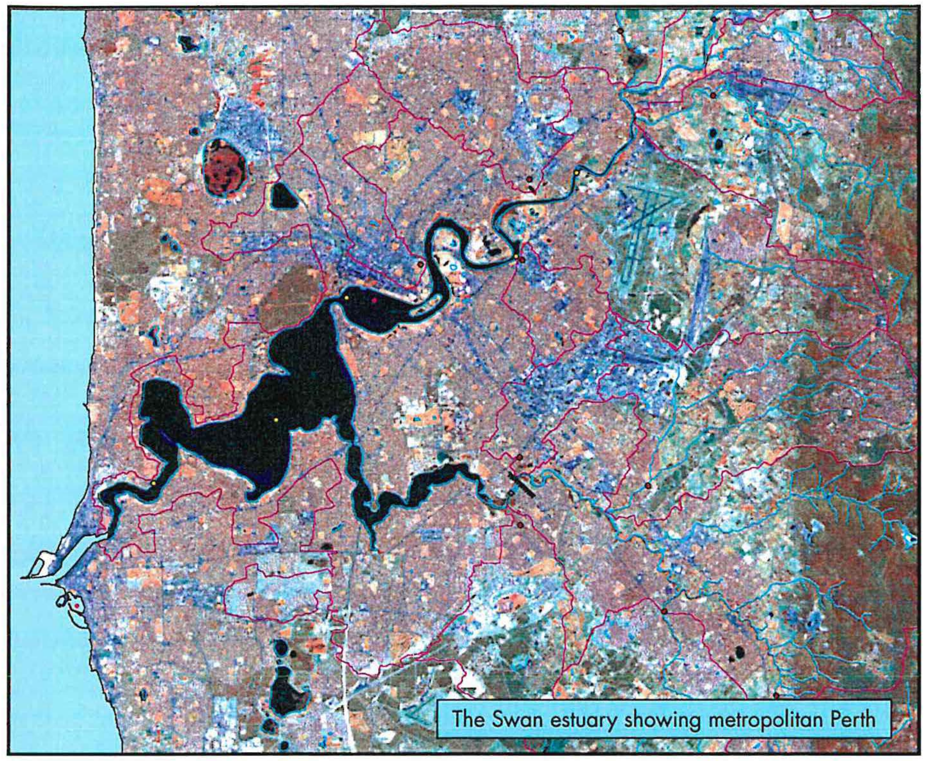
Estuary at Ascot TP Conc

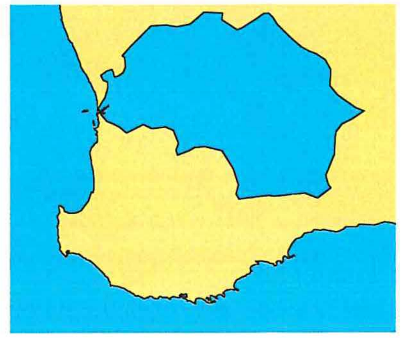
Red and green lines show significant trends (p<0.05)



Coastal plain catchments of the Swan-Canning estuary




The Swan estuary showing metropolitan Perth



Legend

- Tide gauge
- Flow gauge
- Estuarine inventory site
- Head of tide
- Urban drainage area
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- Salinity boundary - Low variability
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Key to nutrient loading estimates

Quality		Error	Data availability
1	Excellent	± 10%	Good
2	Good	± 20-50%	Good to moderate
3	Fair	± 50-100%	Limited
4	Poor	± 100%	Limited to none

Key to basin classification

Basin	Class	Reason
Fremantle to Pt Walter	1	Well flushed low N,P
Melville Water	2	Some blooms
Perth Water	4	Annual blooms
Upstream of Causeway	5	Anoxia, annual blooms

Map sources

1:100,000 topographic series,	DOLA
1:50,000 streamlines	WRC
1:10,000 Estuarine charts	WRC
1:25,000 nautical charts,	DOT
JPEG satelite images	RSAC
Aerial photographs	DOLA

interpretation

The four zones of the Swan estuary have differing ability to concentrate dissolved substances. Fremantle to Pt Walter has a low particle retention efficiency and a low to moderate ability to concentrate dissolved substances. Melville Water has infrequent blooms and a moderate ability to concentrate dissolved substances. Perth Water and upstream of the Causeway have very high particle retention effeciencies and a high ability to concentrate dissolved substances. The lower Canning River has a moderate ability to concentrate dissolved substances. The Canning River upstream of Kent Street Weir is fresh and has a high ability to concentrate dissolved substances.

Upstream of the Causeway requires a 70% reduction in nutrient loading to fall to a Class 3 waterway.

Water and Rivers Commission

Western Australian Rivers & Estuaries Program

Department of Environmental Protection

Total funds required

ITEM		1996/97 6 mths ($000)	1997/98 ($000)	1998/99 ($000)	1999/00 6 mths ($000)
Salaries	*(F/T Scientist, project manager)* *(F/T graduate assistant)* *(F/T GIS modeller)*	$78	$137	$140	$70
Operating	*(travel, analyses)*	$47	$87	$93	$47
Capital	*(4wd, 14 ft dingy)*	$55	$10	-	-
Publishing inventory atlas	To be offset by sale of capital items (~$35) on project completion				$30
TOTAL		$180	$245	$245	$125

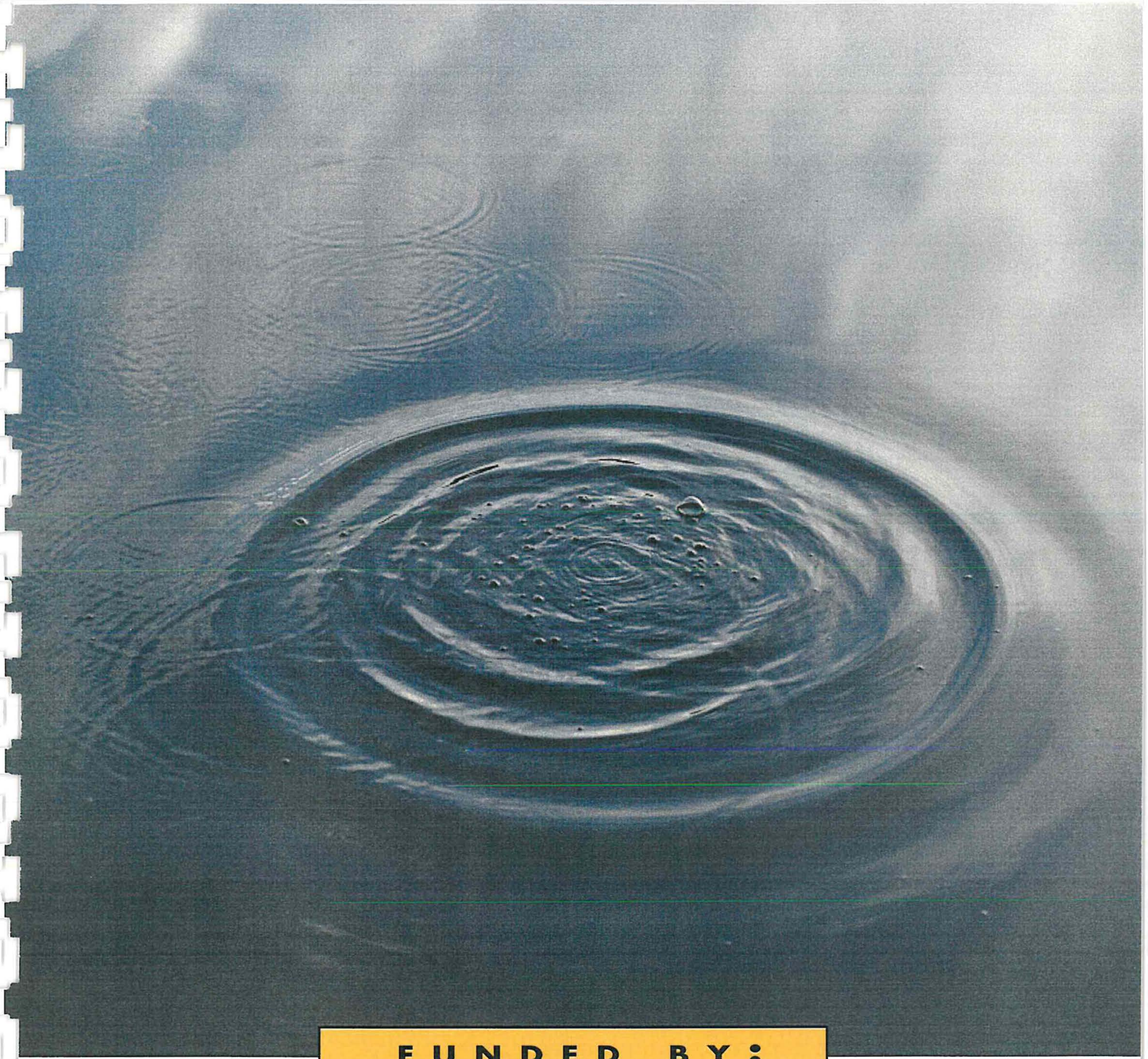
Funds available

Agency	1996/97 6 mths ($000)	1997/98 ($000)	1998/99 ($000)	1999/00 6 mths ($000)
Water & Rivers Commission Resource Investigation Division	$60	$75	$75	$40
Department of Environmental Protection	$50	$60	$60	$30
National Landcare Program	$40	$50	$50	$25
Total available funds	$150	$185	$185	$95
Total funds required	$180	$245	$245	$155
Current funding shortfall	$30	$60	$60	$60

This ambitious but achievable project has a modest requirement for funding, given its statewide focus, and scientific breadth. The project has been loosely based on the US EPA National Estuarine Inventory Program, and the NOAA/EPA Strategic Assessment of Near Coastal Waters Program. These two US programs had multi-million dollar budgets and covered a not dissimilar geographical area and total number of estuaries as will be covered in this project.

It must be appreciated that scientific coverage of some aspects of this project will be at best superficial, when compared to rigour of the US programs, but given both the complete absence of scientific information on the eutrophication risks to Western Australian estuaries, and the real need to prioritize the application of finite management and restorative resources, the project is considered to be timely, and to have an appropriate focus.

Successful completion of the project at the end of 1999 will require a coordinated approach by Government stakeholders. A technical steering committee of stakeholder agencies will be established in early 1997 to establish priorities and to coordinate agency assistance and involvement. The project has a requirement for additional in-kind support, and data from a number of existing agency programs. These include digital coverages, maps and aerial photography from various WALIS agencies, existing remotely sensed images from the Remote Sensing Applications Centre, streamflow and water quality data from the WRC and biological and chemical data from the National monitoring river health program. It is understood that some additional logistical support may also be available through CALM as a large number of estuaries fall within the conservation estate.



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