HAWKESBURY NEPEAN RIVER MANAGEMENT FORUM

INTEGRATED MONITORING PROGRAM

for the Hawkesbury-Nepean, Shoalhaven and

Woronora River Systems

PREPARED BY

Independent Expert Panel on Environmental Flows
for the Hawkesbury Nepean, Shoalhaven and Woronora Catchments

April 2004

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EXECUTIVE SUMMARY

The New South Wales (NSW) Government established the Hawkesbury-Nepean Management Forum (Forum) to make recommendations on an environmental flow regime for the Hawkesbury-Nepean River that would incorporate the maintenance of or improvement in environmental, social and economic conditions. The establishment of the Forum arose out of the Council of Australian Governments' Water Reform Framework of 1994 and the NSW Government's Water Reforms of 1997. To assist the NSW government and the Forum, the NSW government appointed the Independent Expert Panel on Environmental Flows for the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers (Panel). To guide the Forum's work plan and the work of the Panel, environmental, socio-economic, and cultural objectives were established. These objectives incorporate and expand upon the NSW River Flow Objectives.

The health of the Hawkesbury-Nepean, Shoalhaven and Woronora River systems has been impacted through the combined effects of river regulation, irrigation, urbanization (resulting in inputs of sewage effluent and stormwater pollution), other landuse changes, coal mining and sand and gravel extraction. Many significant advances have been made to improve river health over the last decade, mainly through the increased treatment of sewage effluent and stormwater. However, the increase in population and the continuing low rate of flows in the rivers are threatening these investments. Aquatic weeds are spreading rapidly throughout the Hawkesbury-Nepean and deteriorating water quality in some areas is compromising the health of the river, and can lead to lethal toxic events. The incidence of fish detected with diseases is above the regional average. If the decline in river health was allowed to continue it is likely that there will be increased fragmentation of fish populations, disease rates in fish will increase, water quality will deteriorate, biodiversity will be reduced and exotic plants and animals will spread at the expense of native species. The introduction of environmental flows is necessary to ensure that the rivers remain healthy.

The monitoring program integrates many related matters that impact on river health. Environmental flows must be introduced within the context of a water management strategy so that the equitable and inter-generational management of the water resource can be planned. No such strategic approach to water management exists in the region. The Forum, together with the Water Chief Executive Officers Committee (Water CEOs), has developed significant elements of the water management strategy that are linked to river health outcomes. Such a strategic approach necessitates consideration of all river systems within the water supply network for Sydney, the Blue Mountains, Illawarra and Shoalhaven as well as water recycling, water conservation, alternate water resources and pollution management.

Many ancillary programs have been developed by the Forum to address the strategic mechanisms associated with water resource management. Weir investigations, water sensitive urban design, integrated effluent management and institutional arrangements including land use planning, will all play an important part in protecting an environmental flow regime and the long-term viability of the region's water resources. The greatest immediate protection of the benefits of environmental flows will result from the implementation of the Forum's recommended Effluent Reuse Strategy. This Strategy will bring many benefits including improved security of supply for irrigators, improved weir management, reduction of nutrients to the river particularly during low flows and a potential reduction in the quantity of water needed for environmental releases from Warragamba Dam.

Development of the Monitoring Program

There is a vast network of streams to be assessed for river health, water resources and the associated economic, social, cultural and environmental benefits. To assist in the assessment and to identify high priority issues and evaluate the potential benefits, the Panel divided the river systems into 29 separate reaches that primarily reflect differences in physical and hydrological characteristics along the rivers. These covered the Hawkesbury-Nepean system (including the Wingecarribee River), the Shoalhaven River downstream of Tallowa Dam and Woronora River. Conceptual models were then developed from information concerning the ecology, geomorphology, hydrology, cultural and anthropogenic characteristics of each individual reach. Hydrological surrogates based on the scientific knowledge of Panel members were used to assess the environmental benefits of a series of environmental flow options shortlisted by the Forum. The recommended environmental flow regimes for the Upper Nepean, Warragamba and Tallowa Dams were then selected primarily on the basis of minimising the differences in the hydrological surrogates from the modelled natural flow regimes. Modelling of the interaction between environmental flows, the proposed effluent reuse strategy and water quality in each reach was also carried out to inform the selection process.

Determining the environmental, social, cultural and economic benefits of the recommended environmental flow regimes and the associated water management strategies is premised upon the fact that an adaptive management process will be implemented. This will ensure that the optimum benefits of the flow regime in contributing to river health and water management are realised. Adaptive management is an approach that suits ideally the circumstances of the Hawkesbury-Nepean, Shoalhaven and Woronora systems. It is a process based on the understanding that knowledge of the environmental, social, cultural and economic systems of a region is not always complete but is dynamic in nature and that management decisions will be inclusive of stakeholder opinions. Available information is used to formulate objectives, such as to improve the health of the river. The favoured actions are then implemented and subjected to strict monitoring. The results of the monitoring are fed back to modify the management actions until the desired outcome or objective is achieved. Adaptive management requires a monitoring program that drives and informs the process.

The monitoring program described in this report, with its associated adaptive management process, is designed to ensure that the implementation of an environmental flow regime is successful in improving and preserving the environmental, social, economic and cultural health associated with these rivers.

The design of the integrated monitoring program concentrated on the high priority issues identified during the river reaches assessment and was based around four components:

- **Fundamental hydrological monitoring.** This component provides baseline information for other components of the monitoring program and to inform adaptive management.
- **Ecological and physical monitoring.** This component addresses the impact of an environmental flow regime on a range of issues including fish abundance and community structure, habitat features, aquatic macroinvertebrates, aquatic and riparian plants, water quality (particularly temperature) and stratification.
- **Ancillary monitoring.** This component measures improvements arising from related strategies recommended by the Forum (such as the Effluent Reuse Strategy, protection of environmental flows and the impacts of channel changes).
- **Social, economic, cultural and heritage monitoring**. This component measures how social, economic, cultural and heritage issues affect river conditions and how they may in turn be affected by changing river conditions.

In designing the program, the conceptual models were used to characterise the physical and anthropogenic 'template' of the reaches. The high priority issues within each river reach (or group of reaches) were then described in relation to how the environmental flows would provide ecological, social and economic benefits to the river system. Hypotheses were then developed, response variables determined for each hypothesis and field study designs and statistical analysis approaches developed for each high priority issue. A separate methodology was used to develop the social and economic and cultural heritage monitoring (SECH) component of the program. The SECH component is designed to evaluate social change associated with environmental flows and related river management strategies. Successful SECH monitoring will be enhanced by providing information and community education about environmental flows and encouraging strong community engagement in monitoring change. These forms of participation combined with the regular reporting of information and responsive decision-making will promote ownership of the program and encourage the early resolution of potential conflicts.

The monitoring design includes a combination of pre-monitoring and routine (ongoing) studies. Pre-monitoring studies will extend over 1-2 years but will be undertaken in accordance with the Forum's recommended schedule for the introduction of environmental flows which extends from 2004 to about 2014. Pre-monitoring investigations need to take place before the ongoing monitoring program commences as they inform various aspects of that program. The costs of implementing the pre-monitoring and on-going studies were estimated as part of the development of the monitoring program.

A summary of all of the items included in the Panel's recommended monitoring program to address the high priority issues is shown in Tables 1 - 5 below. A summary of the high priority issues on a reach-by-reach basis is shown in Tables 6 – 8.

Prioritising Program Components

A draft report describing the Panel's recommended monitoring program was submitted for peer review as well as for review by members of the Forum. As a result of feedback from that process, the Panel undertook a reassessment of the recommended program to determine the relative importance of each of the high priority issues addressed by the program. This reassessment also recognised that the estimated cost of the recommended program was substantial and that the Forum may need guidance in determining the extent of monitoring that it considered to be absolutely essential.

The results of the reassessment are summarised in Tables 1 – 4. The reassessment found that:

- All of the fundamental hydrological monitoring is essential as it measures inflows and outflows in the rivers and their tributaries and is the basis of many of the other elements of the program.
- Of the 16 items in the ecological/physical monitoring, the top 10 in the ranking are essential. The remaining items could be deferred if there were insufficient funds available.
- Of the 12 items in the ancillary monitoring section of the program, the top 6 in the ranking are essential. The remaining six could await further investigation and consultation.
- The socio-economic monitoring component originally proposed was reduced in scope because there is a need to co-ordinate activities between various agencies before developing new programs. The monitoring of SECH issues could be developed initially by a relatively modest increase in the costs of the Integrated Water Quality Management Framework that exists in the Hawkesbury-Nepean Valley. Further expansion of the program could be developed by the Hawkesbury Nepean Catchment Management Authority in consultation with river stakeholders.

Table 1: Fundamental Hydrologic Monitoring

High Priority Issue	Rank	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Monitoring of weired shale reaches below the dams	1	25,000	67,500
Monitoring of sandstone reaches downstream of the dams	2	25,000	67,500
Monitoring dam inflows	3	25,000	67,500
Monitoring tributary flows	4	25,000	67,500
Total: Fundamental Hydrology		**$100,000**	**$270,000**

Table 2: Ecological and Physical Monitoring

High Priority Issue	Rank	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Cold water releases from dams	1	0	19,000
Reduced connectivity – natural barriers	2	284,000	45,000
Contraction of critical habitat - Macquarie perch spawning/recruitment - Abundance and diversity of dependent biota	 2 4	 70,000 0	 128,000 28,000
General water quality downstream of dams	5	0	68,000
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes	5	60,000	80,000
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers	7	0	60,000
Reduced recreational fish catches	8	0	5,000
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers	9	15,000	10,000
Reduced commercial fish catches	10	0	5,000
Sub-total – Items ranked 1 to 10		**$429,000**	**$448,000**
Connectivity investigations – managing flows for fish passage in the Woronora River	11	96,000	7,000
Stratification of natural pools	12	24,000	36,000
Reduced flushing, scouring and conditioning of habitat	13	98,000	21,000
Elevated iron and aluminium concentrations in discharge waters from dams	14	7,000	15,000
Encroachment of riparian vegetation on channels	15	50,000	60,000
Iron-rich groundwater inflows downstream of Avon and Cataract Dams	16	9,000	21,000
Sub-total - Items ranked 11 to 16		**$284,000**	**$160,000**
Total: Ecological and Physical		**$713,000**	**$608,000**

Table 3: Ancillary Monitoring

High Priority Issue	Rank	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
General water quality associated with the Forum's Effluent Reuse Strategy	1	0	92,000
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management	2	0	48,000
Soil sustainability associated with the Forum's Effluent Reuse Strategy	3	100,000	85,000
Inter-catchment transfer of fish via Glenquarry Cut [a]	3	98,000	57,000
Lack of connectivity – diversion and gauging weirs	5	16,000	90,500
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy	6	100,000	85,000
Sub-total – Items ranked 1 to 6		**$314,000**	**$457,500**
Effectiveness of Tallowa Dam fish lift	7	18,000	74,000
Channel degradation in the mixed-load shale reach downstream of Penrith Weir	8	88,500	0
Connectivity - Penrith Weir fishway	8	2,000	2,500
Channel changes in weired reaches	10	136,750	0
Tidal channel changes in the Hawkesbury River	11	88,000	0
Stormwater runoff	12	10,000	0
Sub-total – Items ranked 7 to 12		**$343,250**	**$76,500**
Total: Ancillary		**$657,250**	**$534,000**

a) Not required if the Forum's recommended strategy for inter-catchment transfers from the Shoalhaven is adopted.

Table 4: Social, Economic, Cultural and Heritage Monitoring

High Priority Issue	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
SECH Co-ordinator (expansion of existing Integrated Water Quality Management Framework)	0	100,000
Sub-total – Initial SECH Monitoring	**$0**	**$100,000**
Sustainable River Fund	tbd	tbd
Pre-monitoring Phase - Social and Economic - Cultural and Heritage	 350,000 240,000	 0 0
Monitoring Phase - Social and Economic - Cultural and Heritage	 0 0	 tbd 130,000
Audit and Review Phase	tbd	tbd
Total: Social, Economic, Cultural, Heritage	**$tbd**	**$tbd**
tbd: To be determined. Scope of program to be developed by the SECH co-ordinator and Hawkesbury Nepean River Management Authority in consultation with stakeholders.		

Monitoring Program Approved by the Forum

The reassessment of the monitoring program was used by the Forum in determining its recommended program which comprises:

- All of the fundamental hydrological monitoring (Table 1);
- The top 10 ranked items of the ecological and physical component (Table 2);
- The top 6 ranked items of the ancillary component (Table 3); and
- An initial socio-economic monitoring component based on expansion of the existing Integrated Water Quality Management Framework (Table 4).

The Panel considers that all of the high priority studies originally identified need to be implemented to avoid compromising the adaptive management program for implementation of environmental flows. Consequently, all of the high priority monitoring is discussed in detail in this report (ie. monitoring design details are not limited to the program approved by the Forum) on the basis that the components of the program not currently approved may be included in the monitoring program in the future.

The estimated costs of the Forum's approved monitoring program are summarised in Table 5.

Table 5: Integrated Monitoring Program – Priority Components

Component of Monitoring Program	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Fundamental hydrological	100,000	270,000
Ecological and physical	429,000	448,000
Ancillary	314,000	457,500
Social, economic, cultural and heritage	0	100,000
Total: Overall Program	**$843,000**	**$1,293,500**

Monitoring Program Report

The final monitoring report describes all of the items summarised in Tables 1 to 4 in detail. The interaction between the findings from the monitoring program for each high priority issue and the adaptive management process, reporting and institutional arrangements are also defined in the report.

The report is intended to be read mainly by a technical/scientific audience. Accordingly, prior knowledge of hydrological, ecological, socio-economic and cultural heritage issues and concepts is assumed.

Table 6: High Priority Issues within Reaches - Fundamental Hydrological, Ecological and Physical (in order of rank)

High Priority Issues	Reach or Reach Group (a)																			
	Shoalhaven River			Woronora River			Wingecarri -bee River		Nepean River								Hawkesbury River			
	1	2.1	2.2	3	4	5	6.1	6.2	7	8 10 11	9 12 13	14	15 17	16 18 19	20 21	22	23	24	25	26 27
Fundamental Hydrological Issues																				
Monitoring of weired shale reaches below dams													■		■					
Monitoring the sandstone reaches downstream of dams				■	■					■	■	■		■	■					
Monitoring dam inflows	(b)			(b)						(b)	(b)			(b)						
Monitoring of tributary flows										■	■	■	■	■	■	■	■	■	■	■
Ecological and Physical Issues																				
Cold water releases from dams	■									■	■	■	■	■	■					
Reduced connectivity – natural barriers	■			■	■	■				■	■					■	■			
Critical habitat contraction (c)	■			■	■					■	■									
General water quality downstream of dams	■									■	■			■						
Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes												■	■	■	■	■	■	■	■	
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers	■			■	■					■	■									
Reduced recreational fish catches	■	■		■	■	■						■	■	■	■	■	■	■	■	
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers												■	■	■	■	■	■	■		
Reduced commercial fish catches		■	■																■	■
Connectivity investigations – managing flows for fish passage in the Woronora River				▒	▒	▒														
Stratification of natural pools	▒									▒	▒	▒								
Reduced flushing, scouring and conditioning of habitat				▒	▒						▒									
Elevated iron and aluminium concentrations in discharge waters from dams	▒																			
Encroachment of riparian vegetation on channels				▒	▒						▒									
Iron-rich groundwater inflows downstream of Avon and Cataract Dams											▒									

a Reaches and reach groups as defined by the Expert Panel – refer Table B1 in Part B of the Monitoring Program report
b Monitoring of the inflows to storage dams will be undertaken upstream of all dams. Existing gauges are adequate for estimation of inflows to Tallowa, Warragamba and Nepean storages. Additional gauging infrastructure is required as a high priority upstream of Woronora, Cataract, Cordeaux and Avon storages to allow reliable estimation of inflows to those storages.
c Includes monitoring of critical habitat for both abundance and diversity of dependent biota and Macquarie perch spawning/recruitment (separated in Table 2 above)
d ■ High priority issues identified: program components approved by Forum ▒ High priority issues identified: program components not approved by Forum □ No high priority issues identified

Table 7: High Priority Issues within Reaches – Ancillary (in order of rank)

High Priority Issues	Reach or Reach Group (a)																			
	Shoalhaven			Woronora			Wingecarri-bee River		Nepean								Hawkesbury			
	1	2.1	2.2	3	4	5	6.1	6.2	7	8 10 11	9 12 13	14	15 17	16 18 19	20 21	22	23	24	25	26 27
Ancillary Issues																				
General water quality associated with the Forum's Effluent Reuse Strategy																				
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management																				
Soil sustainability associated with the Forum's Effluent Reuse Strategy																				
Inter-catchment transfer of fish via Glenquarry Cut																				
Lack of connectivity - diversion and gauging weirs																				
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy																				
Effectiveness of Tallowa Dam fish lift																				
Channel degradation in the mixed-load shale reach downstream of Penrith Weir																				
Connectivity - Penrith Weir fishway																				
Channel changes in weired reaches																				
Tidal channel changes in the Hawkesbury River																				
Stormwater runoff																				

a Reaches and reach groups as defined by the Expert Panel – refer Table B1 in Part B of the Monitoring Program report

b High priority issues identified: program components approved by Forum; High priority issues identified: program components not approved by Forum; No high priority issues identified

Table 8: High Priority Issues within Reaches – Social, Economic, Cultural and Heritage

High Priority Issues	Reach or Reach Group (a)																			
	Shoalhaven			Woronora			Wingecarri-bee River		Nepean								Hawkesbury			
	1	2.1	2.2	3	4	5	6.1	6.2	7	8 10 11	9 12 13	14	15 17	16 18 19	20 21	22	23	24	25	26 27
Social and Cultural Values																				
Social values																				
Heritage values																				
Aboriginal values																				
Institutional performance																				
Land and River Activities - existing																				
Irrigation extraction				tbd	tbd	tbd	tbd	tbd												
Industrial extraction				tbd	tbd	tbd	tbd	tbd												
Riparian extraction				tbd	tbd	tbd	tbd	tbd												
Commercial fishery activities				tbd	tbd	tbd	tbd	tbd												
Recreational fishing				tbd	tbd	tbd	tbd	tbd												
Recreational amenity				tbd	tbd	tbd	tbd	tbd												
River-related tourism				tbd	tbd	tbd	tbd	tbd												
Land use and land management																				
Land and River Activities – following implementation of recommended environmental flow regimes																				
Environmental flow releases from dams				tbd	tbd	tbd	tbd	tbd												
Demand management – urban consumers (b)				tbd	tbd	tbd	tbd	tbd												
Demand management – river extractors				tbd	tbd	tbd	tbd	tbd												
Changes to the level of reliability for urban consumers (b)				tbd	tbd	tbd	tbd	tbd												
Modifications to the access conditions for river extractors				tbd	tbd	tbd	tbd	tbd												
Inter-catchment transfers				tbd	tbd	tbd	tbd	tbd												
Stormwater management				tbd	tbd	tbd	tbd	tbd												
Effluent reuse strategy				tbd	tbd	tbd	tbd	tbd												
Weir management				tbd	tbd	tbd	tbd	tbd												

a Reaches and reach groups as defined by the Expert Panel – refer Table B1 in Part B of the Monitoring Program report.
b These issues are discussed in this report but as they apply to Sydney water customers, they do not affect the river reaches directly.
c tbd = Investigation to be done.

d High priority issues identified; SECH co-ordinator to develop the initial public participation process in conjunction with stakeholders

No high priority issues identified

ABBREVIATIONS

ABS	Australian Bureau of Statistics
ABARE	Australian Bureau of Agricultural and Resource Economics
ACT	Australian Capital Territory
ANOVA	Analysis of variance
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AusRivAS	Australian River Assessment System
BOD	Biochemical Oxygen Demand
CAMBA	China Australia Migratory Bird Agreement
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DDC	Drought dominated climate
DEC	Department of Environment and Conservation
DDR	Drought dominated regime
DIPNR	Department of Infrastructure Planning and Natural Resources
DISTLM	Distance-based general linear modelling
DLWC	Former Department of Land and Water Conservation
EFMC	Environmental Flows Management Committee
EIS	Environmental Impact Statement
EPA	Environment Protection Authority
EFR	Environmental flow regime
FDC	Flood dominated climate
FDR	Flood dominated regime
FRCAC	Fisheries Resource Conservation and Assessment Council
Forum	Hawkesbury Nepean River Management Forum
GIS	Geographic Information System
GLM	General Linear Model
GL/yr	Gigalitres per year
HNCMA	Hawkesbury-Nepean Catchment Management Authority
HRC	Healthy Rivers Commission
IEP	Independent Expert Panel (for the Hawkesbury Nepean, Shoalhaven and Woronora Catchments)
IDMS	Integrated Data Management System
ITAC	Independent Technical Advisory Committee
IWMF	Integrated Water Monitoring Framework
LEP	Local Environmental Plan
LGA	Local Government Area
LTM	Long-term mean
JAMBA	Japan Australia Migratory Bird Agreement
MACROC	Macarthur Regional Organisation of Councils
MBACI	Multiple Before-After-Control-Impact
MBARI	Multiple Before-After-Reference-Impact
ML/d	Megalitres per day
MOU	Memorandum of Understanding
NESB	Non English Speaking Background
NPWS	National Parks and Wildlife Service
NSW AG	New South Wales Agriculture

NSW Health	New South Wales Department of Health
O/E	Observed number of families / Expected number of families
PAR	Photosynthetically available radiation
ppt	Parts per thousand
PWD	Former New South Wales' Public Works Department
RIMC	Regional Integrated Monitoring Centre
RSoE	Regional State of the Environment
RNE	Register of the National Estate
SCA	Sydney Catchment Authority
SoE	State of the Environment
SWC	Sydney Water Corporation
SECH	Social, economic, cultural and heritage
SIGNAL	Stream Invertebrate Grade Number - Average Level
SLA	Statistical Local Area
STP	Sewage treatment plant
UWS	University of Western Sydney
WMA	Water Management Act 2000
WSROC	Western Sydney Regional Organisation of Councils
yBP	Years before present

Integrated Monitoring Program
for the Hawkesbury-Nepean, Wingecarribee, Woronora and Shoalhaven Rivers

Contents

PART A: BACKGROUND TO THE MONITORING PROGRAM

Introduction

The monitoring program for the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers has been developed by the Independent Expert Panel on Environmental Flows for the Hawkesbury Nepean, Shoalhaven and Woronora Catchments (Panel). The program supports a wide range of initiatives taken to address the management of water resources in the Sydney and the surrounding region and associated catchments. These rivers and their catchments provide the nation's largest city with potable water and agricultural produce. They also provide areas for recreation while supporting a wide variety of industries including tourism and commercial fishing. Areas adjacent to these rivers are also the focus of urban expansion. These and a variety of other activities are dependent on the continued health of our river systems, their habitats and riverine processes.

An important step in restoring and maintaining the health of these rivers is the implementation of an environmental flow regime along with other management initiatives such as demand management and an effluent reuse strategy. The monitoring program and associated adaptive management framework have been designed to ensure that the environmental flow regime, together with other strategies, are successful in restoring and preserving the environmental, social, economic and cultural health of the rivers and those who depend on them.

Overview of the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers

This monitoring program relates primarily to the rivers that comprise the Hawkesbury-Nepean river system including the Cordeaux, Cataract, Avon, Nepean and Hawkesbury Rivers downstream of the Sydney Catchment Authority's (SCA) major water storages together with the Shoalhaven River downstream of Tallowa Dam and Woronora River downstream of Woronora Dam.

The Hawkesbury-Nepean River catchment is a highly complex system with sandstone and shales dominating the entire length of the channel. Sandstone gorges dominate the upper and middle non-tidal channels (118.6 km of a total of 339.2 km) while drowned sandstone gorges dominate the tidal channel and estuary (127.9 km). One-third of the system lies in poorly accessible gorges, one-third is flanked by intensively farmed and irrigated alluvium while the lower third has relatively small pockets of alluvium adjacent to estuary drowned gorge slopes – see Warner (2002). The alluvial channel above Wallacia is compartmentalised by weirs, which are of considerable geomorphological, ecological, social, economic and cultural significance.

The monitoring program for the Shoalhaven River focuses primarily on the 22 km reach immediately downstream of Tallowa Dam to the tidal barrier riffle at Burrier (Burrier pondage). The interaction between the tidal and non-tidal river is also recommended for investigation. The reach immediately below the dam consists of a sinuous river valley, which is narrower in the upper half than the lower half. The reach is typified by a mixed sand and gravel bedload from upstream Palaeozoic sources with pool-riffle sequences to the tidal barrier riffle. Water for the Shoalhaven area is extracted from the pondage at Burrier. The river valley below Burrier is wider than in the upstream reach and is incised into Nowra Sandstone benches. Alluvial deposition on these benches marks the sites of former and present floodplains. These would have been forested under natural conditions. Even though the bedload is still mixed, sand becomes more dominant and river flow velocities are reduced. Downstream of Nowra the floodplain is extensively farmed with only the occasional flood able to inundate remnant wetlands due to the introduction of levees.

The sandstone gorges of the Woronora River in the 11.4 km reach between Woronora Dam and Heathcote Junction are wider and more open than those of the upper Nepean gorges allowing the accumulation of river and slope deposits. There are many natural fish barriers due to a combination of the steep gradient and stepped nature of the reach. Supplementary monitoring to that currently being undertaken by the SCA is recommended in the Woronora River downstream of the dam.

Recommended Environmental Flow Regimes

The Hawkesbury-Nepean River Management Forum (Forum) has recommended a combination of transparent and translucent environmental flows for the Hawkesbury-Nepean and Shoalhaven Rivers as well as contingent flow releases in the Hawkesbury-Nepean system to cater for specific environmental needs. Transparent, translucent and contingent environmental flows are defined as follows:

- **Transparent environmental flows** involve releasing all inflows to a water storage during periods of low flow.
- **Translucent environmental flows** involve releasing a fixed percentage of inflows to a water storage.
- **Combined transparent and translucent flow** involves releasing all inflows to a water storage during periods of low flow then releasing a portion of inflows for inflows greater than the set volume for the transparent flow.
- **Contingent environmental flows** involve the release of an environmental contingency allocation from a water storage for the purposes of managing contingent environmental problems such as curtailed fish migration/spawning opportunities, excessive algal build-up or excessive aquatic weed growth.

The Forum has recommended that the following environmental flow rules should be implemented:

- Nepean, Cordeaux, Cataract, Avon and Shoalhaven Rivers: 20% translucency combined with 80^{th} percentile transparency.
- Warragamba and Hawkesbury Rivers: 20% translucency combined with 95^{th} percentile transparency.
- Contingent flows of 5.6 GL/yr and 2.7 GL/yr from the Upper Nepean Dams for fish spawning and for flushing and scouring of algae and detritus and a contingent flow of 3 GL/yr from Warragamba Dam for management of aquatic weeds.

The Forum has recommended that the existing environmental flow from Woronora Dam be continued until a hydrological assessment has been undertaken. Additional monitoring has been recommended in this report, however, to that currently being undertaken in the Woronora River.

Objectives of the Monitoring Program

The principle objective of the monitoring program is to assess the environmental, social, economic and cultural responses of the rivers and those who depend on them, to environmental flows and associated strategies. The monitoring program is the feedback mechanism within the adaptive management framework and is aimed at providing the Government and community with information and knowledge relevant to the on-going management of these rivers and their catchments.

Overview of the Approach to Designing the Monitoring Program

The monitoring program for the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers has been guided by the National Water Quality Management Strategy ANZECC/ARMCANZ (2000) Australian Guidelines for Water Quality Monitoring and Reporting. ANZECC/ARMCANZ (2000) outline a framework for the development of a water quality monitoring program as illustrated in Figure A1. Aspects of the study design and proposed statistical analyses for the ecological monitoring program were guided by Downes *et al*. (2002).

In order to identify issues and to develop conceptual models, the Shoalhaven, Woronora and Hawkesbury-Nepean Rivers were divided into a series of reaches. Essentially, these reaches were defined by a combination of their hydrology, geomorphology and landuse patterns. The defined reaches are as follows (IEP 2004a):

- Shoalhaven River - Reaches 1 - 2.2
- Woronora River - Reaches 3 - 5
- Wingecarribee River - Reaches 6.1 - 6.2

- Upper Nepean River, Doudles Folly and Glenquarry Creeks - Reach 7
- Hawkesbury-Nepean River - Reaches 8 - 27

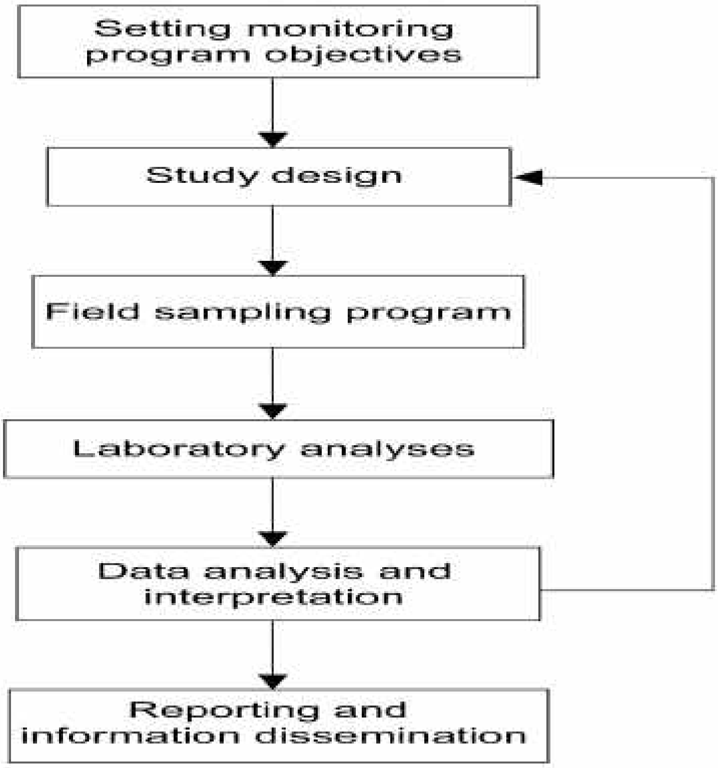


Figure A1: ANZECC/ARMCANZ (2000) Framework for the Development of a Water Quality Monitoring Program

The defined reaches formed the basis for the development of conceptual models of the natural, current and future flow regimes and associated water cycle management strategies. They also aided in the identification of issues associated with environmental flows (and associated strategies) and for defining the scope of the monitoring program. The issues identified during this reaches assessment were categorised into high, medium and low priority. The monitoring program design concentrated on the high priority issues while recognising that medium and low priority issues may need to be reconsidered as part of a future monitoring program following the introduction of the recommended environment flow regime. The identified high priority issues are listed in Table A1 below.

Having defined the high priority issues, hypotheses were then generated based on predictions of the way in which the rivers were expected to respond to environmental flows and associated strategies. The recommended study design was then developed for each hypothesis and was based around four components:

- **Fundamental hydrological monitoring.** This component provides baseline information for other components of the monitoring program and to inform adaptive management.
- **Ecological and physical monitoring.** This component addresses the impact of an environmental flow regime on a range of issues including fish abundance and community structure, habitat features, aquatic macroinvertebrates, aquatic and riparian plants, water quality (particularly temperature) and stratification.
- **Ancillary monitoring.** This component measures improvements arising from related strategies being recommended by the Forum (such as the Effluent Reuse Strategy, protection of environmental flows and the impacts of channel changes).
- **Social, economic, cultural and heritage monitoring.** This component measures how social, economic, cultural and heritage issues affect river conditions, and how they may in turn be affected by changing river conditions.

The Panel's recommended monitoring design includes a combination of pre-monitoring and routine (ongoing) studies. Pre-monitoring investigations need to take place before the ongoing monitoring program commences as they inform various aspects of the ongoing program.

Review of Recommended Monitoring Program

A draft report describing the Panel's recommended monitoring program was submitted for peer review as well as for review by members of the Forum. The Panel's response to the peer review process can be found in the report "*Responses To Peer Reviews Of The Draft Integrated Monitoring Program*" (IEP, 2004b). The comments received as a result of the review process have been taken into account in this final monitoring report.

For the Fundamental Hydrological, Ecological and Physical and Ancillary components of the program, the Panel undertook a reassessment of the recommended program to prioritise determine the relative importance of each of the high priority issues addressed by the program. This resulted in the high priority issues being ranked in order of importance based on the following ranking criteria:

- **Inferential ability** - whether the statistical design for monitoring of the issue is able to isolate the effects of flow changes
- **Community impact** – whether the community is aware of the issue and would be concerned if it was affected
- **Conservation impact** – whether the issue involves threatened taxa such as the Macquarie perch
- **Interpretative value** – whether the monitoring results can be used in other studies for their interpretation
- **Spatial impact** – whether the impact of the issue would cover a large length of river
- **Usefulness to management** – whether management can respond to the monitoring results quantitatively if impacts are detected.

The Social, Economic, Cultural and Heritage (SECH) monitoring program originally proposed was also reviewed as it was recognised that there is a need to coordinate activities between various agencies before developing new programs. Further expansion of the program could be developed by the Hawkesbury Nepean Catchment Management Authority in consultation with river stakeholders.

The results of the program review are summarised in Table A1. For the Fundamental Hydrological, Ecological and Physical and Ancillary components, the ranking of each issue (within each overall program component) is also shown. The reassessment found that:

- All of the fundamental hydrological monitoring is essential as it measures inflows and outflows in the rivers and their tributaries and is the basis of many of the other elements of the program.
- Of the 16 items in the ecological/physical monitoring, the top 10 in the ranking are essential. The remaining items could be deferred if there were insufficient funds available.
- Of the 12 items in the ancillary monitoring section of the program, the top 6 in the ranking are essential. The remaining six could await further investigation and consultation.
- Components of the SECH program could be reduced in scope and developed initially by a relatively modest increase in the costs of the Integrated Water Quality Management Framework (IWMF) that exists in the Hawkesbury-Nepean Valley.

This monitoring program review was used by the Forum in determining its recommended monitoring program which comprises only part of the Ecological and Physical, Ancillary and Social, Economic, Cultural and Heritage monitoring components of the Panel's recommended program). The components of the program approved by the Forum are indicated in Table A1.

The estimated costs of the program components are included in Part E of this report.

The Panel considers that all of the high priority studies originally identified need to be implemented to avoid compromising the adaptive management program for implementation of environmental flows. Consequently, all of the high priority monitoring is discussed in detail in this report (ie. monitoring design details are not limited to the program approved by the Forum) on the basis that the components of the program not currently approved may be included in the monitoring program in the future. For the

Fundamental Hydrological, Ecological and Physical and Ancillary components of the program, the high priority issues are discussed in ranking order in subsequent sections of this report.

Table A1: Identified High Priority Issues and Ranking

High Priority Issue	Rank	Approved by Forum
Fundamental Hydrologic Monitoring		
Monitoring of weired shale reaches below dams	1	Yes
Monitoring of sandstone reaches downstream of dams	2	Yes
Monitoring dam inflows	3	Yes
Monitoring of tributary flows	4	Yes
Ecological and Physical Monitoring		
Cold water releases from dams	1	Yes
Reduced connectivity – natural barriers	2	Yes
Critical habitat contraction - Macquarie perch spawning/recruitment - Abundance and diversity of dependent biota	 2 4	Yes
General water quality downstream of dams	5	Yes
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes	5	Yes
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers	7	Yes
Reduced recreational fish catches	8	Yes
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers	9	Yes
Reduced commercial fish catches	10	Yes
Connectivity investigations – managing flows for fish passage in the Woronora River	11	No
Stratification of natural pools	12	No
Reduced flushing, scouring and conditioning of habitat	13	No
Elevated iron and aluminium concentrations in discharge waters from dams	14	No
Encroachment of riparian vegetation on channels	15	No
Iron-rich groundwater inflows downstream of Avon and Cataract Dams	16	No
Ancillary Monitoring		
General water quality associated with the Forum's Effluent Reuse Strategy	1	Yes
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management	2	Yes
Soil sustainability associated with the Forum's Effluent Reuse Strategy	3	Yes
Inter-catchment transfer of fish via Glenquarry Cut [1]	3	Yes
Lack of connectivity – diversion and gauging weirs	5	Yes
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy	6	Yes
Effectiveness of Tallowa Dam fish lift	7	No
Channel degradation in the mixed-load shale reach downstream of Penrith Weir	8	No
Connectivity - Penrith Weir fishway	8	No
Channel changes in weired reaches	10	No
Tidal channel changes in the Hawkesbury River	11	No
Stormwater runoff	12	No
Social, Economic, Cultural and Heritage Monitoring		
SECH Co-ordinator (expansion of existing Integrated Water Quality Management Framework)	na	Yes

[1] Not required if the Forum's recommended strategy for inter-catchment transfers from the Shoalhaven is adopted.

Sustainable River Fund	na	No
Pre-monitoring Phase	na	No
Monitoring Phase	na	No
Audit and Review Phase	na	No

Structure of this Report

This final monitoring report comprises 6 parts. These are as follows:

- ***Executive Summary***. This section provides a stand-alone overview of the monitoring program including a summary of the background to the monitoring program, the recommended environmental flow rules, the process used to develop the monitoring program, the issues associated with the river system and the reaches in which those issues will be monitored, and a summary of monitoring costs.
- ***Part A*** (this part) provides an introduction to the program including an overview of the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers, a summary of the recommended environmental flow rules, the objectives of the monitoring program, a summary of the identified high priority issues in the river systems and an outline of the structure of the monitoring report.
- ***Part B*** provides conceptual models of the river reaches under natural, current and future conditions, broadly identifies the high priority issues associated with hydrology, ecology, social and economic and cultural heritage factors for each reach and provides an overview of the consequences of the introduction of environmental flows and associated strategies.
- ***Part C*** provides specific details of the proposed hydrological, ecological and physical and ancillary monitoring program including a brief summary of each high priority issue, the hypotheses to be tested, the locations, variables, general approach, field sampling design, statistical analyses, response times and management interactions. Linkages between high priory monitoring components is also discussed.
- ***Part D*** presents the social, economic cultural and heritage monitoring program. It is intended as a guide to the social scientists and decision makers who will be responsible for the implementation of SECH monitoring. The SECH component is designed to evaluate social change associated with environmental flows and related river management strategies. Successful SECH monitoring will be enhanced by providing information and community education about environmental flows and encouraging strong community engagement in monitoring change.
- ***Part E*** provides an outline of the proposed administration and management principles, structures and functions for the program.

The report is intended to be read mainly by a technical/scientific audience. Accordingly, prior knowledge of hydrological, ecological, socio-economic and cultural heritage issues and concepts is assumed.

PART B: UNDERSTANDING OF THE SYSTEM AND IDENTIFICATION OF ISSUES

Introduction

In the development of the monitoring program, the Expert Panel focussed on the 29 defined reaches (or groups of reaches with similar characteristics) which had been set up for the Hawkesbury Nepean, Wingecarribee, Woronora and Shoalhaven Rivers.[1] These reaches, which are based mainly on geomorphological and landuse characteristics, are listed in Table B1 below and shown in Figures B1 (overview map) and B2 to B7 (reach groupings).

Table B1: River Reaches of the Shoalhaven, Woronora, Wingecarribee and Hawkesbury-Nepean River Systems (downstream of Sydney Catchment Authority dams)

Reach Number	Description	Figure Number
1	Shoalhaven River, Tallowa Dam to Burrier	B2
2.1	Shoalhaven River, Burrier to Nowra (Princes Highway Bridge)	B2
2.2	Shoalhaven River, Nowra to Pacific Ocean	B2
3	Woronora River, Woronora Dam to Heathcote Creek junction	B3
4	Woronora River, Heathcote Creek junction to The Needles	B3
5	Woronora River, The Needles to Pacific Ocean	B3
6.1	Wingecarribee River, Wingecarribee Reservoir to Berrima township	B4
6.2	Wingecarribee River, Berrima township to Wollondilly River junction	B4
7	Nepean River, Doudles Folly & Glenquarry Creeks (downstream of Glenquarry Cut)	B4
8,9,10, 11,12,13	Nepean, Cordeaux, Avon and Cataract Rivers downstream of the dams to the diversion weirs; Nepean and Cataract Rivers downstream of the diversion weirs to the Nepean/Cataract confluence	B5
14	Nepean River from the Cataract River junction to Menangle Weir (includes Menangle and Maldon weir pools)	B5
15,17	Nepean River from Menangle Weir to Wallacia Weir (excluding the Bents Basin gorge). These reaches include 10 compensation weirs.	B5; B6
16,18,19	Bents Basin gorge, Nepean River from Wallacia Weir to Nepean/Warragamba confluence and Warragamba River from Warragamba Dam to Nepean/Warragamba confluence	B6
20,21	Nepean River from Nepean/Warragamba confluence to Penrith Weir	B6
22	Nepean River, Penrith Weir to Grose River junction	B6
23	Hawkesbury River, Grose River junction to Wilberforce	B7
24	Hawkesbury River, Wilberforce to Colo River junction	B7
25	Hawkesbury River, Colo River to Macdonald River junction (Wisemans Ferry)	B7

[1] *River Reaches Assessment*; Microsoft Access Database, Expert Panel, March 2004.

26,27	Hawkesbury River, Macdonald River junction to Pacific Ocean	B7

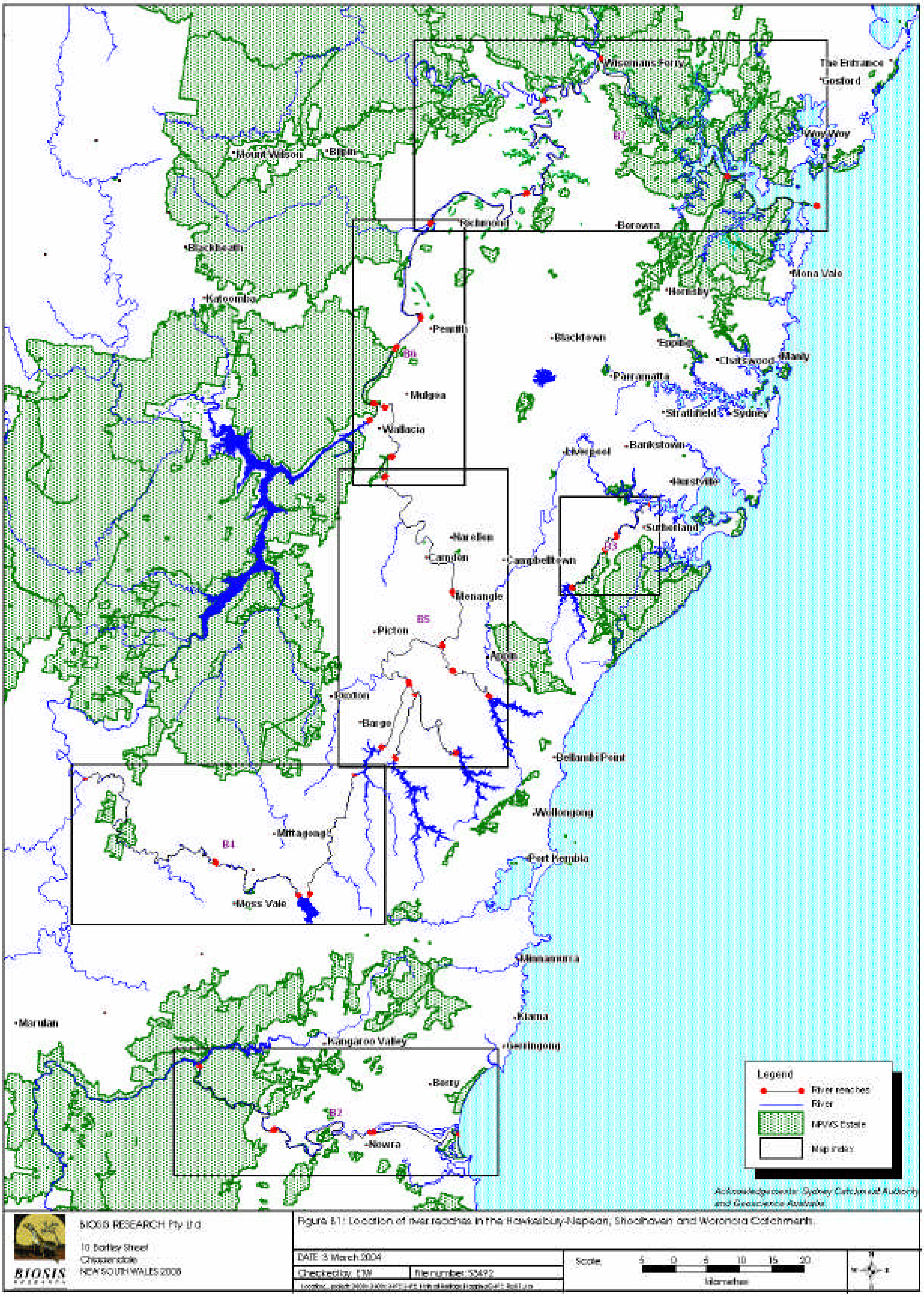


Figure B1: Overview of River Reaches

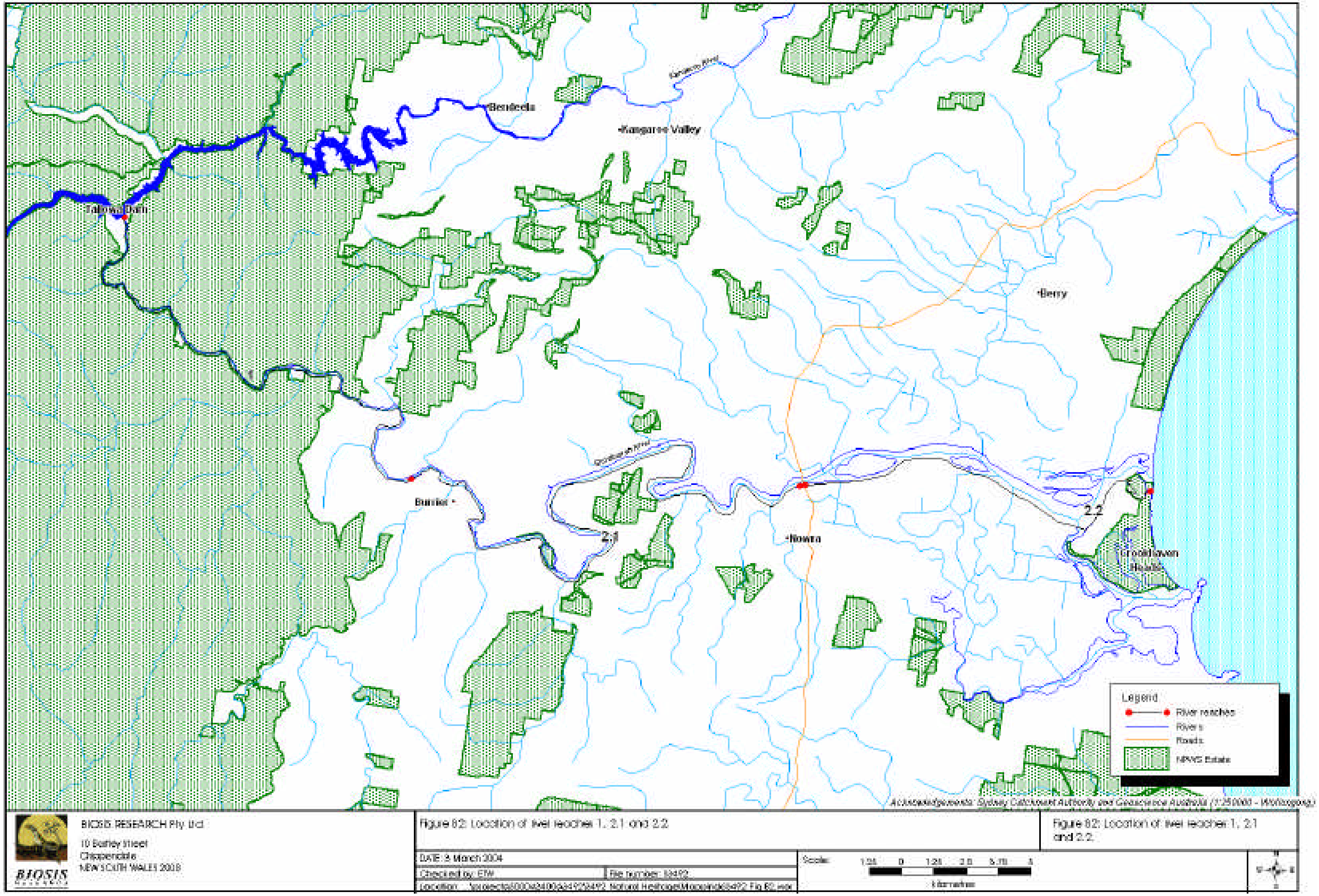


Figure B2: Reaches 1 to 2.2; Shoalhaven River

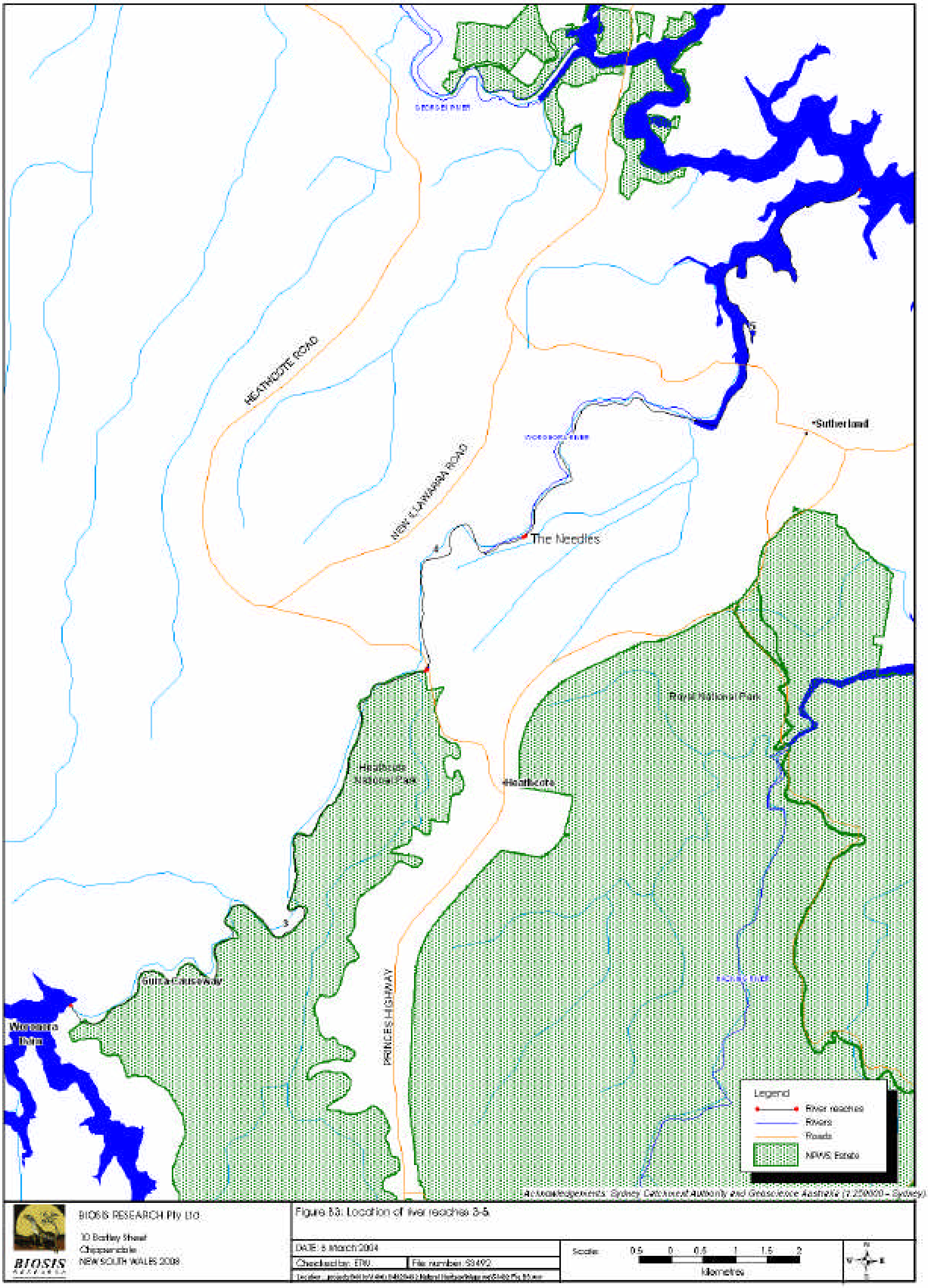


Figure B3: Reaches 3 to 5; Woronora River

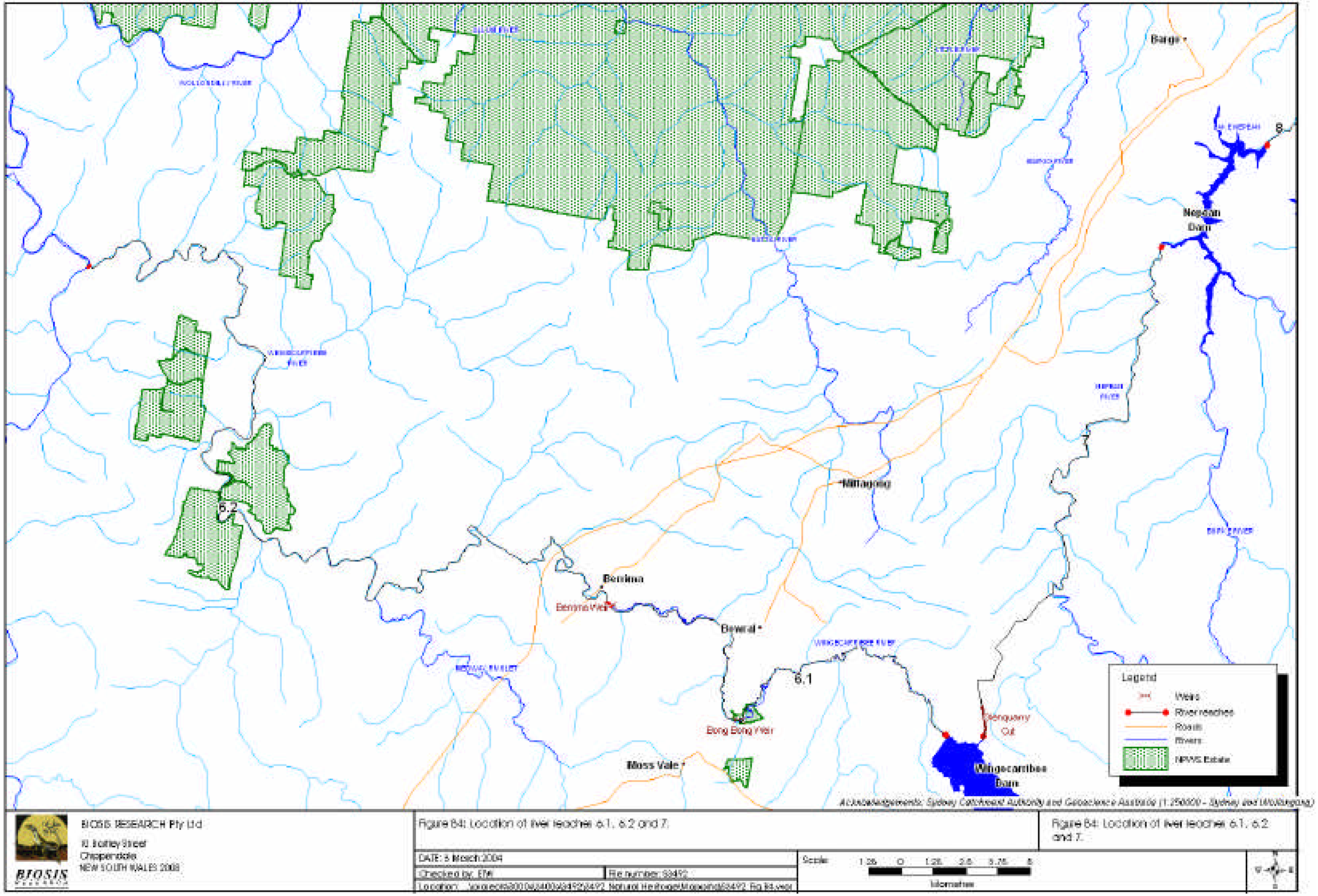


Figure B4: Reaches 6.1 to 7; Wingecarribee and Upper Nepean Rivers

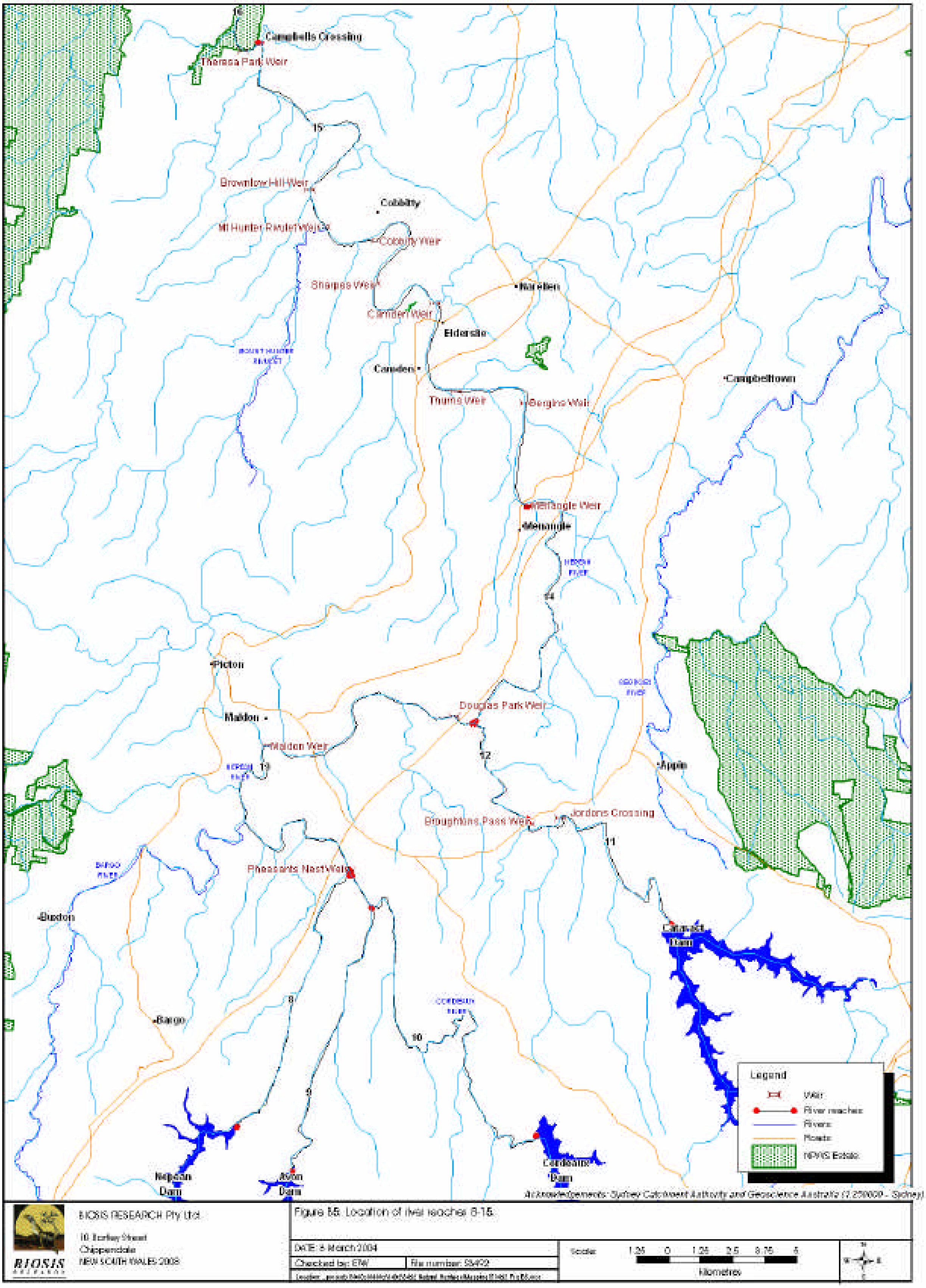


Figure B5: Reaches 8 to 15; Nepean, Avon, Cordeaux and Cataract Rivers

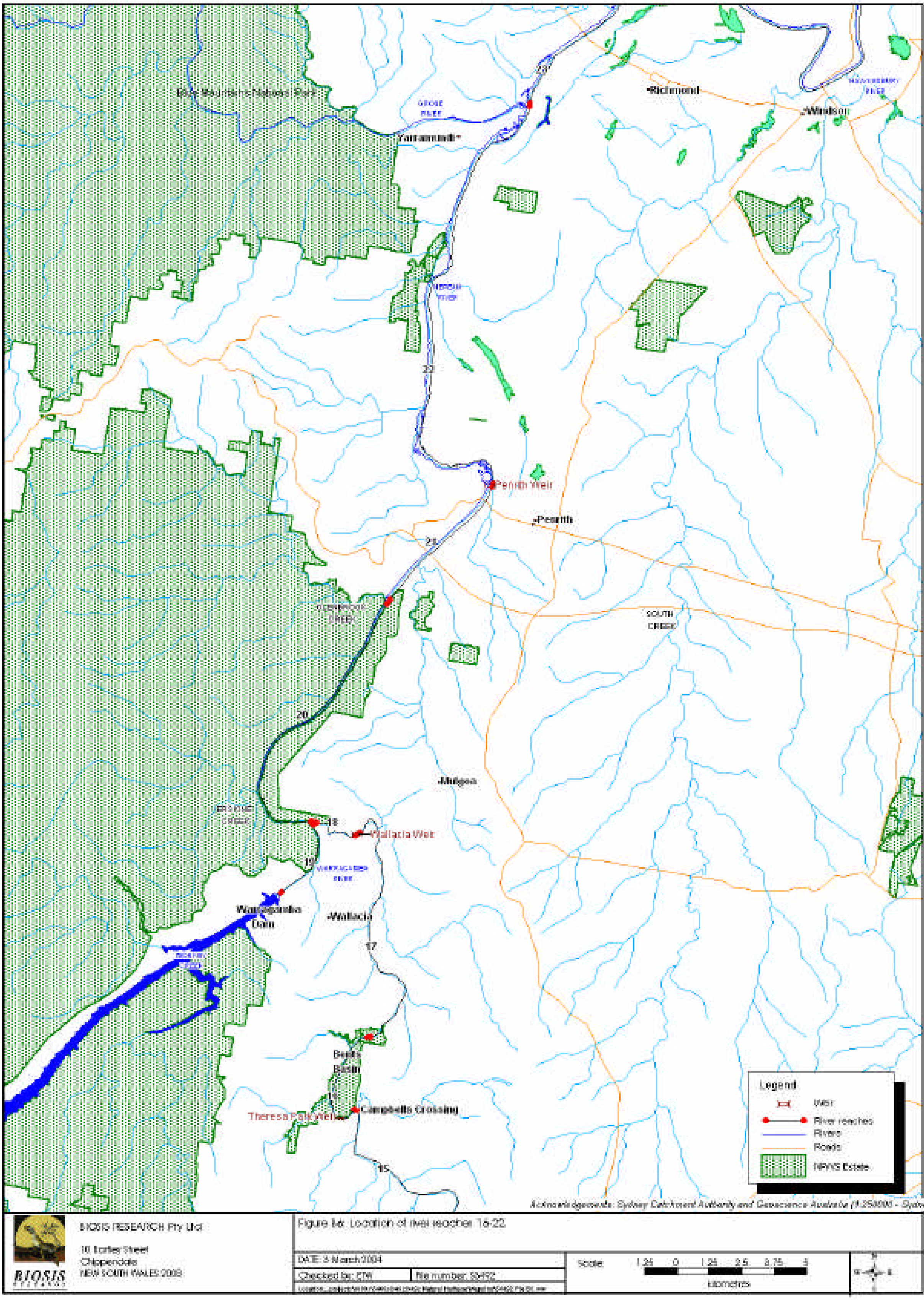


Figure B6: Reaches 16 to 22; Nepean River

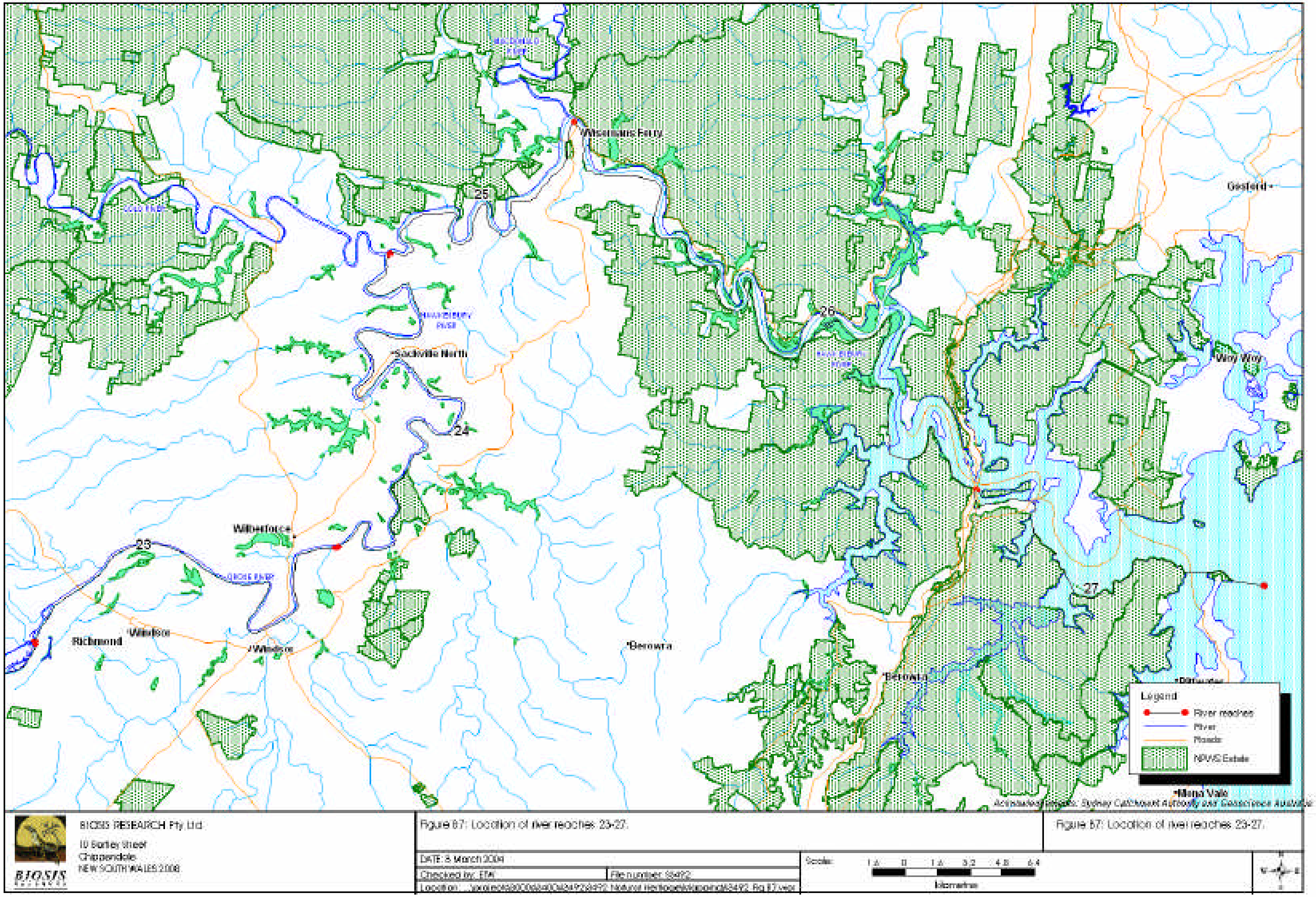


Figure B7: Reaches 23 to 27; Hawkesbury River

Identification of High Priority Issues

This part of the monitoring program report describes the various reaches (or groups of reaches) listed in Table B1 and identifies high priority issues of concern that apply in each. The descriptions are illustrated by conceptual models (expressed as three schematic diagrams for each reach or reach group) which show:

- The presumed state under natural (pre-European) conditions.
- The state under current conditions with high priority issues relevant to each reach being described in detail.
- An hypothesised state under an environmental flow regime, including the expected impact of the flow regime on the current high priority issues.

Lower priority issues are recorded in Part E of this report. These issues have not played a significant role in the development of the monitoring program but may become important for consideration during an ongoing adaptive management program.

Fundamental Hydrological, Ecological and Physical, and Ancillary Issues

Determination of the high priority issues for the fundamental hydrological, ecological and physical, and ancillary components of the monitoring program was based on a detailed reach-by-reach assessment[1] which considered a range of factors including:

- Physical characteristics including gross water inputs and extractions, major tributaries and artificial barriers
- Hydrological characteristics determined using modelling procedures for pre-dam (natural) and post-dam (existing) conditions. Because of the complex interactions between the hydrologic regime of each reach and the ecosystem that each reach supports, the hydrological impacts considered a number of different, but inter-related, hydrological characteristics including:
  - Flow Magnitude and Duration:
  - Flow Frequency:
  - Flow Seasonality
  - Rate of Change of Flow
  - Flow Variability
- Ecological characteristics, including high value and vulnerable habitats, natural passage barriers and threatened species
- Impacts of flow alteration processes on the ecological processes of rivers and estuaries
- Water quality characteristics
- Human-induced (anthropogenic) factors

Details of the monitoring program associated with these fundamental hydrological, ecological and physical, and ancillary issues are provided in Part C of this report.

Social, Economic, Cultural and Heritage (SECH) Issues

The SECH monitoring is concerned with the beneficial and adverse impacts associated with river management strategies to provide and protect environmental flows. The program will evaluate environmental and social change from the viewpoint of both river stakeholders and local communities. The program will also monitor the impacts that people have on the river.

Issues in the SECH Monitoring

The SECH monitoring program contains several distinct but interrelated issues. They are:

1. Social and Cultural Values (including sub-issues of Heritage Values and Aboriginal Values);
2. Institutional Performance;

[1] *River Reaches Assessment*; Microsoft Access Database, Expert Panel, March 2004.

3. Land and River Activities – existing; and
4. Land and River Activities – environmental flows.

The longer-term changes to river conditions are likely to impact on both people's 'Social and Cultural Values' and on their interactions with the river. These interactions are the focus of the SECH monitoring strand for 'Land and River Activities – existing'. It is important, however, to recognise that the longer-term changes to river conditions will be viewed in association with the process of river management employed to achieve this change. The 'Institutional Performance' aspect of the SECH monitoring will focus on these impacts.

A number of key river management strategies will be implemented to provide and protect environmental flows. They work alongside the physical release of water from dams and contribute to longer-term improvement of river conditions. The impact of these strategies will be monitored in the SECH monitoring as 'Land and River Activities – environmental flows'. The implementation of these strategies may be contested amongst different stakeholders because of the potential for adverse impacts. Monitoring these changes is essential, so that appropriate measures are taken to avoid or mitigate adverse impacts and to promote and maximise beneficial impacts. These changes are likely to arise in the shorter term as compared to longer-term changes discussed above.

To understand and interpret SECH issues the following points should be considered:

- The characteristics of social issues depend upon complex and dynamic variables, related not only to changes in the river environment but also to other factors like economic well-being, attitudes towards government and interactions with other stakeholders and the community.
- The SECH issues identified here are necessarily contingent and subject to modification.

The specific issues to be monitored can only be determined with comprehensive and continuing involvement of river stakeholders and local communities. They must be involved in the process of deciding what sort of impacts are expected to arise from each initiative and how these should be managed. The SECH monitoring program is intended to promote participation by the local community at all stages. The recommended pre-monitoring investigations will clarify the specific issues considered significant by stakeholders and local communities. In the initial phases of the monitoring program it is critical to ensure that all stakeholders are involved in determining the objectives of monitoring, the changes to be monitored, the processes associated with data collection and interpretation and the avenues for communication of findings. This process would lead to a more comprehensive assessment of the issues on a reach-by-reach basis.

The issues of Social Values (including Aboriginal Values) and Institutional Performance apply to the whole river. Other SECH issues including non-Aboriginal Heritage and Land and River Activities (both existing and those accompanying environmental flows) apply to different parts of the river, as noted in the following discussion of high priority issues for the specific reaches.

A preliminary reach-by-reach heritage assessment is included as Appendix B1. It should be noted that heritage values are more than physical sites and places associated with the river. They are dynamic and associated with cultural, spiritual, social, historic and aesthetic values that people hold for their environment and for places within that environment. This aspect of heritage values is captured by the broad issue of social values which applies to the whole river.

Details of the monitoring program associated with SECH issues are provided in Part D of this report.

Potential Impacts of Global Warming

Under predicted global warming scenarios, large reductions in water resources availability need to be anticipated. These will adversely affect the provision of urban water supplies, water for other extractors and water for environmental flow regimes. Such conditions may well invoke the adaptive management process, where changes (upwards) in transparent and translucent flows may have to be made. Contingency flows are at set volumes and will not be affected.

Rather than repeat such qualifications for each of the 29 reaches in turn, this general qualification pertains to all reaches, with perhaps differences in detail. Some of these reductions have already been experienced with the present drought-dominated climate (DDC), where decreases in precipitation of up to 30% and perhaps more in some instances have been noted over the period (1991 to 2002). Related decreases in dam inflows for the same period have been more than 70%, compared with inflows in the last flood-dominated climate (FDC) from 1949 to 1990.

These impacts do not include those of global warming associated with anticipated increases in temperatures. Although models developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and others predict small increases in rainfall, the increases in temperatures and the associated rises in evaporation will offset the impacts of increased rainfall and further emphasize the impacts of the current DDC.

Such predicted changes will significantly reduce current estimates of 80% transparency flows for the smaller dams (95% for Warragamba) and the 20% translucencies, which form the bases of recommended environmental flows.

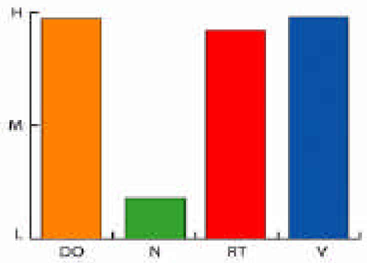
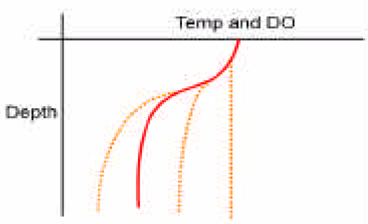
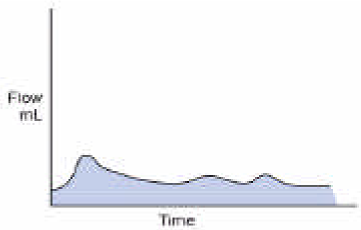
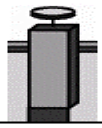
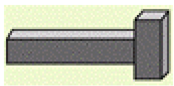
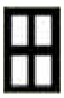
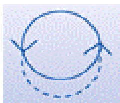
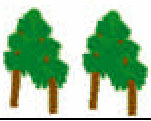
Accurate monitoring of inflows to dams will be most important to determine the net impacts of the DDC and those associated with any rises in temperatures. The detection of temperature increases will be very difficult, as are minor increases in precipitation and large increases in evaporation in such "noisy" (irregular), complex climates. Any measurable changes will only be noted over long periods of time by concerned agencies, like the Bureau of Meteorology and the CSIRO.

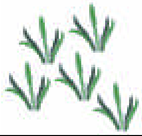
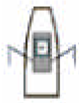
Key to Conceptual Models

The conceptual models are designed to graphically illustrate features of the river reaches and to permit a quick reference for a range of factors between the natural, current and future (environmental flow) conditions. These factors include water quality and hydrological parameters, ecological and geomorphological features and human impacts.

Table B6 below is a key to the symbols used on the conceptual model diagrams.

Table B6: Key to Conceptual Model Diagrams

<table>
<tr><th colspan="4">Visual Aids</th></tr>
<tr><td>Water Quality Parameters</td><td>
</td><td colspan="2">The bars indicate dissolved oxygen (DO), nutrients concentration (N), retention time in the reach (RT) and flow velocity (V) on a scale from low (L) through medium (M) to high (H). The relative lengths of the bars between natural, current and environmental flow conditions gives an assessment of the state of these parameters under those conditions.</td></tr>
<tr><td>Stratification</td><td>
</td><td colspan="2">The diagram shows a typical depth profile for temperature and dissolved oxygen when the water column is vertically stratified. The bold line shows that temperature (and dissolved oxygen) in the well-mixed top few metres of the water column (known as the epilimnion) is similar. Temperature then decreases in the middle layer (the metalimnion) with constant but low temperatures and dissolved oxygen in the bottom layer (the hypolimnion). The dotted lines demonstrate that at times stratification can be greater with depth and at other times the water column can be well mixed. The difference between natural, current and future scenarios is due mainly to the influence of the frequency, magnitude and duration of flows and the ability of flows to mix the water column.</td></tr>
<tr><td>Hydrologic Pattern</td><td>
</td><td colspan="2">The hydrograph shows the variability and magnitude of river flow as a function of time. Comparison of the hydrographs between natural, current and environmental flow conditions gives an assessment of the alteration of the flow patterns from the natural state.</td></tr>
<tr><th colspan="4">Icons</th></tr>
<tr><td>Gate or valve</td><td></td><td>Irrigation pump</td><td></td></tr>
<tr><td>Sewage treatment plant</td><td></td><td>Mixing within water column</td><td></td></tr>
<tr><td rowspan="2">Diversity of biotic communities</td><td rowspan="2"></td><td>Native submerged macrophytes</td><td></td></tr>
<tr><td>Exotic submerged macrophytes</td><td></td></tr>
<tr><td>Native riparian vegetation</td><td></td><td>Exotic riparian vegetation</td><td></td></tr>
</table>

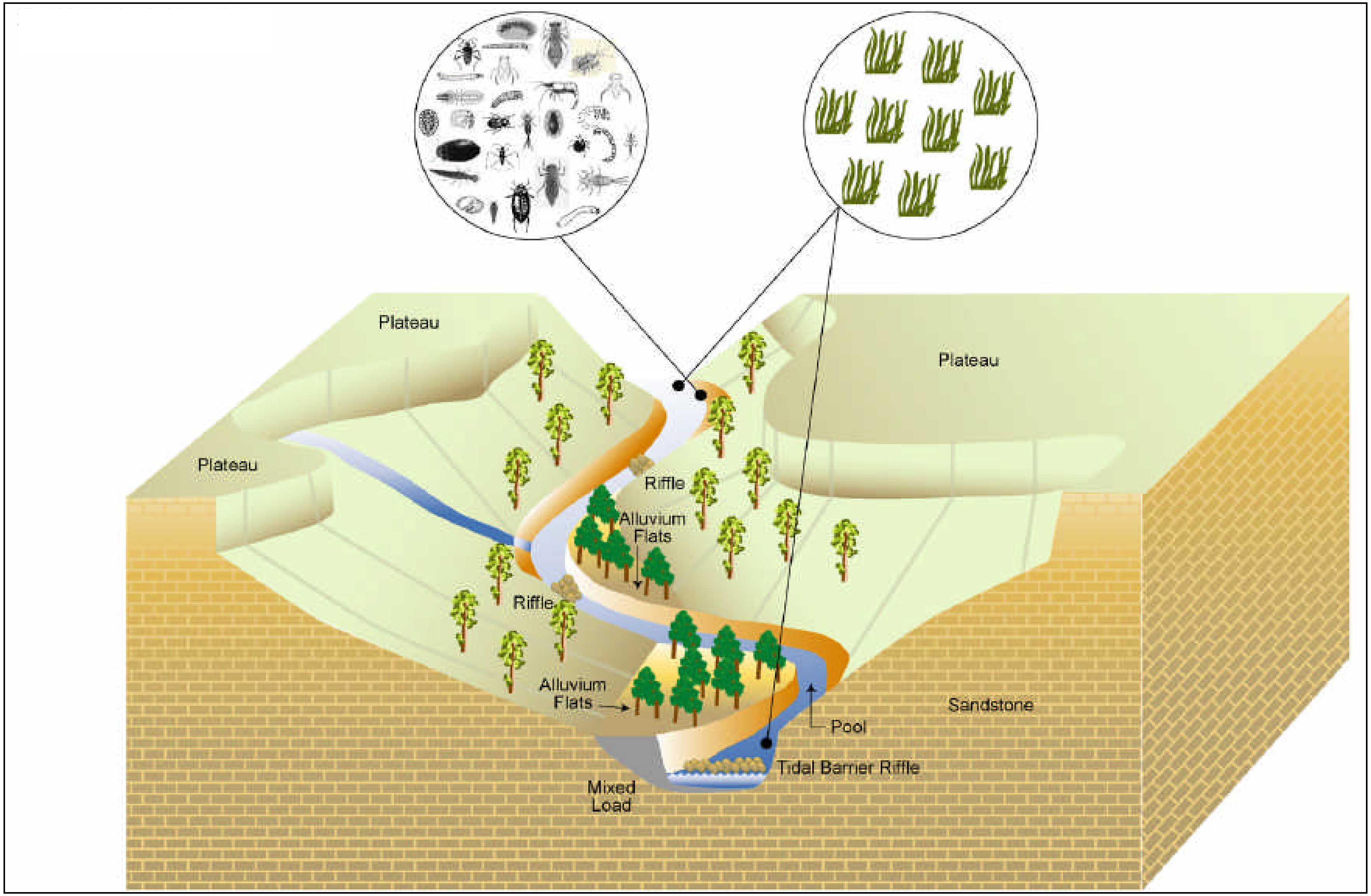
Wetland		**Native woodland forest**	
Wetland emergent vegetation		**Exotic floating macrophytes**	
Recreational activities (water based)		**Recreational activities (land based)**	
Dam on tributary		**Commercial fishing**	
Aboriginal cultural heritage		**European cultural heritage**	
Abbreviations (other than those defined in the visual aids above)			
EF	Environmental Flow	**95%**	95th percentile flow
STP	Sewage Treatment Plant	**FDR**	Flood Dominated Regime
Q_{bf}	Bankfull discharge	**DDR**	Drought Dominated Regime
Q_{10}; Q_{30} etc	1 in 10; 1 in 30 year floods etc	**Tribs**	Tributaries
SSTN	Sandstone	**yBP**	Years before present

Reach 1: Shoalhaven River, Tallowa Dam to Burrier

Natural Regime; Reach 1

Under natural conditions this 22 km reach would not have been much different to the present visually, other than the absence of anthropogenic activities. Flows would have been slightly more regular and more reliable in drought times, without the dam and subsequent pumping. Only about 2% of the long-term average is “lost” to the dam. So this sinuous valley, which is somewhat narrower in the upper half, would have a well- developed suite of pools and riffles (given that it has a mixed bedload from Palaeozoic sources upstream) providing both spatial and temporal instream habitat variability. Fish passage would not have been a problem and higher flows would have scoured riffles for habitat renewal. Energy sources in this river section and organic matter would have been derived primarily from leaf material both from drift of leaves from upstream rivers and inputs directly from riparian vegetation.

Figure B8: Reach 1- Natural Regime: Shoalhaven River, Tallowa Dam to Burrier



Current Regime and High Priority Issues; Reach 1

Tallowa Dam was constructed to augment water supply to Sydney, the Blue Mountains and the Illawarra areas during drought periods and represents the greatest change in this valley. However, only about 2% of the mean annual flow is extracted and in most years there are no water supply diversions to Sydney Catchment Authority storages in the Hawkesbury-Nepean System (all inflows to Tallowa Dam pass through and spill). Diversions are required approximately once a decade, typically for periods of 3-6 months. When this occurs the flows downstream of Tallowa are greatly reduced. This generally occurs when natural flows in the Shoalhaven River are well below average and under these conditions fish passage and critical habitat associated with higher water velocities is impeded.

River flow downstream of Tallowa Dam is complicated by operational requirements for potable water supply for the Shoalhaven Region and for diversions to Sydney Catchment Authority storages. At Burrier, a rock barrier exists across most of the river channel to provide a pondage for the Shoalhaven water supply pumping station. Upstream of Tallowa Dam (Kangaroo River Reach), a pumping station at Bendella delivers water to the hydro-electric power supply system between Bendella Pondage and Fitzroy Falls Reservoir and for diversion of water to the Hawkesbury-Nepean storages when required.

Under current rules the dam theoretically acts as a transparent dam when inflows are less than 180 ML/day, but the flow between 90 and 180 ML/day is available for extraction at Burrier. The main effect of the change in flow is to dampen the temporal variability in habitats, particularly those components associated with the key hydraulic variables, water depth and velocity. The current flow regime appears to severely restrict the availability of critical physical habitat associated with higher water velocities during times of inter-catchment transfers, particularly the size of and depth of water over riffle habitats. Low water depth across these habitats greatly limits connectivity between refuge pools along the rivers. This is particularly important for large-bodied aquatic animals such as fish. These changes, however, are infrequent in real time but they are likely to have had adverse consequences in the past. Water released from the dam for the current environmental flow comes from a bottom-release valve resulting in poor water quality and the deposition of iron oxides immediately downstream of the dam. This has potentially affected the biodiversity below the dam.

On the valleys sides there has only been limited land clearance for isolated farming. These have little impact on flows or the channel. Food webs have been altered by the presence of the dam as energy now comes primarily from photosynthesis rather than leaf litter inputs along the river system.

Fundamental Hydrological Issues

- **Monitoring dam inflows**

  The Forum's recommended environmental flow releases will be based on daily releases from the water supply dams and diversion weirs that are operated by SCA. The environmental flows will be set as a variable proportion of the estimated dam daily inflows.

  Reliable hydrologic information will be required to:

  - provide estimates of daily inflows to the dams so that daily releases can be computed; and,
  - provide estimates of daily through flows from weirs so that environmental flow releases can be verified.

  With the current gauging arrangements it is possible to derive reliable estimates of daily inflows to Tallowa, Warragamba and Nepean Dams, which would form the basis of estimates for environmental flow releases. However, it is not possible to provide accurate estimates of daily inflows to Avon, Cordeaux, Cataract or Woronora Dams. It will therefore be necessary to upgrade the gauging network and devise a methodology for estimating ungauged flows.

Ecological and Physical Issues

- **Cold water releases from dam**

  When dams are not spilling, flow releases are made from a valve located at the base of the dam wall using water extracted at depth. As a consequence the temperature of these releases is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper. These cold water releases thus have the potential to impact on downstream receiving waters.

  Cold water pollution has been linked to:

  - impacts on biota including the loss of native fish via impacts on fish eggs and larvae, reduced fish reproduction, lower growth rates and altered metabolism;
  - localised extinction of some species; and
  - impact on the recreational amenity of rivers.

  Given the potential impacts of cold water on downstream aquatic ecosystems, it is important to monitor water temperatures to ensure that the suppression of water temperatures does not occur.

- **Reduced connectivity – natural barriers**

  Reduced flows over riffles or riffle-like habitats, have decreased connectivity for mobile aquatic fauna along river reaches, and at the interface between river and estuarine reaches. Illustrations of this issue are given in Plates 1 and 2.

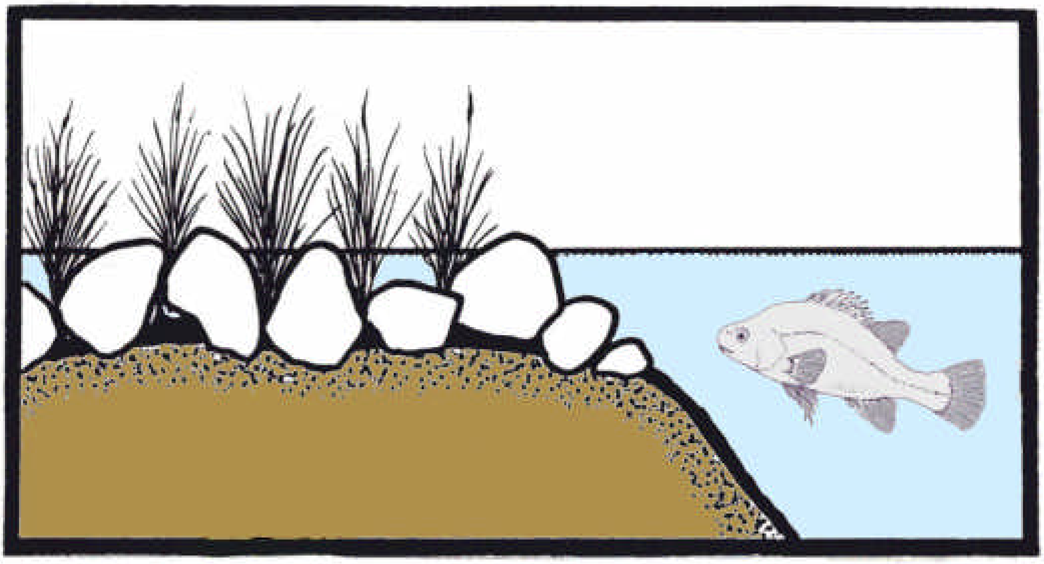
  The potential consequences of reduced connectivity along river reaches are:

  - fragmentation of fish communities and corresponding decrease in their viability;
  - major impacts on fish and invertebrate migration-mediated community dynamics;
  - increased mortality of fish and invertebrates as larger predators can more effectively hunt taxa accumulating below the riffles or riffle-like habitats;
  - increased disease-mediated mortality of fish and invertebrates because they are crowded together in large numbers below the riffles or riffle-like habitats;
  - reduced growth potential as fish and invertebrates are crowded in resource-limited areas below the riffles or riffle-like habitats; and
  - increased mortality of platypus and turtles as predators can more effectively hunt over the shallowed riffles or riffle-like habitats.

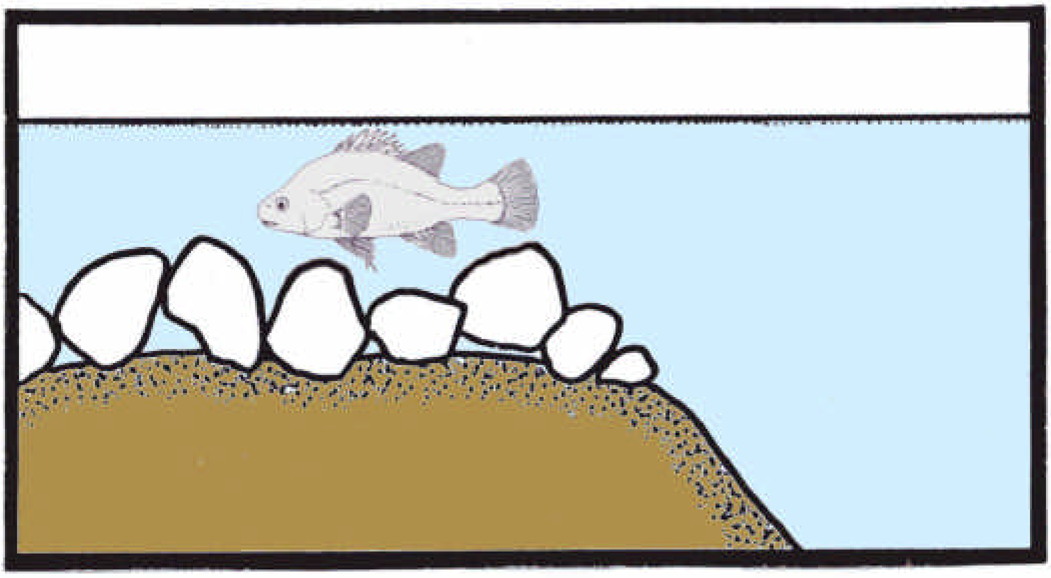
  The potential consequences of reduced connectivity between the river and (upper) estuary reaches are:

  - diadromous species unable to complete their life cycle (eg. the recreationally-important Australian bass);
  - major impacts on fish and invertebrate migration-mediated community dynamics;
  - increased mortality of fish and invertebrates as larger predators can more effectively hunt taxa accumulating below the tidal-barrier riffle;
  - increased disease-mediated mortality of fish and invertebrates because they are crowded together in large numbers below the tidal-barrier riffle;
  - reduced growth potential as fish and invertebrates are crowded in resource-limited areas below the tidal-barrier riffle; and
  - increased mortality of platypus and turtles as predators can more effectively hunt over the shallowed tidal-barrier riffle.

Plate 1 - Illustration of the connectivity Issue for fish

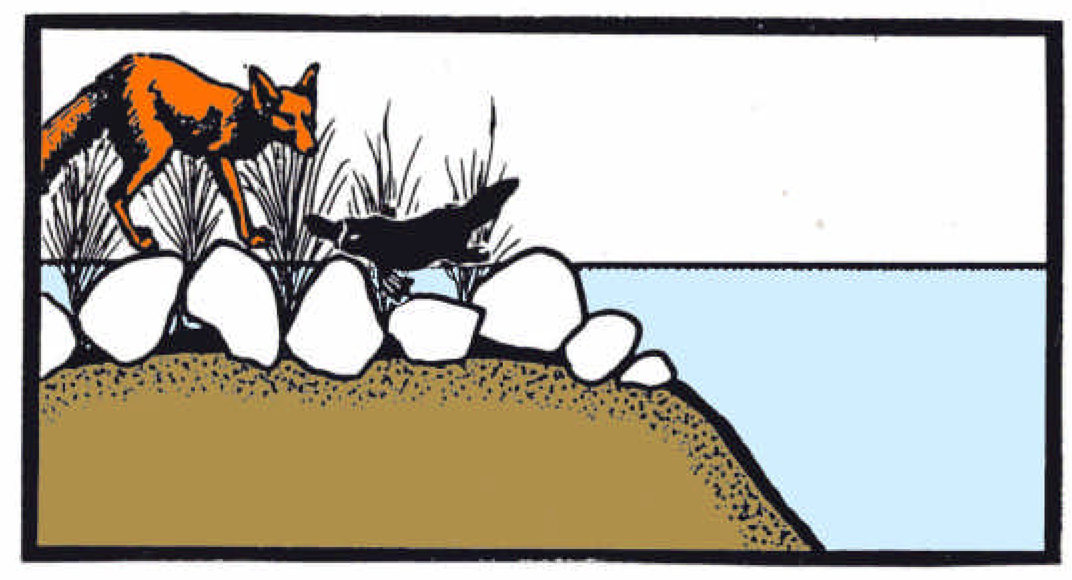


Flows reduced over riffles: passage frequently blocked (major consequences during spawning seasons)

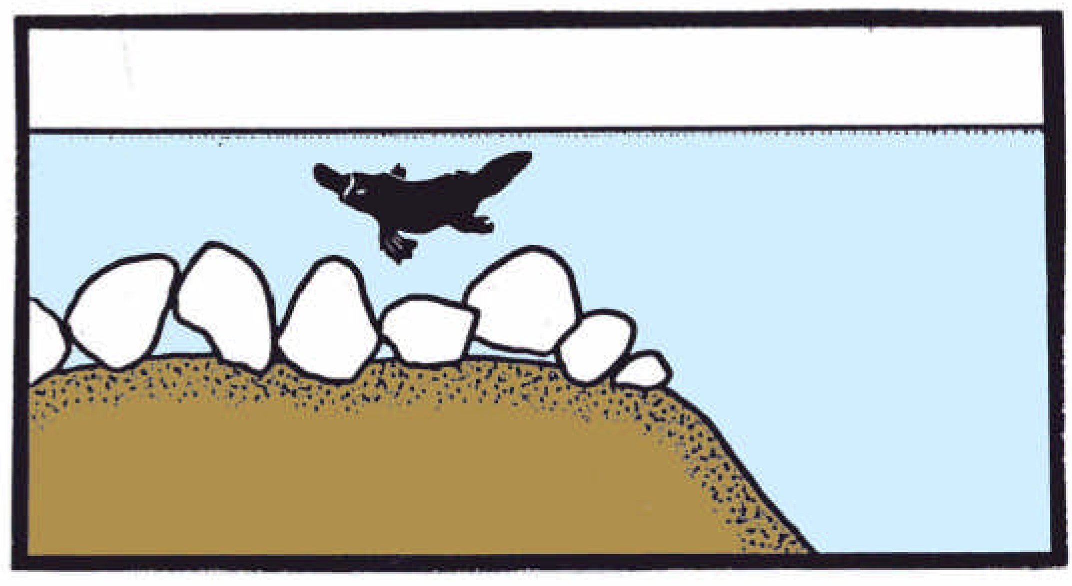


Flows not reduced over riffles (near–natural): passage frequently open

Plate 2 - Illustration of the connectivity issue for platypus



Flows reduced over riffles: passage open, but risk from predation high



Flows not reduced over riffles (near–natural): passage also open, but now risk from predation is low

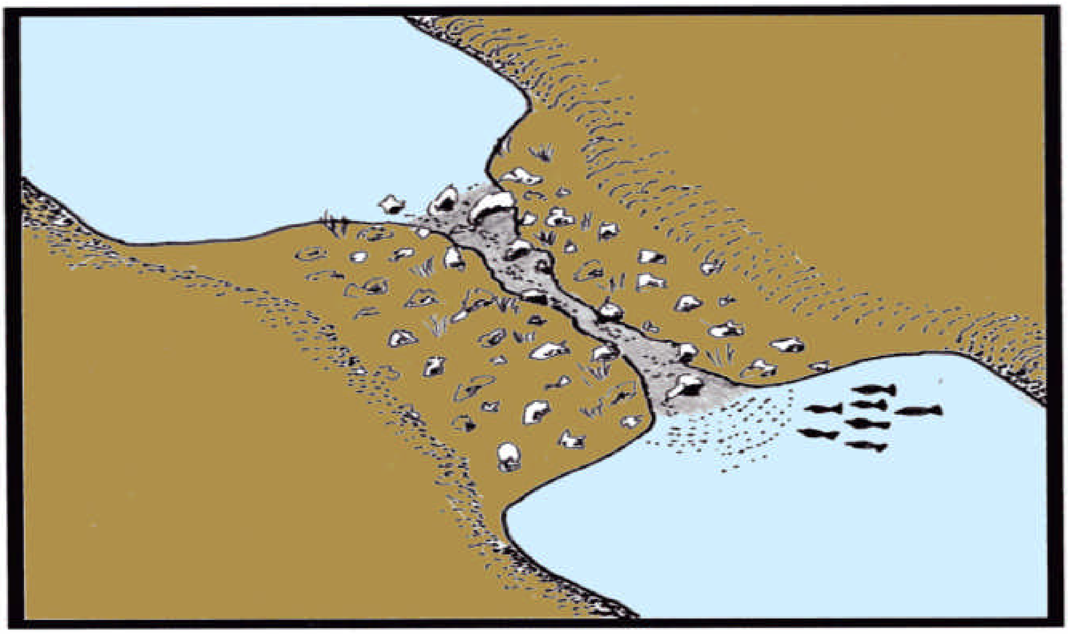
- **Critical habitat contraction**

  Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities (for example riffle habitats). An illustration of this issue is given in Plate 3.

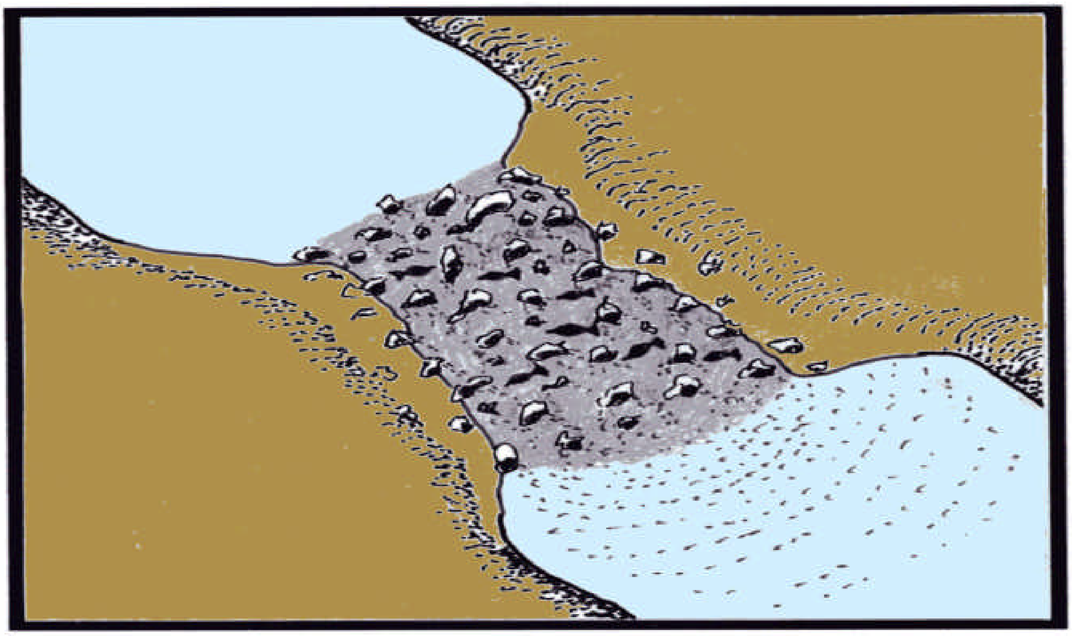
  The potential consequences of such habitat contraction are:

- reduced habitat area and diversity (loss of those microhabitats associated with high velocity);
- reduced diversity of invertebrates and fish (loss of those taxa associated with high water velocities);
- reduced abundance of invertebrates which use higher-water velocity areas, with subsequent reductions in biomass/biovolume, drift rates, etc.;
- diminished growth and abundance of fish and platypus which forage within or immediately downstream of riffles, as arising from reductions in the supply of invertebrate food items (see invertebrate abundance consequences above); and
- reduced spawning/breeding success of riffle-dependent fish species.

Plate 3 - Illustration of the critical-habitat contraction issue



Flows reduced over riffles: riffles contracted frequently (major consequences during spawning seasons)



Flows not reduced over riffles (near–natural): riffles expanded frequently

- **General water quality downstream of dam**

  Waters released from dams is often of poor quality due primarily to the fact that water is released from below the thermocline. These releases then have the potential to impact on downstream receiving water quality. In order to ensure that water released from dams is of satisfactory quality, it is important to undertake routine monitoring immediately downstream of the dams.

- **Altered biotic communities**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Stratification of natural pools**

  Stratification can have significant impacts on both water quality and pool dependent biota.

  Stratification of the water column is a common phenomenon in Australian dams, reservoirs, weirs and natural water bodies whereby a density difference develops generally between surface and bottom waters predominantly during spring and summer. Temperature is the major factor affecting density although pressure, salinity and suspended particles can also cause stratification. When a water body becomes stratified a warm surface layer generally overlays cooler bottom waters. While stratification can occur naturally, the frequency, duration and magnitude of stratification events can be exacerbated by prolonged low flows and increased retention times caused by river regulation.

  During stratification events:

  - dissolved oxygen concentrations in the poorly mixed bottom waters are reduced and over time can approach zero;
  - these anoxic bottom waters can potentially be lethal to oxygen requiring aquatic biota including fish;
  - sediments associated with anoxic bottom waters can release iron, manganese, phosphorus and nitrogen; and
  - habitat availability can be diminished and predation can potentially increase.

  The increased variability in the volumes of water transmitted through natural pools following the introduction of an environmental flow regime will lead to greater velocities of water entering these pools, which will in turn lead to more turbulent mixing and less frequent thermal (and oxygen) stratification. As a consequence, hostile water quality at depth in these pools will occur less frequently.

- **Elevated iron and aluminium concentrations in discharge waters**

  Regulated flows in the Shoalhaven River system appear to have resulted in iron-rich bottom waters being discharged from the dam. Stratification of the water column in the dam can lead to the release of iron (and aluminium) from bottom sediments into the water column which, if released, can lead to elevated iron concentrations in downstream receiving waters. When iron-rich bottom waters are exposed to the atmosphere the iron oxidises and quickly precipitates leaving a rusty-coloured precipitate. This process is mediated by iron-oxidising bacteria, which can also be seen as a rusty-coloured mass in the water. The occurrence of iron precipitate and iron-oxidising bacteria are particularly evident in the Shoalhaven River immediately downstream of Tallowa Dam.

  The implications of this are:

  - loss of habitat or habitat simplification; and
  - loss of both native plants and animals directly via iron toxicity or indirectly via smothering.

  Monitoring data for the system indicates that elevated concentrations of total and filterable iron occur immediately downstream of Tallowa Dam. These concentrations are often in excess of those recommended in the ANZECC/ARMCANZ (2000) guidelines (interim indicative working level of 300 $\mu g.L^{-1}$). For example, during the period 2000 to 2001 the median concentrations of total and filterable iron immediately downstream of Tallowa dam during dry weather were 902 and 534 $\mu g.L^{-1}$ respectively while during wet weather median concentrations were 1131 and 674 $\mu g.L^{-1}$, respectively.

Monitoring data for the system also indicates that elevated concentrations of total and filterable aluminium also occur immediately downstream of Tallowa Dam. These concentrations are often in excess of those recommended in the ANZECC/ARMCANZ (2000) guidelines (moderate reliability trigger of 55 $\mu g.L^{-1}$ at pH>6.5). For example, during the period 2000 to 2001 the median concentrations of total and filterable aluminium immediately downstream of Tallowa Dam during dry weather were 184 and 71 $\mu g.L^{-1}$, respectively while during wet weather median concentrations were 557 and 125 $\mu g.L^{-1}$, respectively.

Ancillary Issues

- **Effectiveness of Tallowa Dam fish lift**

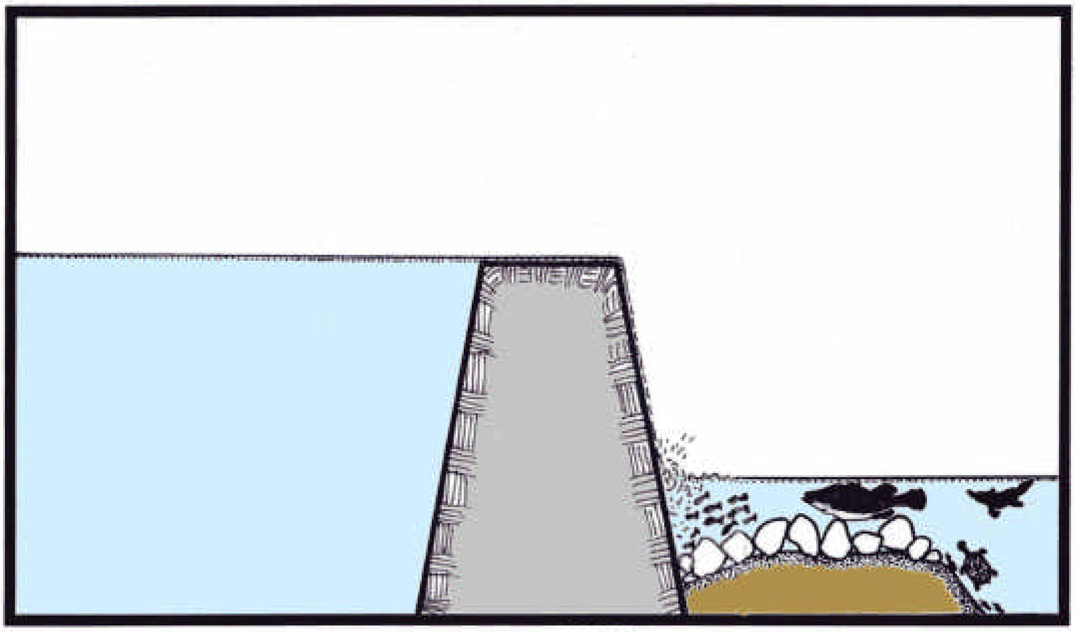
The absence of a fishway at Tallowa Dam has greatly impeded connectivity for mobile aquatic fauna.

The potential consequences of this are:

- fragmentation of fish communities and a corresponding decrease in their viability;
- major impacts on fish and invertebrate migration-mediated community dynamics;
- increased mortality of fish and invertebrates as larger predators can more effectively hunt taxa accumulating below the dam;
- increased disease-mediated mortality of fish and invertebrates because they are crowded together in large numbers below the dam;
- reduced growth potential as fish and invertebrates are crowded in resource-limited areas below the dam; and
- increased mortality of platypus and turtles as predators can more effectively hunt when these taxa skirt the dam.

It is recognised that the SCA is in the late planning stages for installing a fishway, specifically a 'fish lift', at Tallowa Dam. A multiple-level offtake tower is planned to be installed in conjunction with the fish lift. Given that fish lifts have not been installed on any Australian dams as yet, it is not 100% certain that it will be effective in providing passage for Australian native fish. Accordingly, in the context of adaptive management, monitoring is required to determine the effectiveness of the fish lift and suggest improvements if it is found to be ineffective. Fish movement data gathered at this site will be invaluable in assessing the effectiveness of environmental flows to provide fish passage over natural obstacles downstream of the Dam. An illustration of this issue is given in Plate 4.

Plate 4 - Illustration of the connectivity issue associated with dams and weirs



Passage blocked for mobile aquatic fauna because a dam or weir does not have an effective fishway

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Social and cultural values refer to people's feelings, attitudes, aspirations and judgements. Social values about the river influence the extent to which changes in river conditions are seen as positive or negative. Values also influence people's acceptance of change and willingness or ability to adapt to new conditions introduced by change. People from different stakeholder groups or local communities will have diverse social values, depending on where, when and how they relate to the river. Cultural values are a subset of social values relating to the way of life of groups of people.

  Specific social values relating to the river include a sense of place, aesthetic values and appreciation of the river. Sense of place refers to how residents feel about their local area and the river as a part of the local community's identity. Sense of place could be affected by changes in recreational amenity, weir modification, changed aesthetic values, or changes in water quality. Aesthetic values relate to the appeal of visual surroundings for recreation and lifestyle activities, as well as the sound and odour of the river. The aesthetic value of the river might be affected by algal blooms, the colour and turbidity of the water, the visibility of submerged objects during low flows, polluting discharges and stagnation in sections of the river. Appreciation of the river refers both to people's values regarding the river ecosystem in its own right and to their values about its role in social and economic activities. A relationship is likely to exist between an individual's appreciation of the river and their knowledge and views about environmental flows.

  Heritage values

  No recorded cultural heritage items currently listed within this area, although cultural heritage places are present.

Aboriginal values

Integral to understanding Aboriginal values regarding to the river is understanding that it is part of a living cultural landscape, both physical and spiritual. The river is part of an environment encompassing complementary environmental, social, cultural, spiritual and economic objectives. Any changes to the river are considered to have some cultural impact. Although many Aboriginal sites have been destroyed and land use activities in parts of the catchment have been substantial, the significance of the area in terms of Aboriginal values remains relatively high.

Aboriginal cultural heritage sites and places are part of what is traditionally referred to as a "natural landscape" and are a cultural landscape for many Aboriginal people. Relationship to the environment is important in terms of understanding Aboriginal belief systems. Aboriginal knowledge is embedded in cultural and spiritual explanations and symbols that manifest as "sites" (that may include archaeological remains), and places within the environment. Therefore, it is essential to understand that the value Aboriginal people may hold for areas within the catchment may go beyond the physical remains of activity.

Traditionally, Aboriginal people had ways of managing land and water that were not just resource based but spiritually based. Water sources were viewed with great respect and land adjacent to water is usually highly sensitive in terms of Aboriginal site potential. Archaeological remains are common near major water courses as well as floodplains and flats, alluvial terraces and slopes. The most likely types of site are artefact scatters, art sites, earth mounds, shell middens and grinding grooves. Burials and ceremonial sites are present. Rock art sites are common in areas with rock overhangs and exposure of suitable stone.

- **Institutional performance**

  Institutional Performance relates to how people view the quality of river management and broader decision-making processes. This includes the satisfaction of local communities and stakeholder groups with the performance of government institutions in managing the river as an ecosystem and natural resource. There appears to be excessive fragmentation and overlap of responsibilities between agencies, mistrust of government and frustration about the lack of a community say in government decisions. The public need opportunities to participate in, or contribute to, decision-making processes affecting the river and the catchment. There is also a need to recognise that the interests of Aboriginal people are not represented adequately and that consultation with Aboriginal groups needs to be thorough, consistent and involve all groups that have a cultural interest in the area. Aboriginal interest in the management of the river is not restricted to physical sites but encompasses social, environmental, cultural and economic issues.

- **Land and river activities**

  These are activities where people interact directly with the river or riparian zones. Monitoring these activities focuses on physical interactions between people and the river.

Irrigation extraction

Irrigated industries along the river include vegetable growing, plant nurseries, turf farming, orchards and dairy pasture. Irrigators depend upon river water throughout the year. The highest demand is during hot dry seasons, just when the river is at its lowest level. Changes to the river could affect irrigators with consequences for crop choices, crop yields and financial performance. Impacts may also arise because of the cultural significance that certain crops hold for farmers.

The volume of water and reliability for extraction by irrigators may be affected by variable dam releases. Other influencing factors include the quantity of sewage effluent discharged to the river, the availability of recycled effluent and the presence of weirs in the Upper Nepean maintaining sufficient water supply for irrigators during low flow periods. Other variables unrelated to the river affect the performance and viability of agricultural enterprises and these also need to be considered.

Irrigation extractions impact on the river environment by modifying the river hydrology, especially during low flow periods. River extractions and hydrology are examined in the hydrological monitoring component. In addition, agricultural run-off can affect water quality and silting of the river, especially during wet seasons.

Recreational fishing

Recreational fishing relies on an abundance of specific fish species. Water quality affects the abundance of fish and the capacity for fish movement and breeding. Native species, such as Australian Bass, are disadvantaged by the low degree of flow variability under the current dam release regime. Reduced navigability, owing to transient weeds or riverbed silting is of concern to recreational fishers. Environmental flow releases in combination with other river management strategies, aim to address these issues and are expected to have a beneficial impact on recreational fishing.

The aesthetic value of the river and concerns about water quality can affect the popularity of recreational fishing. This is an activity which contributes to people's sense of place and has cultural significance for local communities, as well as economic value for the fishers themselves and associated industries.

Recreational amenity

Recreational amenity of the river environment contributes to people's enjoyment and quality of life. Popular river-related recreational activities include motor boating, water skiing, recreational fishing, canoeing and swimming. Recreational amenity also includes land-based uses of the river, such as bushwalking, picnicking, four-wheel driving and enjoying the river environment from parks and paths near the riverbank. In addition, local businesses providing recreational services benefit from the popularity of the river.

Past surveys of recreational users have indicated they are concerned about water quality and aesthetic values, especially with respect to sewage effluent and blue-green algae. Primary contact recreation activities like water skiing and swimming are strongly affected by water quality and algal blooms. In addition, swimming activities are adversely impacted by high turbidity and large discharges of cold water from Warragamba Dam. Secondary contact recreation activities like motor boating and canoeing are less reliant upon water quality, since water is unlikely to be swallowed. The prevalence of transient weeds in the water may reduce the navigability of the river for motorboats. The aesthetic value of different sections of the river affects all aspects of recreational amenity, including land-based enjoyment of the river environment.

Environmental flow releases are expected to improve water quality, reduce the incidence of algal blooms and decrease the quantity of transient weeds. Such changes are likely to have beneficial social impacts for recreational users. The new flow release regime is also expected to improve the problem of large discharges of cold water from Warragamba dam, which is likely to benefit swimmers.

There are a number of ways in which recreational users affect the river. Boat wash from motor boating and water skiing can accelerate bank erosion. High levels of boating activity can release chemical pollutants and some untreated sewage discharges. Off-road vehicles can erode fire trails and lead to increased turbidity and bank erosion. Some riparian and tidal foreshores have been cleared or excavated to create beaches and recreation areas. Litter is a problem associated with recreational activities.

River-related tourism

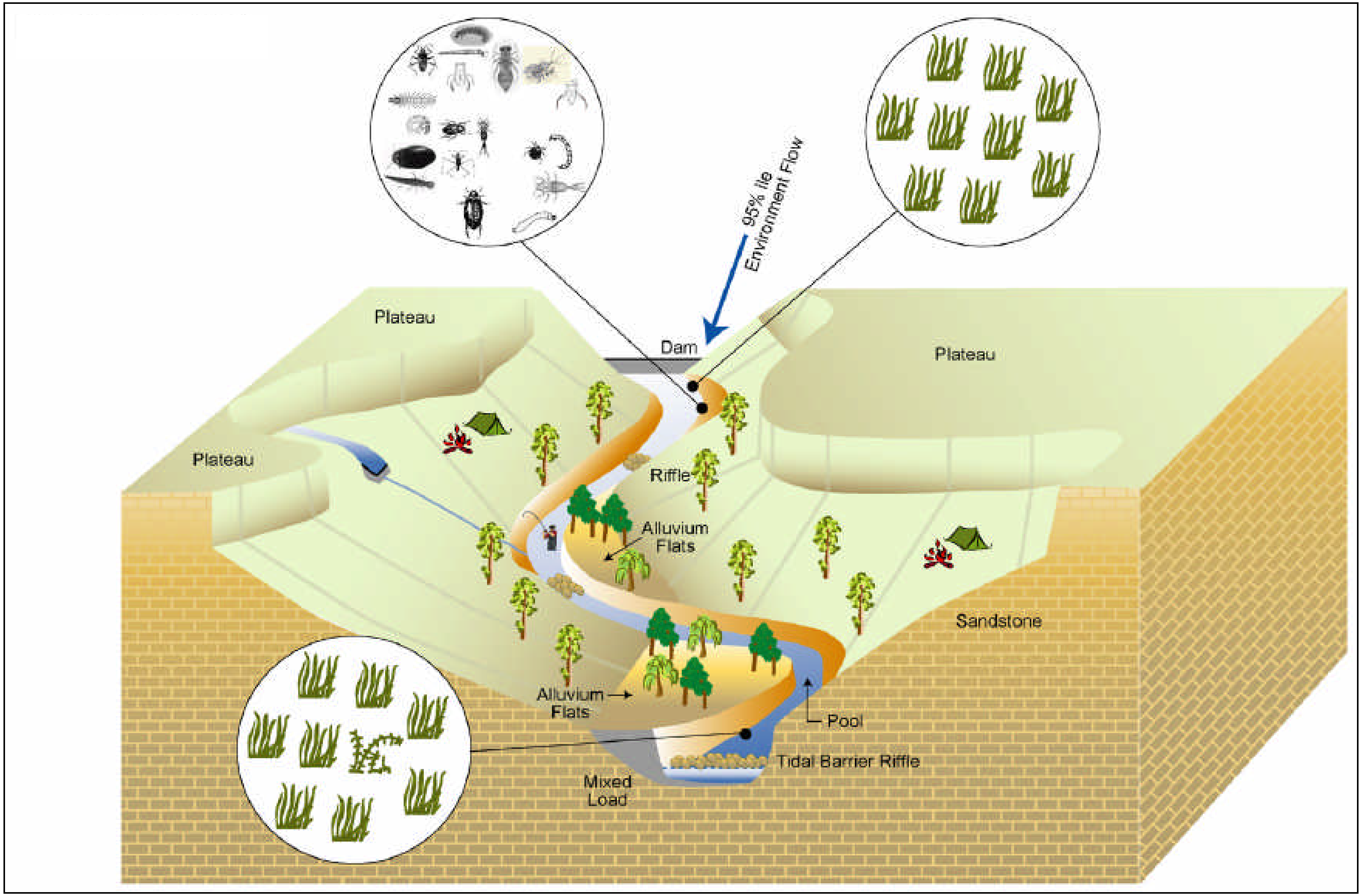
Tourism is popular in the Hawkesbury–Nepean and Shoalhaven catchments and contributes significantly to regional economies. The recreational amenity and aesthetic values of the river are likely to have some effect on the number of tourists who visit the region to enjoy the river. There is some evidence that widespread publicity about pollution levels in the Hawkesbury–Nepean which has created an unfavourable image of river holidays in the region. Environmental flow releases and other river management strategies are expected to improve the river's aesthetic value and recreational amenity and hence its tourism profile, as a natural landmark worth visiting. Increased tourist visits and use of the river's recreational amenity, in turn has the potential to degrade the river environment if not carefully managed.

Land use and land management

Land use and management affects riparian vegetation and river conditions such as water quality. These changes in turn can affect fishery resources, recreational amenity and aesthetic values. Land uses and zoning decisions can either reduce or enhance the beneficial impacts of environmental flows and should be monitored on a regular basis. This will assist in anticipating potential SECH impacts for future monitoring and tracking changing patterns of anthropogenic impacts.

This issue is primarily related to the zoning and use of public lands and the zoning of private lands. Public land use includes urban development, coal mining and sand and gravel extraction. The nature of private land use is relevant and is covered under the issues of river water extraction, riparian extraction and stormwater management. The potential for increased stormwater runoff due to urban growth is a threat to environmental flows addressed within the specific monitoring strand. Coal mining releases polluted discharges to the river and can cause riverbed subsidence. Sand and gravel extraction from the river has significant impacts on river conditions.

Figure B9: Reach 1 - Current Regime Shoalhaven River, Tallowa Dam to Burrier



Recommended Environmental Flow Regime; Reach 1

In the future there may be greater extractions to Hawkesbury-Nepean storages (up to 130 GL/yr compared to 14 GL/yr), but new operating rules will require that extractions target the medium and high flow periods, rather than the low flow periods, which are predicted to reduce present environmental stresses. Tallowa Dam will continue to spill most of the time, but increased extractions will prolong the periods where spills do not occur and river flows will need to be maintained via releases from the dam. Spills during low flow periods will also be diminished. There will need to be a fish way at the dam to allow for fish migrations and a multilevel offtake to ensure suitable temperatures for released flows.

If extractions increase to 130 GL/yr, this will represent approximate 17% of the long-term mean (LTM), however river health will be maintained provided suitable environmental flow and extraction rules are applied.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Cold water releases from dam**

  With the introduction of the recommended environmental flows in the Shoalhaven River, water quality downstream of Tallowa Dam will improve. Water temperatures will be near natural.

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regime will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Critical habitat contraction**

  The recommended environmental flow regime will increase the availability of critical habitat associated with higher water velocities and thus increase: i) habitat area and diversity, ii) the diversity of invertebrate and fish fauna, iii) the abundance/biomass of invertebrates which use higher-water velocity areas, iv) growth and abundance of fish and platypus which forage within or immediately downstream of riffles, and v) increase spawning/breeding success of riffle-dependent fish species.

- **General water quality downstream of dam**

  Water quality downstream of Tallowa Dam will improve.

- **Altered biotic communities**

  Improvements in biodiversity and the structure of aquatic communities are expected.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Stratification of natural pools**

  Overall, thermal stratification of natural pools will occur less frequently and will be of shorter duration and thereby more closely mimic natural conditions.

- **Elevated iron and aluminium concentrations in discharge waters**

  Water quality downstream of Tallowa Dam will improve. Iron and aluminium concentrations will be reduced leading to a decrease in the occurrence of iron precipitate immediately downstream of the dam and any toxicity associated with previously elevated aluminium concentrations.

Summary of Key Changes to Ancillary Issues

- **Tallowa Dam fish lift**

  The construction of a fish lift at Tallowa Dam will increase connectivity and thus reduce fragmentation and mortality of fish and invertebrate communities, reduce impacts on fish and invertebrate migration-mediated community dynamics and reduce mortality of platypus and turtles which no longer need to skirt the dam.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  In addition to the discussion under ‘Current Regime’, improvements in water quality and other ecological benefits produced as a result of an environmental flow regime are expected to produce positive feelings of a sense of place, aesthetic values and appreciation of the river.

- **Institutional performance**

  In addition to the discussion under ‘Current Regime’, broad public support is required for the successful implementation of river management strategies in relation to environmental flows. New institutional arrangements for providing and protecting environmental flows are expected to improve inter-agency coordination and community involvement. These arrangements include the integrated monitoring program. The level of participation by the community in the program itself should be monitored, including the appropriateness of Aboriginal representation.

- **Land and river activities**

  Environmental flow releases from dams

  River stakeholders and local communities have come to rely on the services or amenities provided by the existing river environment, which has been shaped by human interventions such as dams and weirs. People may, however, also place value on the integrity of the river ecosystem as it was before this kind of intervention. These values about the river in its contemporary and ‘natural’ states may conflict.

  Environmental flows include both transparency/translucency release rules and provision for contingency flows. Environmental flow releases are expected to generate changes to the hydrology and ecology of the river. These changes are expected to improve river conditions and generally have beneficial impacts for river stakeholders. Stakeholders who depend upon good water quality and the abundance of fishery resources may benefit the most. The aesthetic values associated with the river are also expected to improve, with fewer algal blooms and weed infestations.

  Environmental flow releases from dams could also have specific adverse social and economic impacts. The timing of dam releases, for example, could affect prawn trawlers’ access to prawn stocks and reduce catch sizes.

  Demand management – river extractors

  Major river extractors include irrigators, industrial extractors and riparian landholders. A high level of water extraction downstream can significantly reduce the improvements intended by release of environmental flows at water storages. Environmental flows may be protected by demand management, that is metering and improving the efficiency of water use by river extractors. It has been argued that the low price of river water provides little incentive for increased water efficiency.

The adverse impacts associated with demand management for river extractors are primarily related to capital and ongoing costs. Subsidies are currently used in NSW Agriculture's WaterWise program. The issue of incentives and subsidies need to be monitored to address concerns about potential upfront and ongoing maintenance costs. Demand management subsidies or obligations may also apply unevenly, in which case inequity may arise or be seen to arise, between different river extractors and between river extractors and urban water consumers. Demand management for irrigators will also change farming practices and crop choices. Adverse impacts may arise when water is used on higher value crops or those that require less water, as well as changed crop patterns (type, yield, quantity, quality). Demand management for industrial users may also affect operations adversely.

Demand management is a form of best practice farming and may hold a number of benefits for river extractors, such as improved crop yields in certain situations, reduced loss of soil nutrients due to runoff and improved effectiveness of fertiliser application.

Modifications to the access conditions for river extractors

Changes to access conditions for river extractors are expected to contribute to longer-term environmental improvements associated with environmental flows. Major river extractors include irrigators, industrial extractors and riparian landholders. Placing restrictions on river extractions during low flow periods is expected to protect environmental flows. Enforcement of these restrictions would entail that all commercial river extractors be licensed and metered. In the case of riparian landholders, enforcement may not be possible under the present regulatory regime.

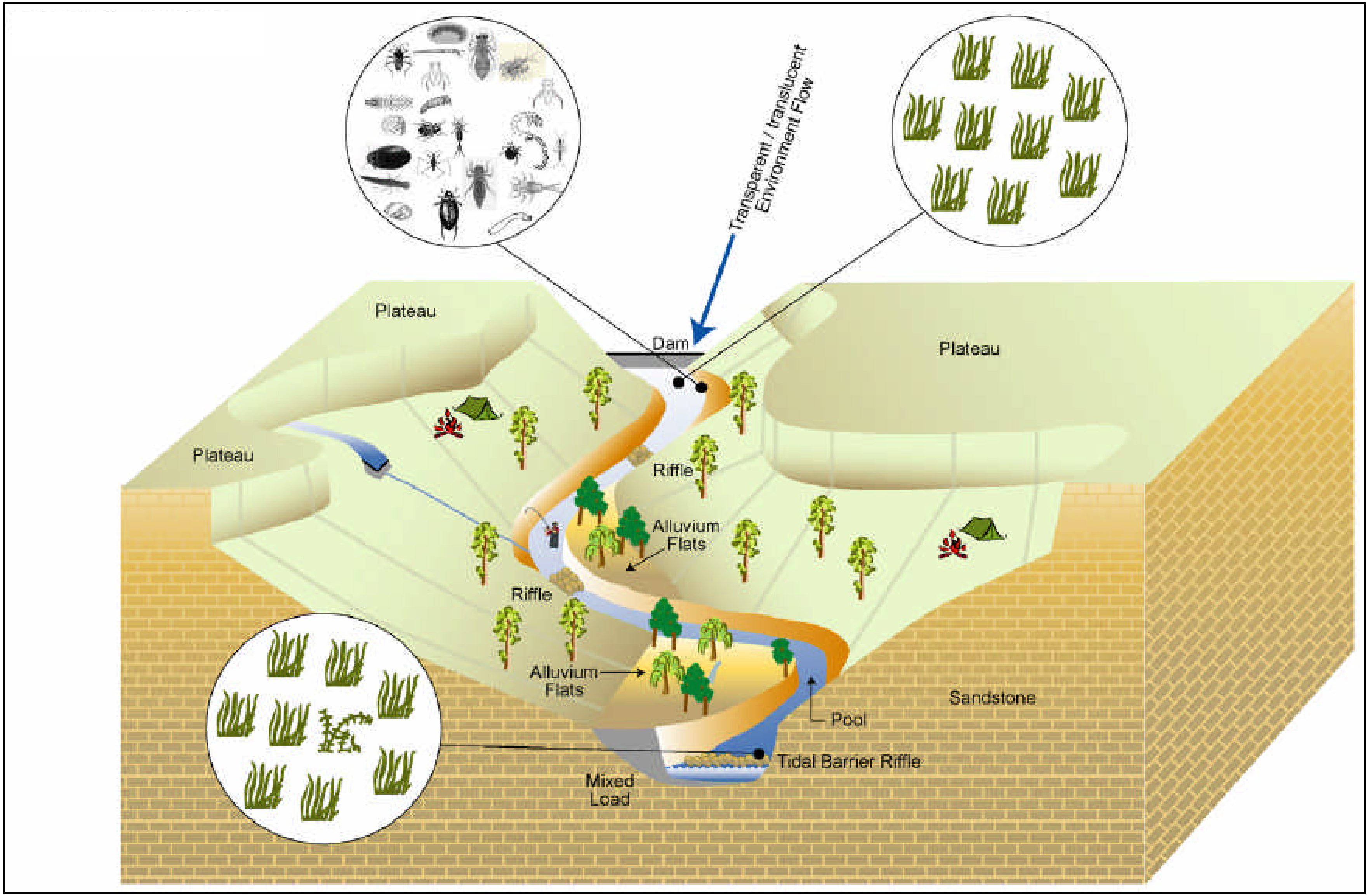
There are number of potential adverse impacts associated with changes to access conditions for river extractors. Such changes may raise the prices of alternative water supplies. The number and volume of farm dams may increase to maintain security of supply, impacting on the land available for agriculture. Irrigators unable to pay for alternative supplies of water could face reduced crops and even crop failure during dry seasons. A substantial proportion of irrigators are currently un-licensed. Licensing and metering could place an additional administrative burden on farming businesses, which may be a barrier to entering or continuing business. Industrial extractors may also require a certain level of reliability for their operations to function, incurring a higher price for water in order to secure supply.

Catchment transfers

At present transfers of water from Tallowa Dam occur in dry conditions when Sydney's water storages are below the 60 per cent pump mark and can occur at a time when the Shoalhaven region is undergoing water restrictions while Sydney is not. This leads to concerns about the equitable distribution of available water.

The Forum's recommended changes to transfer rules for pumping water from the Shoalhaven system will result in transfers of water occurring only under high flow conditions in the Shoalhaven River This, together with other recommendations for filtration of transferred water, will produce a range of benefits including improvement in equitable distribution of available water between the Sydney and Shoalhaven regions, reduction of adverse environmental impacts downstream of Tallowa Dam and minimize the movement of exotic species, diseases and other contaminants from one catchment to another.

Figure B10: Reach 1 – Recommended Environmental Flow Regime Shoalhaven River, Tallowa Dam to Burrier



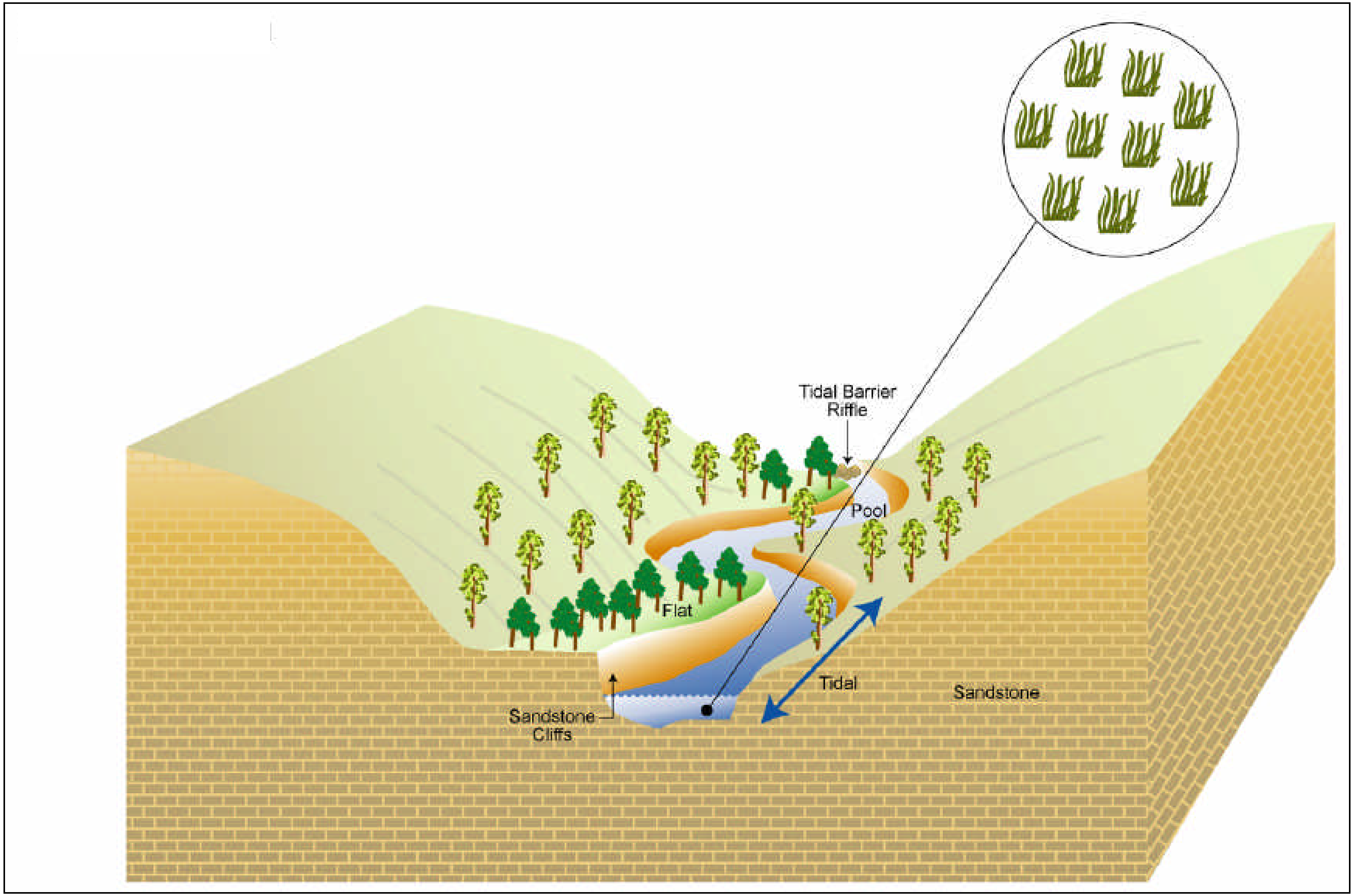
Reach 2.1: Shoalhaven River, Burrier to Nowra

Natural Regime; Reach 2.1

All of this incised meandering reach is a tidal river. The valley is wider than the upstream reach and perhaps more sinuous in plan. Lower parts have incised into Nowra Sandstone benches and alluvial deposition on these marks the sites of former floodplains (terraces) and present floodplains. These would have been forested under natural conditions. This gives a gorge within a gorge effect, which certainly protects alluvia from bank erosion and much channel lateral migration. Even though the bedload is still mixed (sand and gravels), sand becomes more dominant in the channel bed in the lower energy tidal trough, where even river flow velocities are reduced. The post-Pleistocene transgression has drowned the in-channel forms and tidal processes mainly rework these deposits.

Due to the wider river channel the aquatic ecosystem would gain more energy from algal/macrophyte photosynthesis than the terrestrial organic inputs.

Figure B11: Reach 2.1 - Natural Regime Shoalhaven River, Burrier to Nowra (Princes Highway Bridge)



Current Regime and High Priority Issues; Reach 2.1

This 19 km reach has not changed much visually. There is somewhat more clearing in this lower reach than upstream, with isolated farms, fields and roads. There are also sand and gravel extraction areas in two of the upstream meander cores. These seem to be in ponds isolated from the main channel. If they were joined, turbidity would affect the adjacent channel for several kilometres. As photosynthesis is the dominant pathways for energy inputs in this river section, increased turbidity may negatively affect algal/macrophyte populations with flow on effects in the food web. The natural small influence of any terrestrial energy and organic inputs will have been further reduced by the presence of Tallowa Dam.

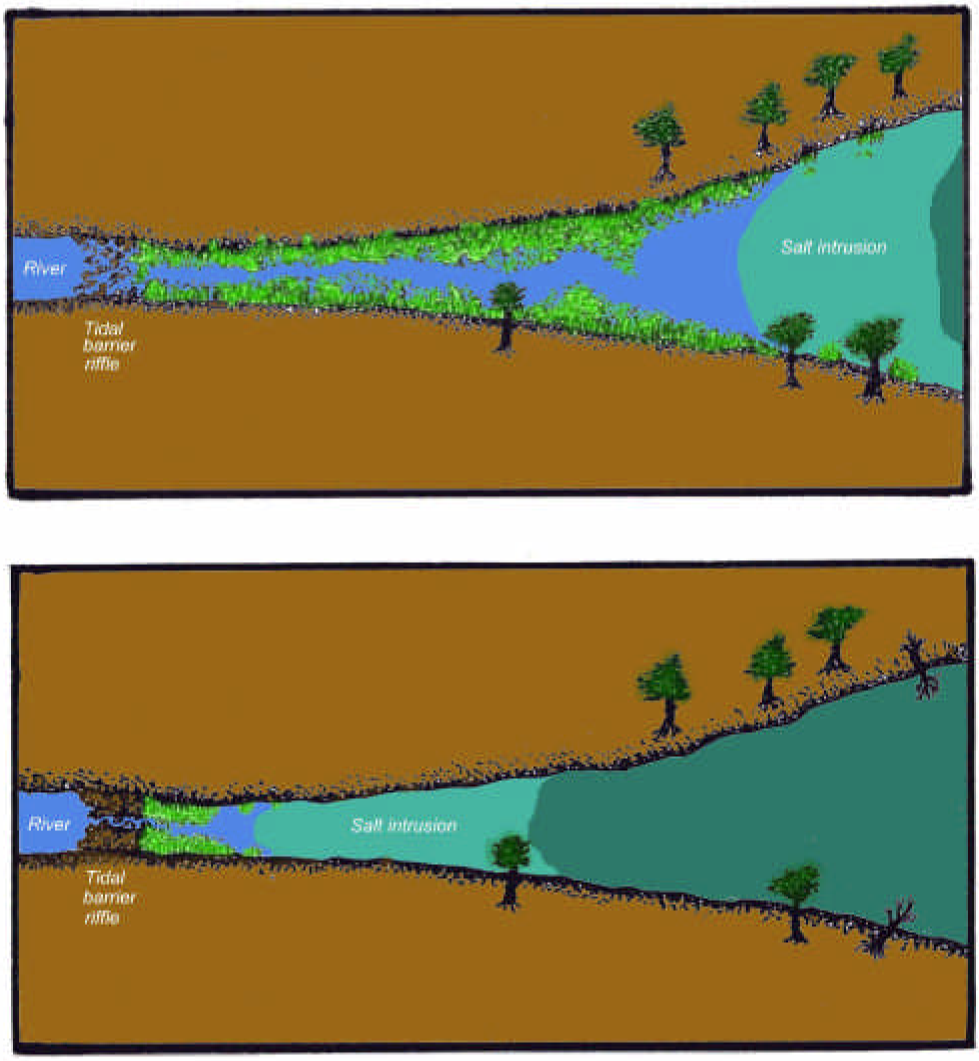
Flows in this reach are affected by extractions for Nowra's water supply at Burrier, which occur on a continuous basis. Flows are also affected by irregular extractions to augment water supply to Sydney, the Blue Mountains and Illawarra areas. Extractions account for a small percentage of totals flows, but become significant during extended dry periods.

The effects of the inter-catchment transfers coinciding with natural low flows will have affected the microhabitats within the tidal-barrier riffle and therefore affected aquatic biota during those times. Also, during these times connectivity between the tidal river and upstream river will be reduced, decreasing changes of fish movement.

The combined effect of the channel cut to the Crookhaven River (see Reach 2.2) and diminished flows creates a situation where saline waters encroach further upstream than under natural conditions. This affects the distribution of animals and plants and potentially alters riparian vegetation. Upstream encroachment of saline waters from the estuary may also kill freshwater aquatic macrophytes which are important nursery habitats for many fish species (see Plate 5). Although the encroachment of saline waters may only be infrequently exacerbated by inter-catchment transfers, or unrestrained water extraction above the tidal limit, the killing of aquatic macrophytes will have long-term flow-on effects. At present this issue is not considered a high priority, although this status is marginal. Given this marginal status, details of investigations needed to address this issue are given in Appendix C1 in Part C of this report.

Plate 5 - Illustration of the Salinity-Driven Contraction of Fish-Nursery Habitat in the Upper Shoalhaven Estuary

Natural condition: river inflows infrequently and briefly low so freshwater-associated beds of aquatic vegetation are infrequently impacted by salt intrusion



Regulated condition: river inflows frequently low for long periods so freshwater-associated beds of aquatic vegetation are frequently lost because of salt-intrusion impacts; riparian vegetation also impacted by salt – bank erosion then activated.

Fundamental Hydrological Issues

None applicable for this reach.

Ecological and Physical Issues

- **Reduced connectivity – natural barriers (tidal-barrier riffle)**

  Reduced flows over riffles or riffle-like habitats, have decreased connectivity for mobile aquatic fauna along river reaches, and at the interface between river and estuarine reaches.

Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Reduced recreational and commercial fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass. There is also a positive relationship between river discharges and commercial catches of prawns and fish species (see Growns and Gray 2003). River regulation is likely to have reduced estuarine productivity due to decreased inflows to estuaries.

Ancillary Issues

None applicable for this reach.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  Two sites listed on the State Heritage Inventory are within this river reach. Please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Industrial extraction

  Industrial water extractors, like irrigators, depend upon a reliable supply of water at all times. Industrial operations extracting water from the river may be affected by changes to river hydrology and water quality. Reduction in base river flows during dry seasons could adversely impact the reliability of their supply, unless alternative supplies are available at an equivalent price. Changes to water quality will also impact some operations.

  Industrial extraction of water affects river conditions. A proportion of the water extracted is sometimes returned to the river, often with degraded quality. Industrial operations also discharge pollutants into the river. The monitoring of river extractions and their hydrological effects are examined in the hydrological monitoring component.

  Riparian extraction

  Riparian landholders extract water for non-potable domestic use: stock watering, gardening or hobby farming. The quantity and distribution of extractions is currently unknown. Landholders may also have an attachment to the river as an immediate feature of their domestic environment, contributing to sense of place, visual appeal and lifestyle. It is expected that riparian landholders will have an interest in the effects of environmental flows.

Key factors include the availability of water for pumping, the quality of the water, the presence of algal blooms and the aesthetic and recreational values of the river. These stakeholders have basic landholder rights and will be concerned about any change to the licence exemption they currently enjoy.

Commercial fishery activities

Commercial fishery operators rely upon the abundance of fishery resources within the river. The estuarine reaches of the river are utilised for commercial fishery activities, primarily fishing, prawn trawling and oyster farming. Fish, oysters and prawns are highly sensitive to changed water quality in the estuarine reaches. Changes to the estuary also affect commercial ocean fish landings, as the estuary provides a source of food for ocean fish. 70 per cent of marine species are estuary dependent at some stage of their lifecycle.

Concern about pollution levels and algal blooms can reduce consumer confidence in fishery products. Transient weeds or riverbed silt can also reduce the navigability of the river for commercial fishers. It is expected that environmental flow releases will have long-term beneficial effects on water quality in the estuarine reaches.

Freshwater reaches are also important for the movement and breeding of fish. Factors influencing these reaches include the effectiveness of weir fishways and inadequate flows over riffle zones.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

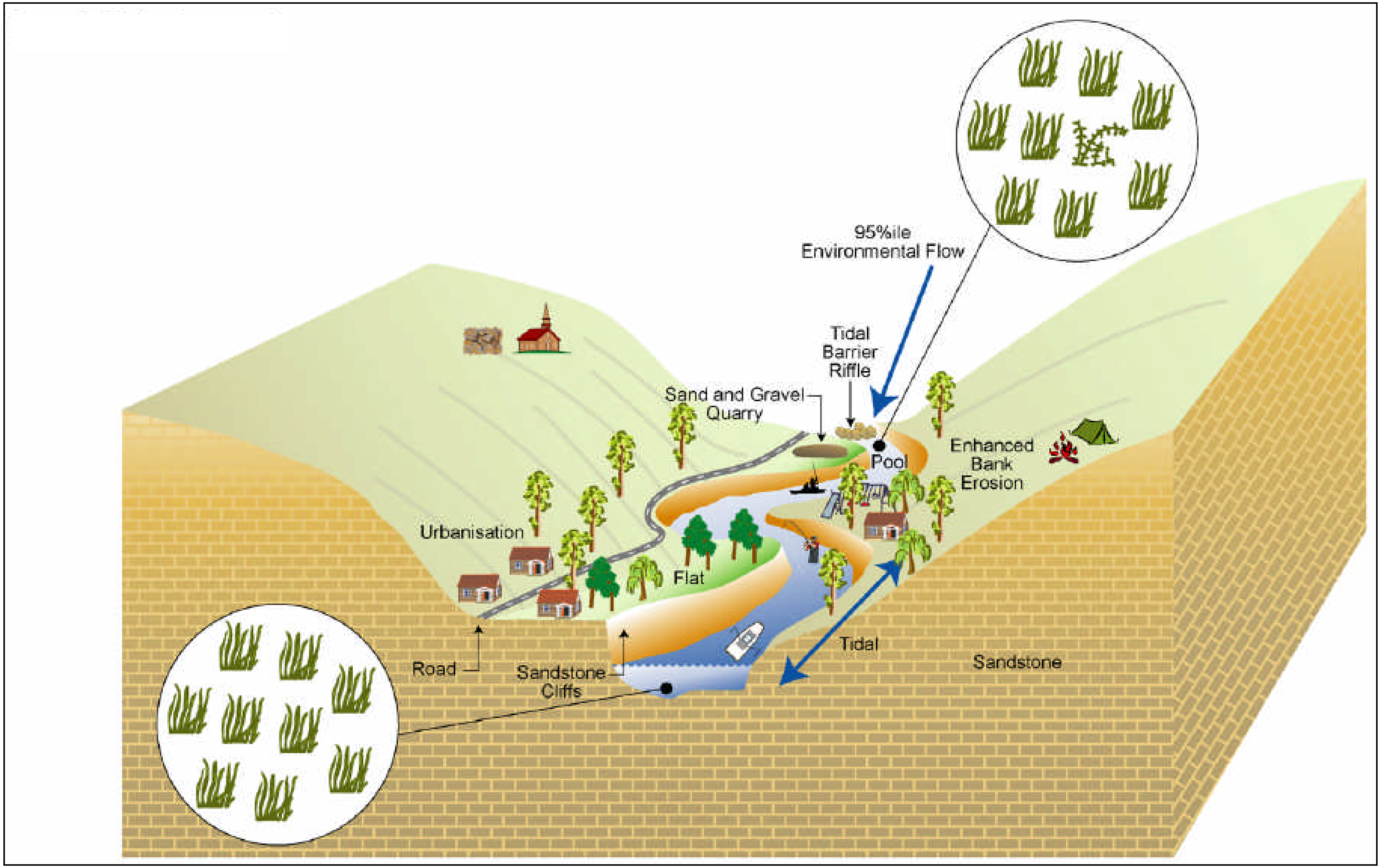
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B12: Reach 2.1 - Current Regime Shoalhaven River, Burrier to Nowra (Princes Highway Bridge)



Recommended Environmental Flow Regime; Reach 2.1

The most significant changes to flows in this reach in the future are likely to be changes to the environmental release and extraction rules at Tallowa. In the future there may be greater diversions of water to storages in the Hawkesbury-Nepean system (up to 130 GL/yr compared to 14 GL/yr), but new operating rules will require that diversions target the medium and high flow periods, rather than the low flow periods, which should reduced present environmental stresses. Tallowa Dam will continue to spill most of the time, but increased extractions will prolong the periods where spills do not occur and river flows will need to be via releases.

Again the future depends to some extent on the management of Tallowa Dam because the possible 130 GL/yr diversion to Hawkesbury-Nepean storages represents perhaps 10% of the LTM. The LTM for Welcome Reef is 540 GL/yr and at Tallowa it is about 1400 GL/yr or 2.6 times more. If the same proportions prevailed for 1991 to 2002, the mean yield at Tallowa would be down to 700 GL/yr (largely a regime shift with global warming to be added). Then the proposed 130 GL/yr would represent 19% of inflow.

The environmental flow from through this river section will not alter the sources of energy and organic matter. Altering the timing of the inter-catchment transfers, in conjunction with the protection of flows through translucency and transparency rules will decrease the chances salt incursion and maintain aquatic habitats.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regime will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Reduced recreational and commercial fish catches**

  Improved recreational catches of Australian Bass can be expected. Increased estuarine productivity can be expected, leading to sustainable commercial catches of fish species and prawns.

Summary of Key Changes to Ancillary Issues

None applicable for this reach.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

Further details of this issue are given in the discussion for Reach 1.

Demand management - river extractors

Further details of this issue are given in the discussion for Reach 1.

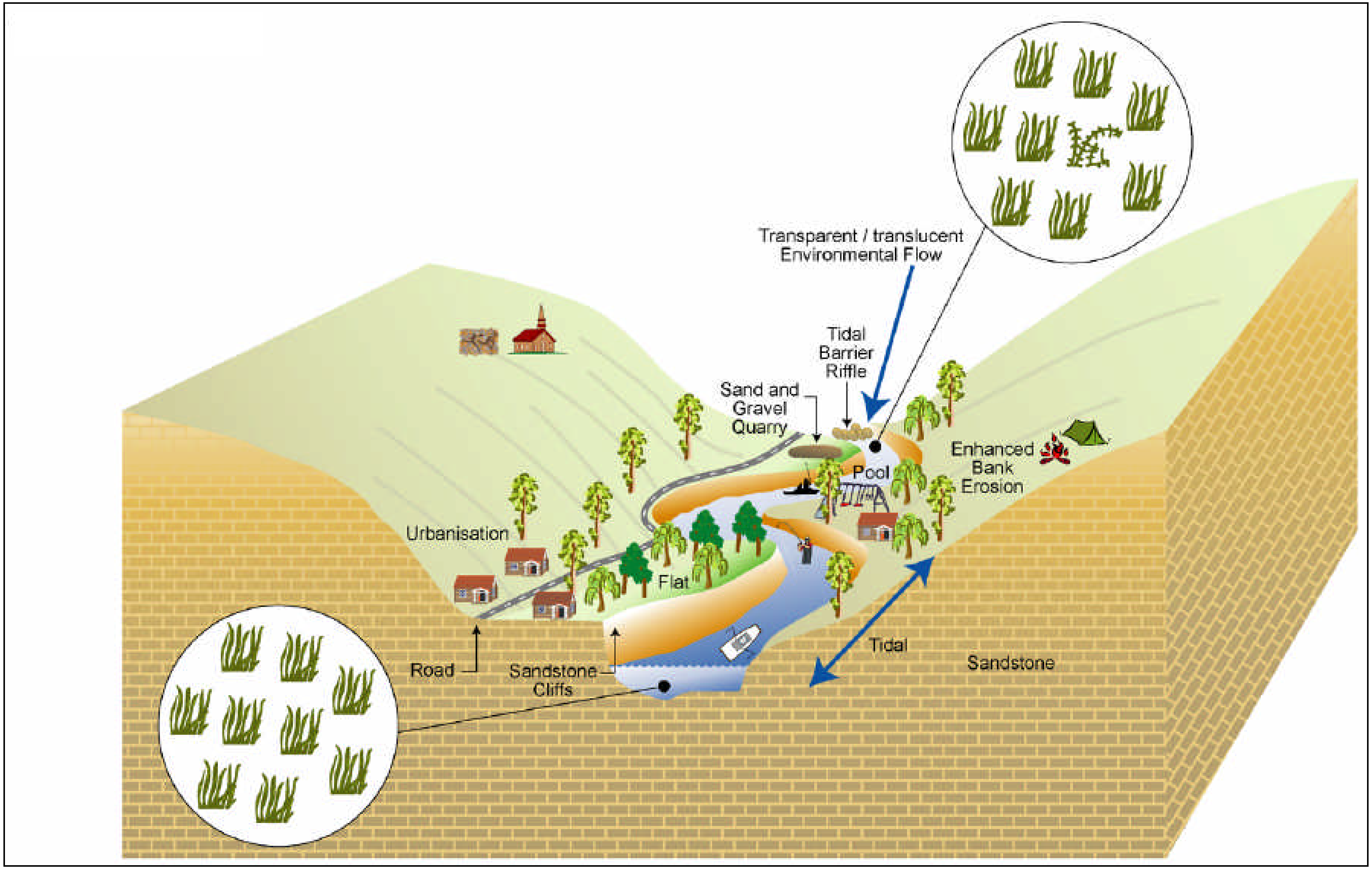
Modifications to the access conditions for river extractors

Further details of this issue are given in the discussion for Reach 1.

Catchment transfers

Further details of this issue are given in the discussion for Reach 1.

Figure B13: Reach 2.1 – Recommended Environmental Flow Regime Shoalhaven River, Burrier to Nowra (Princes Highway Bridge)



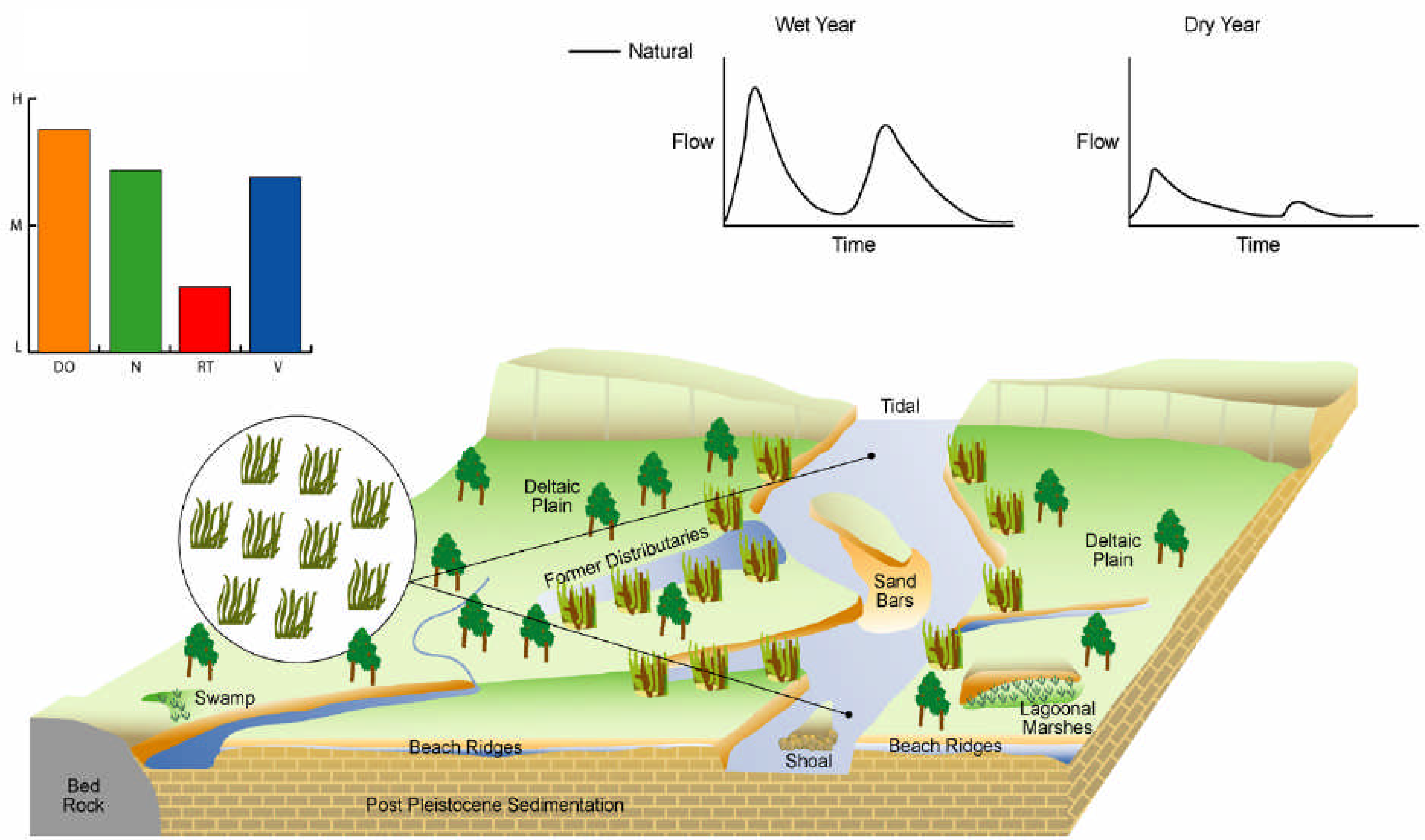
Reach 2.2: Shoalhaven River, Nowra to Pacific Ocean

Natural Regime; Reach 2.2

This reach is 15.5 km long from the Princes Highway bridge at Nowra to Shoalhaven Heads. In natural times before the construction of the Crookhaven Cut (which connects the Shoalhaven and Crookhaven Rivers), the Shoalhaven River channel would only have been tidal after freshes and floods, which would have opened the entrance at Shoalhaven Heads. In quieter flow periods, long-shore sand drift tended to block the entrance from tidal flow and there would have been relatively small freshwater flows and the channel would have been tideless and stagnant. Such a channel with a long flat gradient would induce backwater sedimentation almost from Burrier downstream. During entrance closure periods there would have been no tidal flushing in this broad estuarine reach. The low flat delta, which has formed since sea level returned to its present level some 6,000 years ago, would have been densely forested away from widespread distributary channels and wetlands (back- or flood-basin swamps and lower tributary swamps), as well as lagoons. In-channel sedimentation is apparent from the numerous estuary islands, lee shoals and sand flats. It would have been a stagnant estuary in dry times, with evaporation increasing salinity levels, and river dominant after floods, when the tides returned for restricted periods. The potential biological consequences of a stagnant estuary on aquatic biota include:

- Reduced natural nutrient input causing lower productivity.
- Reduced quality and quantity of organic matter input.
- Zooplankton and phytoplankton decrease in low flow.
- Phytoplankton blooms increase.
- Distribution of vegetation zones.
- Death of freshwater submerged macrophytes.
- Seagrass change.
- Susceptible riparian changes.
- Increase infilling - sedimentation and change of habitats.
- Decreased potential for distribution of suspended eggs and larvae.
- Changes in distribution and abundance of biota.

Figure B14: Reach 2.2 - Natural Regime Shoalhaven River, Nowra to Pacific Ocean



Current Regime and High Priority Issues; Reach 2.2

The delta has been cleared, drained in many places and settled for farming. Following the artificial cut joining the estuary to the permanent entrance at the sheltered Crookhaven Heads, continuous tidal conditions dominate the channel. Flood mitigation measures undertaken mainly in the 1960s have considerably reduced the area of wetlands. These involved levee repair and floodgates on tributaries restricting flooding from the river until levees are topped (at lower frequencies than back-up floods through tributaries). After lower frequency flooding, drainage evacuates excess water through floodgates, which opened at low tides. The estuary is now tide dominated and only the largest floods can connect with wetlands temporarily. Urban areas are found on the higher margins of the delta and at the heads. These produce limited discharges from STPs and stormwater runoff, which add to the local pollution signature.

Fundamental Hydrological Issues

None applicable for this reach.

Ecological and Physical Issues

- **Reduced commercial fish catches**

  There is a positive relationship between river discharges and commercial catches of prawns and fish species (see Growns and Gray 2003). River regulation is likely to have reduced estuarine productivity due to decreased inflows to estuaries.

Ancillary Issues

None applicable for this reach.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  One site listed on the State Heritage Inventory is within this river reach. Please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Industrial extraction

  Further details of this issue are given in the discussion for Reach 2.1.

Riparian extraction

Further details of this issue are given in the discussion for Reach 2.1.

Commercial fishery activities

Further details of this issue are given in the discussion for Reach 2.1.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

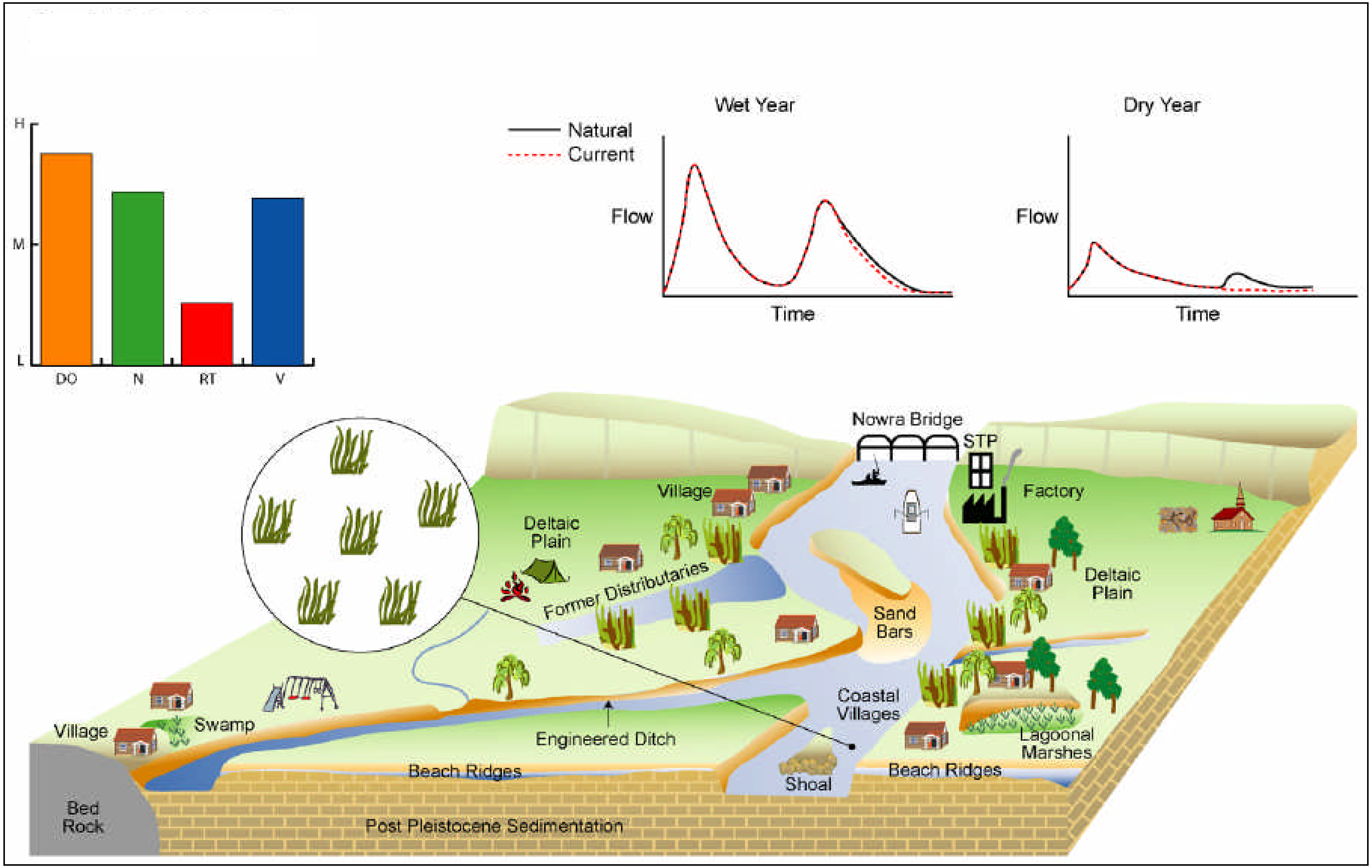
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B15: Reach 2.2 - Current Regime Shoalhaven River, Nowra to Pacific Ocean



Recommended Environmental Flow Regime; Reach 2.2

Proposed environmental flows will have little impact on the broad estuary. Continued urban growth will add to STP discharges and storm water runoff, if they are not managed effectively.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced commercial fish catches**

  Increased estuarine productivity can be expected, leading to sustainable commercial catches of fish species and prawns.

Summary of Key Changes to Ancillary Issues

None applicable for this reach.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

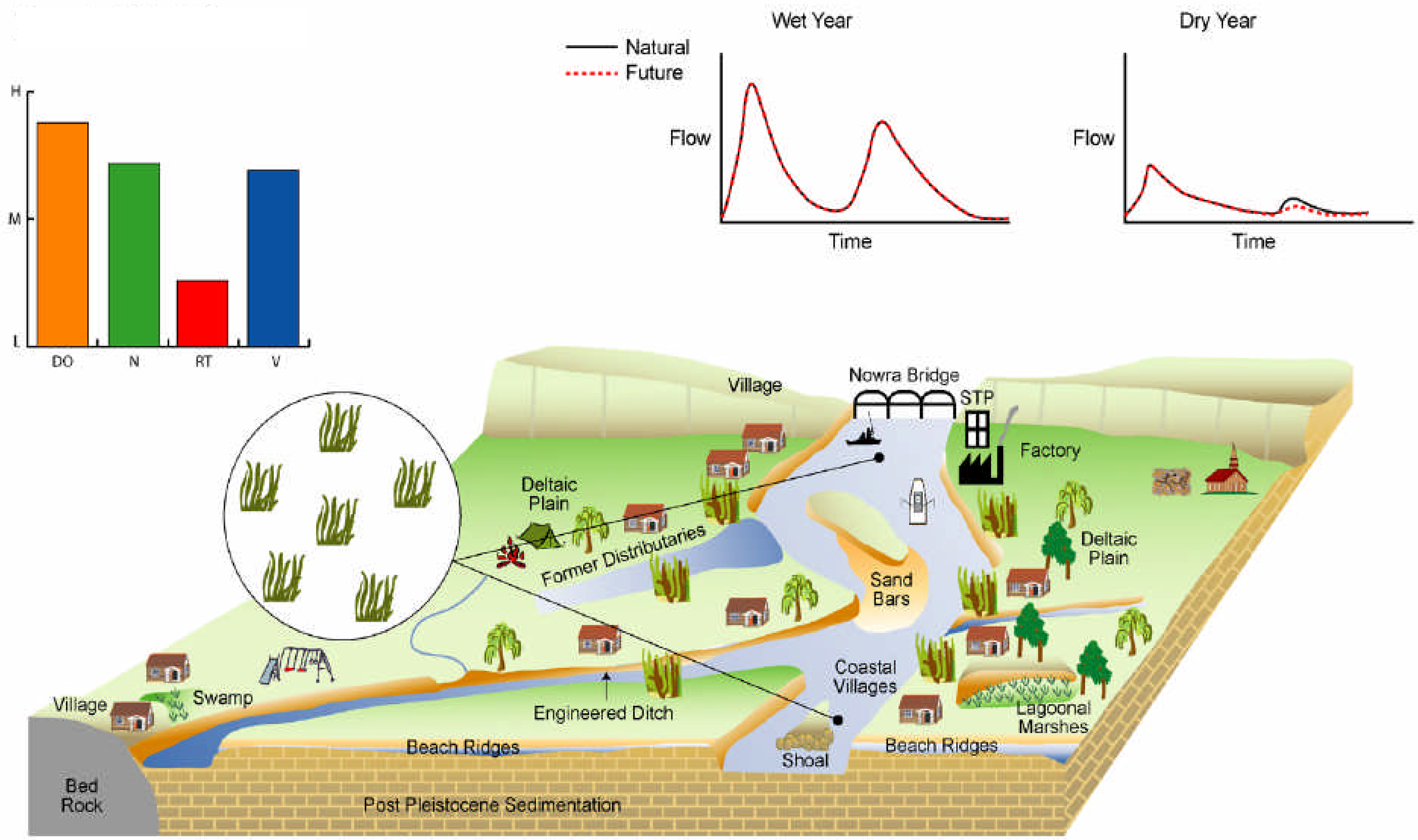
  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Catchment transfers

  Further details of this issue are given in the discussion for Reach 1.

Figure B16: Reach 2.2 – Recommended Environmental Flow Regime Shoalhaven River, Nowra to Pacific Ocean



Reach 3: Woronora River, Woronora Dam to Heathcote Creek Junction

Note: Conceptual model diagrams have not been developed for the Woronora River reaches.

Natural Regime; Reach 3

Under natural conditions this 11.4 km reach (mean gradient 0.0088) would have been similar to that of today, apart from the dam at the upper end. There may have been more sand and other river deposits in the wider, more sinuous upper 7 km. The sandstone gorge is wider and more open than the Upper Nepean gorges, partly, it is presumed, because it is much lower on the north sloping plateau or Illawarra Ramp. This reach falls from 120 to 20 m, where it is only 13.6 km from the Georges River and sea level. The upper sinuous valley-floor trough is 50 to 150 m wide, while the lower 4.4 km is much narrower (less than 50 m) and straighter. The extra width allows the accumulation of both alluvial (river) and colluvial (slope) deposits, with the latter dominating, according to Patterson and Britton (2002). Non-attenuated flows would have been much higher and more frequent, allowing freer movement of fish and scour renewals of riffle-like habitats, which are common. The natural flows would have allowed for large spatial and temporal variation in instream habitats, supporting a large diversity of invertebrate taxa. There are many large natural fish barriers due to the steep gradient and stepped nature of the reach.

The energy inputs in this river section would have been primarily derived from terrestrial leaf litter inputs from the headwater sections. The more open nature of the channel means that there might have been a greater role of algal, macrophyte and biofilm energy production compared with the narrower upper-Nepean gorges.

Current Regime and High Priority Issues; Reach 3

With the addition of the dam, withholding water and sediments from the upper 75 km^2 of the catchment, flows have been greatly reduced and supplies of coarse sediments shut down. Now some of the formerly active alluvial sediments have been left stranded above the present smaller active channel. Sediment-deficient spills have probably reworked some of these deposits from time to time. These would include: the so-called cobble terrace, sand traces on rock benches and "river levees". Lower colluvial or slope deposits would have been reworked at such times also. Pools are not prevalent but rock steps in the channel are thought to be an impediment to fish movement, particularly in the lower flows of the present. Flow velocities were determined at 8 sections for flows of 50, 200 and 800 ML/d. In the reach they varied from 0.04 to 0.83 m/s for 50 ML/d, 0.13 to 0.85 m/s for 200 ML/d and 0.39 to 1.22 m/s for 800 ML/d, with the highest velocities for small rock-bound channels. However, it is not clear if the presence of the dam has increased the amount of time that the natural barriers are impassable by different fish species.

The reduction in the low-flows and average velocities caused by the dam would have greatly dampened spatial and temporal variability in instream habitat types. This in combination of the capture of sediment sources will have also reduced the substrate variability in this reach. These factors in combination will have reduced biodiversity.

Like most reaches downstream of dams the energy inputs from terrestrial sources will have been reduced from natural conditions through reduction in organic matter drift from headwater areas and increased inputs of algal photosynthesis from the dam waters.

The introduction of the environmental flow in late 2002 may have ameliorated some of these ecological processes. However, the relative roles of terrestrial versus instream energy production will not greatly alter.

Fundamental Hydrological Issues

- **Monitoring the sandstone reaches downstream of dams**

  The absence of discharge data and knowledge of hydraulic behaviour of flows over bedrock steps, through inter-pool constrictions and over riffle-like forms in these ecologically sensitive gorges is a major obstacle to ecological monitoring. At present the dams (even with limited environmental flows) acting in much the same way as drought-dominated regimes (DDRs), have reduced available water to the channels giving much lower flows, longer periods (away from bulk transfers) of no flows and only limited spills. The major problems are to ensure that "correct" environmental flows are released, that these reach lower parts of the gorges and that they satisfy requirements for sustaining and enhancing local ecosystems. These cannot be solved without knowledge of flows and their ecological impacts throughout the reaches. This information at present is far from perfect. Hence a detailed flow-monitoring program is warranted (fundamental hydrological monitoring) and this must be supplemented by additional knowledge of flow impacts at ecologically sensitive locations. These reaches are high in ecological value and problems centre on:

  a. channel constrictions, which act as riffle-like forms and are therefore important for habitat, fish passage and invertebrates;
  b. floc and other material accumulations in constrictions, which reduce habitat quality;
  c. low or no flows, which preclude fish passage; and
  d. bio-accumulations in natural pools, which remain unscoured for most of the time.

- **Monitoring dam inflows**

  Knowledge of dam inflows underpins the environmental flow program, as knowledge of these flows is required to:

  - calculate the appropriate daily environmental flow releases at any given time; and,
  - assist in the understanding of the links between flow and river health.

Further details of this issue are given in the discussion for Reach 1.

Ecological and Physical Issues

- **Reduced connectivity – natural barriers**

  Reduced flows over riffle-like habitats, have decreased connectivity for mobile aquatic fauna along the river reach.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Critical habitat contraction**

  Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities (for example riffles or riffle-like habitats).

  The potential consequences of such habitat contraction are: i) reduced habitat area and diversity, ii) reduced diversity of invertebrates and fish, iii) reduced abundance of invertebrates which use higher-water velocity areas, iv) diminished growth and abundance of fish and platypus which forage within or immediately downstream of riffles and v) reduced spawning/breeding success of riffle-dependent fish species.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Altered biotic communities**

  Modified river hydrology changed fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

  Further details of this issue are given in the discussion for Reach 1.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Connectivity investigations – managing flows for fish passage in the Woronora River**

  The Healthy Rivers Commission (HRC) recommended a 800 ML/d (over 3 days) environmental release to provide passage opportunities for diadromous fish species which have entered the system. If the species are not in the system in substantial numbers, then little environmental benefit will arise from such releases. To avoid such low-benefit outcomes, it is recommended not to make releases when diadromous fish numbers are low. It follows that the monitoring of the abundance of diadromous fish in the system will provide vital information for the management of the releases.

- **Reduced flushing, scouring and conditioning of habitat**

  It is likely that the reduced duration and frequency of flushing/scouring flows, together with increased nutrient concentrations, have resulted in i) a build up of algal[1]/detrital material in shallow habitats[2], and ii*)* a reduction in the conditioning[3] of stony-bed areas).

  The potential consequences of the build up of algal/detrital material in shallows are:

[1] Primarily diatomaceous coatings and filamentous-greens.
[2] The shallows of key interest are those associated with biological-important areas, particularly riffle-like habitats.
[3] *Conditioning* is the removal of accumulations of fine organic material from interstitial spaces of the stony beds by the flow-driven 'turning over' of the beds. The beds of key interest are those associated with biological-important areas, particularly riffle-like habitats.

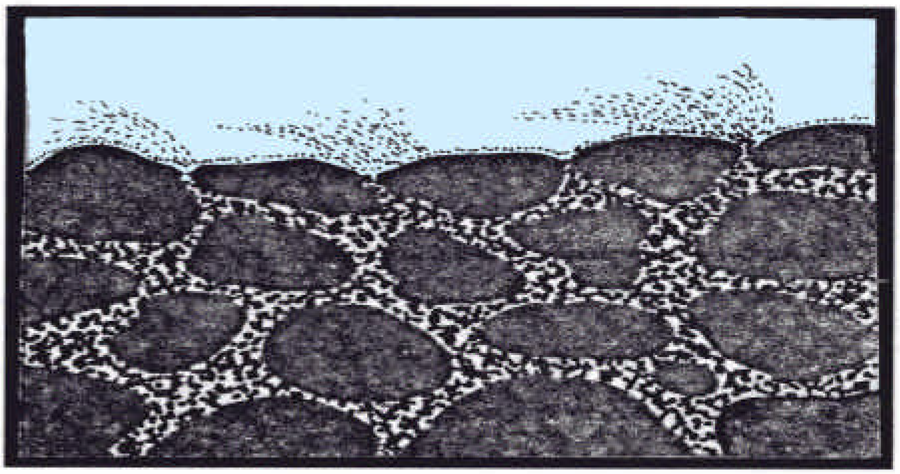
- reduced habitat quality and diversity in shallow habitats;
- subsequent reductions in diversity and altered community structure due to loss the of fauna dependent on clean substrates at some stage in their life cycle;
- subsequent output of decaying organic material which clogs interstitial spaces of stony-bed areas (see below); and
- subsequent output of decaying organic material that is additionally deposited in deep pools and which leads to water quality deterioration therein.

The potential consequences of reduced stony-bed conditioning are:

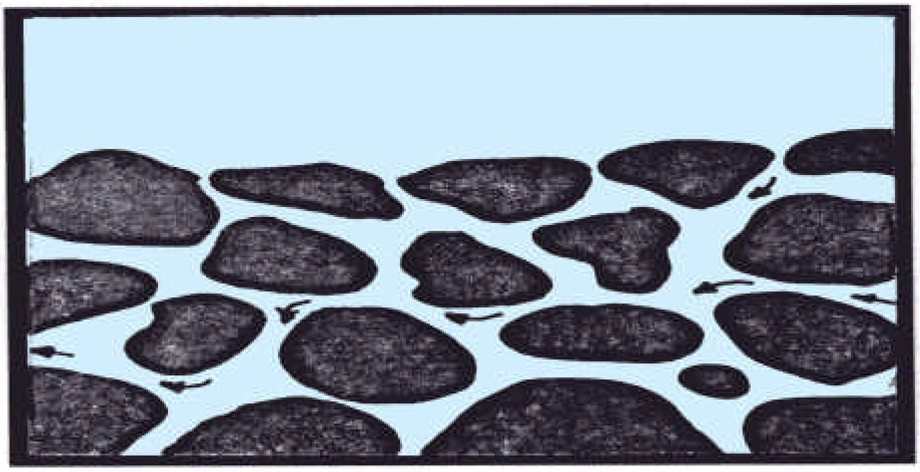
- lowered interstitial habitat quantity (sub-surface spaces within stony beds) due to filling by fines and decaying organic material;
- subsequent reductions in sub-surface water flows which impacts the dissolved-oxygen climate;
- lowered interstitial habitat quality, particularly as a result of decaying organic material which reduces dissolved-oxygen concentrations; and
- reduced abundance of aquatic fauna that are directly or indirectly dependent, during some stage of their life cycle, on spaces within stony substrates that are clear of fines or oxygen-consuming organic material (eg. gudgeon species and the listed threatened species, Macquarie perch, require clean stony beds during spring and early summer for spawning and egg/larval development).

An illustration of this issue is given in Plate 6.

Plate 6 - Illustration of the flushing/scouring/conditioning issue



Moderate-high flows <u>reduced</u>: <u>less frequently</u> flushed/scoured/conditioned (reduced habitat quality, quantity & diversity: surface-coatings, and interstitial spaces clogged with sub-surface flows and dissolved oxygen plummeting)



Moderate-high flows <u>not reduced</u> (near–natural): <u>frequently</u> flushed, scoured, conditioned (frequently improved habitat quality, quantity & diversity).

- **<u>Encroachment of riparian vegetation</u>**

  Low flows and low flow variability are thought to have allowed the establishment and growth of riparian/terrestrial vegetation in the river channel and increased the habitat availability and suitability for weed species (Taylor-Wood 2003). Thus the provision of environmental flows is seen as a means to provide physical disturbance of the riparian vegetation associated with the Woronora and Hawkesbury-Nepean Rivers. Riparian vegetation that is most likely to be susceptible to changes in flows is that which grows within about a 0.5 m vertically of the normal flow levels, ie. river-edge habitat (Benson and Howell 1997). Riparian and terrestrial vegetation that is found higher that this level is less likely to be affected by flows, with flooding only occurring periodically.

  Given the lack of sediments within the systems, the bedrock nature of the river channel and the size of flows required to reach the some of the vegetation growing within the broader river channel, it is thought that the growth of riparian vegetation within the river channel would have occurred naturally. Dam and weir construction has mostly likely to have resulted in the removal or decrease in medium to high flows that would have flooding and scouring of the river channel. Such flooding and scouring would have resulted in the removal and/or reduction of vegetation from within the river-edge habitat and/or higher on a more regular basis (depending on the flow size), such that the vegetation would have to re-establish itself after each flow. Flooding and scouring are known to be an important factors limiting the growth and survival of vegetation within a river channel, with variation in flooding resulting in spatial and temporal variation in species composition of the seedling layer (Siebel and Blom 1998). Flood tolerance, however, increases with the plants age. Thus when flood event occurs, while smaller species plants may be more easily uplifted by the flows, larger plants may have had sufficient time to establish their root systems such that the flows may not result in their removal. In addition, smaller plants that are totally submerged by a flow event are able to survive flooding for much shorter durations than partially submerged plants (Siebel and Blom 1998).

Investigation of the riparian vegetation of the Woronora and Avon Rivers and downstream of the diversion weirs indicates that while floods still occurs (as indicated by the relative young natured of the vegetation stands), the period between flood events may have increased (as a result of dam levels prior to an event) allowing the vegetation to become better established. It has been shown that vegetation that becomes established during periods of low flows becomes increasingly resistant to removal by subsequent flows as a function of time (Merritt and Cooper 2000). Depending on a species tolerance to disturbance, flooding and drought, as well as different competitive abilities, different species and species assemblages will occur along the river channel.

Low flow releases (such as currently occur) result in only a small change in water level, which will only increase the water levels within the river-edge habitat and will not reach the more established riparian and/or terrestrial species. Higher flows are required to reduce the encroachment of riparian vegetation. The impact of environmental flows will depend on the size, duration and, potentially, season of flows. For some plant species, tolerance to flooding can also be dependent on season (Siebel and Blom 1998). It is known that both native and weed species are more likely to be dispersing their seeds and fruit in summer and autumn, with fewer species dispersing in spring and the lowest numbers in winter (Benson and Howell 1997).

As many of the plants beyond the river-edge habitat in the Woronora and Avon Rivers and downstream of the diversion weirs are already well established, it will most likely take a high flow of longer duration to result in a significant change to the riparian vegetation. However, an increase in flow as a result of implementation of the environmental flows may help to control the new and re-establishment of some plant species. However, this will depend on the tolerance of the species to flooding, the size and duration of the flow event, and the period between flooding events.

Along with encroachment of riparian vegetation into the river channel, there is also the problem of encroachment/introduction of weed species. Whilst this is less of a problem in the upper reaches where there is little anthropogenic influence, in downstream reaches especially those impacted by and/or have tributaries which are affected by (eg. Heathcote Creek) surrounding landuse, encroachment/introduction of weed species is a problem. While it is acknowledged that environmental flows will probably influence/aid the distribution of weeds, the presence of weeds in the riparian zone is best addressed through catchment management.

Ancillary Issues

None applicable for this reach.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  One site listed on the State Heritage Inventory is within this river reach. Please see Appendix B1.

  Aboriginal values

Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date, to identify whether land and river activities are present.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Recommended Environmental Flow Regime; Reach 3

Provisional environmental flows are currently being released in accordance with HRC recommendations and are being monitored. Whether or not the selected flow ranges are sufficient for fish passage and habitat renewal will be assessed by the monitoring of the current environmental flow regime.

The provisional HRC environmental flows include the requirement for an annual release of a flow of 800 ML/d over a 3 day period. Based on existing hydrological modelling of reaches downstream of the Nepean dams (which are similar in hydrological characteristics to this reach) flows in the range of 800 ML/d can be expected to occur most years as a result of spills. Currently there is some thought that the 800ML/d flows are redundant. However, in much drier times in the future, they may become necessary as a kind of contingency component.

In Patterson Britton (2002) geomorphological monitoring was recommended for three cross sections in this reach. These were to be located upstream of Gurra, Eckersley Crossing and Heathcote Creek. It was recommended that annual surveys be done either after high environmental flows or after floods. Aims of these surveys are to establish channel changes. Also recommended were sediment analyses to allow calculation of initiation of motion and to assess habitat quality. Such monitoring would take 3 days a year in total.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regimes will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Critical habitat contraction**

  The recommended environmental flow regimes will increase the availability of critical habitat associated with higher water velocities and thus increase: i) habitat area and diversity, ii) the diversity of invertebrate and fish fauna, iii) the abundance/biomass of invertebrates which use higher-water velocity areas, iv) growth and abundance of fish and platypus which forage within or immediately downstream of riffles, and v) increase spawning/breeding success of riffle-dependent fish species.

- **Altered biotic communities**

  Improvements in biodiversity and the structure of aquatic communities are expected.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Connectivity investigations – managing flows for fish passage in the Woronora River**

  These investigations will optimise the benefits of environmental flows for fish passage.

- **Reduced flushing, scouring and conditioning of habitat**

  The recommended environmental flow regimes will increase the incidence of flushing, scouring and stony-bed conditioning and thus increase: i) habitat quality and diversity in shallow habitats, ii) the diversity of clean-substrate fauna, iii) the habitat quality of interstitial spaces in stony beds (subsurface flows and dissolved oxygen climate), and iv) the water quality in deep pools.

- **Encroachment of riparian vegetation**

  Reduced flows in these reaches has allowed riparian vegetation and terrestrial weeds to encroach into the river channel. In the future, increased flow variability will reduce the potential for encroachment of riparian vegetation and weeds into the river channels by more frequently providing medium to high flows and reducing the frequency of very low flows such that vegetation is scoured from the channel more frequently and/or its growth is disrupted.

Summary of Key Changes to Ancillary Issues

None applicable for this reach.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date.

Reach 4: Woronora River, Heathcote Creek Junction to The Needles

Note: Conceptual model diagrams have not been developed for the Woronora River

Natural Regime; Reach 4

This is a very short reach (3.6 km), which is straight for the upper 1.6 km, prior to passing through two meanders to reach the Needles, a rocky barrier above the tidal limits. Mean gradients are less than 0.0050. Downstream of the Heathcote Junction, the valley floor is up to 100 m wide, with again a selection of cobble terraces, colluvium and "fluvial levees". Downstream widths drop to less than 30 m but in the meanders there are wide "riffles". Gravels bars and levees have been mapped (Patterson Britton, 2002). Under natural conditions, with flow and sand additions from Heathcote Creek, the largest tributary, such deposits would have been reworked more frequently and habitats "refreshed" providing varied instream habitats. Natural energy sources would have been mainly derived from upstream leaf litter inputs and to a smaller extent instream photosynthetic processes.

Current Regime and High Priority Issues; Reach 4

In physical appearance, this reach has changed but little. However, flows have been considerably reduced by the presence of the dam reducing the spatial and temporal extent of instream hydraulic habitats and thereby reducing biodiversity and increasing the impassability of natural fish barriers. The lower flows have also reduced upstream sediment supplies to this reach, resulting in sand paths, which are now discontinuous and higher energies in sediment-deficient spills.

Now old river terraces and point bars deposited under natural conditions act as current sources of sand. Heathcote Creek is also an unregulated sand source which has been increased by the degree of urbanisation in the upper part of that catchment. Patterson and Britton (2002) now claim that such deposits reach 1.5 km below the junction. Stormwater runoff from such areas has introduced polluted water to this reach, reducing the distribution and abundance of pollution-sensitive taxa. In addition, the stormwater runoff from the increased urban areas has altered the natural hydrograph of the tributary inflows from Heathcote Creek with flows and water velocities greatly increasing, from natural conditions, following rainfall events. Heathcote Creek is also a source of weeds and nutrients.

Fundamental Hydrological Issues

- **Monitoring the sandstone reaches downstream of dams**

  Improvements in the measurement of discharges or flows are required to support all subsequent ecological and water-quality monitoring. This includes measuring the hydraulic properties of flow through channel constrictions, which act as riffle-like forms and are therefore important for habitat, fish passage and invertebrates.

Ecological and Physical Issues

- **Reduced connectivity – natural barriers**

  Reduced flows over riffles or riffle-like habitats, have decreased connectivity for mobile aquatic fauna along the river reach, and at the interface between river and estuarine reaches.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Critical habitat contraction**

  Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities (for example riffles or riffle-like habitats).

  The potential consequences of such habitat contraction are: i) reduced habitat area and diversity, ii) reduced diversity of invertebrates and fish, iii) reduced abundance of invertebrates which use higher-water velocity areas, iv) diminished growth and abundance of fish and platypus which forage within or immediately downstream of riffles and v) reduced spawning/breeding success of riffle-dependent fish species.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Altered biotic communities**

  Modified river hydrology changed fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

  Further details of this issue are given in the discussion for Reach 1.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Connectivity investigations – managing flows for fish passage in the Woronora River**

  The HRC recommended 800 ML/d (over 3 days) environmental release to provide passage opportunities for diadromous fish species which have entered the system. If the species are not in the system in substantial numbers, then little environmental benefit will arise from such releases. To avoid such low-benefit outcomes, it is recommended not to make releases when diadromous fish numbers are low. It follows that the monitoring of the abundance of diadromous fish in the system will provide vital information for the management of the releases.

- **Reduced flushing, scouring and conditioning of habitat**

  It is likely that the reduced duration and frequency of flushing/scouring flows, together with increased nutrient concentrations, have resulted in a build up of algal/detrital material in shallow habitats, and a reduction in the conditioning of stony-bed areas.

  Further details and an illustration of this issue are given in the discussion for Reach 3.

- **Encroachment of riparian vegetation**

  Riparian vegetation and terrestrial weeds encroaching on the river channel as a result of low flows.

  Further details of this issue are given in the discussion for Reach 3.

Ancillary Issues

- **Stormwater runoff**

  Stormwater runoff impacts general water quality and therefore the effectiveness of environmental flows, which, as dam releases, are generally more pure. Therefore better management of stormwater runoff will enhance the water quality of the system thus making environmental flows more beneficial to the system.

  Currently, much is unknown about stormwater runoff and its management, partly because of the diffuse nature of stormwater entry to the river system and partly because its management is uncoordinated. Since annual volumes of storm water runoff for the whole of the Hawkesbury-Nepean catchment are large (probably in the order of 300 to 500 GL/yr) and since the pollution load is significant (equal to or worse than treated sewage), it will be necessary to get some idea of its impacts in terms of quantity and quality.

  This can be approached in three ways:

  - Firstly, several local authorities have installed small storm water runoff management structures in newly developed areas. These are being monitored to determine levels of efficiency (eg. at Blacktown and Penrith). Such locations need to be tracked down and results need assembling in a database. We need to know the proportions of areas covered by such structures to obtain combined impacts.
  - Secondly, it seems that Sydney Water has conducted a major survey in this area, but the results have yet to be seen and examined. Its existence was revealed at the SCA review of monitoring, where quite clearly and correctly a previous offering, using crude black-box assessments, was deemed to be superficial. However it is very late in the program to be finding out about work that might have helped to formulate a better approach to this topic in relation to environmental flows. It was revealed that much has been made of contaminants from natural areas. This is a very large catchment, with small urban areas and limited agricultural development, when viewed as a whole.

- Thirdly, Salmon Q modelling is being used to determine the potential effectiveness of partial effluent removal in an effluent reuse strategy. Currently such modelling is being done to cover the likely impacts of various environmental flow scenarios. When such effluent contributions are removed, what is left is that part of STP effluent not withheld for effluent reuse, plus urban, rural runoff and contaminated contributions via diffuse sources from natural areas. The latter are thought to be very important. In sub-catchments, which are predominantly urban, rural and natural area contributions are not likely to be of much consequence for most of the time because runoff from intermittent rural shale catchments (these are the main areas of urbanization) only occurs 6 to 10 times a year on average. Rural areas are farmed fairly intensively and intermittent runoff is further depleted by thousands of farm dams. Moving back into a DDC will probably reduce such contributions even more, except after soaking flood rains.

Consequently where tributary (inputs into the main stream) water-quality monitoring is carried out, if discharges are known, they can be used to determine "rest of area" contributions of water and pollutants, because STP volumes and loads are known.

Thus with Salmon Q extracting the effluent, there should be a way at getting close to ballpark loads and discharges from urban areas, given monitoring points at strategic locations.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  No recorded cultural heritage items are listed within this area, although cultural heritage places are present.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date, to identify whether land and river activities are present.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Recommended Environmental Flow Regime; Reach 4

Again, what happens in the future will depend on the selected environmental flow regime and to what extent this is impacted by the drought dominated regime and global warming. Stormwater runoff will probably increase as urbanisation extends, unless there is water sensitive urban design in quite difficult sandstone terrain. Lower flows with more pollution will not help ecological recovery. However, monitoring with adaptive management should help to make sure than enhancement occurs. The ability of the environmental flow regime to alter fish passage over the large natural barrier towards the downstream end of this river section is probably minimal.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regime will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Critical habitat contraction**

  The recommended environmental flow regimes will increase the availability of critical habitat associated with higher water velocities and thus increase: i) habitat area and diversity, ii) the diversity of invertebrate and fish fauna, iii) the abundance/biomass of invertebrates which use higher-water velocity areas, iv) growth and abundance of fish and platypus which forage within or immediately downstream of riffles, and v) increase spawning/breeding success of riffle-dependent fish species.

- **Altered biotic communities**

  Improvements in biodiversity and the structure of aquatic communities are expected.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Connectivity investigations – managing flows for fish passage in the Woronora River**

  These investigations will optimise the benefits of environmental flows for fish passage.

- **Reduced flushing, scouring and conditioning of habitat**

  The recommended environmental flow regimes will increase the incidence of flushing, scouring and stony-bed conditioning and thus increase: i) habitat quality and diversity in shallow habitats, ii) the diversity of clean-substrate fauna, iii) the habitat quality of interstitial spaces in stony beds (subsurface flows and dissolved oxygen climate), and iv) the water quality in deep pools.

- **Encroachment of riparian vegetation**

  Reduced flows in these reaches has allowed riparian vegetation and terrestrial weeds to encroach into the river channel. In the future, increased flow variability will reduce the potential for encroachment of riparian vegetation and weeds into the river channels by more frequently providing medium to high flows and reducing the frequency of very low flows such that vegetation is scoured from the channel more frequently and/or its growth is disrupted.

Summary of Key Changes to Ancillary Issues

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:

  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date.

Reach 5: Woronora River, The Needles to Georges River

Note: Conceptual model diagrams have not been developed for the Woronora River

Natural Regime; Reach 5

The tidal Woronora River consists of 4 km of tidal river and 6 km of more open estuary. The upper part was probably 40 m or less wide initially with a depth of 2 m or so. In distinction, the estuary is 200 m wide at 7 km and 400 m wide at 9.5 km, where depths probably varied from 1 to 4 m away from sandy-muddy shoals. In natural times this would have been an ecologically rich arm of the Georges River, with wide marginal mangrove wetlands, even a mangrove island, and swampy forests on limited alluvial flats.

Current Regime and High Priority Issues; Reach 5

The Woronora has a catchment area of 150 km^2, of which 75 km^2 are dammed. Its catchment area is only 16% of the total Georges catchment (927 km^2). Thus the dam only controls 8% of the total Georges River catchment area. It can be concluded that flows in the lower portions of the Woronora River will be significantly reduced due to the presence of the dam. However, downstream of the Georges River confluence the dam will have little effect on flow. Tidal flushing flows in the Georges River reach dwarf fresh water flows, except during large flood events. The upper tidal river is still fairly pristine, with most settlement as isolated weekend shacks reached by boats. However, sediment-starved spills of the last flood dominated regime plus the downstream impacts of dredging have help to degrade the bed by a metre or more and the banks by several metres. Dredging up to 1976 accounted for 270,000 m^3 below the Woronora Bridge and 157,000 m^3 above the bridge. Surveying based on 25 cross sections revealed a loss of 382,000 m^3, or something like 45,000 m^3 less than that removed by dredging. This discrepancy is probably explained by contributions from two other sources; the tidal river has been degraded (bed and banks) and large sand slugs have emerged from Forbes Creek, after urbanisation of Woronora Heights. Like the Hawkesbury, there has been degradation, including bed dredging in the upper estuary, and accretion in the lower, where fines and throughput materials have accumulated in the widest parts.

Given that inflows to the upper Woronora estuary (ie. upper Reach 5) are likely to have been significantly reduced, there is a possibility that beds of aquatic plants, which provide valuable fish nursery habitat, are frequently impacted by saline-water penetration. The reality of this issue needs to be investigated by initially determining whether or not such plant beds occur in the upper estuary (see Appendix C1 in Part C of this report).

Fundamental Hydrological Issues

None applicable for this reach.

Ecological and Physical Issues

- **Reduced connectivity – natural barriers**

  Reduced flows over riffles or riffle-like habitats, have decreased connectivity for mobile aquatic fauna along river reaches, and at the interface between river and estuarine reaches.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Connectivity investigations – managing flows for fish passage in the Woronora River**

  The HRC recommended 800 ML/d (over 3 days) environmental release to provide passage opportunities for diadromous fish species which have entered the system. If the species are not in the system in substantial numbers, then little environmental benefit will arise from such releases. To avoid such low-benefit outcomes, it is recommended not to make releases when diadromous fish numbers are low. It follows that the monitoring of the abundance of diadromous fish in the system will provide vital information for the management of the releases.

Ancillary Issues

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  One site listed on the State Heritage Inventory is within this river reach. Please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date, to identify whether land and river activities are present.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Recommended Environmental Flow Regime; Reach 5

Environmental flows will benefit the lower portion of the Woronora River. With the abandonment of dredging and the increasing density of urbanisation of the low dissected sandstone plateau, there will probably be a slow infilling of parts of the estuary from these additional sand sources. Volumes of stormwater runoff will increase and there will be some decrease in water quality. However, tidal flushing this close to Botany Bay may help this. Environmental flows will have little impact on this reach, where tide volumes dominate.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regimes will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Connectivity investigations – managing flows for fish passage in the Woronora River**

  These investigations will optimise the benefits of environmental flows for fish passage.

Summary of Key Changes to Ancillary Issues

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
    - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
    - reduced sediment and nutrient export rates from catchments to receiving waters;
    - enhanced in-stream water quality;
    - reduced contaminant transport;
    - protection of riparian ecosystems, including restoration of degraded systems;
    - promotion of the scenic, landscape and recreational values of creeks and rivers;
    - protection of existing ecosystems in the natural drainage systems; and
    - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

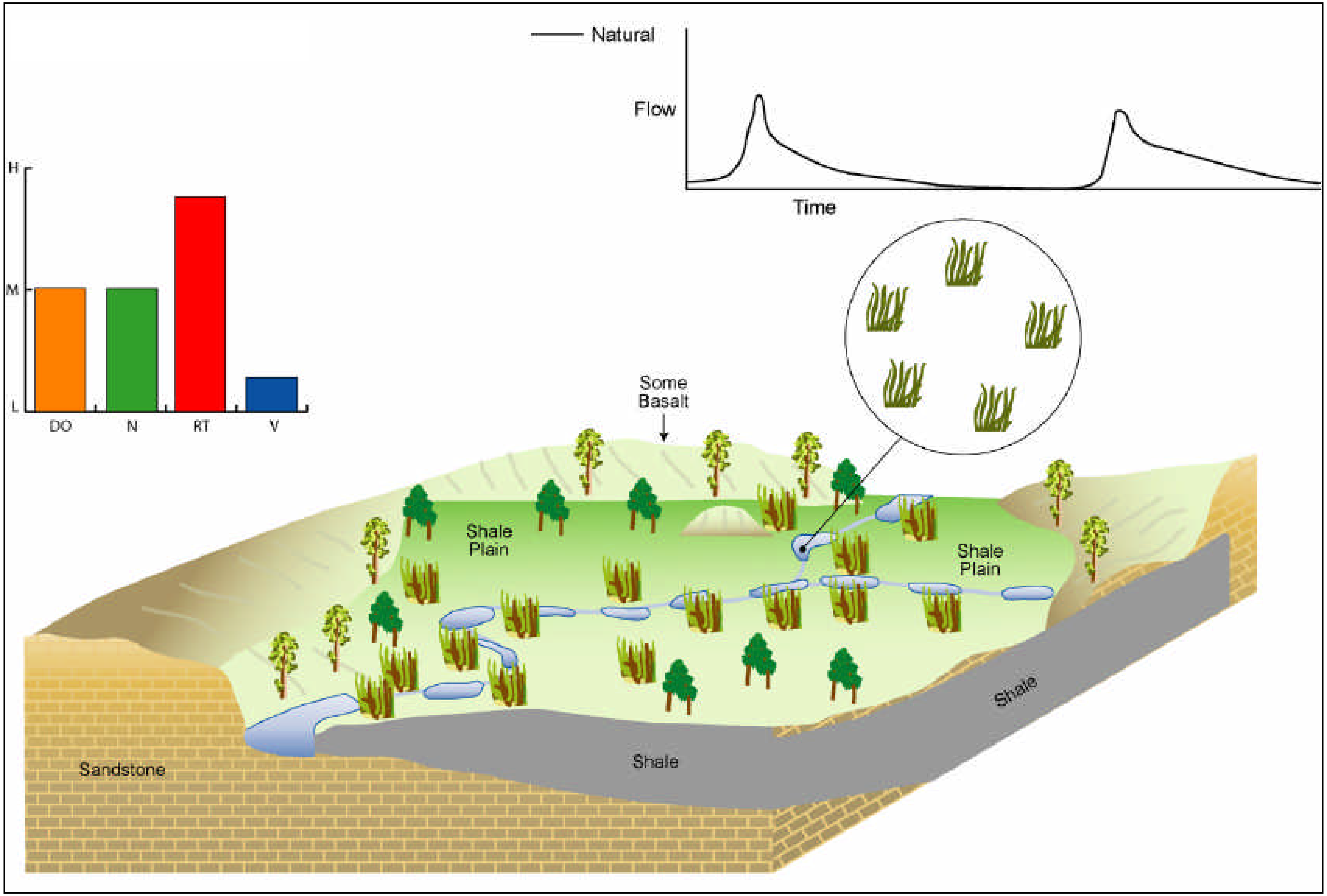
  This reach has not been assessed to date.

Reach 6.1: Wingecarribee River, Wingecarribee Reservoir to Berrima Township

Natural Regime; Reach 6.1

This 29 km reach is contained in the relatively undissected, rolling hill country of the Southern Highlands. Its initial forest cover, low gradients and shale-based impervious soils would have made it conducive to a chain-of-ponds form of drainage. In such systems discontinuous elongated pools or ponds occupied parts of the valley floor; these were separated by grassy depressions. The latter were surcharged by low energy flows to form temporary connectivity but there was insufficient power to cut a continuous channel. The headwater area was occupied by a large wetland known as the Wingecarribee Swamp. This would have sustained great biodiversity, which would have over-spilled into the ponds during higher flows. Due to the open nature of the valley floor and the wide expanses of lotic systems the main energy input into the aquatic ecosystems would have been derived from photosynthetic processes by algae and possibly aquatic macrophytes.

Figure B17: Reach 6.1 - Natural Regime Wingecarribee River, Wingecarribee Reservoir to Berrima Township



Current Regime and High Priority Issues; Reach 6.1

The lands of this reach have now been cleared for mainly grazing. The headwater area has been dammed below the Wingecarribee Swamp to receive both headwater contributions of runoff, as well as water imported from the Shoalhaven. The higher runoff from the cleared land has caused the dissection of a continuous channel, which varies in size and sinuosity throughout this reach. Flow continuity has been disrupted by the erection of three weirs, two for irrigation of farmlands and the lower one for the cement works near Berrima. These cause back-up water for 8 of the 26 km above Berrima Weir and certainly disrupt flows, sediment movement and fish passage. The weirs may also stratify during summer months contributing to water quality problems in the weirs. STP discharges and stormwater runoff have been added from growing urban areas. Organic matter and energy inputs in the aquatic ecosystem would still be primarily derived from algal photosynthesis. The lack of riparian vegetation along this river section would also limit the terrestrial sources of energy.

Rare migratory birds (JAMBA and CAMBA listed) have been recorded on the still waters of Bong Bong weir pool, however they may have used natural pools prior to construction of the weir.

Flows in this reach have been highly modified due to the regulation of flow by Wingecarribee Reservoir, extraction of flows by irrigators and industry, return flows from sewerage treatment plants and storm water runoff.

Groundwater extraction is increasing in this area and the implications for surface water flow is not yet defined.

Further growth in irrigation is likely to occur in this area and this is likely to increase the stress on river health.

Fundamental Hydrological Issues

None applicable for this reach.

Ecological and Physical Issues

None applicable for this reach.

Ancillary Issues

None applicable for this reach.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  No recorded cultural heritage items are listed within this area, although cultural heritage places are present.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

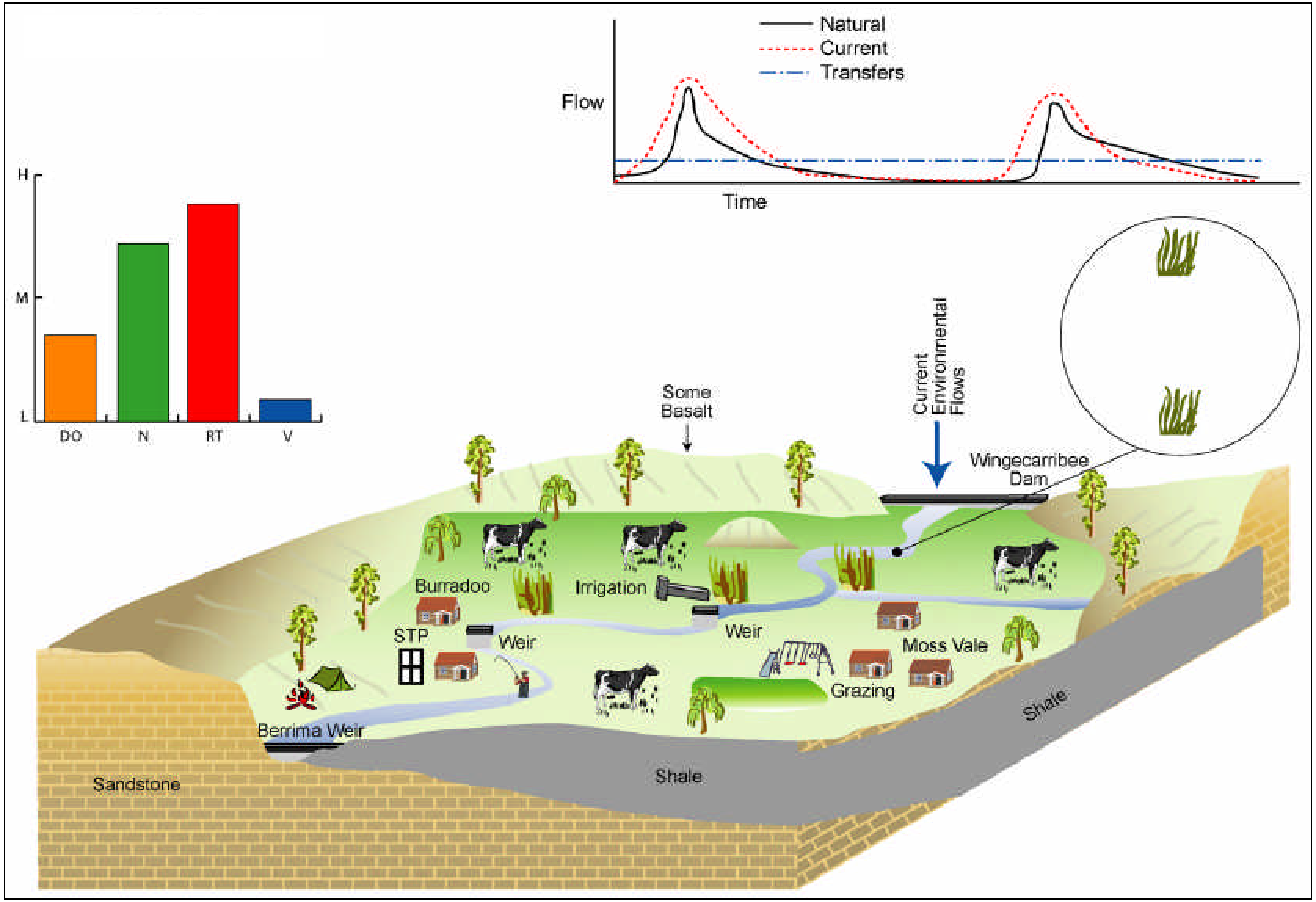
- **Land and river activities**

  This reach has not been assessed to date, to identify whether land and river activities are present.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Figure B18: Reach 6.1 - Current Regime Wingecarribee River, Wingecarribee Reservoir to Berrima Township



Recommended Environmental Flow Regime; Reach 6.1

Without major changes in present in-stream structures and surrounding landuse/catchment management practices, this will remain a problem reach. Environmental problems are further aggravated with pollution from two STPs and a growing population, increased stormwater runoff and the ponded water by weirs. Releases of Wingecarribee Reservoir waters, even at only 400 ML/d cause minor flooding which causes prolonged inundation of parts of the floodplain. Since Berrima weir is no longer used and is sometimes a source of contaminated water, it could be removed subject to cultural heritage considerations, but any plans for environmental flows will be distorted by the weirs and confounded by inter-catchment transfers to Warragamba Dam. High growth rate in the Southern Highlands will increase STP and stormwater runoff discharges, which, unless better managed, add to pollution problems and ecological degradation.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

None applicable for this reach.

Summary of Key Changes to Ancillary Issues

None applicable for this reach.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

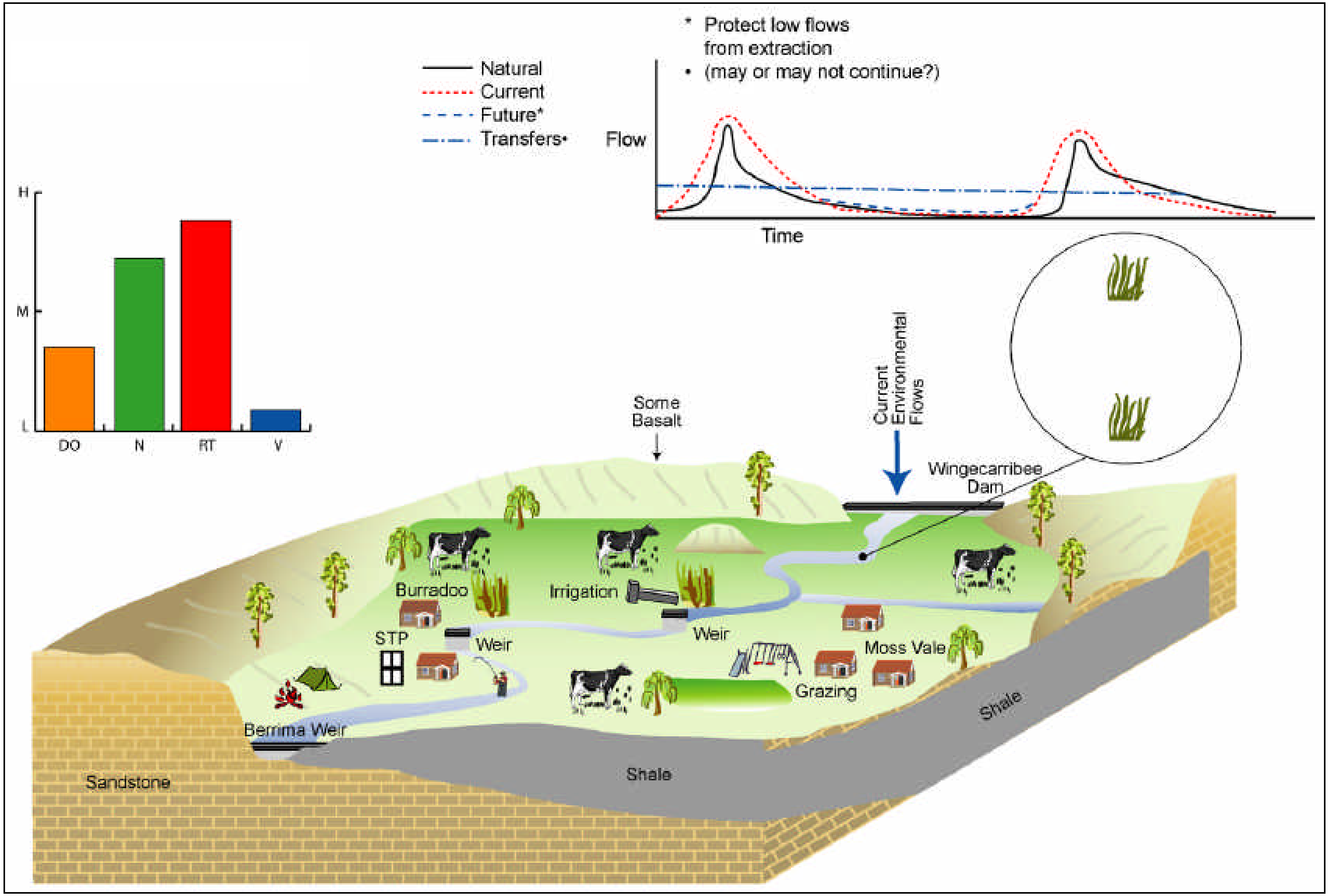
- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date.

Figure B19: Reach 6.1 – Recommended Environmental Flow Regime Wingecarribee River, Wingecarribee Reservoir to Berrima Township

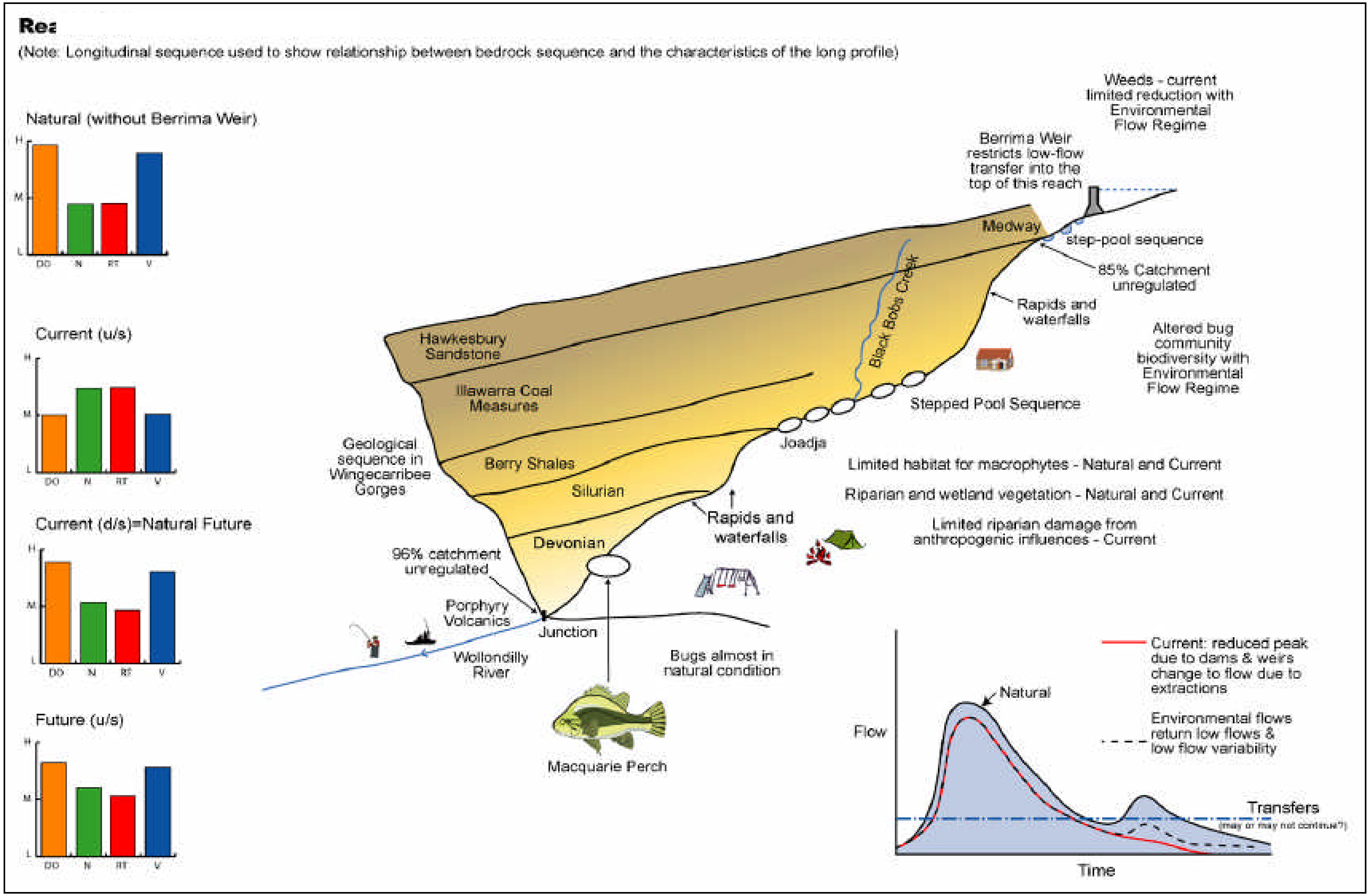

Natural
Current
Future*
Transfers•
Flow
Time
* Protect low flows from extraction
• (may or may not continue?)
H
M
L
DO
N
RT
V
Some Basalt
Current Environmental Flows
Wingecarribee Dam
Burradoo
Irrigation
STP
Weir
Weir
Moss Vale
Grazing
Berrima Weir
Sandstone
Shale
Shale

Reach 6.2: Wingecarribee River, Berrima Township to Wollondilly River Junction

Natural Regime; Reach 6.2

Under truly pristine conditions, this 48 km gorge-like reach would not have been much different to that of today. The Wingecarribee starts to incise in Hawkesbury Sandstone just above the Berrima Weir. It then continues to incise the rest of the Mesozoic rocks and into underlying Palaeozoic formations in first steep and then more gentle gradients in a step-pool form mainly. Steepest gradients are found as the channel cuts through the Illawarra Coal Measures (Permian) and undifferentiated Silurian rocks, whilst flatter profiles are found in the Berry Shales (Permian) and in Devonian rocks above the junction. Small waterfalls and rapids characterize steeper parts; these help to oxygenate the water. The gorge and local narrow floodplains would have been densely wooded.

Figure B20: Reach 6.2 - Natural and Current Regimes and Recommended Environmental Flow Regime Wingecarribee River, Berrima Township to Wollondilly River Junction



Current Regime and High Priority Issues; Reach 6.2

The geomorphology of this reach has changed but little. Limited floodplains have been cleared for isolated farming and the Joadja coalmine was developed in a right bank tributary. The latter probably added to bed load and some water pollution. However, most of the problems have been introduced from the upstream, degraded reach. It seems probable that even those problems diminish over the 48 km but they may have adversely affected local ecology in upstream parts.

This section of the river has sewage effluent disposal via Oldbury Creek (Berrima) and Whites Creek (Moss Vale) to the Wingecarribee River. The Medway Rivulet, which enters the Wingecarribee River downstream of Berrima, has a major weir which prevents low flows into the Wingecarribee River. Algal blooms have occurred in this reach previously.

Fundamental Hydrological Issues

None applicable for this reach.

Ecological and Physical Issues

None applicable for this reach.

Ancillary Issues

None applicable for this reach.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  No recorded cultural heritage items are listed within this area, although cultural heritage places are present.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date, to identify whether land and river activities are present.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Recommended Environmental Flow Regime; Reach 6.2

Any improvements in the upstream reach will certainly reduce problems in this reach. However, any environmental flows, which will be affected by bulk transfers from time to time, will have little impact in this more distant and larger channel. Pristine tributary areas increase the catchment size and the channel capacity.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

None applicable for this reach.

Summary of Key Changes to Ancillary Issues

None applicable for this reach.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  This reach has not been assessed to date.

Reach 7: Nepean River, Doudles Folly and Glenquarry Creeks (downstream of Glenquarry Cut)

Note: Conceptual model diagrams have not been developed for this Reach.

Natural Regime; Reach 7

Under natural conditions, this reach would comprise parts of three tributary waterways flowing into the Upper Nepean. Brennans Gully (1 km) is no more than 1 km from the Wingecarribee Reservoir of today across the divide in the Warragamba drainage area. Its name (gully) implies that its channel cut in Hawkesbury Sandstone was, if not cut prior to settlement, greatly enhanced by subsequent clearing. This flowed into Glenquarry Creek (2.5 km), prior to entering Doudles Folly Creek (3.7 km), which enters the Nepean as a left-bank tributary some 19.9 km above the present reservoir and 27.4 km above the dam. All three sub-catchments would have been forested and their channels would have become progressively larger downstream. All were incised into sandstone. Natural flows would have been small and intermittent from their small catchments.

Current Regime and High Priority Issues; Reach 7

The present condition is that these three small tributary reaches are used as one of two conduits to top up the water supply in the Hawkesbury-Nepean catchment from Shoalhaven sources. Shoalhaven water can be stored in Wingecarribee Reservoir and passed either down the river to Warragamba Dam or the Glenquarry Cut to the Nepean Dam. Originally the Cut breached the divide between the Wingecarribee and Nepean catchments and water was passed downstream, where it was found that flows were too large for such a small channel and caused too much damage. This problem was removed by a 2 km tunnel, which conveys water to Glenquarry Creek directly about 1 km above its junction with Doudles Folly Creek. It would appear that the former is too small and most releases equate to near local flood discharges. However, it seems that this short reach can be stabilised by artificial lining should the need arise. Real problems were perhaps unforeseen in the early stages and involve differences in water quality between the two systems. Unfiltered flows may have added unwanted exotic species to the Nepean system and other ecological disbenefits.

Fundamental Hydrological Issues

None applicable for this reach.

Ecological and Physical Issues

None applicable for this reach.

Ancillary Issues

- **Inter-catchment transfer of fish via Glenquarry Cut**

  Continued inter-catchment transfers of water from the Shoalhaven to the upper Nepean system via Wingecarribee Reservoir will increase the likelihood that aquatic and riparian biota will be translocated between river basins. The potential consequence of this is that translocations could result in reduced viability of naturally-occurring populations of aquatic/riparian biota in the 'receiving' rivers given the commencement of:

  - predation;
  - competition;
  - disease introductions;
  - genetic weakening; and/or
  - habitat degradation.

  Based on this mechanism, a particular concern exists in the river systems upstream of Nepean Dam given:

  1. the presence of many alien fish species within Wingecarribee Reservoir (carp, *Gambusia*, Oriental weatherloach and trout);
  2. the potential for the genetically-distinct Shoalhaven River Macquarie perch (listed threatened species) to be transferred to the reservoir;
  3. the (apparent) current absence of a number of alien fish in the river systems upstream of the Nepean Dam; and
  4. the recorded occurrence of the naturally-occurring and genetically-distinct Nepean River Macquarie perch in the river systems upstream of the Nepean Dam.

  The viability of the Nepean River Macquarie perch populations would be threatened if alien fish species and their diseases, and the Shoalhaven River Macquarie perch[1], were introduced into the

[1] Genetic diversity would be lost in the Nepean River Macquarie perch because of hybridization (hence genetic weakening).

Nepean River system. This could occur as a result of Shoalhaven-to-Wingecarribee then Wingecarribee-to-Nepean inter-catchment water transfers.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  No recorded cultural heritage items are listed within this area, although cultural heritage places are present.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Recommended Environmental Flow Regime; Reach 7

With increasing dependence on Shoalhaven water to meet increasing demand, there is the potential for much greater flows through Glenquarry Cut unless a pipeline replaces it. Without the pipeline and water filtration plant, water quality problems may increase.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

None applicable for this reach.

Summary of Key Changes to Ancillary Issues

- **Inter-catchment transfer of fish via Glenquarry Cut**

  The construction of a water filtration plant incorporating sand filtration (as proposed in the Forum's recommended strategy for inter-catchment transfers from the Shoalhaven) will minimise the likelihood of transfers of alien biota (adults, juveniles, larvae, eggs, seeds and propagules) from the Shoalhaven to the Nepean system. Nevertheless, the effectiveness of such a costly filtration process needs to be monitored.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  None applicable for this reach.

Reaches 8, 9, 10, 11, 12 and 13: Nepean, Cordeaux, Avon and Cataract Rivers downstream of the dams to the diversion weirs; Nepean and Cataract Rivers downstream of the diversion weirs to the Nepean/Cataract confluence.

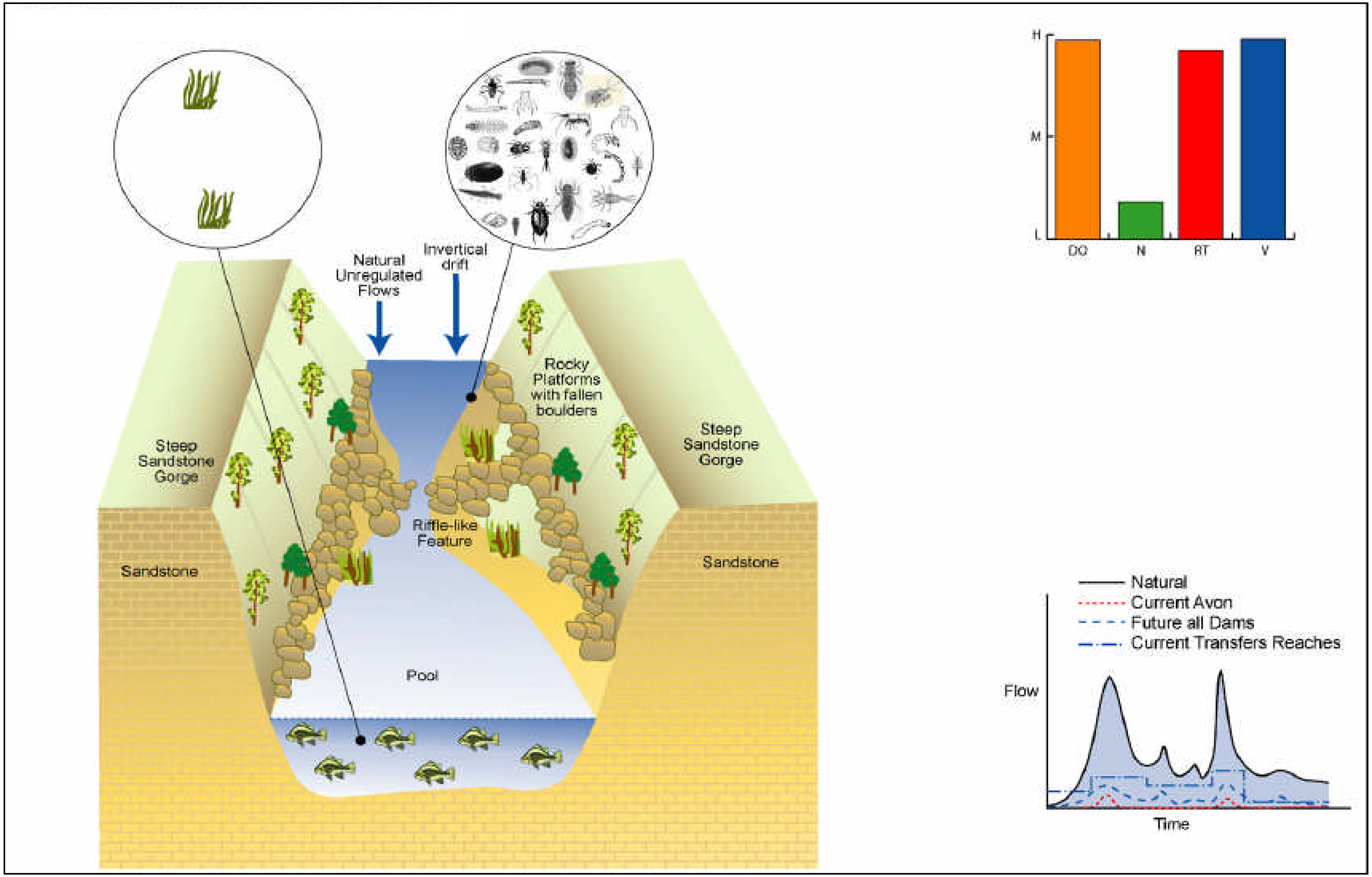
These reaches comprise very old gorges with channel locations and patterns having been derived from the north-flowing channels on the now, largely removed, Wianamatta Shales. The channels have incised into the underlying Hawkesbury Sandstones. The valley floors are dominated by large, angular sandstone blocks that have fallen down from the gorge sides. Bed material ranges from such blocks, through sandstone boulders and gravels to sand.

Natural Regime; Reaches 8, 9, 10, 11, 12, 13

Before construction of the upper Nepean Dams between 1907 and 1935, the natural flow regimes probably alternated in a step-like fashion between FDRs and DDRs. Prior to any dam construction, a FDR prevailed from 1857 to 1900 when flood flows were much higher and more frequent than was the case subsequently. Some of these floods would have imposed torrential conditions in these gorges. These would certainly have flushed flocs and organic accumulations from riffle-like constrictions and even had the power to flush bed sediments from the deeper pools.

The very small, steep catchments above the dams did not yield much sediment, but what was available passed through the system as bedload in the form of sand and small sandstone blocks. Large accumulations of somewhat rounded boulders caught up at and above constrictions probably reflected very-high-energy flows in pre-dam times.

Figure B21: Reaches 8, 9, 10, 11, 12, 13 - Natural Regime Nepean, Avon, Cordeaux and Cataract Rivers downstream of the dams to the diversion weirs; Nepean and Cataract Rivers downstream of the diversion weirs to the Nepean/Cataract confluence



Current Regime and High Priority Issues; Reaches 8, 9, 10, 11, 12, 13

The construction of the dams has meant that the river channels have had up to 95 years to adjust to a modified flow regime consisting of sediment-starved spills. The substrate adjustments have largely been limited to the evacuation of exposed transportable fines and smaller bed material. With the storage of all but the largest inflows (floods) within the dams, the below-dam flow regimes have been greatly modified due to major losses of low to moderate flows and subsequent changes to flow variability, flow-event frequency and seasonality.

Dams shut off such sediments and there have now been up to 95 years for channels to adjust to attenuated sediment-starved spills. The latter have removed most of the transportable fines and smaller bed material. Below-dam flow regimes have been greatly modified with changes in flow variability, event frequency and seasonality. In three reaches (8, 10 and 11) semi-random bulk-water releases have been superimposed on modified regimes as far as the diversion weirs. These have further distorted flow patterns. Interim environmental flows have been set at the 95th percentile but are not synchronized with natural flows. Bulk flows adversely impact riverine biota in two ways: they are turned on and off over very short periods, which can cause stranding or displacement of biota, and cold water releases affect water quality and cause further problems for biota. So the present regime reduces connectivity (riffles, dams and weirs), critical habitat availability and conditioning of stony beds. It also helps promote stratification in pools, poor water quality (cold releases) and altered biotic communities.

The main effect of the current flow regime is to dampen the temporal variability in habitats, particularly those components associated with the key hydraulic variables, water depth and velocity. The current (provisional) environmental flow regime appears to severely restrict the availability of critical physical habitat associated with higher water velocities, particularly the size of and depth of water over riffle-like habitats. Low water depth across these habitats greatly limits connectivity between refuge pools along the rivers. This is particularly important for large-bodied aquatic animals such as fish and platypus. Connectivity is also limited by weirs along the rivers.

Aquatic macrophytes are limited in these reaches due to reduced habitat availability (rocky bottoms with little soft/fine sediments) and low light availability for photosynthesis due to the steep gorges, narrow channels and overhanging vegetation. The natural input of terrestrially-derived nutrients, carbon and other materials from the headwaters has been stopped by the dams and it is likely that material inflowing from dams in spills and bulk water transfers will have been derived through photosynthesis by phytoplankton.

Longwall mining activities have the potential to open existing joints in the bedrock of these reaches and loss of water and deterioration of water quality are likely.

Fundamental Hydrological Issues

- **Monitoring the sandstone reaches downstream of dams**

  Improvements in the measurement of discharges or flows are required to support all subsequent ecological and water-quality monitoring. This includes measuring the hydraulic properties of flow through channel constrictions, which act as riffle-like forms and are therefore important for habitat, fish passage and invertebrates. Potential water losses due to long wall mining require further investigation.

  Further details of this issue are given in the discussion for Reach 3.

- **Monitoring dam inflows**

  Knowledge of dam inflows underpins the environmental flow program, as knowledge of these flows is required to:

  - calculate the appropriate daily environmental flow releases at any given time; and,
  - assist in the understanding of the links between flow and river health.

  Further details of this issue are given in the discussion for Reach 1.

- **Monitoring of tributary flows**

  Since the tributaries downstream of the dams represent a significant portion of the total catchment flows then the environmental flow rules may (now or in the future) include protection of a portion of the flows from these catchments (ie. the rules will limit the amount of water that can be extracted for consumptive uses). At present the indications are that there will need to be a translucent flow of 20% in the tributaries. This is only of concern for the Nepean River downstream of Pheasants Nest Weir and downstream of the Grose junction in the Hawkesbury River where most extractions are made, as consumptive use in the other rivers is relatively insignificant.

Ecological and Physical Issues

- **Cold water releases from dams**

  The temperature of water released from dams is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper.

  Further details of this issue are given in the discussion for Reach 1.

- **Reduced connectivity – natural barriers**

  Reduced flows over riffle-like habitats, have decreased connectivity for mobile aquatic fauna along river reaches, and at the interface between river and estuarine reaches.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Critical habitat contraction**

  Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities (for example riffles or riffle-like habitats)

  The potential consequences of such habitat contraction are: i) reduced habitat area and diversity, ii) reduced diversity of invertebrates and fish, iii) reduced abundance of invertebrates which use higher-water velocity areas, iv) diminished growth and abundance of fish and platypus which forage within or immediately downstream of riffles and v) reduced spawning/breeding success of riffle-dependent fish species (notably the listed threatened species, the Macquarie perch).

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **General water quality downstream of dams**

  Waters released from dams can impact on downstream receiving water quality. To ensure that these water releases are of satisfactory quality, routine monitoring immediately downstream of the dams is required.

- **Altered biotic communities**

  Modified river hydrology changed fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

  Further details of this issue are given in the discussion for Reach 1.

- **Stratification of natural pools**

  Stratification can have significant impacts on both water quality and pool dependent biota.

  Further details of this issue are given in the discussion for Reach 1.

- **Reduced flushing, scouring and conditioning of habitat**

  It is likely that the reduced duration and frequency of flushing/scouring flows, together with increased nutrient concentrations, have resulted in a build up of algal/detrital material in shallow habitats, and a reduction in the conditioning of stony-bed areas.

  Further details and an illustration of this issue are given in the discussion for Reach 3.

- **Encroachment of riparian vegetation**

  Riparian vegetation and terrestrial weeds encroaching on the river channel as a result of low flows in Reaches 9, 12 and 13.

  Further details of this issue are given in the discussion for Reach 3.

- **Iron-rich groundwater inflows downstream of Avon and Cataract Dams**

  Iron-rich groundwater inflows are a natural feature of many river systems including those of the upper Nepean system. Regulated flows in these systems appear to have resulted in iron-rich groundwater discharges being exposed to the atmosphere for considerable periods of time. When iron-rich groundwater is exposed to the atmosphere the iron oxidises and quickly precipitates leaving a rusty-coloured precipitate. This process is mediated by iron-oxidising bacteria, which can also be seen as a rusty-coloured mass in the water. The occurrence of iron precipitate and iron-oxidising bacteria are particularly evident in the Avon River immediately downstream of the dam and in the Cataract River downstream of Broughtons Pass weir. It appears that a combination of decreased surface flows due to water harvesting and longwall coal mining and reduced scouring and flushing flows has lead to a substantial increase in the occurrence of iron precipitate and iron-oxidising bacteria in these reaches. This renders the waters and associated habitats unsuitable for biota and can lead to the loss of both native plants and animals directly via iron toxicity or indirectly via smothering. It should also be noted that stratification of the water column in dams can also lead to the release of iron from bottom sediments into the water column which, if released, can lead to elevated iron concentrations in downstream receiving waters.

Ancillary Issues

- **Lack of connectivity – diversion and gauging weirs**

  All of the dams and weirs in the upper Nepean River system do not have fishways to provide passage for mobile aquatic fauna. The most upstream of these are the four high-level dams that create the major storages on the Nepean, Avon, Cordeaux and Cataract Rivers. At least nine weirs are present below these dams within the reach limits:

  - Nepean River – one SCA gauging weir, SCA's Pheasants Nest Weir, Maldon Weir (private and almost high-level), and Douglas Park Weir.
  - Avon River – one SCA gauging weir.
  - Cordeaux River – one SCA gauging weir.
  - Cataract River – two SCA gauging weirs and SCA's Broughtons Pass Weir.

  There is a complete lack of knowledge/experience in Australia on the effectiveness of installing fishways on high-level dams. Given this, and because such fishways are very expensive, it is currently not recommended that fishways be installed on the high-level dams in the upper Nepean. However, this situation may change in the next few years given knowledge that will accrue from the monitoring of the effectiveness of the 'fish lift' soon to be installed on the SCA's Tallowa Dam (as discussed under Reach 1).

  Accordingly, fishways are currently only recommended on the weirs and therefore they are the focus of this component. Given that fishways have not yet been trialed for the listed threatened species, Macquarie perch, let alone a range of other native species which occur in the upper Nepean system, it is important that they (or at least representative/key fishways) are monitored to determine their effectiveness for this species. In an adaptive management context, monitoring is required to determine the effectiveness of the fishways and suggest improvements if they are found to be ineffective.

An illustration of this issue is shown in Plate 4 (Reach 1).

- **Stormwater runoff**

  This issue applies only to Reach 13 in this group of reaches.

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  - Reach 8: One site listed on the State Heritage Inventory is within this river reach.
  - Reach 9: One site listed on the State Heritage Inventory is within this river reach.
  - Reach 10: One site listed on the State Heritage Inventory is within this river reach.
  - Reach 11: Two sites listed on the State Heritage Inventory is within this river reach.
  - Reach 12: No recorded cultural heritage items are listed within this area, although cultural heritage places are present.
  - Reach 13: One site listed on the State Heritage Inventory is within this river reach.

  For further information, please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

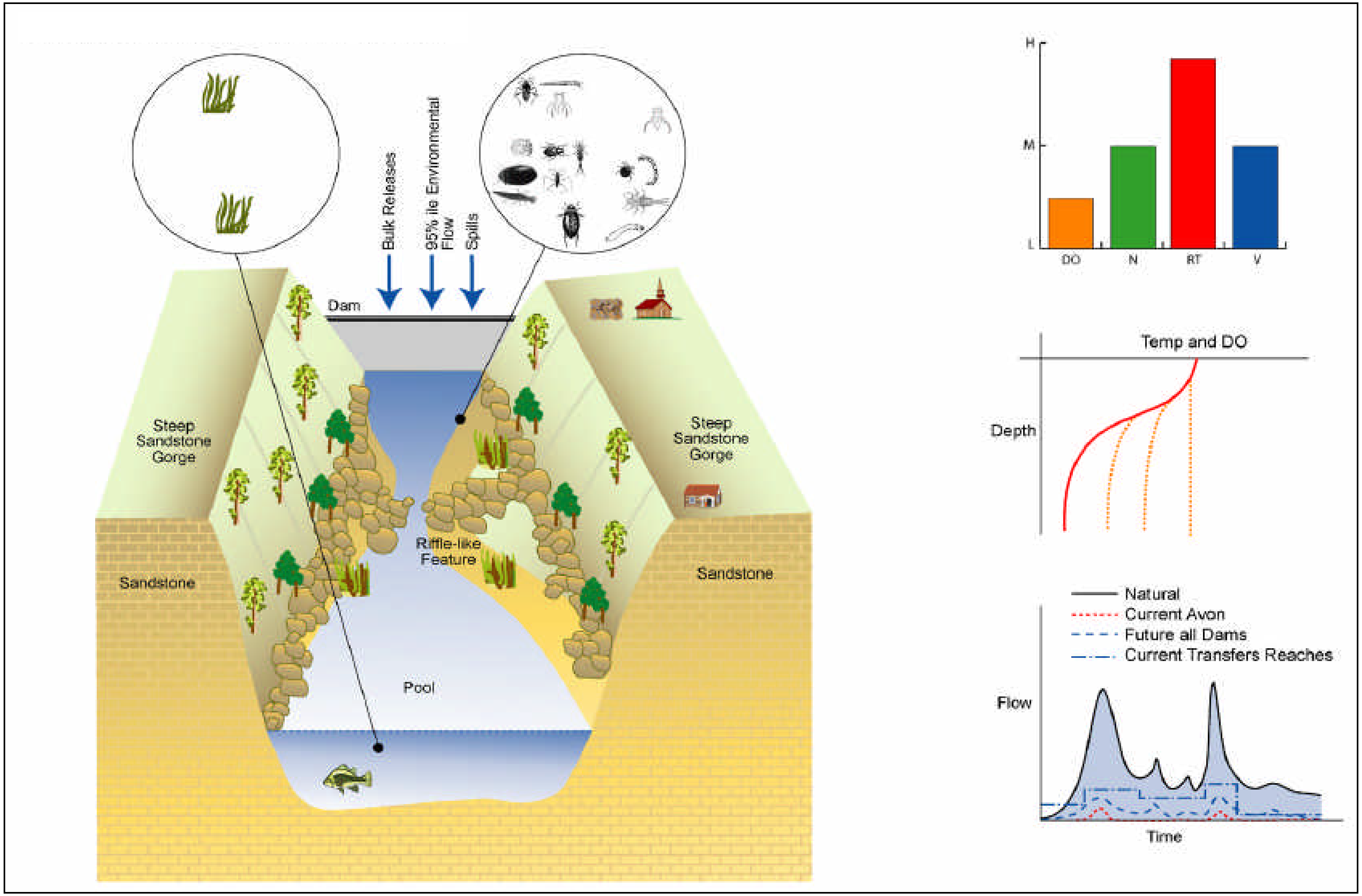
  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Figure B22: Reaches 8, 9, 10, 11, 12, 13 - Current Regime Nepean, Avon, Cordeaux and Cataract Rivers downstream of the dams to the diversion weirs; Nepean and Cataract Rivers downstream of the diversion weirs to the Nepean/Cataract confluence



Recommended Environmental Flow Regime; Reaches 8, 9, 10, 11, 12, 13

The introduction of an environmental flow regime (including contingent flows) will ensure that these gorges will have a flow regime that resembles a natural regime in its variability, frequency and seasonality. There will certainly be improvements in terms of flow enhancement through riffle-like habitats, which should improve the flushing/scouring of algae, flocs and organic sediments, increase the frequency of connectivity between refuge pools and increase the availability critical physical habitat associated with higher water velocities. The magnitudes of flows passing through the dams will only be a fraction of inflows, based on the levels of transparency and translucency in the accepted environmental flow regime. While it is unlikely that flow magnitudes will be sufficient to scour pool-bed sediment accumulations, these accumulations may be moved in occasional spills.

Greater and more regular releases from dams will deplete storage levels and reduce the magnitude of any spills (thereby reducing spill power). In the longer time frame, with the reimposition of DDR conditions and the effects of global warming, all flows (including environmental flows) will be further reduced. Such changes to these flows and those available for urban use will need to be considered as part of longer-term adaptive management.

Future outcomes will depend on what decisions are made regarding the transfer of bulk water supplies. If the rivers continue to be used to transfer bulk water supplies then those reaches will continue to experience highly modified flows. However, the impacts will be modulated by adopting natural rates of change when transfers are commenced and ceased. Also environmental flows would apply during periods when transfers are not taking place. Temperature effects can be modulated by taking water from near the surface during summer. If tunnels are used to transfer bulk water supplies then the environmental flow regime will ensure a more natural regime in terms of variability, frequency and seasonality.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Cold water releases from dams**

  With the introduction of the recommended environmental flows in the Cataract, Cordeaux, Avon and Nepean Rivers, water quality downstream of the dams will improve. Water temperatures will be near natural.

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regimes, together with the contingent flows, will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Critical habitat contraction**

  The recommended environmental flow regimes, together with the contingent flows, will increase the availability of critical habitat associated with higher water velocities and thus increase: i) habitat area and diversity, ii) the diversity of invertebrate and fish fauna, iii) the abundance/biomass of invertebrates which use higher-water velocity areas, iv) growth and abundance of fish and platypus which forage within or immediately downstream of riffles, and v) increase spawning/breeding success of riffle-dependent fish species (notably the listed threatened species the Macquarie perch).

- **General water quality downstream of dams**

  With the introduction of the recommended environmental flows in the Cataract, Cordeaux, Avon and Nepean Rivers, water quality downstream of the dams will improve.

- **Altered biotic communities**

  Improvements in biodiversity and the structure of aquatic communities are expected.

- **Stratification of natural pools**

  Water quality downstream of the dams will improve. Thermal stratification of natural pools will occur less frequently and will be of shorter duration.

- **Reduced flushing, scouring and conditioning of habitat**

  The recommended environmental flow regimes will increase the incidence of flushing, scouring and stony-bed conditioning and thus increase: i) habitat quality and diversity in shallow habitats, ii) the diversity of clean-substrate fauna, iii) the habitat quality of interstitial spaces in stony beds (subsurface flows and dissolved oxygen climate), and iv) the water quality in deep pools.

- **Encroachment of riparian vegetation**

  Reduced flows in these reaches has allowed riparian vegetation and terrestrial weeds to encroach into the river channel in Reaches 9, 12 and 13. In the future, increased flow variability will reduce the potential for encroachment of riparian vegetation and weeds into the river channels by more frequently providing medium to high flows and reducing the frequency of very low flows such that vegetation is scoured from the channel more frequently and/or its growth is disrupted.

- **Iron-rich groundwater inflows**

  Water quality downstream of the dams will improve. The occurrence of iron precipitate in the Avon River downstream of the dam and in the Cataract River downstream of Broughton's Pass will be decreased.

Summary of Key Changes to Ancillary Issues

- **Lack of connectivity – diversion and gauging weirs**

  The installation of effective fishways, with adequate maintenance systems, on dams and weirs, will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:

  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Modifications to the access conditions for river extractors

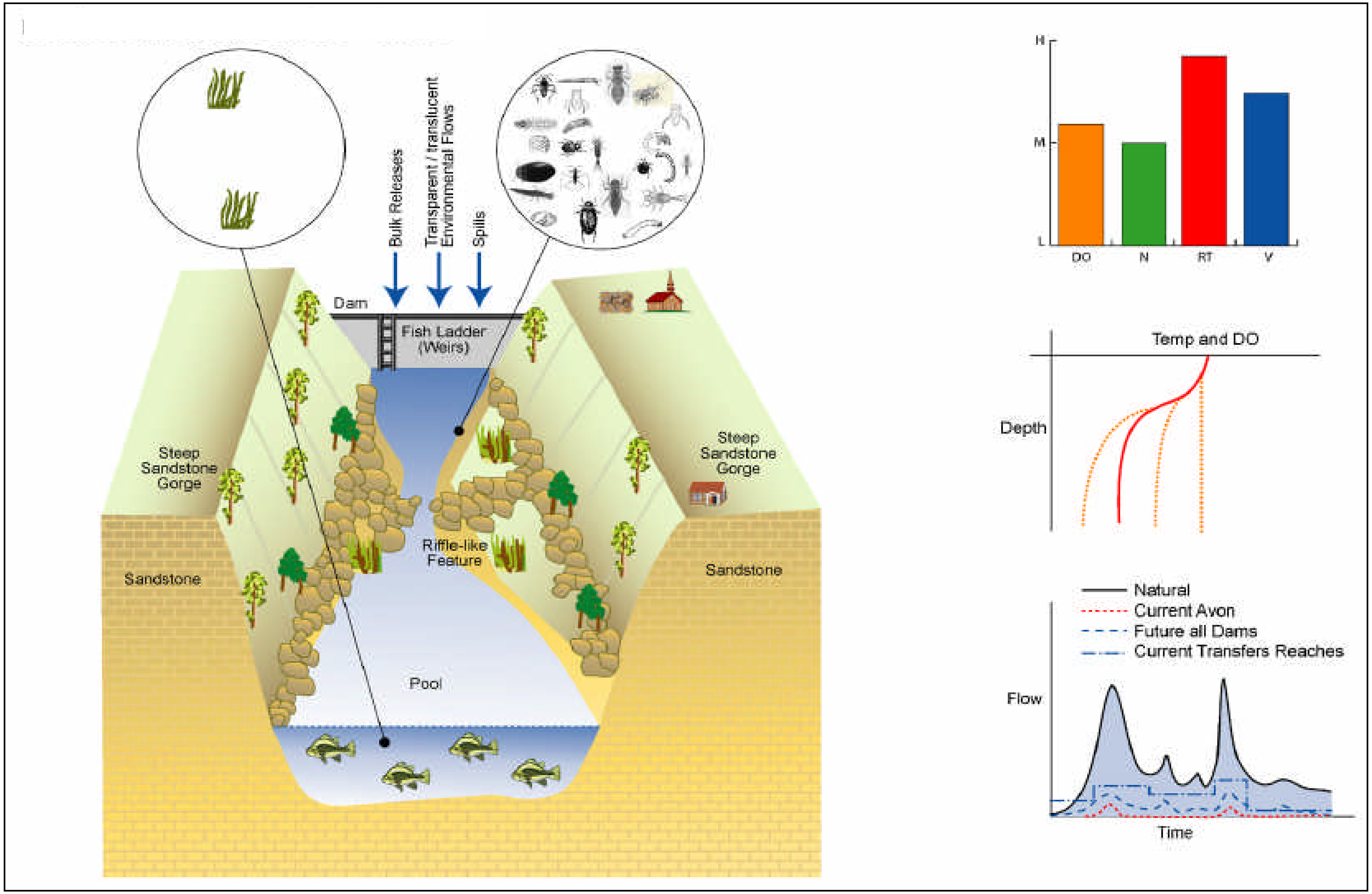
  Further details of this issue are given in the discussion for Reach 1.

  Stormwater management

  Stormwater management is expected to improve water quality, potentially leading to beneficial impacts for commercial fishery activities, recreational fishing, recreational amenity and river-related tourism. The aesthetic values of the river are also expected to improve. Stormwater management strategies primarily address urban runoff and aim to manage the volume and quality of stormwater released during wet weather. These strategies may require new urban developments to utilise water sensitive designs, or retrofitting of old developments. They may require behaviour changes on the part of residents, as well as restricting their housing choices. Building and associated industries are likely to be affected by regulation imposing stormwater management conditions.

  This issue applies only to Reach 13 in this group of reaches.

Figure B23: Reaches 8, 9, 10, 11, 12, 13 – Recommended Environmental Flow Regime Nepean, Avon, Cordeaux and Cataract Rivers downstream of the dams to the diversion weirs; Nepean and Cataract Rivers downstream of the diversion weirs to the Nepean/Cataract confluence

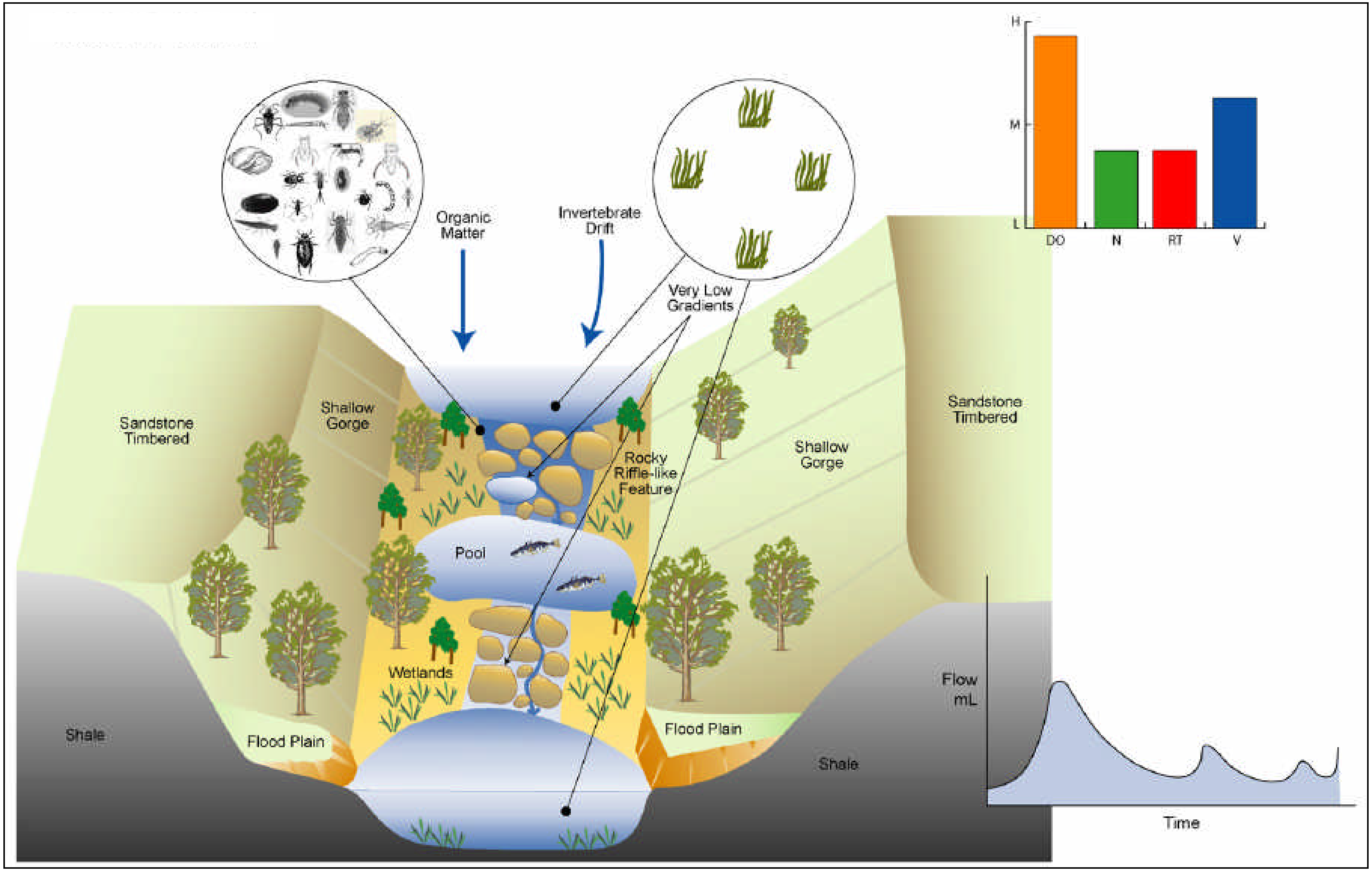


Reach 14: Nepean River from the Cataract River junction to Menangle Weir

Natural Regime; Reach 14

This 12.3 km shallow gorge occupies the toe location of the Illawarra Ramp (sloping plateau) before entering a shale channel downstream of Menangle weir. The low, dissected plateau surface is veneered by shale remnants, which would have been forested together with the gorge slopes. Downstream of the Nepean junction (upstream gradients in Nepean and Cataract are 0.0033 and 0.0111 respectively) the gradient flattened out even under natural conditions to 0.0002 (that is 0.2 m/km as against 3.3 and 11.1 m/km upstream). The lower gorge slopes produced fewer boulders to flank the stream. Much more sand was present in this reach, with alternating sand bars in places. However, the bed had been scoured by turbulent flood flows to form deep holes (eg. The Black Hole). This represents a change from the steep-pool sequences upstream, where boulder riffle-like constrictions would have provided a variety of habitats and fish passage between deeper elongated pools. In view of the low gradient, it appears that riffles would not have existed in this reach. However, in the absence of weirs together with much greater pre-dam flows fish passage would not have been a problem. Energy sources and organic matter would have been derived both from algal photosynthesis and terrestrial leaf litter inputs.

Figure B24: Reach 14 - Natural Regime Nepean River from the Cataract River junction to Menangle Weir



Current Regime and High Priority Issues; Reach 14

The existing gradient was so flat that a small weir at the end of the sandstone gorge was able to create a backwater slope that extended almost to the upstream junction. Water behind the weir drowned most of the low bars and deepened water in the holes. In spite of more sand being added to this reach by clear-water erosion caused by spills below the dams, the holes have survived at about the same depth as in the case of the Black Hole. This was in spite of massive sand accumulation behind the weirs by the 1970s. Upstream sand sources, together with local bank erosion, have provided much of the sand, which accumulated in the downstream chain of weirs. This reach has never been dredged, presumably because of access problems. Stormwater runoff and sewage overflows in wet periods from upstream have introduced water quality problems to this reach but it is not known if the holes are stratified in summer. Most of the trees on the plateau have been removed for farming. Thus local increases of water and fine sediment discharge would have been added to the channel, but areas of such contributions are small. Irrigation extractions occur from the Menangle Weir pool. The aquatic biota would have been radically changed with the installation of the weir, forming a suite of biota more indicative of a lake than a river system. The importance of terrestrial inputs into the aquatic ecosystem would have substantially decreased, with almost all energy sources being derived from instream photosynthesis.

Flows in this reach have been significantly reduced by the operation of the dams and transfer weirs, particularly the low and moderate flows. The current environmental releases are constant and so there is a loss of variability and during low flows these flows do not pass beyond the weir due to extractions and transmission losses.

Fundamental Hydrological Issues

- **Monitoring the sandstone reaches downstream of dams**

  Improvements in the measurement of discharges or flows are required to support all subsequent ecological and water-quality monitoring. This includes measuring the hydraulic properties of flow through channel constrictions, which act as riffle-like forms and are therefore important for habitat, fish passage and invertebrates. Potential water losses due to long wall mining require further investigation.

  Further details of this issue are given in the discussion for Reach 3.

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Cold water releases from dams**

  The temperature of water released from dams is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper.

  Further details of this issue are given in the discussion for Reach 1.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  The distribution of macrophytes species is related to several inter-related factors including flow rate, habitat availability, seasonal variations, water quality, recruitment sources and current composition of beds. Regulation of the Hawkesbury-Nepean River is generally considered to have changed the distribution of macrophytes by changing the channel morphology, flow rates and nutrient levels. Changes to channel morphology caused by changes to the flow regime, sediment starvation and sand extraction, has reduced the available habitat for macrophyte beds within the Hawkesbury-Nepean system.

Of the submerged macrophyte species recorded in the Hawkesbury-Nepean River, two species (*Egeria densa* and *Elodea canadensis*) are exotics of concern (Taylor-Wood 2002). *Elodea canadensis* is currently primarily located in the weir reaches (Menangle to Camden), forming monospecific beds around Camden-Cobbitty (Figure B25). In comparison, *Egeria densa*, is the dominant macrophyte species in the Hawkesbury-Nepean River downstream of the Warragamba River confluence (Figure B25). While the presence of macrophytes is considered to be healthy as they provide a nutrient sink and habitat for a range of fauna species, excessive growth by either native or exotic species can be detrimental. *Where Elodea canadensis* and *Egeria densa* occurs in high densities, native macrophyte species are out competed, resulting in macrophyte beds of decreased diversity (almost monospecific in some cases). Excessive growth such as this can also cause associated changes in aquatic fauna. In some reaches of the Hawkesbury-Nepean River, the growth of *Elodea canadensis* and *Egeria densa* almost covers the entire river channel, with it only not found in areas where water flows fastest (main channel). Excessive growth such as this slows water flows, interferes with boating, prevents swimming and fishing, and has the potential to affect infrastructure when it is transported during high flows (eg. snapping ferry cables).

Floating macrophytes currently of concern in the Hawkesbury-Nepean River are Alligator Weed *Alternanthera philoxeroides*, Ludwigia *Ludwigia peruviana*, Salvinia *Salvinia molesta* and Water Hyacinth *Eichhornia crassipes* (Figure B26, Taylor-Wood 2002). Alligator Weed has been observed in outbreaks in the Nepean River at Menangle, Camden and Bents Basin downstream to Wallacia. In addition, outbreaks of Alligator Weed, Ludwigia, Salvinia and Water Hyacinth have all been recorded between Penrith Weir and Yarramundi. As Alligator Weed is known to invade irrigation areas as well as being able to spread to surrounding terrestrial areas it is of particular concern to agricultural and turf industries along the Hawkesbury-Nepean River as it can potentially cause a significant loss of production and increased costs. Other species of concern which are known to occur in the local area but have not been recorded directly associated with the Hawkesbury-Nepean River or if they have been recorded, have not been recorded in excessive numbers are Lagarosiphon *Lagarosiphon major*, Senegal Tea Plant *Gymnocoronis spilanthoides* and Water Lettuce *Pistia stratiotes* (Figure B26). All of the species mentioned above have been declared noxious weeds within local council areas bordering the Hawkesbury-Nepean River and have the potential to invade waterways and wetlands. The Hawkesbury River County Council currently undertakes mechanical and chemical control of noxious weeds within the local council areas of Penrith, Blacktown, Hawkesbury and Baulkham Hills including Alligator Weed, Salvinia and Water Hyacinth outbreaks associated with the Hawkesbury-Nepean River. In addition, biological control agents have been released for Alligator Weed, Salvinia and Water Hyacinth with varying success rates.

Excessive growth of submerged and floating macrophytes in the Hawkesbury-Nepean River is most likely a result of increased nutrient levels and low, slow flows - reduced water flows partially as a results of excessive macrophyte growth but also channel modification/structure in this area eg. weirs, sediment accretion, channel widening (Taylor-Wood 2003b,c,d). Downstream of Wilberforce, while there is increased nutrient levels (especially downstream of South Creek), increased turbidity, salinity, depth and flow rates reduces the potential for excessive growth.

In Reach 14, the main issues of concern are:

- Loss of native macrophytes due to the excessive growth of exotic macrophyte species, and
- Potential for the distribution of Alligator Weed to increase as a result of environmental flows leading to a subsequent loss in agricultural production.

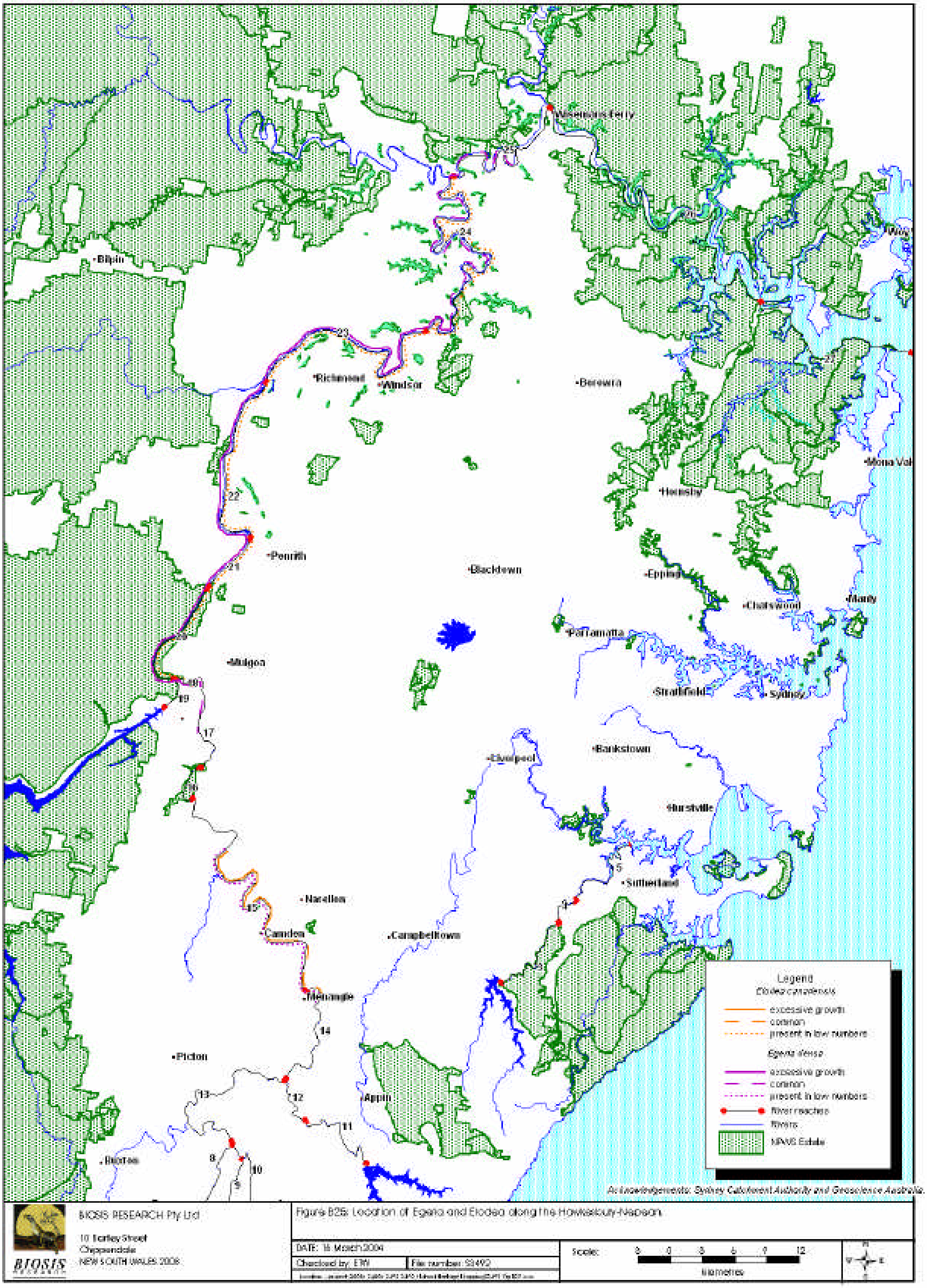


Figure B25: Location of *Egeria* and *Elodea* along the Hawkesbury-Nepean River

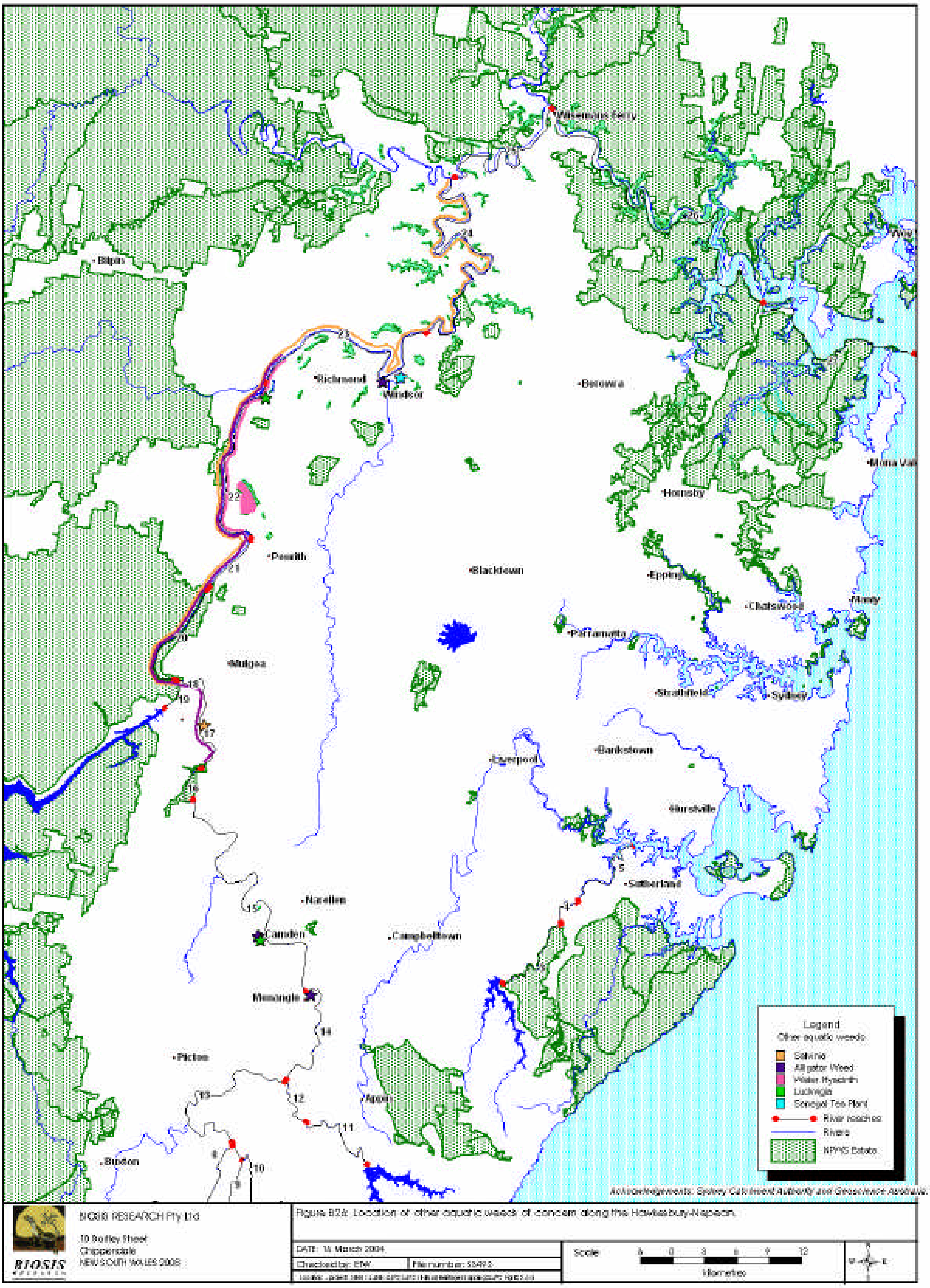


Figure B26: Location of other aquatic weeds of concern along the Hawkesbury-Nepean River

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

- **Stratification of natural pools**

  Stratification can have significant impacts on both water quality and pool dependent biota.

  Further details of this issue are given in the discussion for Reach 1.

Ancillary Issues

- **Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management**

  A combination of altered/regulated flows and irrigation extractions particularly during dry conditions have the potential to cause stratification in deep weir pools and to cause the river to cease to flow immediately downstream of the weir pool. The increased retention time of water in deep weir pools combined with diffuse and point source nutrient inputs can cause hostile water quality conditions including the occurrence of potentially toxic cyanobacteria together with anoxic bottom waters.

  Stratification can have significant impacts on both water quality and associated biota. For example, during stratification events:

  - dissolved oxygen concentrations in the poorly mixed bottom waters are reduced and over time can approach zero;
  - these anoxic bottom waters can potentially be lethal to oxygen requiring aquatic biota including fish;
  - sediments associated with anoxic bottom waters can release iron, manganese, phosphorus and nitrogen; and
  - habitat availability can be diminished and predation can potentially increase.

  The increased variability in the volumes of water transmitted through weir pools will lead to more turbulent mixing and less frequent thermal (and oxygen) stratification. The introduction of discharge valves into these weirs will aid in the transmission of water through the weirs and will reduce retention time. In addition, the introduction of the effluent management strategy and reduced discharges of treated sewage effluent into Sharpes Weir pool which will result in improved water quality. As a consequence, hostile water quality at depth in these pools will occur less frequently as will the occurrence of potentially toxic cyanobacterial blooms.

- **Channel changes in weired reaches**

  The reaches from Cataract junction to Menangle, from Menangle to Campbells Crossing, from Bents Basin to Wallacia, and from Warragamba junction to Penrith Weir will need to be resurveyed at some stage for several reasons:

- to help determine present weir storage capacities (they have changed much due to the impacts of sand and soil removals, to sediment starvation imposed by dams, to the high flow impacts of the last FDR and to other anthropogenic impacts);
- to determine the amount, nature and location of changes since the last surveys (these have been both variable in space and time but they will help determine the impacts of dredging and sediment movement);
- to determine present base-line conditions prior to the removal of any weirs (the latter may require an EIS and subsequent monitoring to assess the nature of channel adjustment; without current base-line data such exercises will be futile);
- to obtain knowledge of present dimensions to ascertain the impacts of environmental flows on local hydraulics and ecology (channel enlargement reduces the impact of environmental flows and the degree of this impact will affect the positive role of introduced flows);
- to determine the impact of spills on current dimensions both in terms of bank and bed changes; and
- to determine channel capacities for use in estimating surcharging discharge levels required to produce floods (estimates of bankfull discharges have changed from once in 2.33 years or less when the channel had sanded up in the 1970s to once in 30 to 40 years now with the great enlargement of channel through dredging).

Although some work has been done since the 1970s, much of this is now dated and cannot be used as reliable base-line data.

- **Stormwater runoff**

In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

Social values

Further details of this issue are given in the discussion for Reach 1.

Heritage values

Three sites listed on the State Heritage Inventory is within this river reach. Please see Appendix B1.

Aboriginal values

Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

Irrigation extraction

Further details of this issue are given in the discussion for Reach 1.

Riparian extraction

Further details of this issue are given in the discussion for Reach 2.1.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

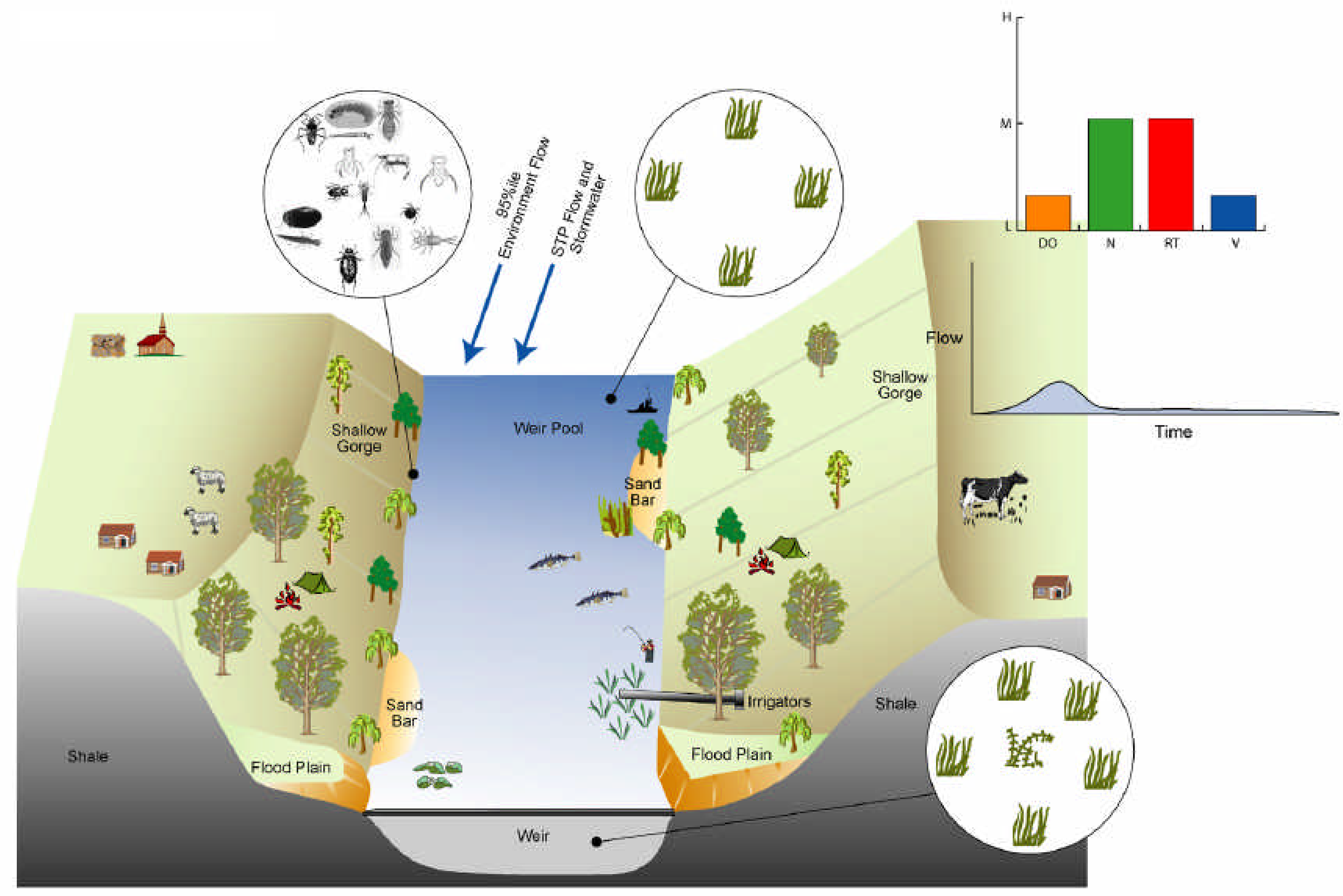
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B27: Reach 14 - Current Regime Nepean River from the Cataract River junction to Menangle Weir



Recommended Environmental Flow Regime; Reach 14

This reach will receive combined environmental flows the upper Nepean River dams. The proposed environmental flows will enhance the low to moderate flows and substantially restore natural variability. Velocities through this reach will be much lower than upstream and it seems unlikely that they would induce much sand scouring. Upstream water quality should improve with greater flows and better source management. However, it is imperative that fish passage and environmental flows are allowed to pass through the weir. With the introduction of environmental flows the upstream end of the weir pool will have inputs of terrestrially derived energy and organic matter. However, the terrestrial inputs will still be of small importance compared to instream photosynthetic processes.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Cold water releases from dams**

  With the introduction of the recommended environmental flows in the Cataract, Cordeaux, Avon and Nepean Rivers, water quality downstream of the dams will improve. Water temperatures will be near natural.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently *Elodea canadensis* and *Egeria densa* are both found in this reach but as yet that have not replaced the native macrophyte beds. In the future increased flow variability combined with nutrient reduction will reduce the potential for exotic macrophytes species such as *Elodea canadensis* and *Egeria densa* to replace native macrophyte beds as has occurred downstream. Alligator Weed and Ludwigia have also been recorded in this reach and it is expected that environmental flows along with nutrient reduction will reduce the potential for excessive growth of these and other aquatic weed species.

  As Alligator Weed has been recorded in this reach it has the potential to affect irrigation/agricultural areas that rely on water from the river or have river frontages. In the future, increased flow variability combined with nutrient reduction will help to reduce the abundance of Alligator Weed. While flows in the river will increase on average, it is not expected that these flows will increase the distribution of Alligator Weed above that which would occur as a result of the current flow regime.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

- **Stratification of natural pools**

  Water quality downstream of the dams will improve. Thermal stratification of natural pools will occur less frequently and will be of shorter duration.

Summary of Key Changes to Ancillary Issues

- **Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management**

  Water quality in and downstream of the weirs will improve with the introduction of the recommended environmental flows, the implementation of the effluent management strategy and the installation of gates or valves in the weirs. Thermal stratification in the weirs will occur less frequently and will be of shorter duration. Cyanobacterial blooms will occur less frequently, nutrient concentrations will trend downwards and overall water quality will improve.

- **Channel changes in weired reaches**

  Re-survey of channel cross section will reveal channel changes that might influence the adaptive management process for the implementation of environmental flows.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Catchment transfers

  Further details of this issue are given in the discussion for Reach 1.

  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

  Effluent reuse strategy

An effluent reuse strategy will substitute river water with treated effluent, primarily for purposes of agricultural irrigation but also for reintroduction into the River as flows. Consequently, water extraction from and sewage effluent discharge to the river are expected to decrease.

The reuse strategy has potential adverse impacts for affected river extractors, related to the costs they must bear and the characteristics of recycled effluent provided. The costs of obtaining treated effluent are expected to raise concerns if they are significantly higher than the current cost of extracting water from the river. These costs include not only the effluent itself but also associated equipment and required safety procedures. Costs will be particularly important where effluent is provided at locations where weir management is also being implemented. Inequity may arise or be seen to arise, if the cost of recycled effluent or other water supplies differs across extractors.

The characteristics of recycled effluent are relevant for river extractors, including reliability, water quality, volume and pressure. A reuse strategy may have adverse impacts for irrigators in that certain crops cannot be grown with the recycled effluent, significant changes to farming practices are required, or the long term exposure to recycled effluent causes soil to become increasingly saline or otherwise polluted. Some industrial consumers may require a high quality grade of recycled effluent for their operations.

The issue of recycled effluent characteristics interacts with the issue of costs, because higher grades of recycled effluent are expected to be more expensive. Finally, consumer reaction to crops grown with recycled effluent may lead to an adverse impact for irrigators if they face lower market demand.

The beneficial impacts arise primarily from the reduction of sewage effluent discharges to the river and resultant improvements in water quality. For river extractors the supply of recycled effluent is likely to be more reliable than the river and the nutrients contained may lead to some cost savings. Recreational activities, tourism, commercial fishery activities and recreational fishing are also expected to benefit.

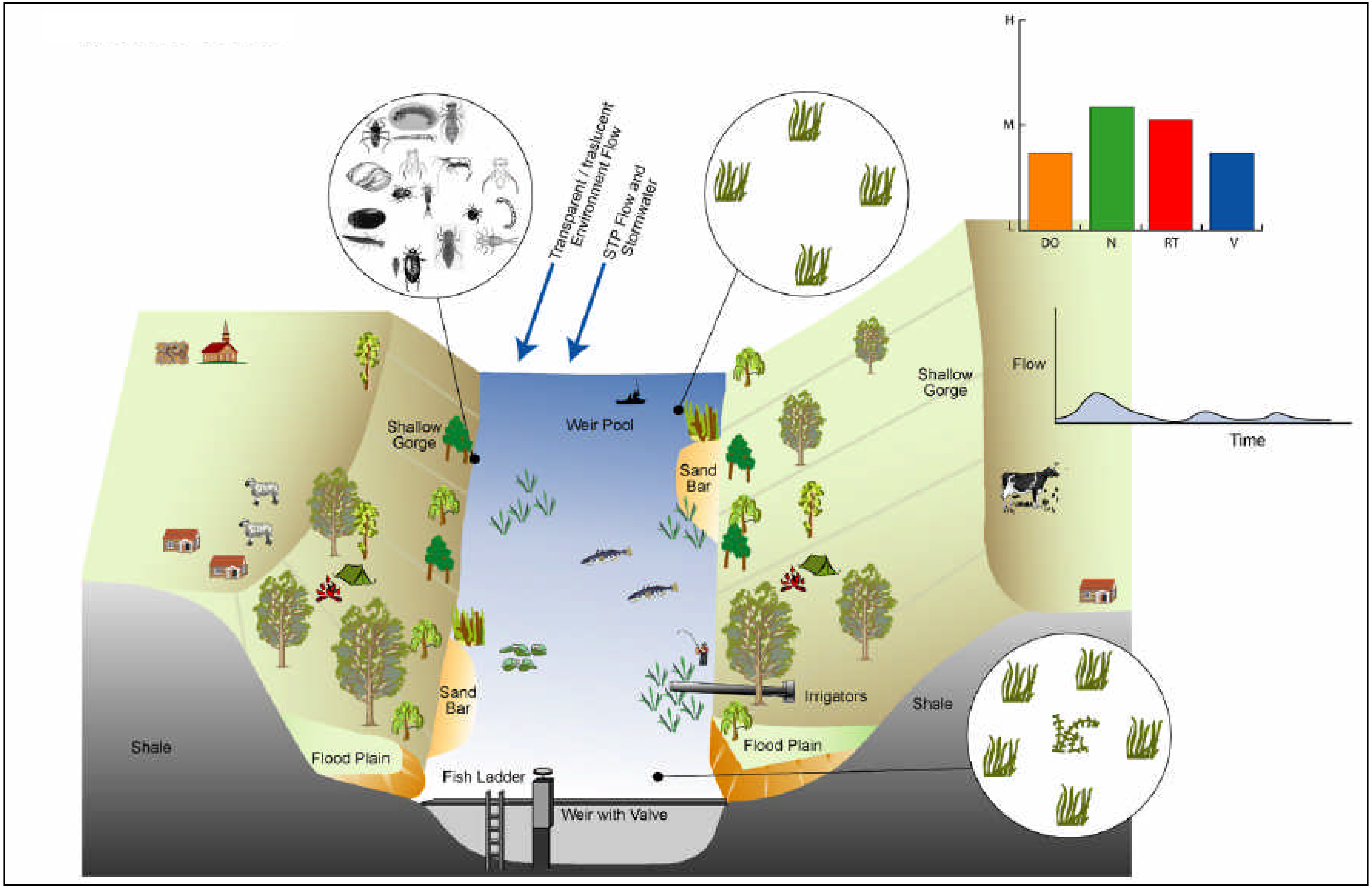
Weir Management

The weirs on the river vary greatly in working characteristics and states of repair. Weir management may include weir modification, repair of weir structures and fishways, or removal. Weir management is expected to increase the beneficial impacts of environmental flows. Weirs are valued by river stakeholders and local communities for a number of reasons. Weir structures may be a feature of the local heritage that contributes to residents' sense of place. Weir pools provide greater reliability of supply for irrigators drawing from the weir pool. Weir pools are also used for recreational fishing and other recreational activities.

Impacts of weir management will vary depending upon the extent of changes made and the way they are managed. Adverse impacts potentially arise if changes to the visual appearance of the weir affect the sense of place for local residents or the aesthetic value of the weir site. Any reductions in the level of the weir pool following modification are expected to reduce the reliability of supply for irrigators extracting from the weir pool. In addition, lower weir pool levels may reduce opportunities for recreational users.

The construction or repair of fishways has long-term beneficial impacts for commercial and recreational fishers. These include improving the movement and breeding of fish in the freshwater reaches.

Figure B28: Reach 14 – Recommended Environmental Flow Regime Nepean River from the Cataract River junction to Menangle Weir

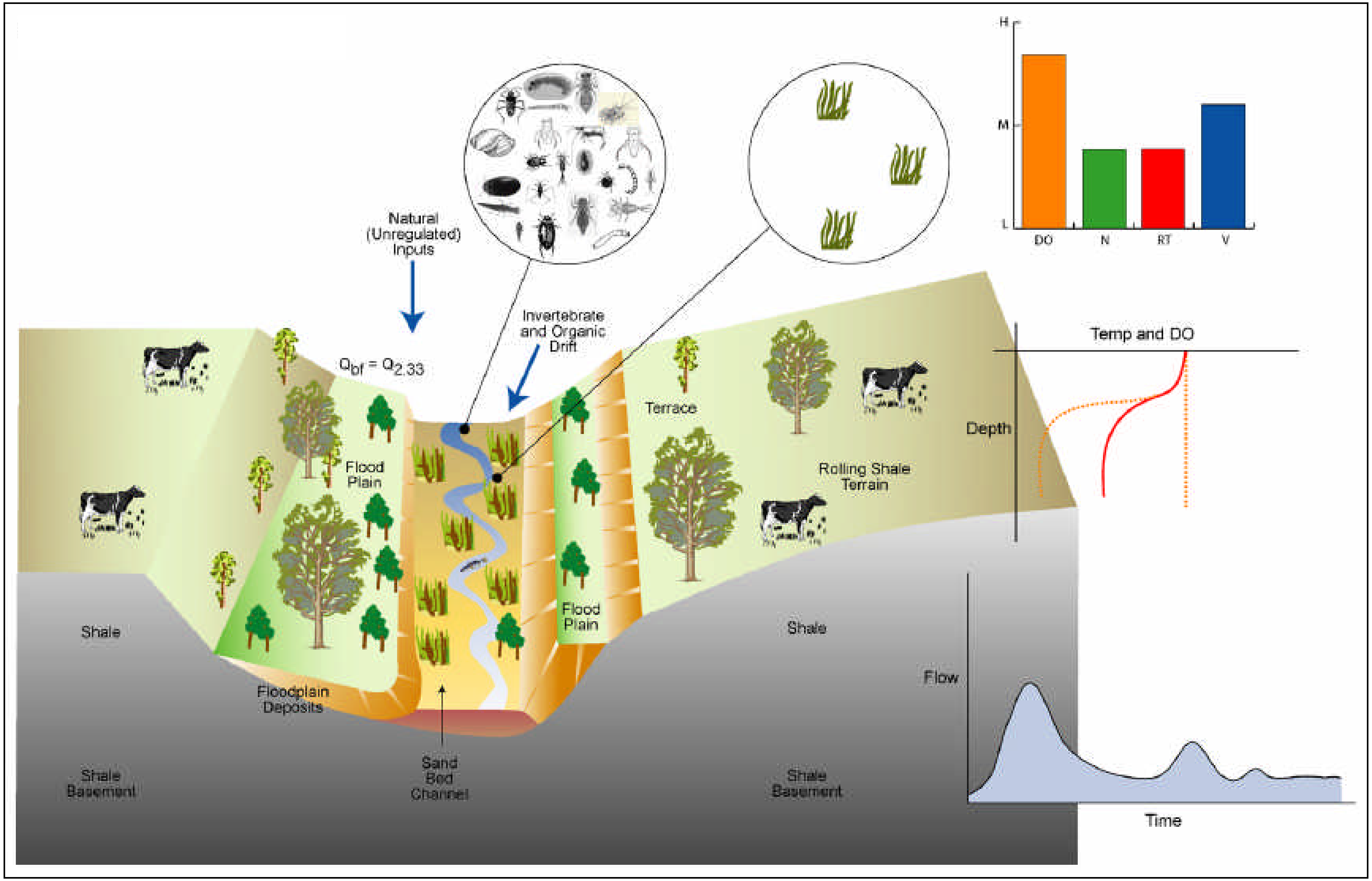


Reaches 15 and 17: Nepean River from Menangle Weir to Wallacia Weir (excluding the Bents Basin Gorge). These reaches include 10 compensation weirs.

Natural Regime; Reaches 15, 17

Reach 15 is 32 km long, with a mean slope of 0.0006, while Reach 17 is 12.5 km and has a mean slope of 0.0003. It is hard to say what the natural channel in this alluvially flanked shale reach would have looked like under natural conditions. The channel would have been in much the same location but it has been much modified by weirs, post-weir sedimentation and subsequent extractions. This is an alluvial channel, flanked by narrow floodplains and in places by fossil floodplains (terraces). These and the rolling shale lands would have been forested. The system was too big for a chain-of-ponds system, although its shale tributaries would probably have had such a form, with intermittent low energy runoff contributing little to the main stream, compared with natural flows from higher on the much wetter sandstone ramp. Much of this part of the valley is in a rain shadow area, with rainfall well below 1000mm, compared with over 1500mm on the escarpment. With upstream sand sources, low gradients and little energy (except in floods), it would seem that the channel might have been floored by sand. The low flow stream may have threaded its way between alternate sand bars, which created some local relief on the channel floor. Floods would undoubtedly have scoured holes in the sandy substrate, probably up to half the depth of flow, depending on depth of sand present. Such holes may well have infilled during the recession of the hydrograph. Thus in dry times these long sandy channels may have posed a barrier for fish movement but periodic high-flow connectivity at low velocities would have permitted passage. Energy sources would have been primarily derived from instream photosynthesis by algae and aquatic macrophytes. Habitats for invertebrate species would be largely different in this reach compared to any of the more upstream areas, mainly due to the differences in substratum. The main habitat types would have primarily been emergent and submerged aquatic plants and sediment.

Figure B29: Reaches 15, 17 - Natural Regime Nepean River from Menangle Weir to Wallacia Weir (excluding the Bents Basin Gorge).



Current Regime and High Priority Issues; Reaches 15, 17

This gentle gradient but continuous stream has been greatly modified by the presence of seven weirs in the upper reach and one in the lower. These were located so that their crests ponded water back as far as the foot of the next weir upstream. Thus the reaches were compartmentalised, restricting movement of fish, water and sediments, and their gentle gradients became stepped between long flat stretches. Adjacent shale and alluvial lands were cleared for grazing and cropping and the weirs were installed to provide water for riparian owners, as the dams were cutting off continuous flows from upstream. Urbanisation around Camden has introduced stormwater runoff and effluent from the STP to these often, stagnant ponds. Thus water quality has deteriorated. Rural runoff is lower in unit yield and has been intercepted in shale areas by many farm dams. Major problems of today came about because of attempts to alleviate sedimentation problems, increase weir pond capacities and decrease potential flooding. By the 1970s many weirs ponds were greatly reduced by sand sedimentation behind weirs. It was so bad that trees were beginning to appear on these deposits. Sand and soil extractions were deemed to be the solution. They increased the weir ponds, cut down flood potentials, provided aggregate and cleaned up the river but dredging holes have become areas of stratification and environmental flows, such as they are, cannot pass through weirs. Existing fishways are thought to be inappropriate and compartmentalisation has become more pronounced. Flows have been reduced by the operation of the dams and diversion weirs. Large volumes of water are extracted for irrigation (10.3 GL/yr SMEC 2002); evaporation is probably in the order of 3 to 4 GL/yr with increased water areas; and 2.7 GL/yr of effluent is added from Camden and 0.2 GL/yr from Warragamba (SMEC, 2002). The main energy sources and macroinvertebrate habitats would not have greatly changed. However, the lower flow velocities in the weir pools may have encouraged a more lake type of biota than a natural river biota.

Fundamental Hydrological Issues

- **Monitoring of weired shale reaches below the dams**

  Soil and sand aggregate removal from weired alluvial reaches above Wallacia (no dredging above Penrith Weir but clear-water erosion caused by the nearness of Warragamba Dam) inset in Wianamatta Shales, have greatly increased widths, depths, cross-sectional areas and channel capacities, thereby creating stratification problems in dredged pools, decreased overbank surcharging (reducing flood incidence to the 1 in 30 to 40 year event in some places) and considerably reducing channel-wetland connections. Such changes will probably decrease the effectiveness of environmental flows. Thus flow measurements and verification that environmental flows pass through the weirs will need to be checked at certain weir locations. Such data will also be needed for other ecological and water-quality monitoring planned for these reaches.

  These reaches are adjacent to fertile shale and alluvial lands. Consequently anthropogenic impacts have been high. Also, because the alluvial channels are less stable, responses to anthropogenic impacts (dams, weirs, dredging, land-use changes, irrigation extractions, rural and urban runoff) and to natural regime variations (FDRs and DDRs plus global warming) have and will be more significant than in sandstone gorges.

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Cold water releases from dams**

  The temperature of water released from dams is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper.

Further details of this issue are given in the discussion for Reach 1.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reaches 15 and 17, the main issues of concern are:

  - Loss of native macrophytes due to the excessive growth of exotic macrophyte species; and,
  - Potential for the distribution of Alligator Weed to increase as a result of environmental flows leading to a subsequent loss in agricultural production.

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Ancillary Issues

- **Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management**

  A combination of altered/regulated flows and irrigation extractions have the potential to cause stratification in deep weir pools and, in addition, the river may cease to flow immediately downstream.

  Further details of this issue are given in the discussion for Reach 14.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  The ongoing protection of environmental flows requires that irrigated agriculture be maintained on the Hawkesbury-Nepean floodplain in a sustainable manner. To ensure sustainable agriculture (and in so doing maintaining demand for rural effluent) requires a three-staged approach:

  - Firstly, undertake soil and hydrogeological investigation to identify lands suitable for land based disposal of treated effluent;
  - Secondly, provide security of tenure for those rural activities which have the potential to receive treated effluent for irrigation purposes; and,
  - Thirdly, to encourage farmers to use treated sewage effluent for irrigation purposes.

  It is important therefore to provide a mix of regulation, incentives and education to provide greater security of tenure for working farms in Sydney and the surrounding area and to encourage agricultural producers to use irrigated treated effluent as a substitute for water abstraction. None of these responses can succeed alone but together they may ultimately facilitate the reuse of significant levels of treated effluent with the associated benefits for the Hawkesbury Nepean River.

  The productivity of crops, pastures or turf grown in the region could be reduced because of salinity or other degradation in soil quality. Treated effluent water has higher salinity than river or rainwater. This could lead to a build up of salt in soil particularly during dry years when a significant portion of plant water requirements are met with effluent irrigation and there is little leaching of salt due to natural rainfall events. The problem will be greatest on soils already, or prone to being, affected by salinity. For example poorly drained soils are prone to salinity.

Treated effluent can also have high levels of sodium which may increase the concentration of sodium ions relative to other cations in the soil. On soils with significant clay contents this can lead to dispersion of clay minerals and a subsequent reduction in soil permeability and aeration which in turn will lead to lower plant productivity. This issue is of less concern in light sandy soils. Sodicity can be overcome by regular applications of lime or gypsum.

Contaminants in reclaimed water could leach into local groundwater tables thereby impacting directly on the value of the groundwater resource and indirectly on the river through shallow connections between ground and surface waters. Contaminants of concern are nitrogen (in particular nitrate), phosphorus and salt as well as pathogens, heavy metals, organochlorines and other potential groundwater contaminants.

- **Channel changes in weired reaches**

  Channel changes in weired reaches need to be resurveyed for management and interpretation of other monitoring relating to weir pools.

  Further details of this issue are given in the discussion for Reach 14.

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  - Reach 15: Five sites listed on the State Heritage Inventory is within this river reach.
  - Reach 17: Three sites listed on the State Heritage Inventory is within this river reach.

  For further information, please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Industrial extraction

  Further details of this issue are given in the discussion for Reach 2.1.

  Riparian extraction

Further details of this issue are given in the discussion for Reach 2.1.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

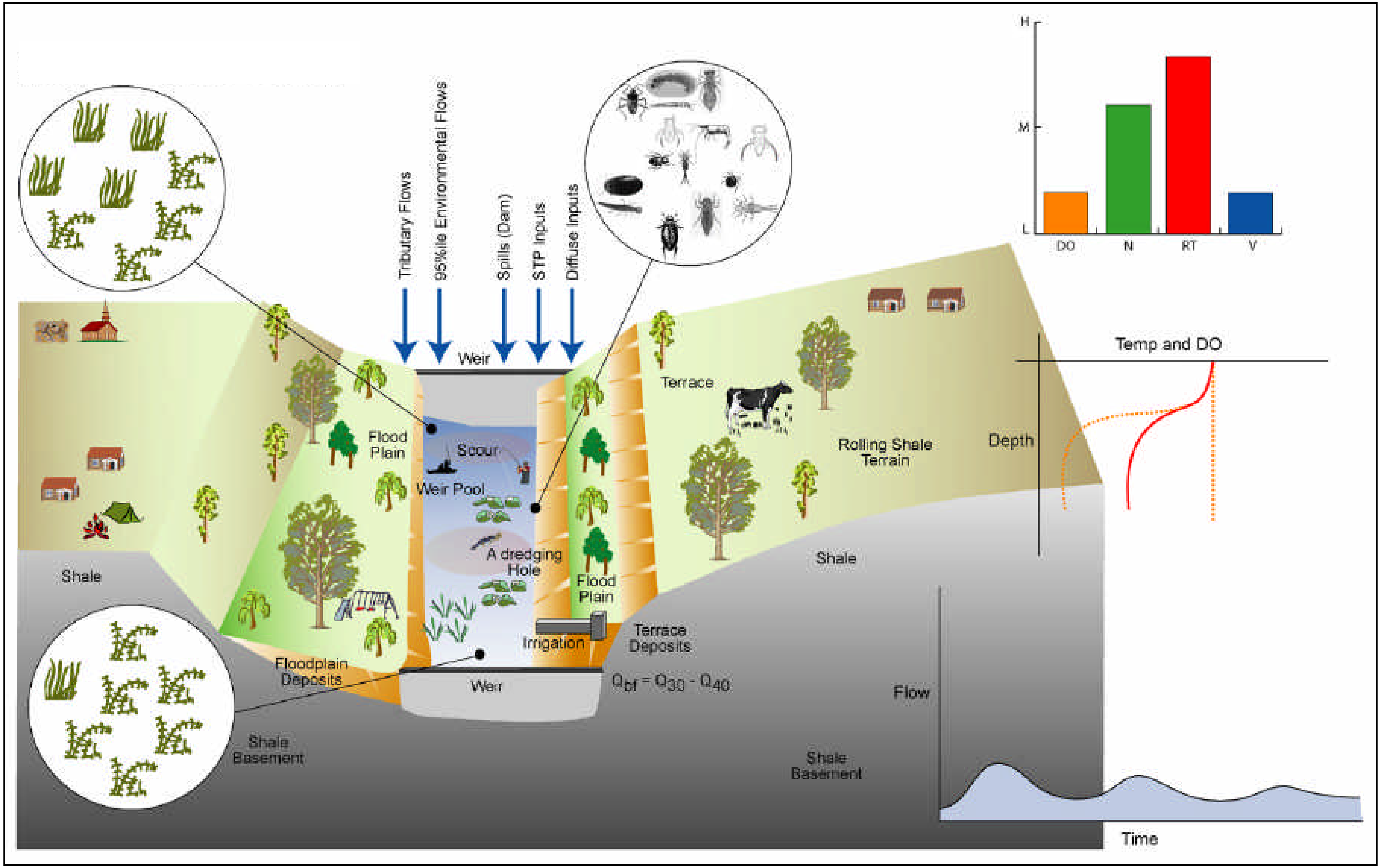
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B30: Reaches 15, 17 - Current Regime Nepean River from Menangle Weir to Wallacia Weir (excluding the Bents Basin Gorge)



Recommended Environmental Flow Regime; Reaches 15, 17

With advocated environmental flows and their passage through weir valves, together with more appropriate fish ladders, and the diversion of effluent for irrigation, the ecology in these compartmentalised reaches should improve. The efficiency of environmental flows through greatly enlarge stretches of channel will not be as high as in upstream gorges but improved connectivity and flow will help. Stratification problems will need specific flows to help with their removal. Potential removal of some weirs will merely lengthen some of the compartments and help recreate natural slopes by removing backwater ponding. The increased gradient and spill flows will rework bed sands downstream and there will need to be careful observations made on potential problems from such actions. With increased instream velocities from environmental flows, the lake-like biota should return to a more river-like biota.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Cold water releases from dams**

  Water quality downstream of the dams will improve. Water temperatures will be near natural.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently *Elodea canadensis* and *Egeria densa* are both found in this reach, with native macrophyte beds often replaced with monospecific beds of *Elodea canadensis*. In the future increased flow variability combined with nutrient reduction will reduce the growth and distribution of exotic macrophytes species such as *Elodea canadensis* and *Egeria densa* as well as reduce any further loss of native macrophyte beds in these reaches. Alligator Weed and Salvinia have also been recorded in this reach and it is expected that environmental flows along with nutrient reduction will reduce the potential for excessive growth of these and other aquatic weed species.

  As Alligator Weed has been recorded in these reaches it has the potential to affect irrigation/agricultural areas that rely on water from the river or have river frontages. In the future, increased flow variability combined with nutrient reduction will help to reduce the abundance of Alligator Weed. While flows in the river will increase on average, it is not expected that these flows will increase the distribution of Alligator Weed above that which would occur as a result of the current flow regime.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

Summary of Key Changes to Ancillary Issues

- **Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management**

  Water quality in and downstream of the weirs will improve with the introduction of the recommended environmental flows, the implementation of the effluent management strategy and the installation of gates or valves in the weirs. Thermal stratification in the weirs will occur less frequently and will be of shorter duration. Cyanobacterial blooms will occur less frequently, nutrient concentrations will trend downwards and overall water quality will improve.

- **<u>Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy</u>**

  Sustainable agriculture will ensure that reclaimed water from sewage effluent is used to its maximum extent, thus protecting the quality of the environmental flow releases.

  Monitoring of groundwater in areas used for irrigation of reclaimed water from sewage effluent will ensure that groundwater and surface water resources are protected.

- **<u>Channel changes in weired reaches</u>**

  Re-survey of channel cross section will reveal channel changes that might influence the adaptive management process for the implementation of environmental flows.

- **<u>Stormwater runoff</u>**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

<u>Summary of Key Changes to Social, Economic, Cultural and Heritage Issues</u>

- **<u>Social and cultural values</u>**

  Further details of this issue are given in the discussion for Reach 1.

- **<u>Institutional performance</u>**

  Further details of this issue are given in the discussion for Reach 1.

- **<u>Land and river activities</u>**

  <u>Environmental flow releases from dams</u>

  Further details of this issue are given in the discussion for Reach 1.

  <u>Demand management - river extractors</u>

  Further details of this issue are given in the discussion for Reach 1.

  <u>Modifications to the access conditions for river extractors</u>

  Further details of this issue are given in the discussion for Reach 1.

  <u>Stormwater management</u>

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

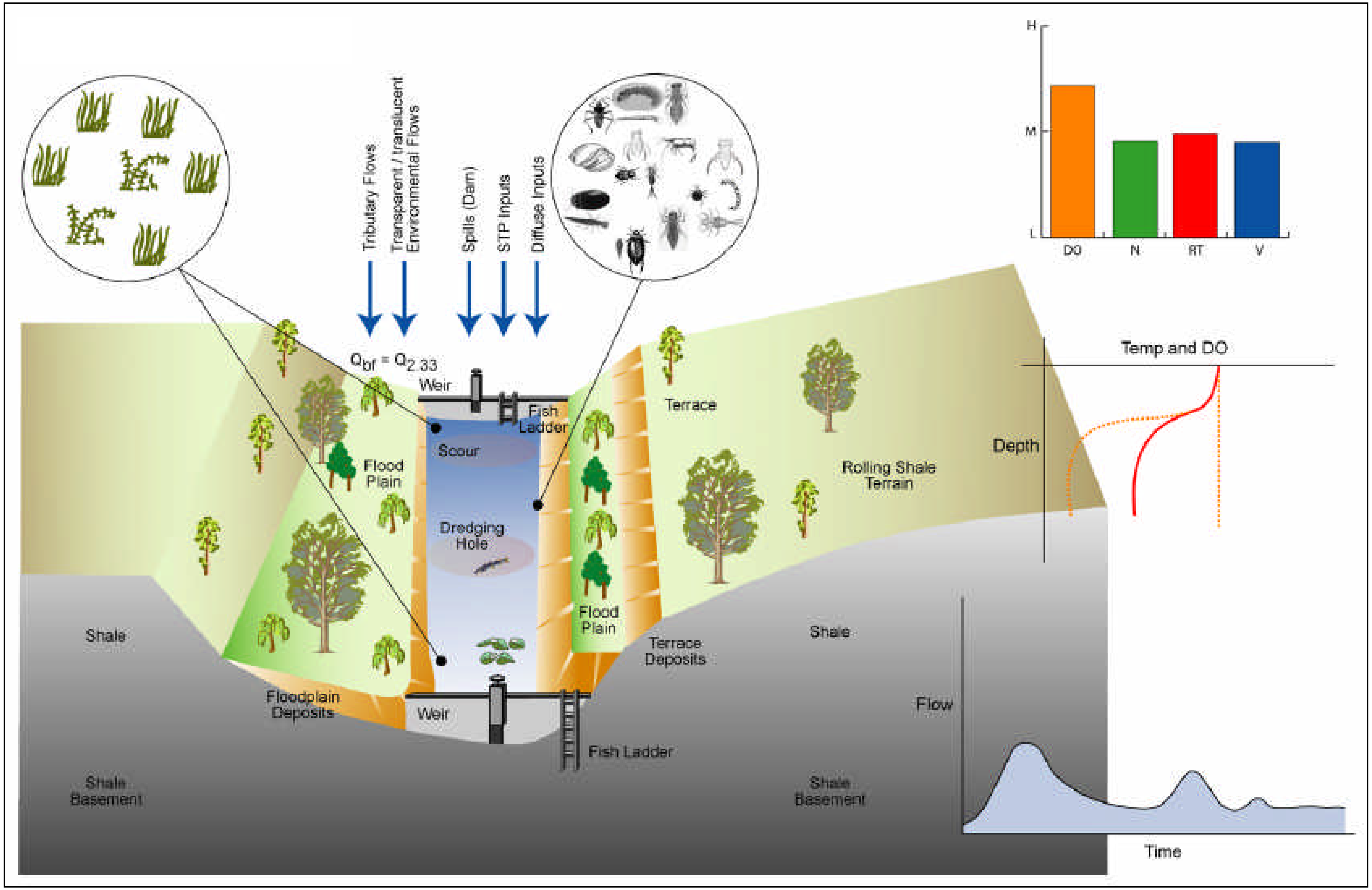
  <u>Effluent reuse strategy</u>

  Further details of this issue are given in the discussion for Reach 14.

  <u>Weir Management</u>

  Further details of this issue are given in the discussion for Reach 14.

Figure B31: Reaches 15, 17 – Recommended Environmental Flow Regime Nepean River from Menangle Weir to Wallacia Weir (excluding the Bents Basin Gorge)

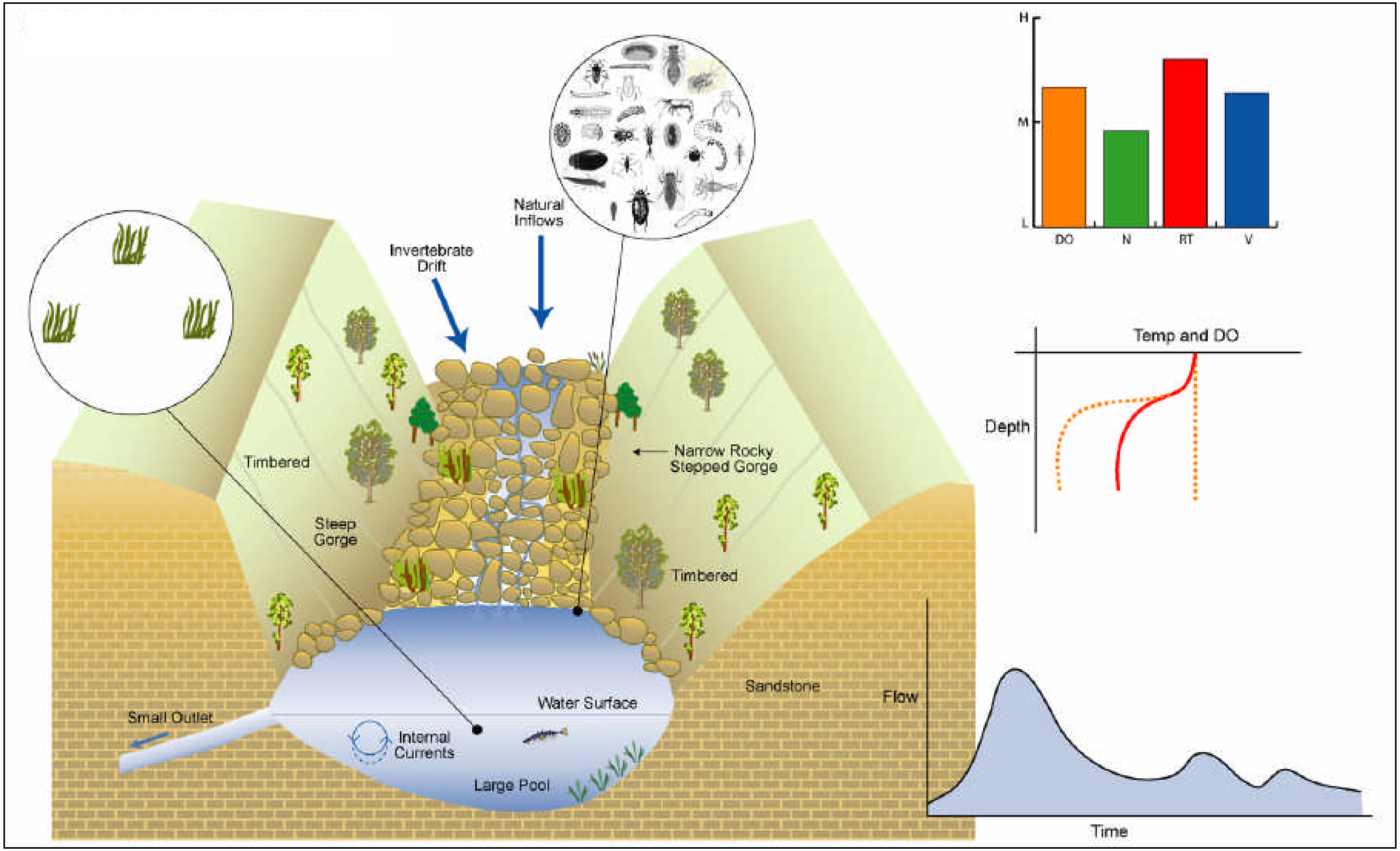


Reaches 16, 18 and 19: Bents Basin gorge, Nepean River from Wallacia Weir to Nepean/Warragamba confluence and Warragamba River from Warragamba Dam to Nepean/Warragamba confluence

Natural Regime; Reaches 16, 18, 19

The three gorge reaches which total 10.2 km (4.2, 2.7 and 3.3 km respectively) are locations where the Nepean River re-enters the sandstone flanks of the Blue Mountains. They are examples of what is called antecedent drainage, where the channel down cutting kept pace with the tectonic uplift on the flanks of Sydney and the surrounding area. In a sense, the drainage has been superimposed from above. In spite of there being large ponds or basins on the Nepean reaches, all three have fairly steep mean gradients (0.0028. 0.0044 and 0.0030 respectively). Under natural conditions the gorges would be much the same as they are today, except for modifications in flow and water quality, which have adversely affected aquatic fauna and flora. Natural flows were not attenuated and natural high flows would have made basin stratification more infrequent than today. The higher energy flows down the Warragamba gorge from the much larger catchment were competent to move the gravels and boulders of its mixed load into lower sandstone and shale reaches. In Pleistocene such loads were taken well downstream from Windsor, where they form the base materials of terraces. Due to the general hard nature of the substratum there would have been large variety of flow-related microhabitats which would have varied both spatial and temporally and supported a diverse range of macroinvertebrate species. In contrast the importance of macrophyte and sediment habitats would be reduced compared to other river sections. The overall biodiversity of this river section would have been high due the diversity of pool and riffle habitats.

Figure B32: Reaches 16, 18 and 19 - Natural Regime Bents Basin Gorge, Nepean River from Wallacia Weir to Nepean/Warragamba Confluence and Warragamba River from Warragamba Dam to Nepean/Warragamba Confluence



Current Regime and High Priority Issues; Reaches 16, 18, 19

Physically the gorges are unchanged (they are thought to be about 30 million years old) but flows and sediment loads have been greatly attenuated by dams and weirs. The Nepean River has more polluted flow from effluent discharges at Camden and stormwater runoff from urban areas. Lower summer flushing has increased the frequency and durations of basin stratification. In the Warragamba River, high post-dam, clear-water flows have swept much of the coarse load from the trough above the junction. The combination of decreased river discharge and river pollution have reduced the habitat quality and quantify for macroinvertebrates, thereby reducing biodiversity.

Fundamental Hydrological Issues

- **Monitoring the sandstone reaches downstream of dams**

  Improvements in the measurement of discharges or flows are required to support all subsequent ecological and water-quality monitoring. This includes measuring the hydraulic properties of flow through channel constrictions, which act as riffle-like forms and are therefore important for habitat, fish passage and invertebrates.

  Further details of this issue are given in the discussion for Reach 3.

- **Monitoring dam inflows**

  Knowledge of dam inflows underpins the environmental flow program, as knowledge of these flows is required to:

  - calculate the appropriate daily environmental flow releases at any given time; and,
  - assist in the understanding of the links between flow and river health.

  Further details of this issue are given in the discussion for Reach 1.

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Cold water releases from dams**

  The temperature of water released from dams is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper.

  Further details of this issue are given in the discussion for Reach 1.

- **General water quality downstream of dams**

  Waters released from dams can impact on downstream receiving water quality. To ensure that these water releases are of satisfactory quality, routine monitoring immediately downstream of the dams is required.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reaches 16, 18 and 19, the main issue of concern is loss of native macrophytes due to the excessive growth of exotic macrophyte species.

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Ancillary Issues

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  - Reach 16: No recorded cultural heritage items are listed within this area, although cultural heritage places are present.
  - Reach 18: One site listed on the State Heritage Inventory is within this river reach.
  - Reach 19: Three sites listed on the State Heritage Inventory is within this river reach.

  For further information, please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Riparian extraction

  Further details of this issue are given in the discussion for Reach 2.1.

  Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

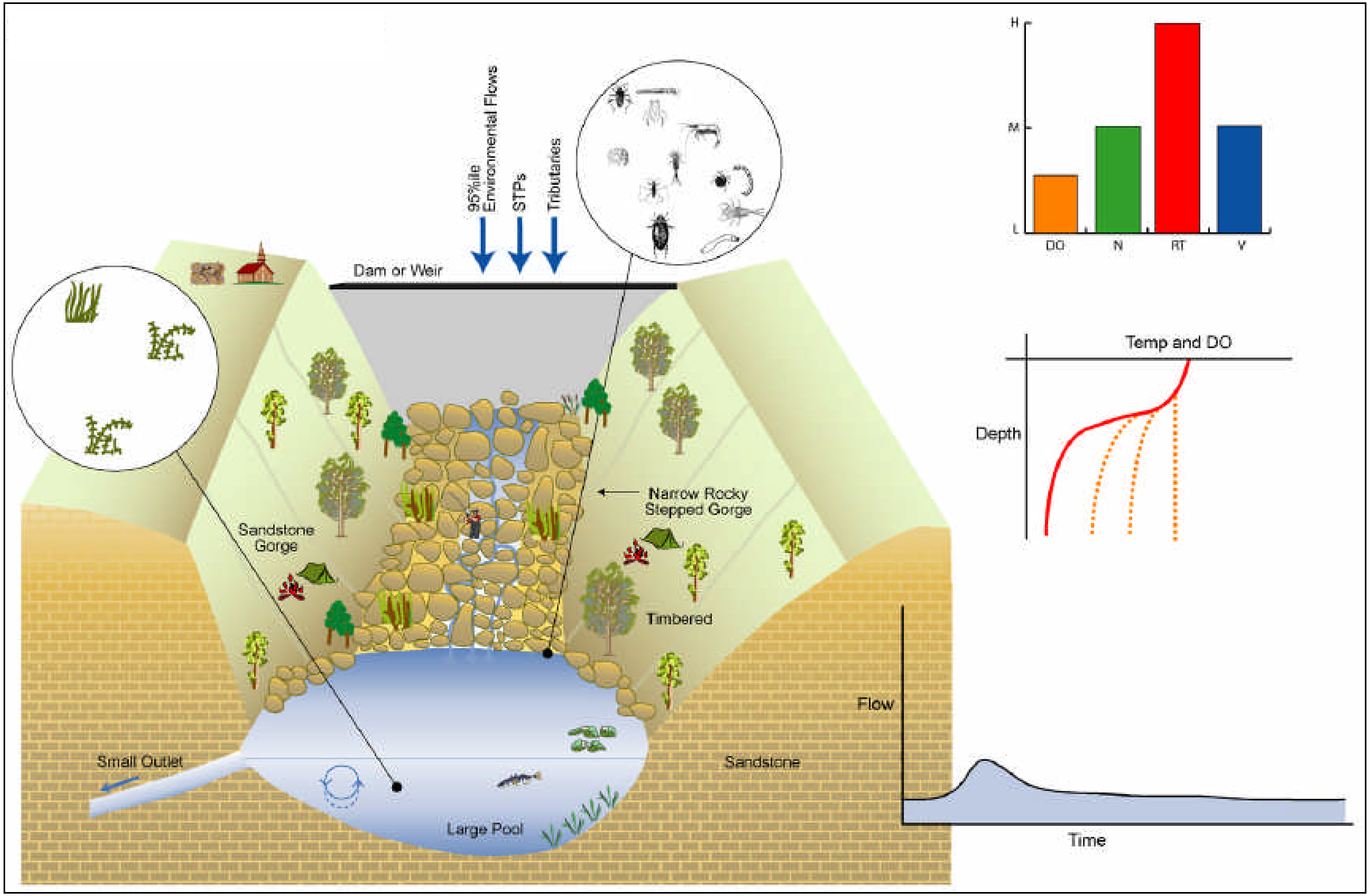
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B33: Reaches 16, 18 and 19 - Current Regime Bents Basin Gorge, Nepean River from Wallacia Weir to Nepean/Warragamba Confluence and Warragamba River from Warragamba Dam to Nepean/Warragamba Confluence



Recommended Environmental Flow Regime; Reaches 16, 18, 19

There will be no great physical changes in the gorges, but cleaner, higher and better regulated environmental flows (minus effluent diverted to effluent reuse) will improve water quality, gorge habitats and local ecology. However, there is a need to improve fish passage through the Wallacia Weir. Presumably Warragamba Dam and its weir will remain obstacles to fish migration.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Cold water releases from dams**

  With the introduction of the recommended environmental flows in the Cataract, Cordeaux, Avon and Nepean Rivers, water quality downstream of the dams will improve. Water temperatures will be near natural.

- **General water quality downstream of dams**

  Water quality downstream of the dams will improve.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently *Elodea canadensis* and *Egeria densa* are both found in this reach, with native macrophyte beds often replaced with monospecific beds of *Elodea canadensis* or *Egeria densa*. In the future increased flow variability combined with nutrient reduction will reduce the growth and distribution of exotic macrophytes species such as *Elodea canadensis* and *Egeria densa* as well as reduce any further loss of native macrophyte beds in these reaches.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

Summary of Key Changes to Ancillary Issues

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:

  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

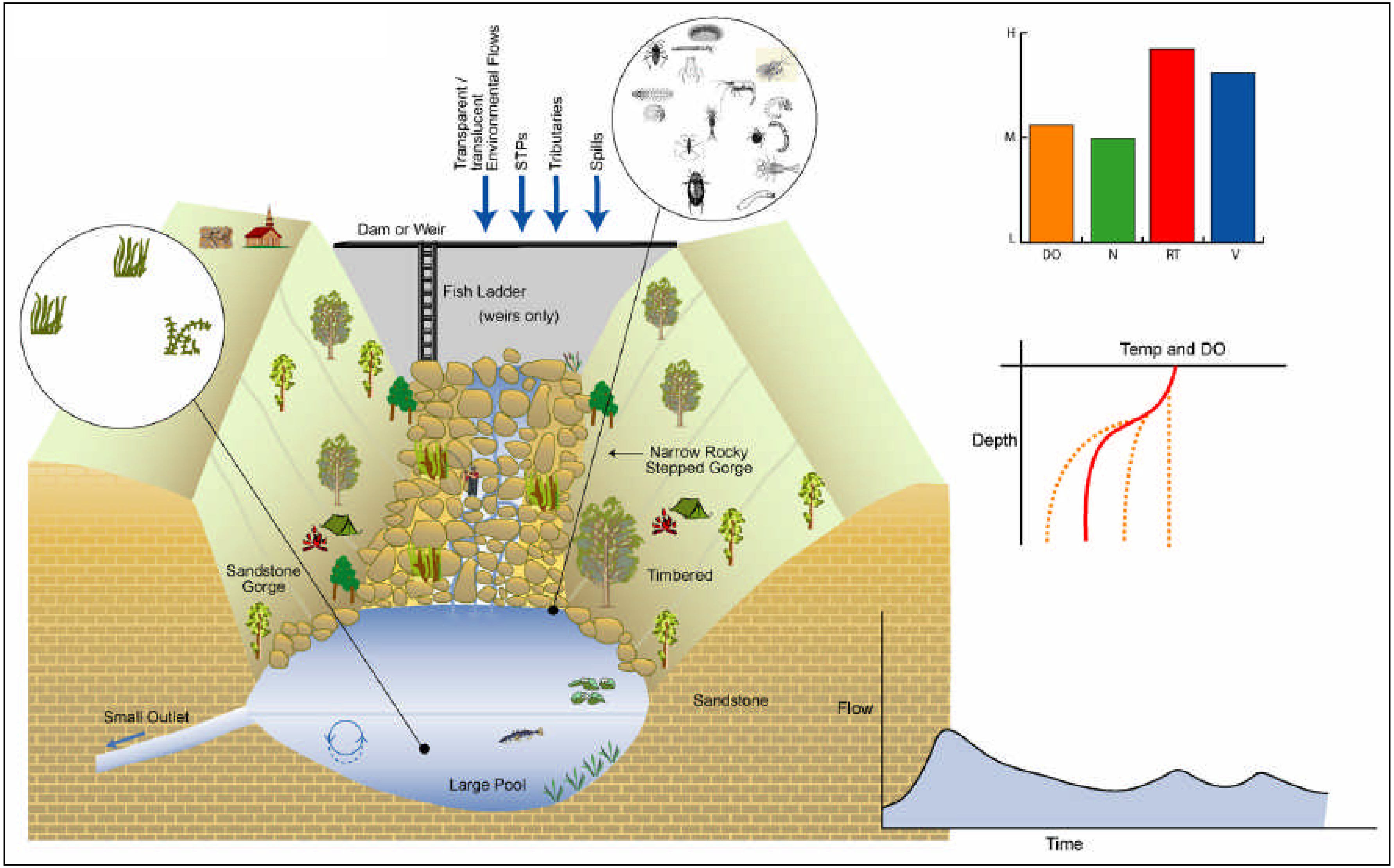
  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

Figure B34: Reaches 16, 18 and 19 – Recommended Environmental Flow Regime Bents Basin Gorge, Nepean River from Wallacia Weir to Nepean/Warragamba Confluence and Warragamba River from Warragamba Dam to Nepean/Warragamba Confluence



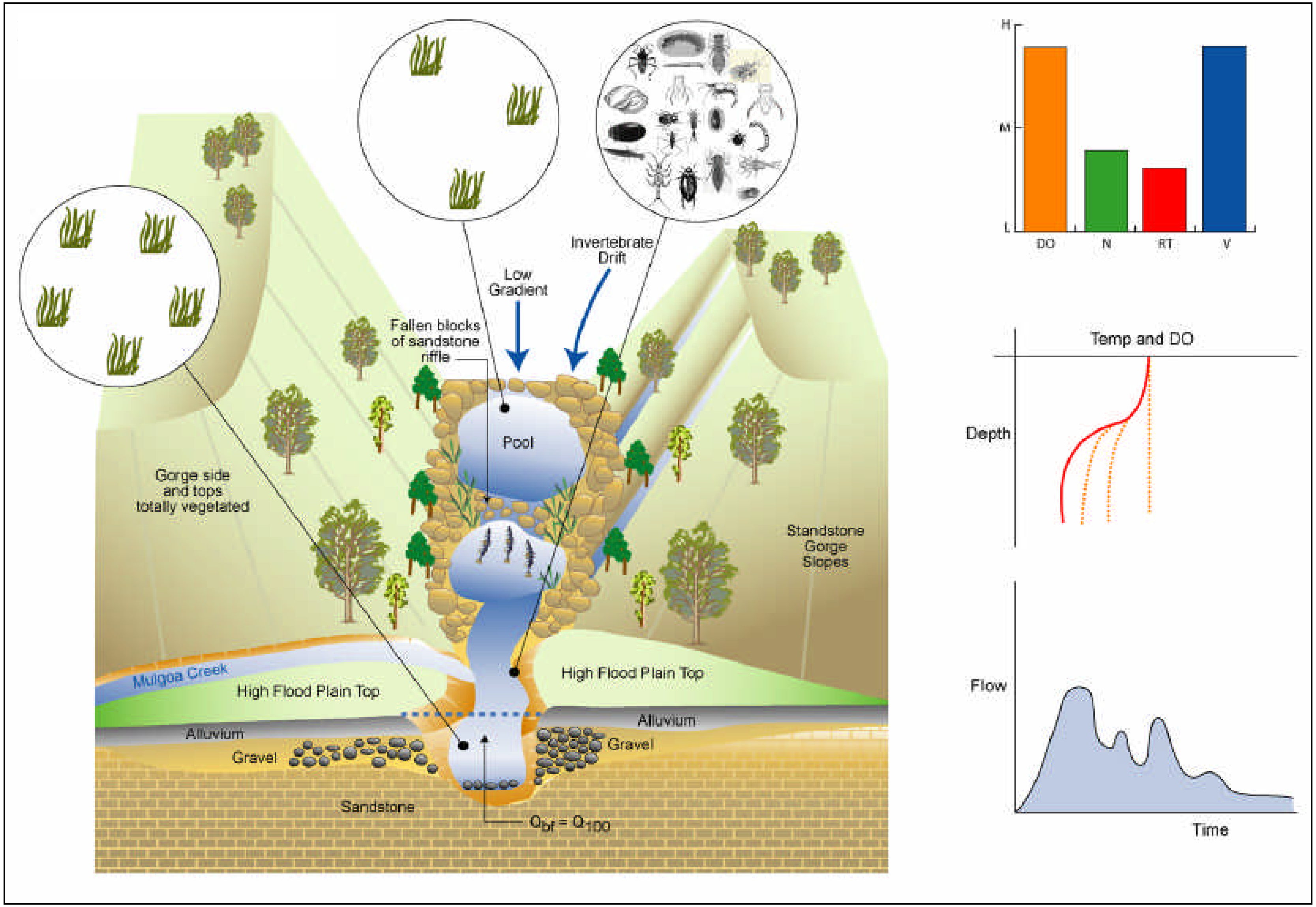
Reaches 20 and 21: Nepean River from Nepean/Warragamba confluence to Penrith Weir

Natural Regime; Reaches 20, 21

These two reaches consist of a spectacular sandstone gorge (12.7 km) and a high incised alluvial plain (5.4 km). Below the junction of the two major arms, the Warragamba (over 9000 km^2) and the Nepean (1750 km^2), the steeper gradients flatten considerably, with a natural fall of only about 5 m in 18.1 km or 0.3 m/km (0.0003). The gorge has changed little and was for the most a long deep pool (maximum depth over 10 m). However the alluvial reach consisted of a terrace, veneered and flanked by modern alluvium. This would have been densely timbered but its elevation ensured infrequent surcharging (about once in 100 years).

Two large, left bank tributaries (Erskine and Glenbrook Creeks) add significant unregulated runoff from sandstone areas of the lower Blue Mountains. Mulgoa Creek, a right bank tributary, adds water from shale areas where currently salinity problems have been found.

Figure B35: Reaches 20 and 21 - Natural Regime Nepean River from Nepean/Warragamba confluence to Penrith Weir



Current Regime and High Priority Issues; Reaches 20, 21

The imposition of Warragamba Dam on the main arm and other more distant dams on the Nepean River has greatly attenuated flows, as well as cutting off the coarser sediment loads from the former.

The weir at Penrith has drowned the most of the gorge and alluvial slopes and increased the maximum depth to about 14m in the gorge pool. An act of nature has further complicated the lower gorge. In May 1944 a massive flood in Glenbrook Creek evacuated a huge slug of boulders into the weir pond at the creek junction. This consists mainly of huge lumps of sandstone, many of which were blasted into the creek bed when the railway cutting high above was constructed. Something like 500,000 m^3 of material, all sandstone, was involved and it has remained there ever since. It is at least 200 m long and occupies two-thirds of the channel width. Maximum elevations are about 3 to 4 m. This has acted as a barrier to flow and subsequent movement of the coarse load downstream. The presence of boulders and gravel (up 300 mm) on the surface from above Warragamba is testimony to the power of floods and spills in the gorge. The weir has obstructed the movement of coarse load to the next reach and there have been many documented changes in the alluvial reach, made possible by earlier surveys.

The plain is now partially urbanized by Emu Plains and Penrith but major stormwater runoff discharge is below the weir. Fish passage is a problem at the weir and the quiet water in the lower weir pond has provided a suitable habitat for exotic macrophytes.

Under the terms of its Water Management Licence, the Sydney Catchment Authority is required to release sufficient water from Warragamba Dam to ensure that a minimum flow of 50 ML/day is maintained over Penrith Weir. This requirement dates from the construction of the Dam and is designed to ensure adequate water remains available for downstream irrigation and town water supply requirements.

Fundamental Hydrological Issues

- **Monitoring of weired shale reaches below the dams**

  Soil and sand aggregate removal from weired alluvial reaches have changed channel characteristics – this will probably decrease the effectiveness of environmental flows.

  Further details of this issue are given in the discussion for Reaches 15 and 17.

- **Monitoring the sandstone reaches downstream of dams**

  Improvements in the measurement of discharges or flows are required to support all subsequent ecological and water-quality monitoring. This includes measuring the hydraulic properties of flow through channel constrictions, which act as riffle-like forms and are therefore important for habitat, fish passage and invertebrates.

  Further details of this issue are given in the discussion for Reach 3.

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Cold water releases from dams**

  The temperature of water released from dams is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper.

  Further details of this issue are given in the discussion for Reach 1.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reaches 20 and 21, the main issue of concern is loss of native macrophytes due to the excessive growth of exotic macrophyte species.

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Ancillary Issues

- **Channel changes in weired reaches**

  Channel changes in weired reaches need to be resurveyed for management and interpretation of other monitoring relating to weir pools.

  Further details of this issue are given in the discussion for Reach 14.

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  - Reach 20: Four sites site listed on the State Heritage Inventory is within this river reach.
  - Reach 21: Six sites listed on the State Heritage Inventory is within this river reach.

  For further information, please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Industrial extraction

  Further details of this issue are given in the discussion for Reach 2.1.

  In the Penrith Lakes Scheme, a series of artificial lakes provide recreational amenity and residential development opportunities. When operational, it is expected to extract 26,000 ML/year from the Hawkesbury–Nepean, returning most of it further downstream. A highly variable flow regime may affect the Scheme's ability to extract water, since pumping can only occur during periods of moderate to high river flow.

  Riparian extraction

  Further details of this issue are given in the discussion for Reach 2.1.

  Recreational fishing

  Further details of this issue are given in the discussion for Reach 1.

  Recreational amenity

  Further details of this issue are given in the discussion for Reach 1.

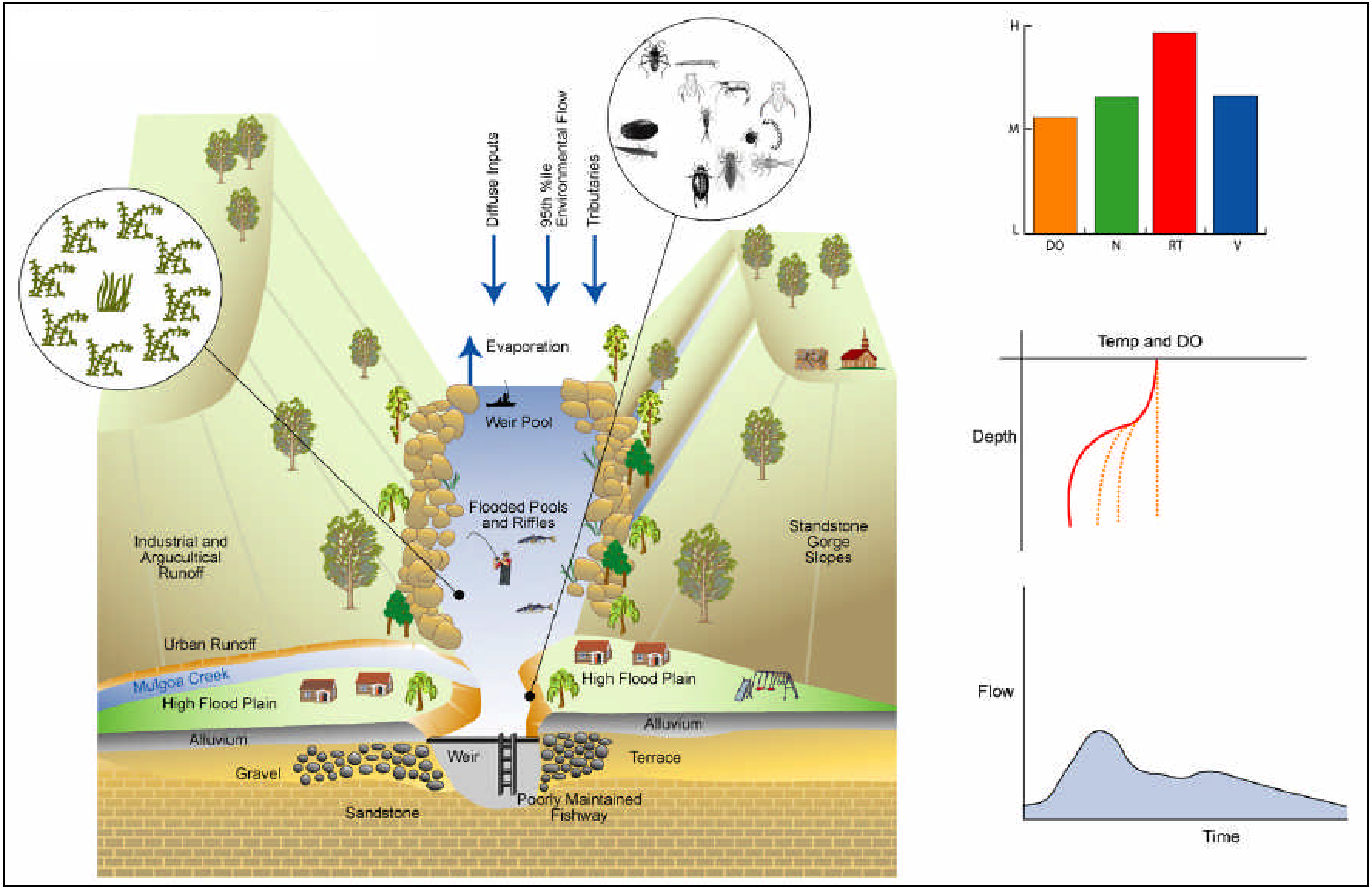
  River-related tourism

  Further details of this issue are given in the discussion for Reach 1.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Figure B36: Reaches 20 and 21 - Current Regime Nepean River from Nepean/Warragamba confluence to Penrith Weir



Recommended Environmental Flow Regime; Reaches 20, 21

It seems unlikely that the weir will be removed but fish passage and the transmission of environmental flows will have to be improved. The delivery of cleaner and less polluted environmental flows, with no bulk transfers in this case, should improve water quality and movement through this long weir pond. However contingent flows may be needed to help control exotic plant problems.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Cold water releases from dams**

  With the introduction of the recommended environmental flows in the Cataract, Cordeaux, Avon and Nepean Rivers, water quality downstream of the dams will improve. Water temperatures will be near natural.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently, while both *Elodea canadensis* and *Egeria densa* are both found in these reaches, only *Egeria densa* is found in excessive amounts such that native macrophytes beds have been lost. *Egeria densa* is now the dominant macrophyte in these reaches. Salvinia is also known to occur in this reaches. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of aquatic weeds such as *Egeria densa* and Salivinia in these reaches and reduce the potential for other exotic macrophytes (eg. Alligator Weed, *Elodea canadensis*, Ludwigia and Water Hyacinth) to occur and grow excessively, such that native macrophyte beds are restored over time.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

Summary of Key Changes to Ancillary Issues

- **Channel changes in weired reaches**

  Re-survey of channel cross section will reveal channel changes that might influence the adaptive management process for the implementation of environmental flows.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:

  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;

- protection of existing ecosystems in the natural drainage systems; and
- prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  A significant extractor in Reach 21 will be the Penrith Lakes Scheme.

  Further details of this issue are given in the discussion for Reach 1.

  Modifications to the access conditions for river extractors

  A significant extractor in Reach 21 will be the Penrith Lakes Scheme.

  Further details of this issue are given in the discussion for Reach 1.

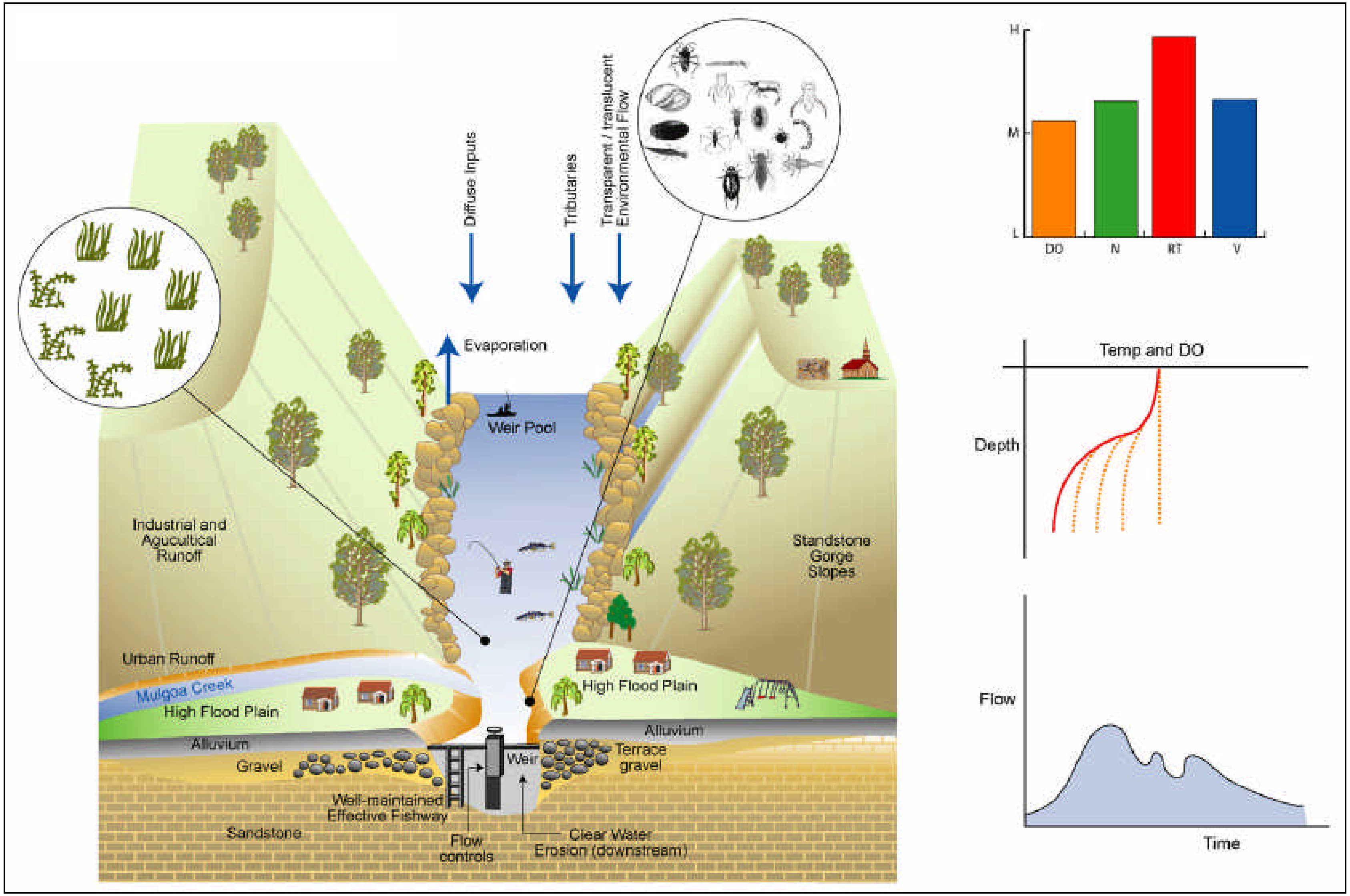
  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

  Weir Management

  Further details of this issue are given in the discussion for Reach 14.

Figure B37: Reaches 20 and 21 – Recommended Environmental Flow Regime Nepean River from Nepean/Warragamba confluence to Penrith Weir

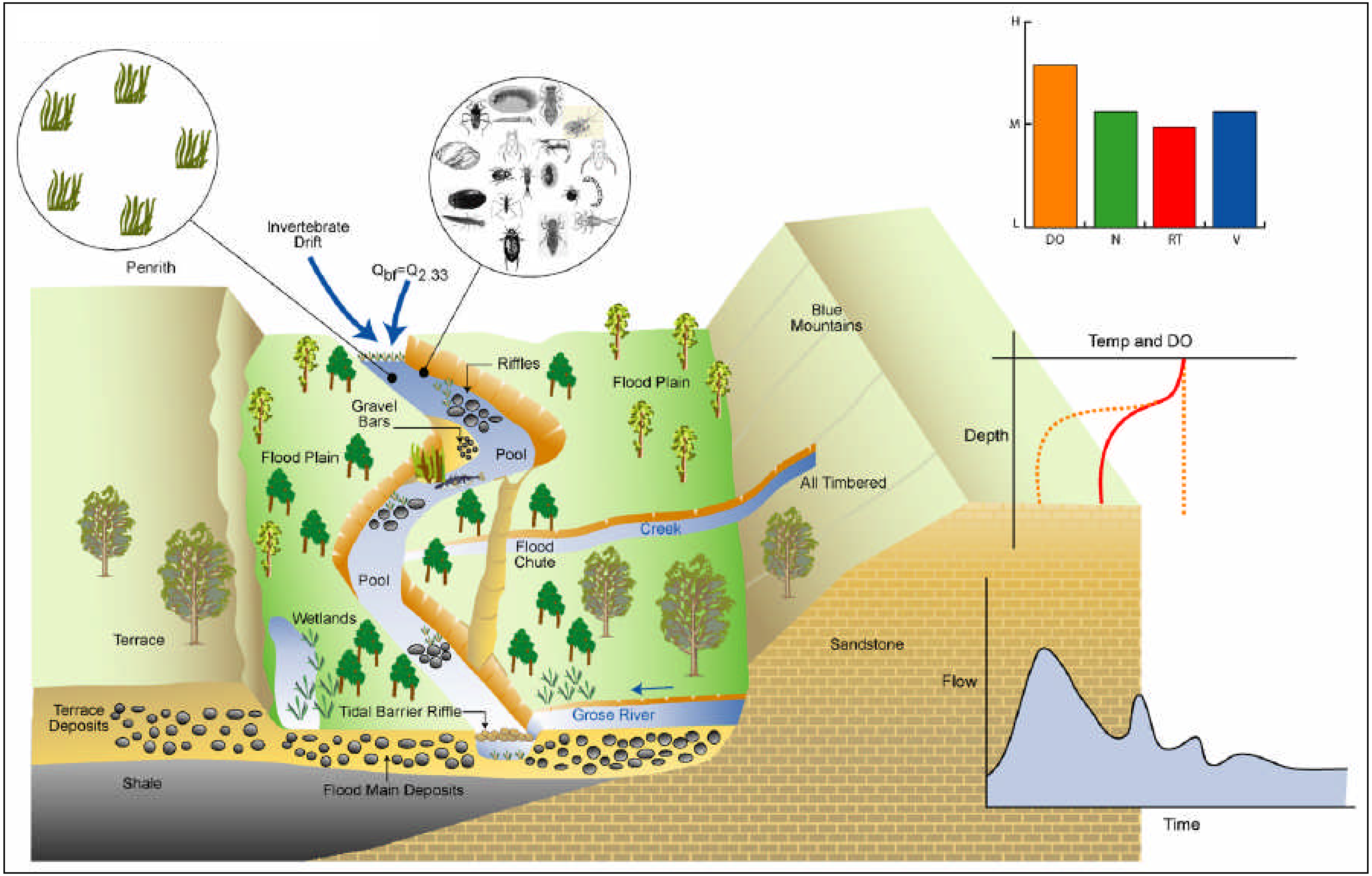


Reach 22: Nepean River, Penrith Weir to Grose River Junction

Natural Regime; Reach 22

This 18.9 km reach, with a mean slope of only 0.7 m/km (0.0007), would have been one of the richest areas ecologically in the whole valley, being that reach between the upper arms of the sandy Nepean River and the mixed-load Warragamba River and the tidal river. The presence of real boulder and gravel riffles would have provided prime habitat and the natural flows from the 11,000 km^2 catchment would have been sufficient in the non-compartmentalized channel to scour and revitalize riffles and to allow fish passage both up- and downstream for migration and spawning. The high alluvial banks and floodplains would have been densely timbered and adjacent wetlands would have been connected to the river more frequently than today.

Figure B38: Reach 22 - Natural Regime Nepean River, Penrith Weir to Grose River Junction



Current Regime and High Priority Issues; Reach 22

From perhaps the best reach, this has now become one of the most ecologically damaged. Flow attenuation, particularly by Warragamba Dam, has removed effective flows for scouring and fish passage. The dam and the weir have cut off gravel sources and coarse organic matter. Huge volumes of sand and gravel have been removed from the bed and banks by dredging and quarrying the contemporary channel, which as been greatly increased in width and depth. Land clearance and large-scale urbanisation have increased pollution levels from stormwater runoff and two STPs (16.5 GL/y). Irrigation losses are small (1 GL/y) and are exceeded by those of evaporation from greatly increased water surface area. Weir water is used to supply the adjacent Penrith Lakes and some flow may well be lost to these through ground water transfers. Water is returned from the lakes with lower quality. The greatly increased channel size and the lower attenuated flows have combined to lower flow velocities and stream power, such that this reach is now conducive to the proliferation of *Egeria densa* and other aquatic weeds. This, plus the mutilated habitats, have not helped fish migrations in this reach connecting river and tidal waters.

Fundamental Hydrological Issues

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Reduced connectivity – natural barriers**

  Reduced flows over riffles or riffle-like habitats, have decreased connectivity for mobile aquatic fauna along the river reach, and at the interface between river and estuarine reaches.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reach 22, the main issues of concern are:
  - Loss of native macrophytes due to the excessive growth of exotic macrophyte species,
  - The impact of excessive growth and transportation of aquatic macrophytes, in particular *Egeria* on riparian zone, river amenity and river infrastructure, and
  - Potential for the distribution of Alligator Weed to increase as a result of environmental flows leading to a subsequent loss in agricultural production.

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Ancillary Issues

- **Channel degradation in the mixed-load shale reach downstream of Penrith Weir**

  Channel degradation peaks in the reach from Penrith Weir to Grose River, where it is extensive and has resulted from large-scale aggregate removal from both bed and banks, from the effects of flood-dominated regime erosion (1949-1990) and clear-water erosion after the closure of Warragamba to the passage of sediments. This degradation may well affect adversely the effectiveness of environmental flows.

  This reach was the main source of aggregate prior to opening up the Penrith Lakes area for extraction. The southern part provided most of aggregate for the building of Warragamba Dam in the 1950s. Changed channel dimensions have greatly affected local hydraulic conditions and the way water moves through this reach. They have also greatly changed local ecology.

  This was the only really mixed-load (sand, gravel and boulders) alluvial reach in the whole river (other than the short Reach 21 drowned by Penrith Weir). It was the location of real riffles but these have either been permanently removed or greatly modified. Widths and depths have been greatly increased in many cases, although contemporary base-line data are sparse. The attenuated regimes, imposed by the dams, the change back to a drought-dominated regime and the lower velocities in the much increased channel dimensions have combined, together with storm water runoff and STP discharges from Penrith and Winmalee, to provide prime conditions for the proliferation of *Egeria densa* and other aquatic weeds. These dominate in this reach and need to be managed by physical removal and contingent flows, where natural flows do not remove them. Ecologically this reach is very important because it connects the upper reaches with the tidal river and is thus vital to fish migration and spawning.

  It has received much less research attention in terms of channel change and surveys will be necessary to see if any recovery has taken place, as well as to assess the hydraulic potential of environmental flows.

- **Connectivity – Penrith Weir Fishway**

  Poor maintenance of the Penrith Weir fishway can greatly impede connectivity for fish and invertebrates for the majority of time, ie. when the weir is not flooded out. Being reasonably close to the tidal limit, impeded connectivity at Penrith Weir can greatly impact the movements of fish, invertebrates, turtles and aquatic mammals between the river and the estuary; some of these impacts could extend upstream and downstream of the weir for at least 100 kilometres. Clearly, it is very important that the installed fishway works effectively and is well maintained. Observations made by the IEP during mid-May 2002 showed that the fishway would not be providing passage for fish because of poor maintenance. Specifically, it was observed that:

  - upstream trash racks were clogged with vegetation thus greatly restricting the amount of water entering the fishway,
  - this clogging also appeared to be creating water-velocity barriers which would halt fish movements at the upstream end, and
  - rock arrangements downstream of the fishway had been washed away resulting in the lower edge of the fishway being perched above and away from the downstream pool – water thus emerged from the fishway as a jet -it was clearly impossible for fish to swim through this

  Maintenance of the fishway is obviously vital.

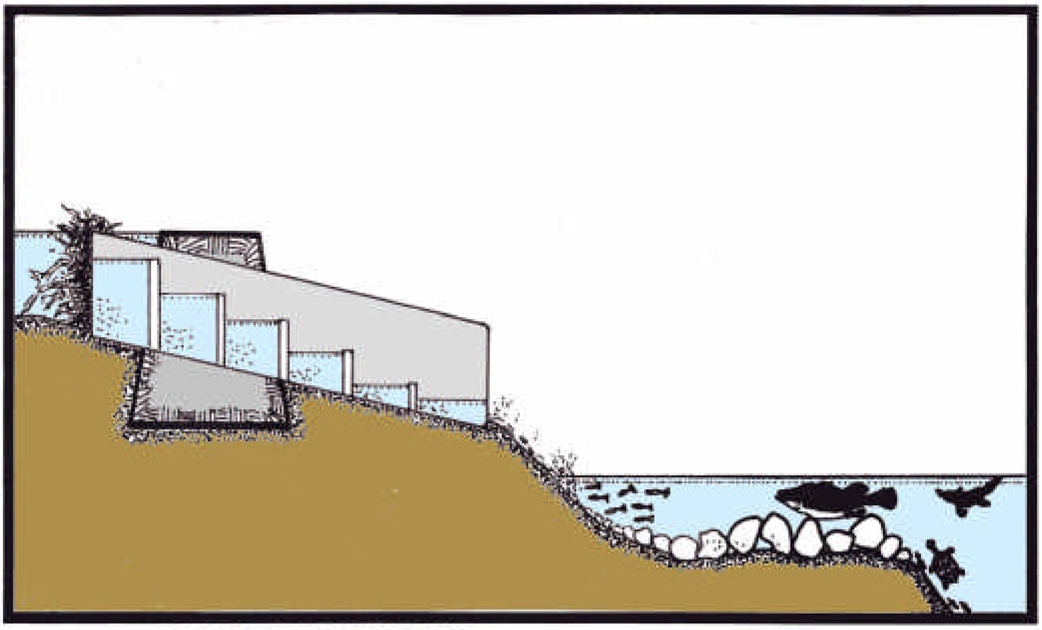
  An illustration of this issue is given in Plate 7.

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

Further details of this issue are given in the discussion for Reach 4.

Plate 7 - Illustration of the connectivity issue associated with poor maintenance of a fishway



Passage <u>blocked</u> for mobile aquatic fauna because of an ineffective fishway on Penrith Weir (upstream end blocked by 'trash' & downstream end inaccessible to fauna).

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  Five sites listed on the State Heritage Inventory are within this river reach. Please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Industrial extraction

  Further details of this issue are given in the discussion for Reach 2.1.

Riparian extraction

Further details of this issue are given in the discussion for Reach 2.1.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

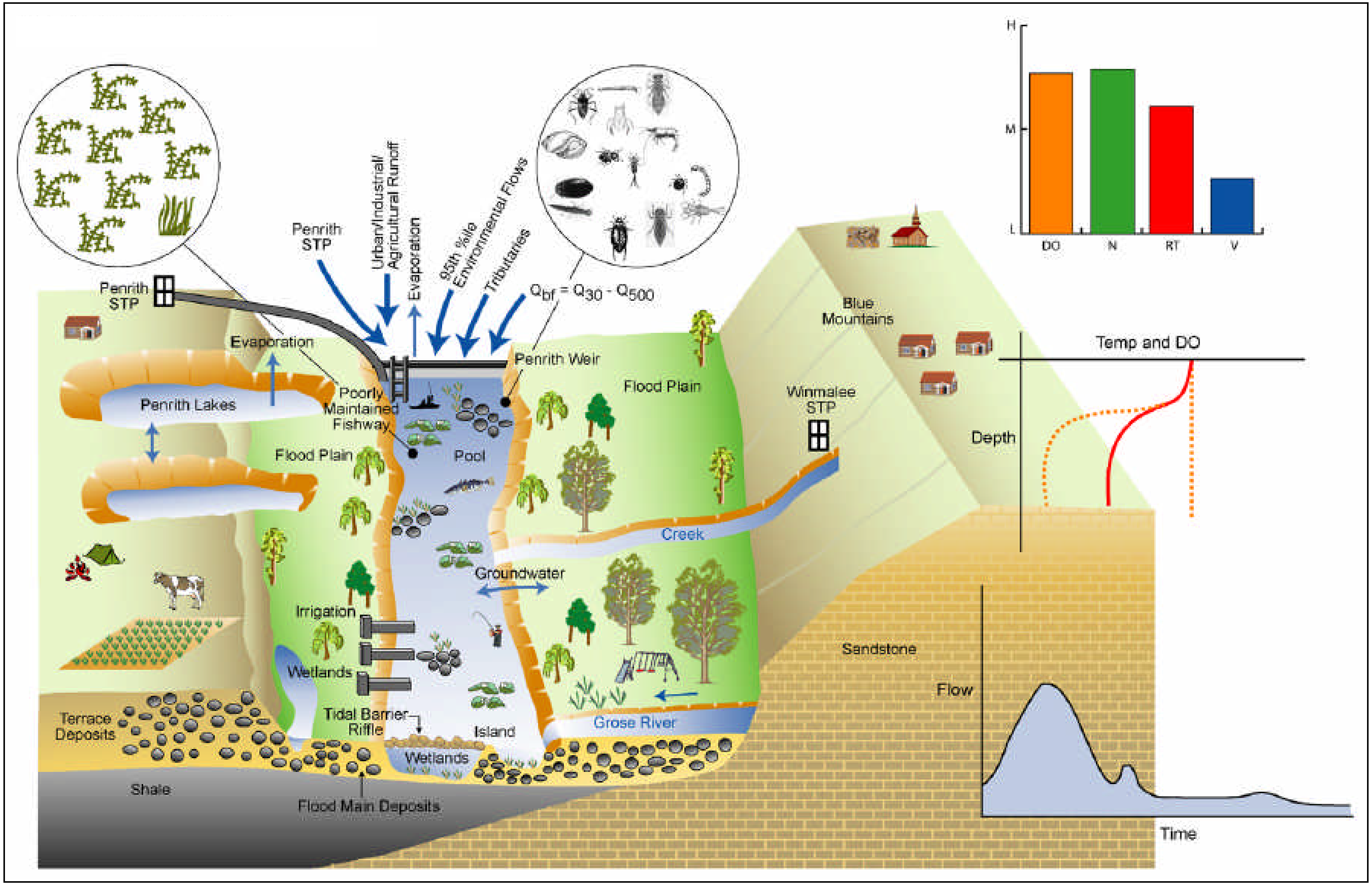
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B39: Reach 22 - Current Regime Nepean River, Penrith Weir to Grose River Junction



Recommended Environmental Flow Regime; Reach 22

A fully operational effluent reuse strategy will partially improve water quality but stormwater runoff will also need to be improved from rapidly expanding urban areas for better water quality. Better rehabilitation of gravel extractions sites and the removal of causeways could improve the passage of water, especially with the introduction of better environmental flows and occasional contingent flows. However, the greatly enlarged channel will render such flows less effective. Returned water from the Penrith Lakes will need to be improved. More efficient fish passage through the weir will aid their migrations. However, it may still be necessary eventually to consider the placement of structures to constrict flows to aid their scouring of aquatic weeds. Without a wide range of improvements through better management of flows, water quality and aquatic weeds, this will remain a problem reach.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regimes, together with the contingent flows, will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently, while both *Elodea canadensis* and *Egeria densa* are both found in these reaches, only *Egeria densa* is found in excessive amounts such that native macrophytes beds have been lost. *Egeria densa* is now the dominant macrophyte in these reaches. Alligator Weed, Ludwigia, Salvinia and Water Hyacinth are also known to occur in these reaches. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of aquatic weeds such as Alligator Weed, *Egeria densa* and Salivinia in these reaches and reduce the potential for other exotic macrophytes (eg. *Elodea canadensis*, Ludwigia and Water Hyacinth) to grow excessively, such that native macrophyte beds are restored over time.

  Transportation of *Egeria densa* during high flows has the potential to threaten river infrastructure such as bridges and ferries because of damage that may be caused to these structures by the sheer weight and volume of *Egeria densa* that can transported during high flows. Transportation of excessive amounts of *Egeria densa* also reduces the health of the riparian zone. Excessive growth of *Egeria densa* in these reaches also affects recreational use of the river. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of *Egeria densa* in these reaches and thus reduce the potential for damage to river infrastructure during high flows and the transportation of excess material into the riparian zone. Reduced abundance of *Egeria densa* will also increase the recreational appeal of the river as a swimming and fishing area.

  As Alligator Weed has been recorded in this reach it has the potential to affect irrigation/agricultural areas that rely on water from the river or have river frontages. In the future, increased flow variability combined with nutrient reduction will help to reduce the abundance of Alligator Weed. While flows in the river will increase on average, it is not expected that these flows will increase the distribution of Alligator Weed above that which would occur as a result of the current flow regime.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

Summary of Key Changes to Ancillary Issues

- **Channel degradation in the mixed-load shale reach downstream of Penrith Weir**

  Surveys and investigation will inform the adaptive management process for the implementation of environmental flows.

- **Connectivity – Penrith weir fishway**

  The maintenance of an effective fishway will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

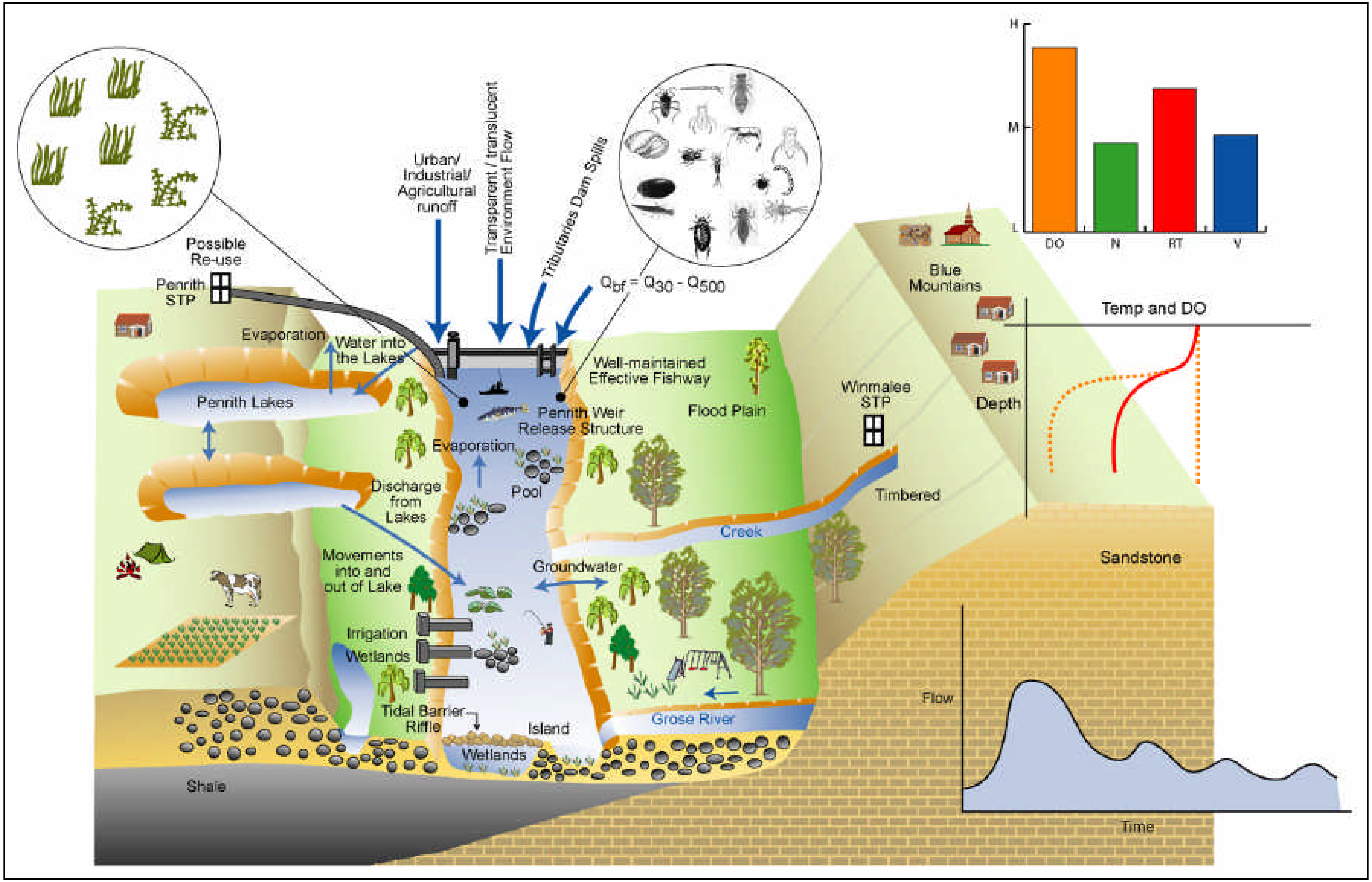
  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

Figure B40: Reach 22 – Recommended Environmental Flow Regime Nepean River, Penrith Weir to Grose River Junction

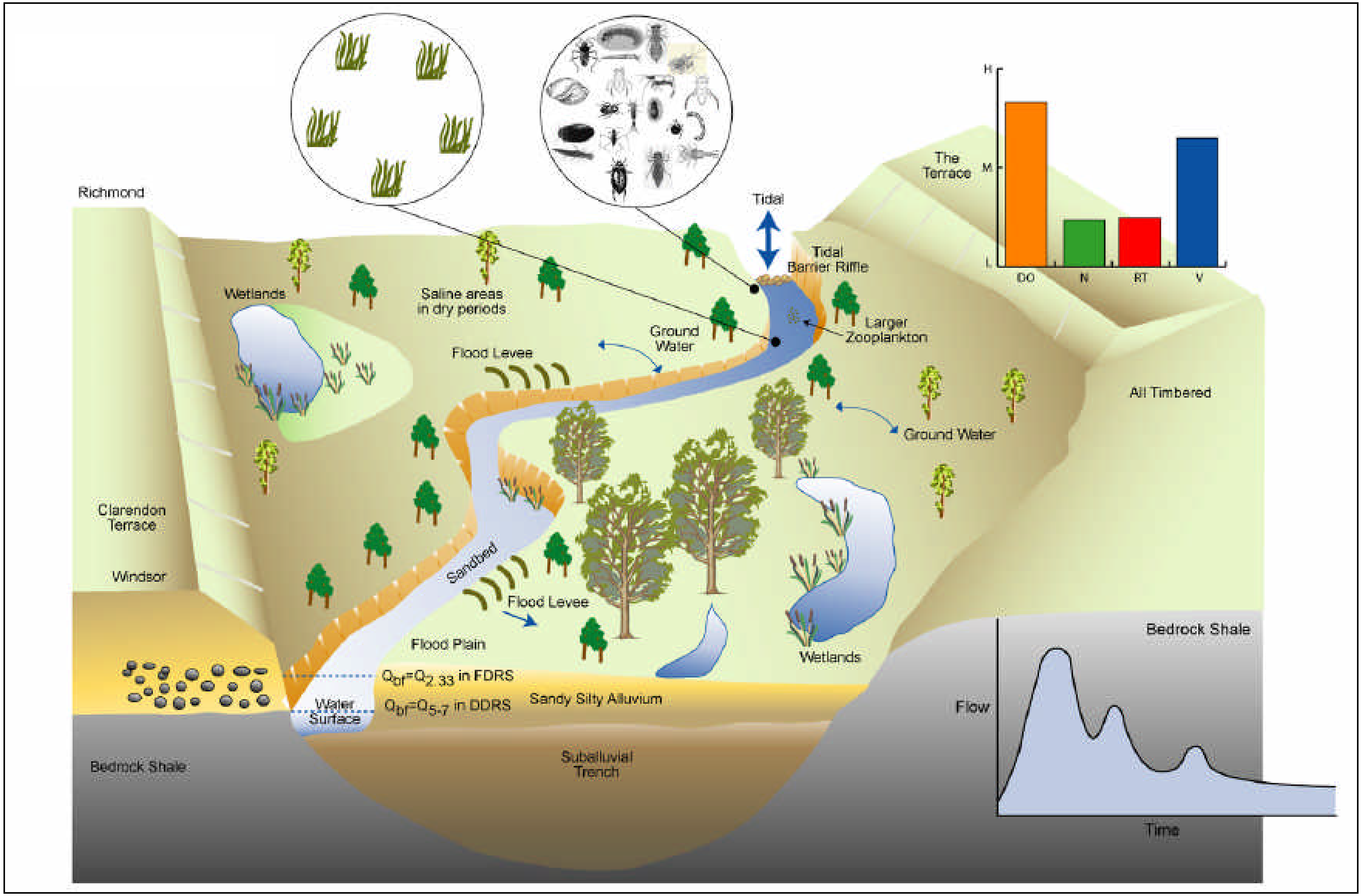


Reach 23: Hawkesbury River, Grose River Junction to Wilberforce

Natural Regime; Reach 23

This 24.8 km reach is the upper part of the tidal river. Very low gradients prevail and are dominated by tides. It is the last alluvially flanked shale reach at the northern end of the Cumberland Plains. Downstream the river passes back in antecedent form into the sandstones of the tectonically uplifted Hornsby Plateau. This is the reach with the biggest floodplains (Richmond Lowlands), which are about 6 km wide near Windsor. Under natural conditions these would have been densely wooded, away from the semi-permanent lagoons and their wetland margins. Non-attenuated flows would have flooded the 9-10 m levees about once every 2.33 years on average and in the first FDR noted (pre 1798 to 1820) the first European settlers had to abandon their farms when a series of 16m floods washed most of their endeavours away. They had ignored Aboriginal advice, where they had pointed out flood debris in the tops of trees. They retreated to South Creek. Again this would have been a rich ecological area.

Figure B41: Reach 23 - Natural Regime Hawkesbury River, Grose River Junction to Wilberforce



Current Regime and High Priority Issues; Reach 23

Dam-attenuated flows and currently a DDC have considerably reduced flows in this reach over the last 12 years. This is in spite of large STP discharges (25.4 GL/yr) and storm water runoff from urban areas, notably in South Creek, both of which have greatly decreased water quality. In the channel, bed degradation and bank erosion associated with the former FDR runoff and clear water erosion downstream of the dam, weir and extraction sites have increased sub-tidal capacities and the volume of the tidal prism. This reach, which includes South Creek, is a likely source for the algal blooms downstream near Sackville. Water losses to irrigation are significant (32.3 GL/yr). The Richmond Lowlands were an important source of vegetables and fruit originally. Much of the land at present is devoted to turf farming, where each harvesting lowers the floodplain surface a few centimetres. A few more decades of this could increase the flood threat, although lower flows associated with global warming may offset such trends. However, the removal of fine upper sediments will eventually expose underlying sands and there will be pressure to quarry these for aggregate, but there are many geomorphological problems with this.

Fundamental Hydrological Issues

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Reduced connectivity – natural barriers**

  Reduced flows over the tidal-barrier riffle have decreased connectivity for mobile aquatic fauna at the interface between river and estuarine reaches.

  Further details and an illustration of this issue are given in the discussion for Reach 1.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reach 23, the main issues of concern are:

  - Loss of native macrophytes due to the excessive growth of exotic macrophyte species,
  - The impact of excessive growth and transportation of aquatic macrophytes, in particular *Egeria* on riparian zone, river amenity and river infrastructure, and
  - Potential for the distribution of Alligator Weed to increase as a result of environmental flows leading to a subsequent loss in agricultural production.

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Ancillary Issues

- **General water quality associated with the Forum's Effluent Reuse Strategy**

  Point and diffuse sources of pollution have resulted in poor water quality in the river system. This has culminated in the excessive growth of plants, particularly phytoplankton and aquatic weeds. Poor water quality due to diffuse and point source discharges is aggravated by a combination of altered/regulated flows, irrigation extractions and STP inflows particularly during dry conditions.

  In the estuary, the longitudinal excursion of the salinity profile has been impacted by a combination of regulated flows and the discharge of sewage effluent from South Creek.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  Productivity of crops and pastures could be impacted through changes in soil salinity levels or other soil qualities that impact on plant productivity.

  Contaminants in reclaimed water could leach into local groundwater tables thereby impacting directly on groundwater and indirectly on the river through shallow connections between ground and surface waters.

  Further details of these issue are given in the discussion for Reaches 15 and 17.

- **Tidal channel changes in the Hawkesbury River**

  The (former) Public Works Department's (PWD) was aware of the potential for tidal channel change from earlier hydrographic surveys in the 19th Century. This is why they surveyed nearly 200 cross sections between Richmond and the Ocean in the late 1970s and early 1980s. There has been no systematic resurvey, except between Windsor and Sackville by Sydney University (Warner, 1994).

  Resurveys of the former PWD's monumented cross sections in the 1980s between Richmond and Sackville revealed general degradation of the channel bed and banks. This erosion or net loss of sediments can be attributed to the erosive power of FDR flows (1949-1990), as well as to clear water erosion below Warragamba Dam and downstream of channel dredging (Penrith to Yarramundi). Bank erosion was largely confined to part of the sandy alluvium added to the channel sides in the 1901-1948 DDR.

  At that time the fate of the sediments removed was unknown. However, Forum's commercial fishing representatives indicated that reductions in channel depth downstream from Sackville were adversely affecting prawning. This deposition was confirmed in part by two cross sections resurveyed by Manly Water Research Laboratory and by their work with prawn fishermen. Originally this was thought to be the case because little sand is exported through Broken Bay.

  Similar trends have been found in both the Georges and Woronora Rivers (Warner and Pickup. 1978; Warner et al, 1977).

  The main geomorphological issue in these reaches is the potential impacts of sediment redistribution on:

  - environmental flows;
  - tidal dynamics;
  - current hydraulic models;
  - salinity structures;
  - water quality (as modelled by Salmon-Q);
  - commercial fishing; and
  - sustainable estuary management.

Since about 1949 with the onset of the last FDR, of the 151.8 km of tidal channel (44.7% of the total channel length of 339.3 km), approximately the upper 51 km (15%) of channel has been subject to bank erosion and bed degradation. These processes have been enhanced (in spite of the completion of Warragamba Dam in 1960) by clear-water erosion caused by large dam spills up to the 1990s and by further sediment starvation on flows passing through the heavily dredged reach (ie. Reach 22: Penrith Weir to Grose Junction). These processes have increased the sub-tidal capacity (with bed deepening) and the tidal prism (with bank erosion). In contrast, in the lower 101 km (29.7%) of channel, sandy material eroded from upstream sources appears to have been deposited on the bed, leading to a decrease in sub-tidal capacity. Where discontinuous alluvial floodplains are found, bank erosion has continued, giving increases in tidal prism, but probably at lower rates than upstream.

The geomorphology of channel changes and their ramifications have been studied in the upper part (Warner, 1994). However, little information can be found on the lower channel, although it is known that Sydney Water did work on tidal hydraulics and sedimentation in part of the estuary and that Webb McKeown produced a model for PWD in their flood management studies for Warragamba Dam. Earlier, the PWD had surveyed at least 200 cross sections in the tidal reaches in the 1970s and 1980s, marking locations, with a view to their resurvey to assess change and its impacts on hydraulics, the working and verification of various models etc. It is suggested that some systematic resurvey is due, in view of time lapsed since the last survey, known in part changes in the interim and their importance for environmental flow impacts and effluent management strategy.

- **<u>Stormwater runoff</u>**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **<u>Social and cultural values</u>**

  <u>Social values</u>

  Further details of this issue are given in the discussion for Reach 1.

  <u>Heritage values</u>

  One site listed on the State Heritage Inventory are within this river reach. Please see Appendix B1.

  <u>Aboriginal values</u>

  Further details of this issue are given in the discussion for Reach 1.

- **<u>Institutional performance</u>**

  Further details of this issue are given in the discussion for Reach 1.

- **<u>Land and river activities</u>**

  <u>Irrigation extraction</u>

  Further details of this issue are given in the discussion for Reach 1.

  <u>Industrial extraction</u>

  Further details of this issue are given in the discussion for Reach 2.1.

  <u>Riparian extraction</u>

  Further details of this issue are given in the discussion for Reach 2.1.

Commercial fishery activity

Further details of this issue are given in the discussion for Reach 2.1.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

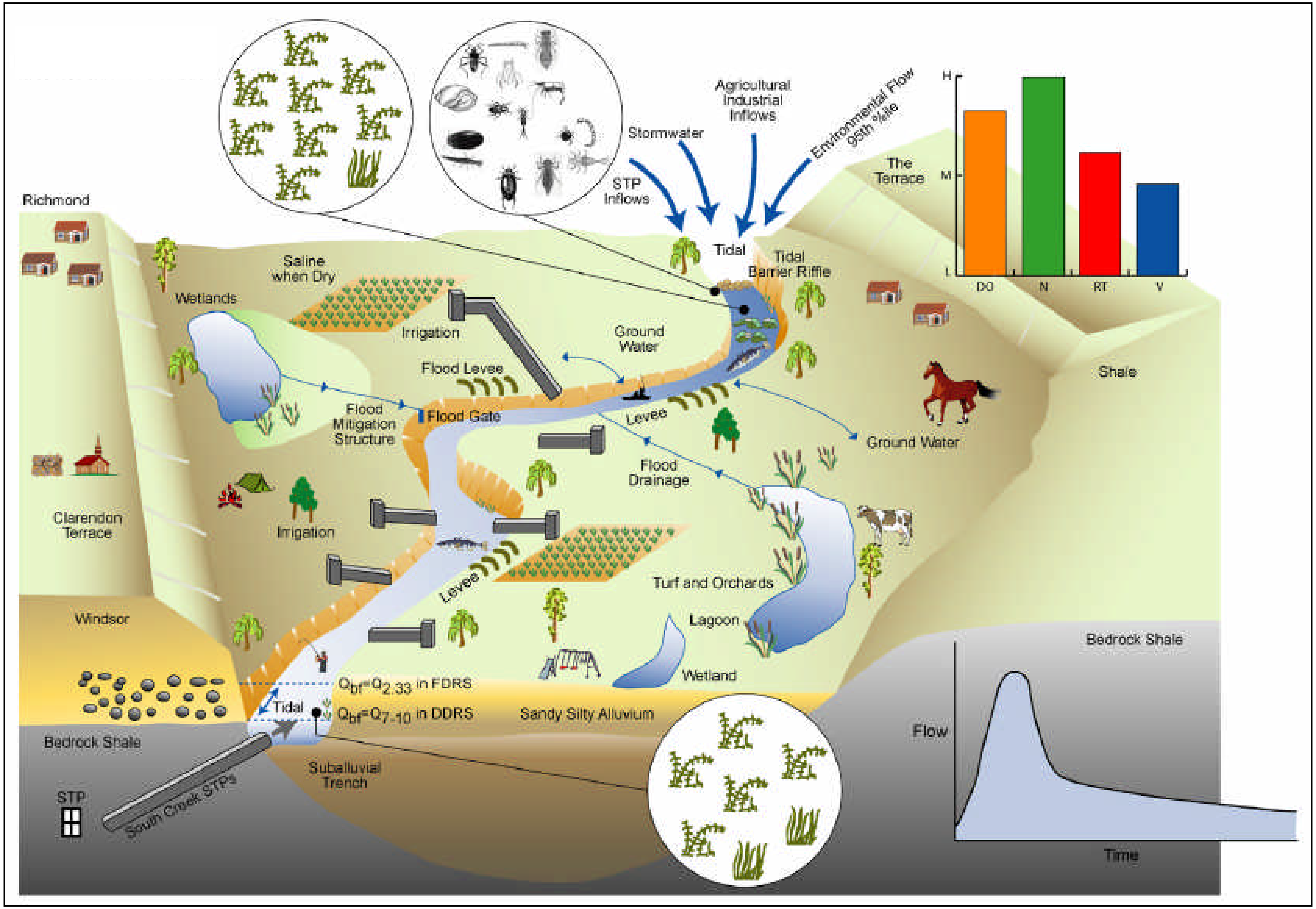
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B42: Reach 23 - Current Regime Hawkesbury River, Grose River Junction to Wilberforce



Recommended Environmental Flow Regime; Reach 23

In this much-degraded reach, it will be necessary to manage more effectively the factors which contribute to it. Effluent reuse will ease some of the water quality problems and reduce irrigation extractions. The management of storm water runoff will be much more difficult, especially in older established urban areas. Improved environmental flows will have lower impacts in this more distant reach, where tide domination is significant. Urban expansion will, if anything, increase problems but new areas can be incorporated in water sensitive urban design. Clearly this is a vital area where better source management will be a priority.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced connectivity - natural barriers**

  The recommended environmental flow regimes, together with the contingent flows, will increase connectivity and thus reduce: i) the fragmentation of fish communities, ii) major impacts on fish and invertebrate migration-mediated community dynamics, iii) the incidence that diadromous species are unable to complete their lifecycle, iv) predation- and disease-mediated mortality of fish, platypus, turtles and invertebrates, and v) lowered growth potential of fish.

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently, while both *Elodea canadensis* and *Egeria densa* are both found in these reaches, only *Egeria densa* is found in excessive amounts such that native macrophytes beds have been lost. *Egeria densa* is now the dominant macrophyte in these reaches. Alligator Weed and Salvinia are also known to occur in these reaches. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of aquatic weeds such as Alligator Weed, *Egeria densa* and Salivinia in these reaches and reduce the potential for other exotic macrophytes (e. g. *Elodea canadensis*, Ludwigia and Water Hyacinth) to occur and grow excessively, such that native macrophyte beds are restored over time.

  Transportation of *Egeria densa* during high flows has the potential to threaten river infrastructure such as bridges and ferries because of damage that may be caused to these structures by the sheer weight and volume of *Egeria densa* that can transported during high flows. Transportation of excessive amounts of *Egeria densa* also reduces the health of the riparian zone. Excessive growth of *Egeria densa* in these reaches also affects recreational use of the river. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of *Egeria densa* in these reaches and thus reduce the potential for damage to river infrastructure during high flows and the transportation of excess material into the riparian zone. Reduced abundance of *Egeria densa* will also increase the recreational appeal of the river as a swimming and fishing area.

  As Alligator Weed has been recorded in this reach it has the potential to affect irrigation/agricultural areas that rely on water from the river or have river frontages. In the future, increased flow variability combined with nutrient reduction will help to reduce the abundance of Alligator Weed. While flows in the river will increase on average, it is not expected that these flows will increase the potential for transportation of Alligator Weed above that which occurs currently.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

Summary of Key Changes to Ancillary Issues

- **General water quality associated with the Forum's Effluent Reuse Strategy**

  Water quality in the mainstream Hawkesbury River will improve with the introduction of the recommended environmental flows and the implementation of the effluent management strategy. Nutrient concentrations will trend downwards and algal blooms will be rare as conditions become less conducive to their formation.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  Sustainable agriculture will ensure that reclaimed water from sewage effluent is used to its maximum extent, thus protecting the quality of the environmental flow releases.

  Monitoring of groundwater in areas used for irrigation of reclaimed water from sewage effluent will ensure that groundwater and surface water resources are protected.

- **Tidal channel changes in the Hawkesbury River**

  Survey of cross sectional areas will inform the adaptive management process for the implementation of environmental flows.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:

  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

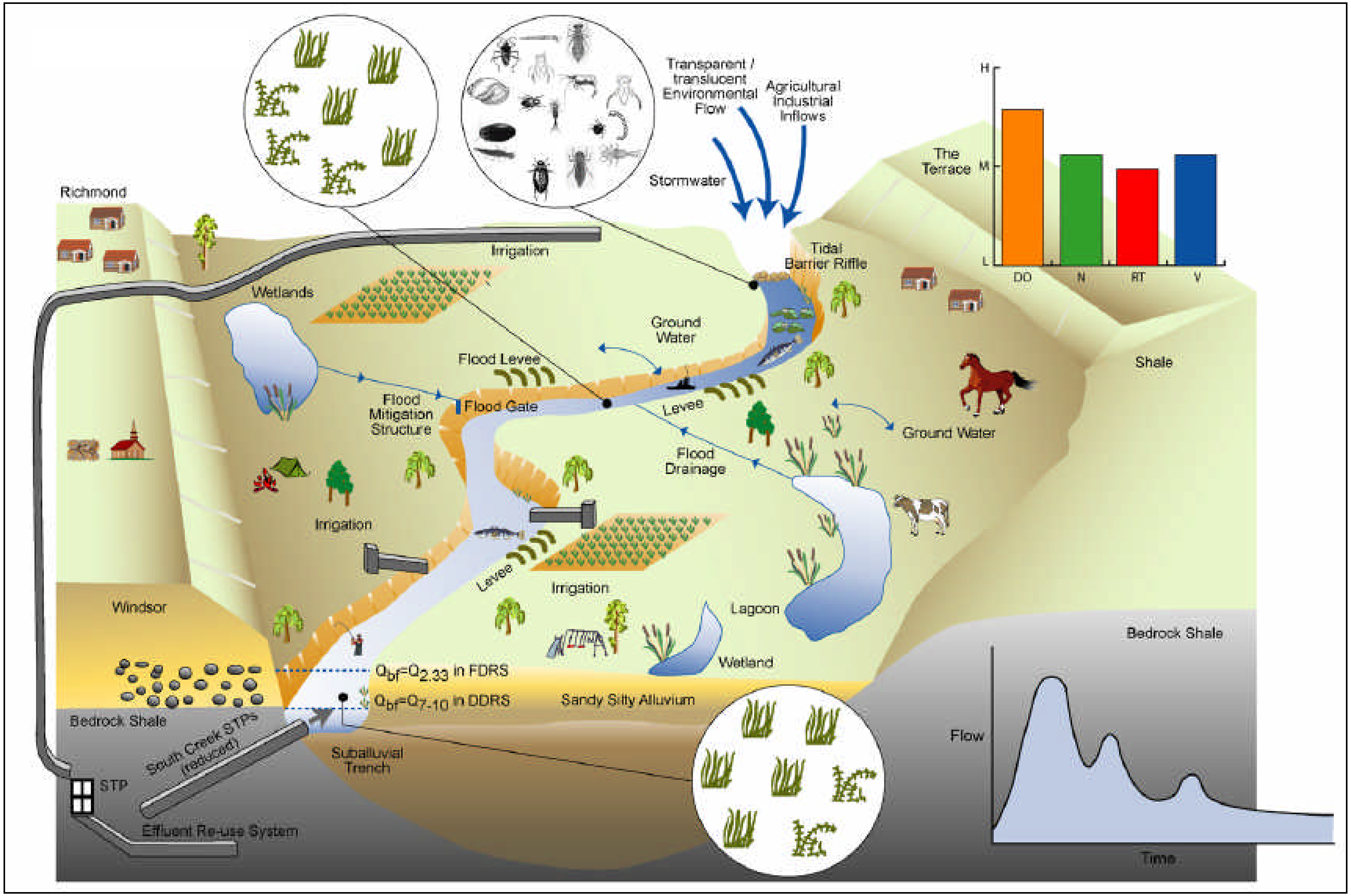
Stormwater management

Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

Effluent reuse strategy

Further details of this issue are given in the discussion for Reach 14.

Figure B43: Reach 23 – Recommended Environmental Flow Regime Hawkesbury River, Grose River Junction to Wilberforce

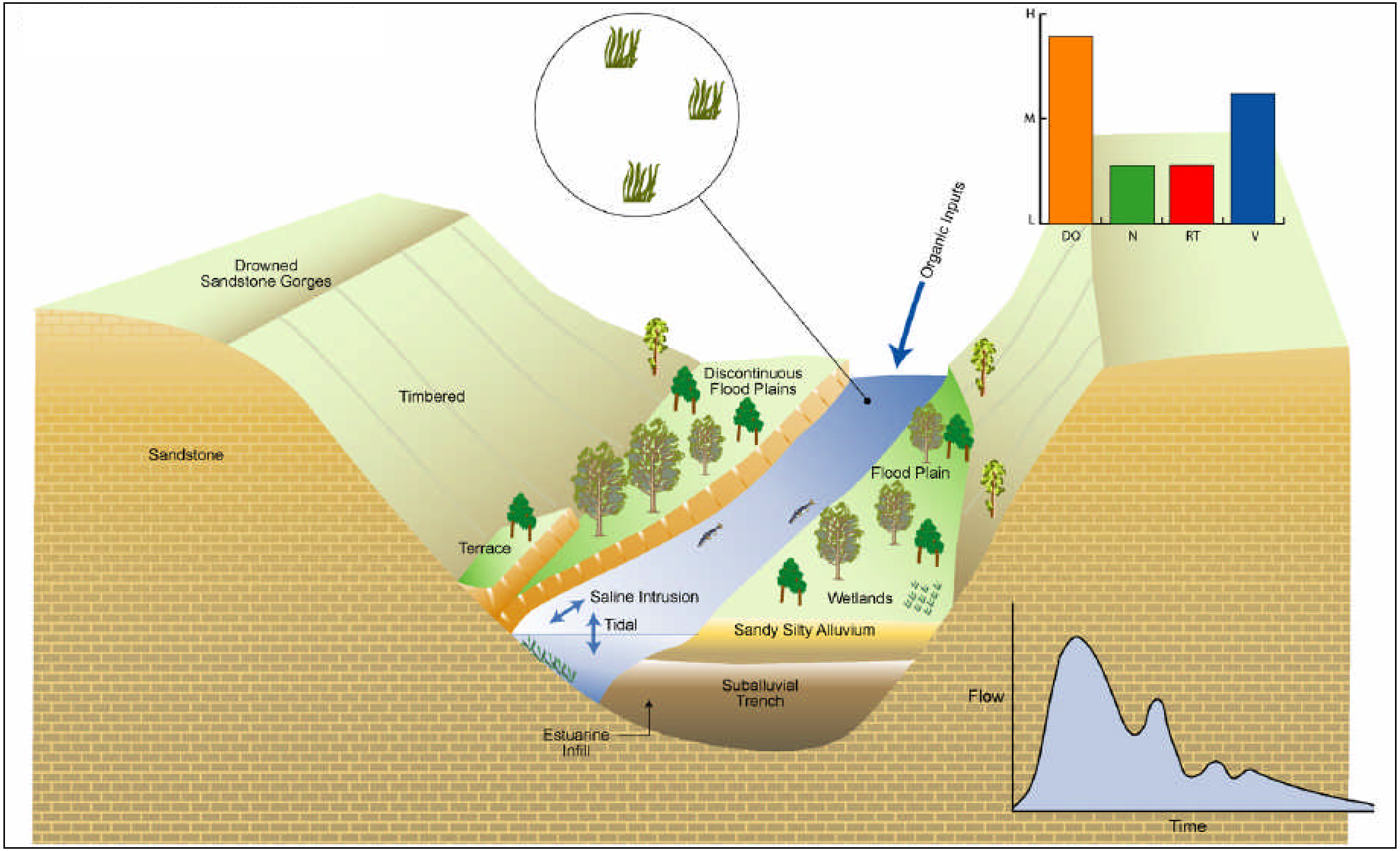


Reach 24: Hawkesbury River, Wilberforce to Colo River Junction

Natural Regime; Reach 24

This 36 km reach is the uppermost of those in the drowned sandstone gorge. In the last glacial period of the Pleistocene, sea level was as low as –200m 18,000 yBP. The lower Hawkesbury channel was attempting to cut down to that level. This down cutting probably extended from Richmond to well off shore. Basal gravels from upstream of Warragamba Dam would have been injected into the steeper gradient, higher energy channel. However with the subsequent transgression (raising of sea level), this lower valley has been drowned and the gravels ceased to be found in the low energy channel much below the Grose Junction. The drowning affected tributary valleys also and this helps to explain the presence of many levee dammed (by the main river) wetlands. The drowned trough has been partially infilled to leave only the present channel in two ways: by sandy deposits from riverine sources and by estuarine sediments (muds and shells) from the seaward end. Alluvium has been deposited by overbank flows to form discontinuous floodplains, which occupy concave banks of the entrenched meanders. These levees are about 10 m high at Wilberforce and 6 m at Sackville, getting lower downstream as the channel becomes wider and sand sources more remote. Under natural conditions, floodplain pockets would have been densely timbered. Biodiversity was far greater than at present.

Figure B44: Reaches 24 and 25 - Natural Regime Hawkesbury River, Wilberforce to Colo River Junction and Hawkesbury River, Colo River to Macdonald River Junction (Wisemans Ferry)



Current Regime and High Priority Issues; Reach 24

The sandstone slopes remain forested but alluvial flats have been cleared for cropping and citrus orchards. No great urban centres exist but the riverbanks have become popular places for new housing developments, camping sites and water skiing bases. Attenuated flows are less important in this area, although pollution from South Creek and urban runoff through Cattai Creek are thought to be the cause of blue green algal blooms at Sackville. From Cattai Creek sources there are also 4.1 GL/yr of effluent. There are also discharges of septic effluent to this section of the River from unsewered houses and tourist facilities. High turbulence during high flows under sandstone cliffs has created many deep holes, some exceeding 20 m. In spite of bed degradation above Sackville and the mobilization of much sand, these have survived in the same place and with roughly the same depths since the 19th Century surveys. Irrigation losses of 19.1 GL/yr apply mainly to the upstream sections. Flows in this reach have been reduced by extraction for Sydney's water supply but the effects are substantially moderated by inflows from unregulated tributaries.

Fundamental Hydrological Issues

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reach 24, the main issues of concern are:

  - Loss of native macrophytes due to the excessive growth of exotic macrophyte species,
  - The impact of excessive growth and transportation of aquatic macrophytes, in particular *Egeria* on riparian zone, river amenity and river infrastructure, and
  - A combination of altered/regulated flows and STP inflows during dry conditions have created a salinity structure that is reduced in its upstream extent.

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  River hydrology in regulated reaches has been modified and this in turn modifies fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and results in loss of important life-cycle signals. Reduced water quality, whether arising from dam releases, stagnation of pools or other anthropogenic activities, further exacerbates the negative effects of hydrological alterations. This in turn, and in combination, has resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Ancillary Issues

- **General water quality associated with the Forum's Effluent Reuse Strategy**

  Point and diffuse sources of pollution have resulted in poor water quality in the river system. This has culminated in the excessive growth of plants, particularly phytoplankton and exotic aquatic macrophytes. Poor water quality due to diffuse and point source discharges is aggravated by a combination of altered/regulated flows, irrigation extractions and STP inflows particularly during dry conditions.

  In the estuary, the longitudinal excursion of the salinity profile has been impacted by a combination of regulated flows and the discharge of sewage effluent from South Creek.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  Productivity of crops and pastures could be impacted through changes in soil salinity levels or other soil qualities that impact on plant productivity.

  Contaminants in reclaimed water could leach into local groundwater tables thereby impacting directly on groundwater and indirectly on the river through shallow connections between ground and surface waters.

  Further details of this issue are given in the discussion for Reaches 15 and 17.

- **Tidal channel changes in the Hawkesbury River**

  The impact of channel changes in the tidal reaches of the Hawkesbury River is unclear. Resurveys may be necessary to assess these impacts and for other purposes such as water quality, hydraulic and hydrological modelling.

  Further details of this issue are given in the discussion for Reach 23.

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  Two sites listed on the State Heritage Inventory are within this river reach. Please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Riparian extraction

Further details of this issue are given in the discussion for Reach 2.1.

Commercial fishery activity

Further details of this issue are given in the discussion for Reach 2.1.

Recreational fishing

Further details of this issue are given in the discussion for Reach 1.

Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

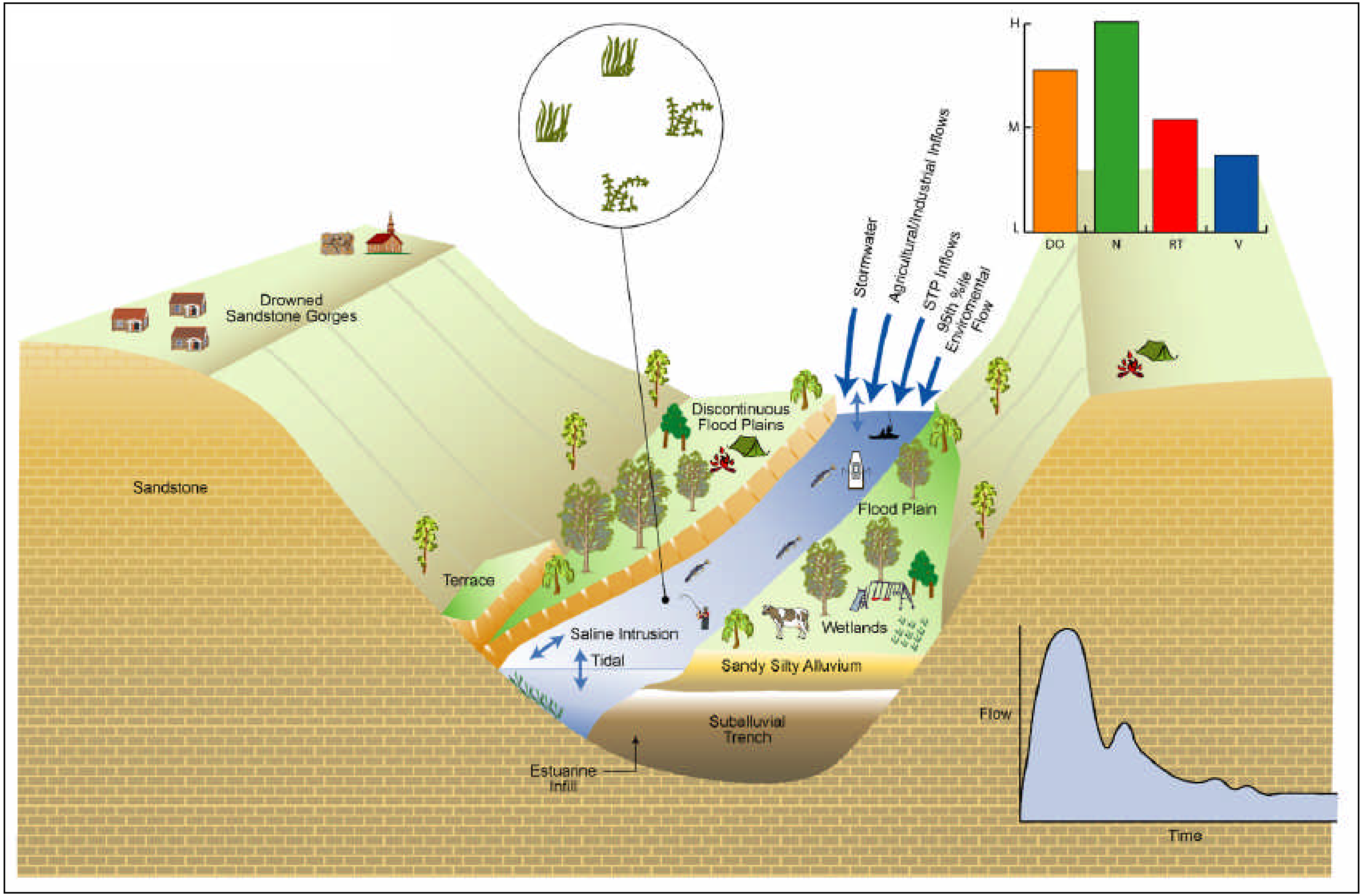
River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Figure B45: Reaches 24 and 25 - Current Regime Hawkesbury River, Wilberforce to Colo River Junction and Hawkesbury River, Colo River to Macdonald River Junction (Wisemans Ferry)



Recommended Environmental Flow Regime; Reach 24

Upstream improvements in water quality through expanded effluent reuse and better stormwater runoff management should see the reduction of algal blooms. A DDR with much lower runoff and fewer floods should slow bed and bank degradation in the upper part of this reach and Reach 23. This will reduce sedimentation in the lower tidal estuary and improve conditions for commercial fishing operations. Large and improved environmental flows will have little direct impact on this reach, although the improvements they effect upstream will contribute to the improvement of this reach.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently, while both *Elodea canadensis* and *Egeria densa* are both found in this reach, only *Egeria densa* is found in excessive amounts such that native macrophytes beds have been lost. *Egeria densa* is now the dominant macrophyte in this reach. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of *Egeria densa* in this reach and reduce the potential for other exotic macrophytes (eg. *Elodea canadensis*) to grow excessively, such that native macrophyte beds are restored over time.

  Transportation of *Egeria densa* during high flows has the potential to threaten river infrastructure such as bridges and ferries because of damage that may be caused to these structures by the sheer weight and volume of *Egeria densa* that can transported during high flows. Transportation of excessive amounts of *Egeria densa* also reduces the health of the riparian zone. Excessive growth of *Egeria densa* in these reaches also affects recreational use of the river. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of *Egeria densa* in these reaches and thus reduce the potential for damage to river infrastructure during high flows and the transportation of excess material into the riparian zone. Reduced abundance of *Egeria densa* will also increase the recreational appeal of the river as a swimming and fishing area.

  Under the current flow regime combination of altered/regulated flows and STP inflows during dry conditions have created a salinity structure that is reduced in its upstream extent, reducing the potential distribution of marine/estuarine/brackish water species from that which would have occurred naturally during dry periods. In the future, increasing the variability of flows will increase the upstream extent of marine/estuarine species (eg. seagrasses and mangroves) and decrease the distribution of fresh/brackish water species (eg. *Vallisneria gigantea* sp., *Phragmites* sp.) during dry periods as total flows will be reduced thus allowing the salinity structure to increase its upstream extent.

- **Reduced recreational fish catches**

  Improved recreational catches of Australian Bass can be expected.

- **Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers**

  With the optimisation of the recommended environmental flows and the further reduction of pollutants from treated sewage effluent (due to the implementation of the Forum's Effluent Reuse Strategy), improvements in biodiversity and the structure of aquatic communities are expected.

Summary of Key Changes to Ancillary Issues

- **General water quality associated with the Forum's Effluent Reuse Strategy**

  Water quality in the mainstream Hawkesbury River will improve with the introduction of the recommended environmental flows and the implementation of the effluent management strategy.

Nutrient concentrations will trend downwards and algal blooms will be rare as conditions become less conducive to their formation.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  Sustainable agriculture will ensure that reclaimed water from sewage effluent is used to its maximum extent, thus protecting the quality of the environmental flow releases.

  Monitoring of groundwater in areas used for irrigation of reclaimed water from sewage effluent will ensure that groundwater and surface water resources are protected.

- **Tidal channel changes in the Hawkesbury River**

  Survey of cross sectional areas will inform the adaptive management process for the implementation of environmental flows.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Environmental flow releases from dams

  Further details of this issue are given in the discussion for Reach 1.

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

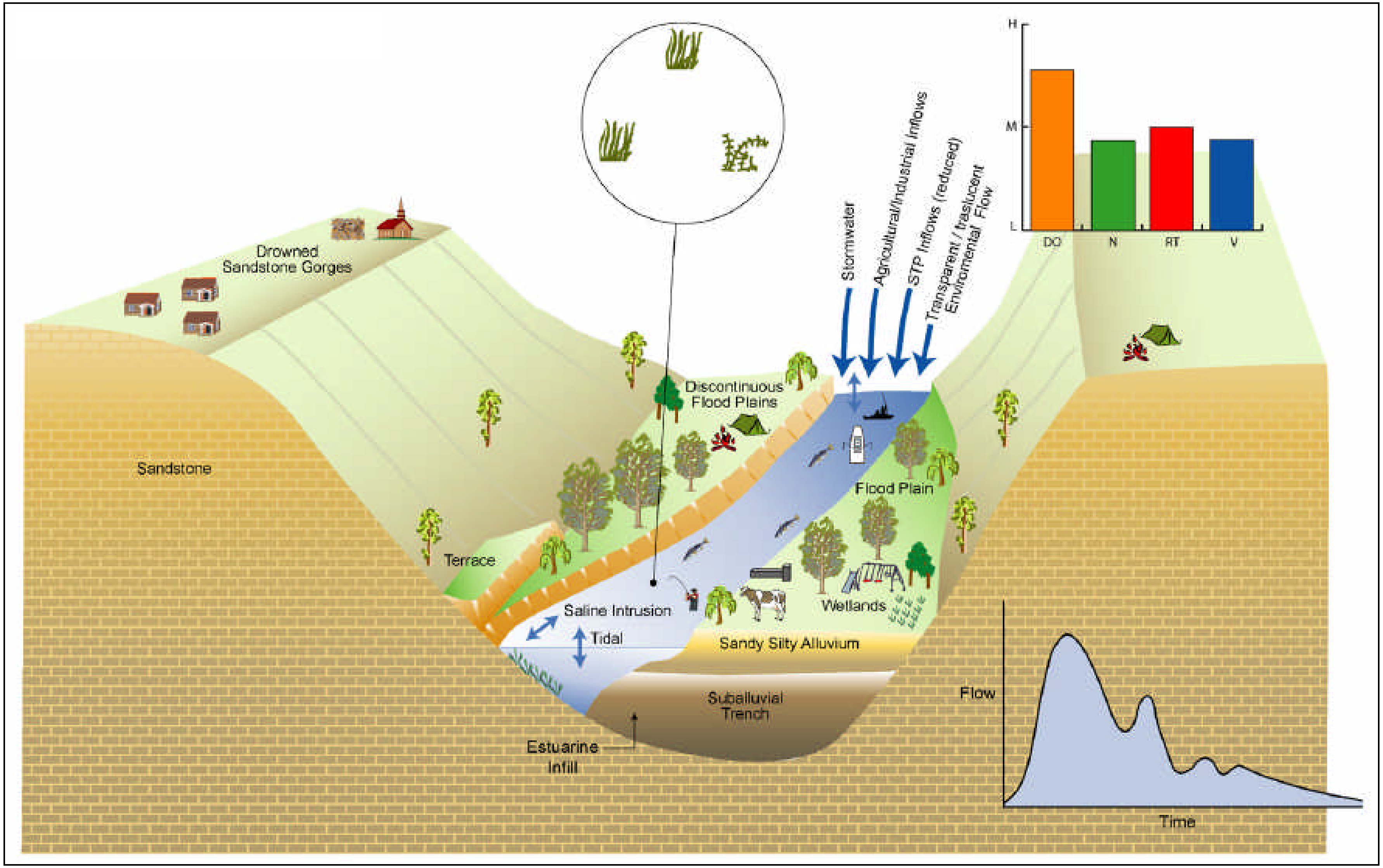
  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

  Effluent reuse strategy

  Further details of this issue are given in the discussion for Reach 14.

Figure B46: Reaches 24 and 25 – Recommended Environmental Flow Regime Hawkesbury River, Wilberforce to Colo River Junction and Hawkesbury River, Colo River to Macdonald River Junction (Wisemans Ferry)



Reach 25: Hawkesbury River, Colo River to Macdonald River Junction (Wisemans Ferry)

The conceptual models for this Reach are the same as those for Reach 24

Natural Regime; Reach 25

This 24 km reach was formed in the same way as Reach 24. It is lower down the system, where alluvial pockets become fewer and smaller, and where the channel is wider and still in places very deep in turbulence holes. Under natural conditions the flats would have been densely timbered and ecology rich.

Current Regime and High Priority Issues; Reach 25

Not much has happened in this reach, other than the clearance of alluvial flats for riverside farming. In earlier days, the river was the main mode of transport and this was a reason for hydrographic surveys in the 19th century. Roads came later. Cold-water releases from dams are thought by some to extend this far and cause adverse conditions for fishing, but this needs to be confirmed by closer monitoring. Bed sedimentation, which needs to be confirmed by survey, in this reach is claimed to have adverse impacts on commercial fishing. Eroded upstream bed and bank deposits were reworked in the last FDR and have been deposited in downstream locations. Local bank erosion of alluvium has marginally increased the tidal prism. However, it seems that sub-tidal capacities may have been reduced by the sedimentation. If this is the case, tidal flushing in this reach should have improved and would see some upstream movement in more saline conditions. This is also a popular reach for camping and water skiing. Only 2.1 GL/yr are extracted for irrigation.

Fundamental Hydrological Issues

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  In Reach 25, the main issues of concern are:
  - Loss of native macrophytes due to the excessive growth of exotic macrophyte species,
  - The impact of excessive growth and transportation of aquatic macrophytes, in particular *Egeria* on riparian zone, river amenity and river infrastructure, and
  - A combination of altered/regulated flows and STP inflows during dry conditions have created a salinity structure that is reduced in its upstream extent

  Further details of this issue are given in the discussion for Reach 14.

- **Reduced recreational and commercial fish catches**

  There is a strong relationship between river flows and recreational catches of Australian Bass, see Growns (2003). Reduced freshwater flows due to river regulation might have resulted in lower catches of Australian bass. There is also a positive relationship between river discharges and commercial catches of prawns and fish species (see Growns and Gray 2003). River regulation is likely to have reduced estuarine productivity due to decreased inflows to estuaries.

Ancillary Issues

- **General water quality associated with the Forum's Effluent Reuse Strategy**

  Point and diffuse sources of pollution have resulted in poor water quality in the river system. This has culminated in the excessive growth of plants, particularly phytoplankton and exotic aquatic macrophytes. Poor water quality due to diffuse and point source discharges is aggravated by a combination of altered/regulated flows, irrigation extractions and STP inflows particularly during dry conditions.

  In the estuary, the longitudinal excursion of the salinity profile has been impacted by a combination of regulated flows and the discharge of sewage effluent from South Creek.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  Productivity of crops and pastures could be impacted through changes in soil salinity levels or other soil qualities that impact on plant productivity.

  Contaminants in reclaimed water could leach into local groundwater tables thereby impacting directly on groundwater and indirectly on the river through shallow connections between ground and surface waters.

  Further details of this issue are given in the discussion for Reaches 15 and 17.

- **Tidal channel changes in the Hawkesbury River**

  The impact of channel changes in the tidal reaches of the Hawkesbury River is unclear. Resurveys may be necessary to assess these impacts and for other purposes such as water quality, hydraulic and hydrological modelling.

  Further details of this issue are given in the discussion for Reach 23.

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  One site listed on the State Heritage Inventory are within this river reach. Please see Appendix B1.

  Aboriginal values

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Irrigation extraction

  Further details of this issue are given in the discussion for Reach 1.

  Riparian extraction

  Further details of this issue are given in the discussion for Reach 2.1.

  Commercial fishery activity

  Further details of this issue are given in the discussion for Reach 2.1.

  Recreational fishing

  Further details of this issue are given in the discussion for Reach 1.

  Recreational amenity

Further details of this issue are given in the discussion for Reach 1.

River-related tourism

Further details of this issue are given in the discussion for Reach 1.

Land use and land management

Further details of this issue are given in the discussion for Reach 1.

Recommended Environmental Flow Regime; Reach 25

A DDC and global warming will reduce river inflows from larger adjacent tributaries and from the main channel, in spite of the introduction of environmental flows. This will increase tidal domination, which already prevails, and the salinity structure. Reduced sedimentation resulting from lower erosion upstream should stabilize conditions for the fishing industry.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes**

  Currently, while both *Elodea canadensis* and *Egeria densa* are both found in these reaches, only *Egeria densa* is found in excessive amounts such that native macrophytes beds have been lost. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of *Egeria densa* in these reaches and reduce the potential for other exotic macrophytes (eg. *Elodea canadensis*) to grow excessively, such that native macrophyte beds are restored over time.

  Transportation *Egeria densa* during high flows potentially threatens river infrastructure such as bridges and ferries because of damage that may be caused to these structures by the sheer weight and volume of *Egeria densa* that can transported during high flows. Transportation of excessive amounts of *Egeria densa* also reduces the health of the riparian zone. Excessive growth of *Egeria densa* in these reaches also affects recreational use of the river. In the future increased flow variability combined with nutrient reduction will help to reduce the abundance of *Egeria densa* in these reaches and thus reduce the potential for damage to river infrastructure during high flows and the transportation of excess material into the riparian zone. Reduced abundance of *Egeria densa* will also increase the recreational appeal of the river as a swimming and fishing area.

  Under the current flow regime a combination of altered/regulated flows and STP inflows during dry conditions have created a salinity structure that is reduced in its upstream extent, reducing the potential distribution of marine/estuarine species from that which would have occurred naturally during dry periods. In the future, increasing the variability of flows will increase the upstream extent of marine/estuarine species (eg. seagrasses and mangroves) and decrease the distribution of fresh/brackish water species (eg. *Vallisneria gigantea*., *Phragmites* sp.) during dry periods as total flows will be reduced thus allowing the salinity structure to increase its upstream extent.

- **Reduced recreational and commercial fish catches**

  Improved recreational catches of Australian Bass can be expected. Increased estuarine productivity can be expected, leading to sustainable commercial catches of fish species and prawns.

Summary of Key Changes to Ancillary Issues

- **General water quality associated with the Forum's Effluent Reuse Strategy**

  Water quality in the mainstream Hawkesbury River will improve with the introduction of the recommended environmental flows and the implementation of the effluent management strategy. Nutrient concentrations will trend downwards and algal blooms will be rare as conditions become less conducive to their formation.

- **Soil and groundwater sustainability associated with the Forum's Effluent Reuse Strategy**

  Sustainable agriculture will ensure that reclaimed water from sewage effluent is used to its maximum extent, thus protecting the quality of the environmental flow releases.

Monitoring of groundwater in areas used for irrigation of reclaimed water from sewage effluent will ensure that groundwater and surface water resources are protected.

- **Tidal channel changes in the Hawkesbury River**

  Survey of cross sectional areas will inform the adaptive management process for the implementation of environmental flows.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Demand management - river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Modifications to the access conditions for river extractors

  Further details of this issue are given in the discussion for Reach 1.

  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

  Effluent reuse strategy

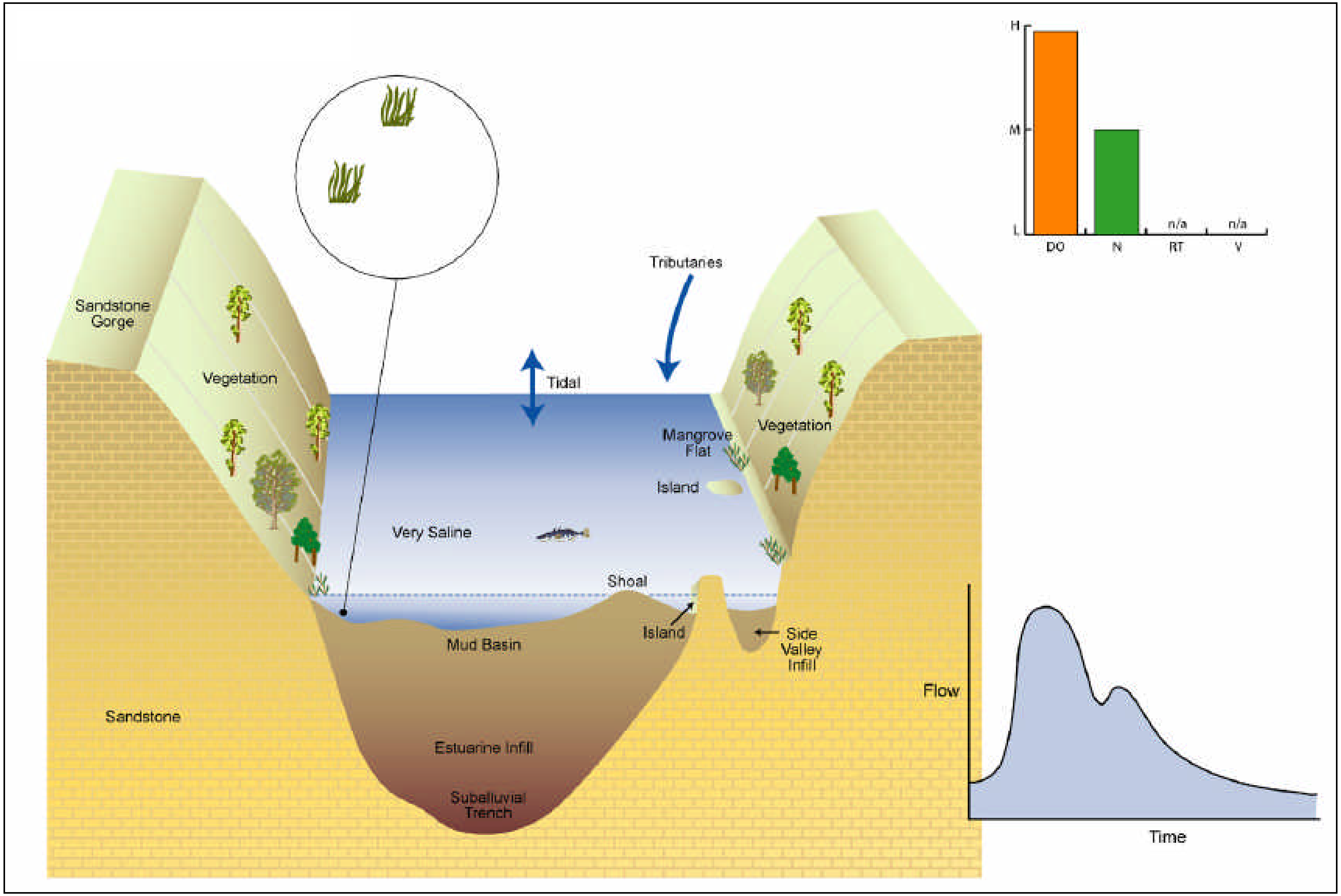
  Further details of this issue are given in the discussion for Reach 14.

Reaches 26 and 27: Hawkesbury River, Macdonald River junction to Pacific Ocean

Natural Regime; Reaches 26, 27

Reach 26 (49 km) can be regarded as the upper estuary of this long tidal river and Reach 27 (16 km) the lower estuary. Under natural conditions these were very wide channels, still with deep holes in places and shoaling off concave banks. In lower parts there are rocky islands, resulting from the drowning of peaked ridges. Mudflats were common and a hazard to early navigation. Brooklyn Bridge spans a trough, which was about 100 m deep, a measure of late Pleistocene cut down. Present water depths are less than 10 m indicating about 90 m of estuarine sedimentation. The upper reach is still dominantly sand floored, with holes. Alluvial margins become smaller and smaller and virtually disappear in the lower reach. The upper part of Reach 27 is known as a mud basin. Fine sediments form the bed of this section, marking the limit of upstream sand deposition and the downstream influence of marine sands in Broken Bay. In this reach even the tributary valleys are drowned to form wide expanses of water (Pittwater, Brisbane Waters, etc). Large inter-tidal wetlands are prevalent where sedimentation has occurred at low level in embayments and on concave bends. Mangroves and other water dependent species colonize these flats.

Figure B47: Reaches 26, 27 - Natural Regime Hawkesbury River, Macdonald River junction to Pacific Ocean



Current Regime and High Priority Issues; Reaches 26, 27

Most of the terrain in these two reaches was too rugged for farming but fishing hamlets and other settlements were founded along the channel. The coastal embayments were even more popular places to settle as is now seen around Pittwater, Berowra and Brisbane Waters. These have increased local stormwater runoff and STP inputs (7.9 GL/yr from Hornsby Heights and West Hornsby STPs) but tidal flushing in the lower estuary is much more efficient than upstream. Farming was confined to shale-capped dissected plateau ridges, which was more prevalent on the north side. Irrigation extractions amount to 14.2 GL/yr in Reach 26 and 11.3 GL/yr in Reach 27, but these could hardly be from the estuary, where saline conditions prevail. The attenuation effects of the distant dams are minimal in these reaches but heavy metal accumulations have been noted in the finer sediments. These would presumably adversely affect some biota.

Fundamental Hydrological Issues

- **Monitoring of tributary flows**

  Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

  Further details of this issue are given in the discussion for Reach 13.

Ecological and Physical Issues

- **Reduced commercial fish catches**

  There is a strong relationship between river discharges and commercial catches of prawns and fish species (see Growns and Gray 2003). River regulation is likely to have reduced estuarine productivity due to decreased inflows to estuaries.

Ancillary Issues

- **Tidal channel changes in the Hawkesbury River**

  The impact of channel changes in the tidal reaches of the Hawkesbury River is unclear. Resurveys may be necessary to assess these impacts and for other purposes such as water quality, hydraulic and hydrological modelling.

  Further details of this issue are given in the discussion for Reach 23.

- **Stormwater runoff**

  In order to protect the recommended environmental flows, the impacts of stormwater runoff in the catchment needs to be assessed.

  Further details of this issue are given in the discussion for Reach 4.

Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Social values

  Further details of this issue are given in the discussion for Reach 1.

  Heritage values

  There are numerous sites listed on the State Heritage Inventory within these river reaches.

  For further information, please see Appendix B1.

Aboriginal values

Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Riparian extraction

  Further details of this issue are given in the discussion for Reach 2.1.

  Commercial fishery activity

  Further details of this issue are given in the discussion for Reach 2.1.

  Recreational fishing

  Further details of this issue are given in the discussion for Reach 1.

  Recreational amenity

  Further details of this issue are given in the discussion for Reach 1.

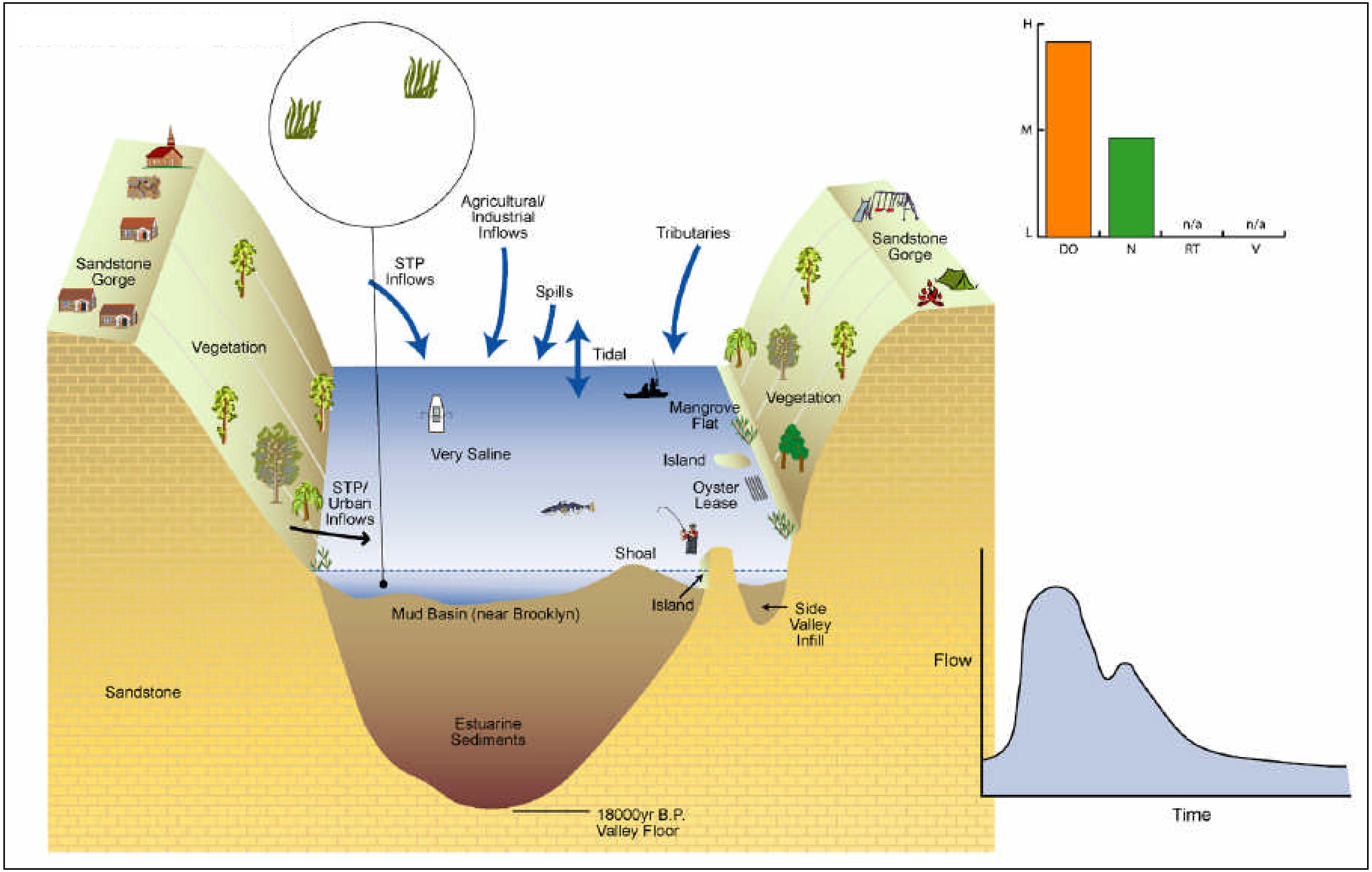
  River-related tourism

  Further details of this issue are given in the discussion for Reach 1.

  Land use and land management

  Further details of this issue are given in the discussion for Reach 1.

Figure B48: Reaches 26, 27 - Current Regime Hawkesbury River, Macdonald River junction to Pacific Ocean



Recommended Environmental Flow Regime; Reaches 26, 27

These reaches will be little affected by environmental flows; they are dependent on occasional floods for flushing. The lower flows of the DDC and those associated with global warming will reduce the magnitude and frequency of flooding, as well as adverse sedimentation downstream of Wisemans Ferry. Heavy metals adhere to finer sediments and these may continue to cause problems in mud basins and other deposits. Urbanisation is increasing in intensity in these areas marginal to Sydney because they are popular places to live. However, stormwater runoff and STP discharges have lower impacts in the well-flushed estuary.

Key changes to high priority issues brought about by the recommended environmental flow regime are summarised below.

Summary of Key Changes to Ecological and Physical Issues

- **Reduced commercial fish catches**

  Increased estuarine productivity can be expected, leading to sustainable commercial catches of fish species and prawns.

Summary of Key Changes to Ancillary Issues

- **Tidal channel changes in the Hawkesbury River**

  Survey of cross sectional areas will inform the adaptive management process for the implementation of environmental flows.

- **Stormwater runoff**

  The implementation of water sensitive urban design will provide a range of environmental benefits for stormwater management, including:
  - reduced stormwater run-off peak flows, velocities and volumes and the associated protection of environmental flows;
  - reduced sediment and nutrient export rates from catchments to receiving waters;
  - enhanced in-stream water quality;
  - reduced contaminant transport;
  - protection of riparian ecosystems, including restoration of degraded systems;
  - promotion of the scenic, landscape and recreational values of creeks and rivers;
  - protection of existing ecosystems in the natural drainage systems; and
  - prevention of erosion in creeks and riparian corridors.

Summary of Key Changes to Social, Economic, Cultural and Heritage Issues

- **Social and cultural values**

  Further details of this issue are given in the discussion for Reach 1.

- **Institutional performance**

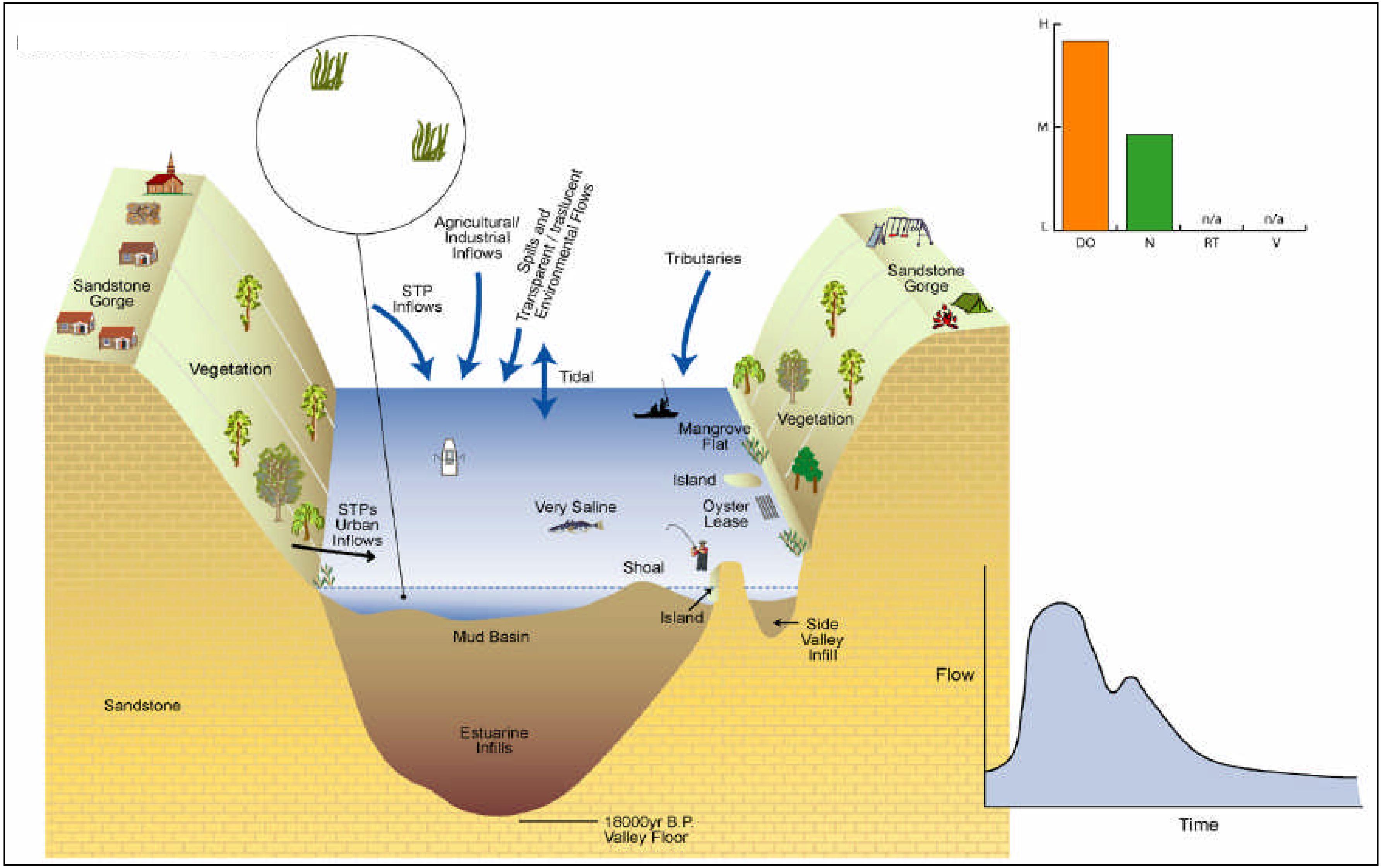
  Further details of this issue are given in the discussion for Reach 1.

- **Land and river activities**

  Stormwater management

  Further details of this issue are given in the discussion for Reaches 8, 9, 10, 11, 12, 13.

Figure B49: Reaches 26, 27 – Recommended Environmental Flow Regime Hawkesbury River, Macdonald River junction to Pacific Ocean



Appendix B1: Heritage Assessment

Non-Indigenous Cultural Heritage Items

For non-Indigenous cultural heritage sites the following was undertaken.

The river reaches GIS layer was overlaid on a scanned copy of the NSW Local Government Area map. Due to the scale some inaccuracies can be expected.

A search by each LGA was undertaken of the State Heritage Inventory via NSW Heritage's web site. The level of information for each item varies extensively. It is sometime difficult to ascertain the exact location of an item.

In general terms, items were only listed if they appeared to have some 'association' with the river. In some areas houses, hotels, commercial properties etc. have all been built in close proximity to the river but have not been considered to be significant in terms of cultural heritage. Obviously all human settlement patterns could be said to be influenced by presence of fresh water/river. This is particularly the case in towns such as Camden.

Site such as 'Mountain View' has a specific relationship due to positioning to avoid flooding although it is over 500m away from river itself, many houses/items are built closer to the river but no more than a 'general' association. Efforts were made to identify items beyond those such as weirs or bridges etc. however not every house or random item could be checked for association with the River. Known large estates such as Camden and Brownlow Hill were included.

Only the NSW Heritage Inventory and State Register were searched. The Register of the National Estate (RNE) was used for additional information on some sites. But sites which only occur on the RNE have not been included. Local Environmental Plans (LEP) were referred to directly in some cases, but generally were assumed to be up-to-date on the Inventory for the purposes of this summary assessment. Statements of significance are from NSW Heritage data unless otherwise stated.

There are numerous sites that are also considered to have maritime heritage significance. The NSW Maritime Heritage Program maintain the Historic Shipwrecks Database and are in the process of recording underwater sites that occur inland, eg. jetties and weirs. Many of these sites are currently listed on the NSW Heritage Inventory but there are numerous sites that have not been listed to date due to lack of survey.

What is presented here is essentially an overview of the reaches in relation to non-Indigenous cultural heritage and is by no means inclusive of all sites and places. Baseline survey in conjunction with community consultation (eg. with local historical societies) of each river reach would be essential to create a comprehensive list of all cultural heritage sites and places that people place value on.

Preliminary Site Categories

A number of categories of sites/site types have emerged which can be grouped together for similarities in requirements for impact assessment, monitoring or likely impact. It is clear that some sites may fall within more than one category. For example the dam sites are part of the water supply system but also valued for their recreational uses. In regard to the statutory protection for some of these sites a number of standard exemptions apply to some sites for maintenance purposes etc.

- **Water supply facilities/engineering works**

  This is a large group, including some highly significant sites, which need to be taken in to consideration as part of overall management. Not only will changes in water management affect the sites but the sites themselves are designed to effect water management. Weirs, dams and pipelines have a direct influence on the way the rivers are managed. They are also evidence of the past water management practices of non-Indigenous people in the most highly populated region of the colony.

- **'Natural' areas**

  Certain areas without direct physical evidence of human beings within the landscape still have cultural significance because of people's regard for them or the associations of people with them. Areas of rare natural phenomena or illustrating the diversity of ecosystems can also be recognised as having heritage significance to our society.

  Places can also be significant because they demonstrate a part of society - people working for and recognising nature.

- **River transport and traversing**

  This category includes ferries, punts and other movable heritage items associated with traversing the river as well as wharves and jetties.

  Other places included here are crossing places of significance such as Blaxland's Crossing where the Nepean River was crossed and illustrates early European people's relationship with the river as a barrier allowing the exploration of the region to continue.

  This category also includes road bridges, rail bridges (viaducts), over both the Hawkesbury and Nepean Rivers. This may include disused bridge remains where bridges have been replaced, but supports or remnants are still present. Although it is unlikely a change in water flow regimes will have a large impact on these types of items (they were built to be in the river), they will need to be considered in long term management.

- **Industry**

  Industrial sites may include physical evidence of early industry in the colony such as mills, coal mines, gold fields, quarrying for gravel and road metal, brick and tile works, canneries, tanneries, vineyards and sawmills.

- **Leisure**

  The rowing course at Penrith Lakes is an example of a well known leisure site that holds significance for people and other designated areas where people's leisure activities associated with the river form part of the significance of the area such as dams, weirs, boating tours. Fishing, water skiing, boating, holiday spots and other water oriented activities hold great significance for people.

- **Homesteads/ farms**

  There are numerous residential and pastoral sites that are adjacent to the rivers and creeks in the catchment. Their association with the water makes them dependent and they may be influenced by any major changes to the river they are located on. However, it is not practical to include all items adjacent to the rivers so particular examples have been given such as Brownlow Hill Estate and Camden Park.

Reaches Assessment

The following presents a summary of the *known* non-Indigenous cultural heritage items or places within each reach as taken from the NSW Heritage Inventory and Register. There is likely to be more sites listed on recent local government LEPs in addition to unrecorded, sites within the area. However, if a reach does not contain listed sites that may be a reflection of lack of recording and subsequent listing on a heritage listing rather then a lack of cultural heritage sites.

- **Reach 2.1**

  The site of Bundanon - listed as "Bundanoon and surrounding landscape" - was the home of Arthur Boyd and is associated with the artist. Some of Boyd's famous paintings of river views were done here, hence its link to the river. A second site - the bridge across Shoalhaven River at Nowra, which is also on the Register of the National Estate - is near the border of this reach and Reach 2.2. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 2.2**

  This reach contains Coolangatta Estate, which is listed on the State Heritage Inventory. It is a collection of around nineteen buildings including cottages, a community hall, blacksmith's shop and coach house. It is the oldest settlement on the south coast, dating to 1822. It was part of explorer Alexander Berry's 10,000 acre grant. It is associated with Australia's first canal and swampland reclamation and shipbuilding, which began in 1824. It is currently a hotel. Following the death of Berry's brother, the estate was broken up. This site has highly significant river associations. Changes in the river flow and salinity levels may have an impact on some heritage sites by increasing the rate of deterioration.

- **Reach 3**

  Woronora Dam is within this reach. The Heritage Listing for the dam provides the following information:

  > *In 1888, the Upper Nepean Scheme was instigated, with the construction of Cataract, Cordeaux, Avon and Nepean Dams. Nepean was completed in 1935. By that time, it was appreciated that the growth of Sydney would necessitate the construction of a major storage dam on the Warragamba River. The construction of the Woronora Dam commenced in 1927, with the objective of providing a water supply for the Sutherland/Cronulla area and of supplementing the Upper Nepean Scheme. Woronora Dam has immense historic and technological value. It is a unique element within the Sydney water system as it exists independently of the collection and storage dams of the Upper Nepean–Warragamba schemes and supplies only the southern suburbs of the metropolitan area, including Sutherland, Cronulla and Heathcote.*

  In addition, there are a number of boatsheds listed that may fall within the reach. Little is known regarding these boatsheds and inspection and further research would be essential to ascertain their significance. Changes in the river flow and salinity levels may have an impact on some heritage sites by increasing the rate of deterioration.

- **Reach 5**

  This reach has one item of State significance, the Como Rail Bridge. The historical notes in the listing state:

  > *The old Como railway bridge was completed in 1885 as a part of the original Illawarra line infrastructure. It is a very fine example of a single track steel lattice girder bridge of the 1870s and 1880s. Como is the longest single track steel lattice girder bridge in NSW and the only such bridge within 250kms of Sydney. The bridge is the older of two important man-made elements in a scenic estuarine landscape, contrasting with the strong natural quality of the environs. The simple, rugged quality of the engineering contrasts with the Australian bush, cliff and shore settings.*

  Changes in the river flow and salinity levels may have an impact on some heritage sites by increasing the rate of deterioration.

- **Reach 8**

  The upstream boundary of this reach is the Nepean Dam. It is listed on the State Heritage Register as "Nepean Dam – Wall and Valve House" The Heritage Register statement of significance includes the following:

  > *Nepean Dam has a high level of historic significance. The last of the Upper Nepean supply dams to be built, it was completed in 1935, signalling the conclusion of the*

> *Upper Nepean Scheme. During the period, major advances in engineering technology had been made. The Dam represents the culmination of innovation in civil infrastructure, epitomising the first thirty years of the 20th century. The Dam thus possesses a high level of technological and historical significance. It is valued by the community as it provides an open, public area for passive recreation, and facilities are maintained for that purpose. The Dam presently serves suburbs of greater Sydney, and remains a symbol of engineering innovation at the turn of the century.*

- **Reach 10**

  The upstream boundary of this reach is Cordeaux Dam. The statement of significance (from the NSW State Heritage Inventory) for the Cordeaux Dam includes the following:

  > *The Cordeaux Dam was the second major storage dam built during the second stage of the Upper Nepean Water Supply Scheme. It evidences the progress towards a reliable and adequate water supply for metropolitan Sydney, and the increasing entrenchment of municipal services. It is valued aesthetically for the fine execution of the decorative Egyptian pylons which flank the entrances to the dam wall, and for the strong contribution it makes to the surrounding landscape. The dam is valued by the community for its recreational usage and as it exists as an area of public open space. It nestles harmoniously within the visual catchment of the upstream woodland area.*

  As with the other dams, it was built by public works and contains some engineering innovations. It also has significance for the broader community for recreational use.

- **Reach 11**

  The upstream boundary of this reach is Cataract Dam and the downstream boundary is Broughtons Pass Weir. Cataract Dam is on the Register and Broughtons Pass Weir on the Inventory. Cataract Dam is highly significant and the statement of significance includes the following:

  > *Cataract Dam has a high level of historic significance as it evidences a major step towards the ultimate provision of a reliable water supply for Sydney. It is the first of the major water supply dams to be built in Australia, being larger than both of the earlier Avon and Nepean Dams. The dam was a testing ground for engineering innovation and structural technology. It is technologically significant, being the first water storage apparatus constructed within Australia to utilise the cyclopean masonry civil engineering technique. It provides a venue for passive recreation within the curtilage of the dam and its immediate surrounding catchment.*

  Broughtons Pass Weir was built across the Cataract River, as part of the Upper Nepean Scheme. Work on this scheme was carried out between 1880–1888. Two weirs were built to divert the water, which previously would have flowed down the lower stretches of the Nepean River (Camden and Penrith), into the Upper Canal by means of which it was conveyed to Prospect Reservoir and thence to Sydney. One was Broughtons Pass and the other Pheasants Nest. These two weirs remain today an integral part of the Upper Nepean Scheme. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 9**

  The Avon Dam is the upstream boundary of this reach. Like the Nepean Dam it is also on the State Heritage Register and retains significance for many reasons. The statement of significance (from NSW Heritage Register) for the Avon Dam includes the following:

  > *Avon Dam was the third and largest of the four water supply dams built in the development of the Upper Nepean Water Supply Scheme. It is historically significant as it evidences the progress towards a reliable and adequate water supply for metropolitan Sydney, and the increasing entrenchment of municipal services. It has a high level of technological significance, derived from the record of innovative construction methods used by the Public Works Department. It is valued aesthetically*

for the fine execution of its decorative Egyptian pylons which flank the entrances to the dam wall, and for the strong contribution it makes to the surrounding landscape. The dam is valued by the community for its recreation usage and as an area of public open space. It is visually consistent with the visual catchment of the surrounding woodland area.

This dam serves Wollongong and the whole dam area is used as a recreation area too. A large section of sandstone from an adjacent creek was taken to use as the spillway during construction.

- **<u>Reach 13</u>**

Pheasants Nest Weir is the upstream boundary of this reach. It is listed on the Heritage Inventory. Pheasants Nest Weir was built across the Upper Nepean River (immediately below the junction with the Cordeaux), diverting the flow of the Cordeaux, Avon and Upper Nepean rivers. Work on the weirs was undertaken between 1880-1888. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **<u>Reach 14</u>**

The Menangle Rail Bridge over the Nepean River is listed on the State Heritage Register within this reach. This bridge has recently been in the media relating to concerns over public safety. The statement of significance has been recently updated and is as follows:

The Menangle rail bridge constructed in 1863 is the oldest surviving bridge on the State rail system and is of highest significance in the development of railway technology in the State. It is an excellent example of early [rail] bridge construction. The bridge is one of two identical bridges constructed for the NSW Railways, the other being over the Nepean River at Penrith. The bridge is of national, if not international, significance as there are few such bridges still in use in the United Kingdom.

The Nepean River weir at Maldon is listed on the Inventory, the Menangle Weir forms the downstream boundary, a suspension bridge at Maldon is also listed. The suspension bridge at Maldon over the Nepean River was constructed in 1903. The site was previously known as 'Harvey's Crossing' and contained a stone causeway. The bridge had to be reconstructed in 1939 after a fire. It was closed to traffic in the 1970s. It is known as a scenic spot for swimming etc. There is also a Trust, set up in November 1981, to care for the bridge.

The following extract from the statement of significance for Menangle Weir is from the Sydney Water Section 170 Register:

It is one of the two earliest weirs on the Nepean River, dating from the 1902 drought, and enjoys a picturesque setting alongside a historic and highly significant railway bridge across the Nepean River. It has particular technical interest for its form of construction based upon a combination of sandstone rubble, masonry and timber, which is not repeated at any other Nepean Weir.

Little historical information is available on Maldon weir although it has been referred to as "concrete dam built by and for the Maldon Cement Works, rather than a weir". Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **<u>Reach 15</u>**

This reach contains State Heritage Registered old agricultural/rural properties, Camden Park, Brownlow Hll Estate and Camelot/Kirkham. All are considered highly significant pastoral properties. It is clear that this area of the river is associated with early agriculture/farming in the colony. There are numerous items associated with these three estates, such as gatehouses, cottages etc.

The whole of Camden and such places are associated with the river in terms of a heavily modified cultural landscape.

There are also two weirs in this reach: Brownlow Hill and Thurns. Brownlow Hill Weir is one of the original nine 'Compensation Weirs' erected in 1908 to compensate for the loss of flow in the Nepean River from the diversion created by the Upper Nepean Scheme. It is intact and in working condition. Thurns Weir was also one of the 'Compensation Weirs'. It is currently intact but does not function as a weir. The river has by-passed the weir on the western side, causing a build up of sediment and slime on the weir wall and on the backwater created by the by-pass.

In addition, two further Inventory sites are adjacent to the river. The Carrington Hospital at Camden and the 'Teen Ranch', operating as a Christian youth camp.

- **<u>Reach 17</u>**

Wallacia Weir is the downstream boundary of this reach and is listed on the Heritage Inventory. The statement of significance taken from the Sydney Water Heritage Inventory is as includes the following:

> *The Wallacia Weir is one of the original nine compensation weirs. It is one of the few of these weirs, which remains in relatively original condition. It demonstrates the extent of associated works which were needed to implement it. It illustrates the impact of the Upper Nepean Scheme, upon the communities and agriculture along the river. The construction of the 'Compensation Weirs' provides evidence of the approach taken by the Public Works Department to balancing the needs of the rural communities along the Nepean River against the needs of metropolitan Sydney. The construction of the Wallacia Weir demonstrates the importance of Wallacia as a settlement in the early twentieth century and the weir structure is a representative example of this type of facility.*

Blaxland's Crossing (over the Nepean) is listed on the Inventory. It was originally a ford paved with river pebbles to form a causeway. The original ford location is hidden under a later (1859) bridge.

Blaxland's farm, currently listed on the Heritage Inventory, is potentially of State significance according to assessment. The statement of significance includes:

> *Blaxland's Farm is significant as a cultural landscape where the farm landscape together with the remains of the flour mill and the brewery provides important historical evidence of early agricultural processing activities in the colony and constitute an unusual survival of early farming technology. The area has scientific significance because of the high potential of the sites to reveal information which is not available from the documentary sources. The full significance of the site is not yet fully understood.*

Some remnant foundations of the mill are visible under the water at low water times. There is an associated weir built in 1911, which replaced an earlier wooden dam.

The site of the brewery is currently identified by mounds of stone on a hill, south east of the weir. Changes in river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **<u>Reach 18</u>**

The Nepean River itself is listed as a heritage item on the Penrith LEP with the following significance statement:

> *Of significance for both local and state as during this century, the river has been the focus for tourism, rural settlement, industrial development and recreation.*

- **<u>Reach 19</u>**

Three State Register items are within this reach. Two are associated with Warragamba Dam, which is itself on the Inventory. The two State significant sites are Warragamba Dam - Haviland Park and Warragamba Emergency Scheme.

The statement of significance for Haviland Park includes the following:

> *Haviland Park has a high level of state heritage significance for several reasons. It represents the pinnacle of quality visitor facilities provided by the Board at Dam sites. It contains numerous archaeological, architectural and engineering remnants from the dam's construction. The Park displays a high degree of formality and planning and is rich in both exotic and native botanical species which contribute to the landscape significance of the park. It is highly valued by the community of New South Wales as a place for passive recreation, leisure activities and sightseeing pursuits.*

The Emergency Scheme was built by the [former] Water Board on the east bank of the Warragamba River. The plans were passed for construction in 1925. At the height of construction, the scheme and its pipeline employed 2000 workers. All buildings were later re-used as housing for maintenance employees. The elements recorded as still existing include: the weir, a 10-cable cableway, sheds, batching plants, roads, electrical substation, chlorination plant, maintenance staff accommodation, balance reservoir, Megarritys bridge (see below), water pumping station, tunnels, and associated pipelines.

Megarritys Bridge was designed to carry an outlet main from Warragamba Dam, for the Emergency Scheme. The statement of significance includes the following:

> *Megarritys Bridge is considered to be of high significance as it serves the function of carrying the major Warragamba pipeline across Megarritys Creek. It is historically associated with the Warragamba Emergency Scheme, and at the time of construction, was one of the largest concrete arch bridges to be built in NSW. It is a unique item of engineering heritage as its design is based on an innovative 'bow string' arch design rather than the more common 'decked' arch design.*

As previously mentioned, Warragamba Dam is on the Inventory. It forms the upstream boundary of the reach. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 20**

The Nepean River is a heritage item on the Penrith LEP. The other sites in this reach are also highly associated with natural features of the landscape. They are, the Lapstone monocline, the Blue Mountains National Park and some sedimentary dykes of intruding Hawkesbury sandstone near Lapstone station.

The Lapstone monocline is a geological feature associated with the sedimentary layers of the Sydney Basin. The uplifting took place gradually, meaning that the Nepean River was able to continue to cut down into the rock strata while maintaining its course. This also means that on the banks of the western side of the river, the strata rise over 500m above those on the east. There are three entries on the Inventory for different parts of the monocline.

There is an Inventory listing for some sedimentary dykes of intruding Hawkesbury sandstone near Lapstone Station. The Blue Mountains National Park meets the River at some points in this reach. It is listed on the Heritage Inventory and is listed as a World Heritage Area.

- **Reach 21**

There are six Inventory sites within this reach. Two have been previously dealt with, the Nepean River and the Blue Mountains National Park. The other four are, a Ferry Crossing at Emu Plain, the Rowing Course, Penrith Weir and Victoria Bridge at Penrith.

The Ferry/Punt crossing was in use between 1820-1870. Its significance is in emphasising the barrier nature of the river and the efforts required to cross it. The Rowing course is associated with international events. First used in 1882, it has seen world championships and Empire [Commonwealth] Games and continues to be used.

Victoria Bridge (see also Menangle Bridge) is the oldest in the State. It is important for its role in the history of the railway line and the Western Highway. It no longer carries the rail line, but the Great Western Highway over the Nepean River between Penrith and Emu Plains.

Penrith Weir and the former pumping station are on the Inventory. The weir forms the downstream boundary of this reach. It was constructed in 1909 to provide a permanent water supply to Penrith. The pumping station drew water from the weir pond. Before the current weir, there had been a sandbag weir, which was washed away in 1902 floods. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 22**

  The Natural Area at Agnes Banks it on the State Register. It is located around one kilometre from the river, but is associated with significant sand deposits that are in turn associated with the River. It contains alluvial and aeolian sands deposited during the Pliocene and Pleistocene and fluvial clays and silts of Tertiary age. These are considered important for studies of geomorphology and climate in the past. They are also associated with highly significant vegetation.

  The Penrith LEP lists the Nepean River, so all sections running through Penrith are on the Inventory.

  The sites of three early water mills are listed for this reach. It is not known at this point how much material might remain at these sites. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 23**

  The Windsor Bridge over the Hawkesbury River is the only site listed on the Inventory. There is no information on the entry. This area is also associated with early agriculture and one of the 'Macquarie Towns'. Windsor was originally known as Green Hills, until renamed by Governor Lachlan Macquarie on the 6th December 1810. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 24**

  There are two Register items in this reach that may relate to the river. The exact location of Cattai Estate is not known, however, it is in Cattai National Park and the Park borders the River.

  The other Register item is, 'The great drain & 2 house sites". The statement of significance includes the following:

  > *The three items in the group, dating between 1795 and 1830, are historically extremely rare and associated with a series of early Hawkesbury settlers (Williams, Carr, Cox, Johnston), predating official settlement down river. They are aesthetically valuable because of the siting in bushland of the house foundations and the dramatic vistas within the cutting of the Great Drain. They are scientifically extremely significant because they provide unique information about drainage and house building techniques.*

  Two Cable Ferry sites are within this reach: Lower Portland and Sackville, both on the Inventory. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 25**

  One Cable Ferry site is listed in this reach. Cable Ferry Webbs Creek River Road and Wisemans Ferry. The cable ferries are also on the Hawkesbury-Nepean Regional Environmental Plan. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

- **Reach 26**

  At the junction of Berowra and Murramurra Creeks there is a significant ballast heap, which was used by early the Hawkesbury River traders bringing produce to and from Sydney. This site is considered significant for its remains of early navigation and contributes to the understanding of 19th century life on the river.

  There are cut stone blocks at Bennetts Bay, located on the bank of the Berowra Creek. This jetty site is thought to be part of early agricultural development of Berowra Creek by George Peat and others from the 1840s.

  A boatshed is listed at Berowra Waters Road (at ferry terminal), and is an integral part of Berowra Waters history. It was developed to accommodate local people, then visitors, first for fishing then more general leisure pursuits. The history is poorly documented and should be more fully researched.

  George Peat's Farmhouse Remains at Peats Bight, Berowra Waters. This site has the important remains of a farmhouse built by George Peat, a major Hawkesbury entrepreneur, to oversee his grazing and orchard properties on either side of the river and the Hawkesbury ferry from Kangaroo Point to Mooney Mooney Point.

  Other sites include the Cable Ferry at Wiseman's Ferry, the Wiseman's Ferry Inn and Grounds. Also at Wiseman's Ferry are the remains of the Mill Creek/Mill Ruins.

- **Reach 27**

  This reach contains numerous heritage sites both in the water and on the river banks. Being an estuary, salinity changes can be a significant threat to underwater heritage sites, which are common in this reach.

  Some of the main sites located in this area include the Hawkesbury River Rail Bridge, significant being the largest and most significant rail bridge in the State. The listing includes the causeway, the present rail bridge and remains of the earlier bridge. The remains of the first bridge, abutments and pylons in the river, are a major feature of the area and the bridge is a landmark structure in the river, clearly seen from many vantage points including the road bridge further upstream. The area is also important for the evidence of the construction of both bridges with the construction site still clearly visible cut into the rock waterfront and the abandoned formations for the earlier bridge approaches.

  A jetty, boatshed, well and foreshore land associated with Mulholland's Farm is listed at Greens Point. This is a significant site complex dating from 1891 and 1975. It is highly significant as the most intact surviving farm on the Brisbane Water (from the farm subdivison era of the 1880s to 1945) derives from the fact that it retains the physical and visual evidence of the Farm's association with the waterway.

  The aforementioned site is a separate listing from Mulholland's Farm, a former farm, albeit subdivided, with its house and foreshore farm structures, is one of a small number of farms established from subdivisions of the 1880s to survive in the local area. In this instance it is Green Point Estate subdivision of 1885. The place has retained its full visual setting and physical relationship with the water, farm structures, and a meaningful rural setting with key historic elements. The farm is one of a number of former farming properties in the local area associated with a pioneering family. Changes in the river flow and salinity levels may have an impact on some heritage sites in terms of increasing the rate of deterioration.

PART C: FUNDAMENTAL HYDROLOGICAL, ECOLOGICAL AND PHYSICAL, AND ANCILLARY MONITORING - DESIGN AND METHODS

Introduction

The design of the program for fundamental hydrological, ecological and physical and ancillary monitoring is generally structured under the following headings.

- **Hypothesis -** Each hypothesis attempts to predict the impacts of the recommended environmental flow regimes on the high priority issues.
- **Location -** The reaches or groups of reaches relevant to the high priority issues.
- **Pre-monitoring investigations -** Studies, surveys and other preliminary work that are required to support the proposed monitoring program.
- **Variables** - Lists the variables that are relevant to this monitoring of each priority issue.
- **General approach** - Provides an overview of the particular monitoring program.
- **Field sampling design** - Outlines a recommended approach to the collection of field data.
- **Statistical analyses** - Provides guidance on statistical analyses to aid the interpretation of monitoring data.
- **Response time** - Estimates the likely time period before a response resulting from the introduction of the recommended environmental flow regime.
- **Management interaction** - This section suggests what action could be taken to increase the beneficial effects caused by the introduction of the recommended environmental flow regimes.

As described in Part A, the Forum has adopted a program comprising only part of the Ecological and Physical and Ancillary components of the Panel's recommended program. However, as the Panel considers that all of the high priority studies originally identified need to be implemented to avoid compromising the adaptive management program for implementation of environmental flows, all of the high priority monitoring is discussed in detail in this part of the report (ie. monitoring design details are not limited to the program approved by the Forum).

Tables C1 and C2 summarises the high priority issues which are the subject of the detailed monitoring design in this Part.

Table C1: High Priority Issues within Reaches - Fundamental Hydrological, Ecological and Physical (in order of rank)

High Priority Issues	Reach or Reach Group (a)																			
	Shoalhaven River			Woronora River			Wingecarri-bee River		Nepean River							Hawkesbury River				
	1	2.1	2.2	3	4	5	6.1	6.2	7	8 10 11	9 12 13	14	15 17	16 18 19	20 21	22	23	24	25	26 27
Fundamental Hydrological Issues																				
Monitoring of weired shale reaches below dams													■		■					
Monitoring the sandstone reaches downstream of dams				■	■					■	■	■		■	■					
Monitoring dam inflows	(b)			(b)						(b)	(b)			(b)						
Monitoring of tributary flows										■	■	■	■	■	■	■	■	■	■	■
Ecological and Physical Issues																				
Cold water releases from dams	■									■	■	■	■	■	■					
Reduced connectivity – natural barriers	■			■	■	■				■	■					■	■			
Critical habitat contraction	■			■	■					■	■									
General water quality downstream of dams	■									■	■			■						
Loss of native aquatic macrophytes and excessive growth of exotic aquatic macrophytes												■	■	■	■	■	■	■	■	
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers	■			■	■					■	■									
Reduced recreational fish catches	■	■		■	■	■						■	■	■	■	■	■	■	■	
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers												■	■	■	■	■	■	■		
Reduced commercial fish catches		■	■																■	■
Connectivity investigations – managing flows for fish passage in the Woronora River				▒	▒	▒														
Stratification of natural pools	▒									▒	▒	▒								
Reduced flushing, scouring and conditioning of habitat				▒	▒						▒									
Elevated iron and aluminium concentrations in discharge waters from dams	▒																			
Encroachment of riparian vegetation on channels				▒	▒						▒									
Iron-rich groundwater inflows downstream of Avon and Cataract Dams											▒									

a Reaches and reach groups as defined by the Expert Panel – refer Table B1 in Part B of the Monitoring Program report
b Monitoring of the inflows to storage dams will be undertaken upstream of all dams. Existing gauges are adequate for estimation of inflows to Tallowa, Warragamba and Nepean storages. Additional gauging infrastructure is required as a high priority upstream of Woronora, Cataract, Cordeaux and Avon storages to allow reliable estimation of inflows to those storages.
c ■ High priority issues identified: program components approved by Forum ▒ High priority issues identified: program components not approved by Forum □ No high priority issues identified

Table C2: High Priority Issues within Reaches – Ancillary (in order of rank)

High Priority Issues	Reach or Reach Group (a)																			
	Shoalhaven			Woronora			Wingecarri-bee River		Nepean								Hawkesbury			
	1	2.1	2.2	3	4	5	6.1	6.2	7	8 10 11	9 12 13	14	15 17	16 18 19	20 21	22	23	24	25	26 27
Ancillary Issues																				
General water quality associated with the Forum's Effluent Reuse Strategy																	■	■	■	
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management												■	■							
Soil sustainability associated with the Forum's Effluent Reuse Strategy													■				■	■	■	
Inter-catchment transfer of fish via Glenquarry Cut									■											
Lack of connectivity - diversion and gauging weirs										■	■									
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy													■				■	■	■	
Effectiveness of Tallowa Dam fish lift	▒																			
Channel degradation in the mixed-load shale reach downstream of Penrith Weir																▒				
Connectivity - Penrith Weir fishway																▒				
Channel changes in weired reaches												▒	▒		▒					
Tidal channel changes in the Hawkesbury River																	▒	▒	▒	▒
Stormwater runoff					▒	▒					▒	▒	▒	▒	▒	▒	▒	▒	▒	▒

a Reaches and reach groups as defined by the Expert Panel – refer Table B1 in Part B of the Monitoring Program report
b ■ High priority issues identified: program components approved by Forum ▒ High priority issues identified: program components not approved by Forum □ No high priority issues identified

Linkages between Individual Components of the Monitoring Program

The components of the monitoring program have been designed for specific fundamental hydrological, ecological and physical responses to environmental flow releases and associated ancillary works. Many of these components are interlinked, with information gain in one helping the interpretation of another, thus forming an integrated monitoring program. Table C3 summarises the linkages between specific components.

These linkages strengthen the outcomes of the monitoring program by providing additional, and often key, information to a specific program component that may not be recorded otherwise. Whilst individual monitoring designs are sufficient in their own right, the linkages improve the interpretability of individual results. This will be achieved by inclusion of additional information that will allow a better understanding of the results thus increasing the power to draw conclusions.

In Table C3, the linkages have been defined as being strong (blue), medium (red) or weak (yellow) depending on the relationship between one program component and another. Where a strong relationship is indicated, this reflects that information collected in one component directly affects/influences another, for example water quality monitoring will provide key information in regards to nutrient levels that will assist in the interpretation of the macrophyte monitoring. For medium and weak linkages, the information provided by the secondary program component is indirectly related, and of more or less importance. For example, altered biotic communities may provide additional information on the distribution of macrophytes in the Hawkesbury-Nepean River system (especially in areas that are not being directly monitored by macrophyte monitoring) however this information will not directly influence interpretation of the results, hence the linkage strength was assessed as weak.

Links between high priority issues selected for monitoring and the impact mechanisms identified in the rivers reaches assessment

Within the river reaches assessment[1], a series of impact mechanisms were identified and given a likely-intensity rating per river reach. The mechanisms were partitioned as follows:

- Flow-alteration impact mechanisms in rivers.
- Flow-alteration impact mechanisms in estuaries.
- Dam-induced water quality alteration impact mechanisms.
- Anthropogenic non-flow impact mechanisms.

Links between the more significant of these mechanisms (specifically, those mechanisms with two or more reaches having a moderate or high likely-intensity rating) and the high-priority monitoring components are discussed in Appendix C2.

[1] *River Reaches Assessment*; Microsoft Access Database, Expert Panel, March 2004

Table C3: Summary of Linkages between Components of the Monitoring Program

Monitoring Program Components that Link to Primary Component	Component of Monitoring Program (Primary): Fundamental Hydrological Monitoring				Ecological and Physical Monitoring															Ancillary Monitoring									
	Weired Shale Reaches Flows	Sandstone Reahces Flows	Dam Inflows	Tributary Flows	Cold Water Releases	Reduced Connectivity-Natural Barriers	Critical Habitat Contraction	General Water Quality	Macrophytes	Altered Biotic Communities - Reaches 1-13	Recreational Fish	Altered Biotic Communities - Reaches 14-24	Commercial Fish	Connectivity - Woronora	Stratification in Pools	Reduced Flushing, Scouring	Iron and Aluminium in Releases	Riparian Vegetation	Iron Rich Groundwater Inflows	Water Quality - Effluent Reuse Strategy	Water Quality Weir Pools	Soil Sustainability - Effluent Reuse Strategy	Inter-basin Transfers of Fish	Connectivity/Fishways - Weirs /dams	Groundwater Sustainability - Effluent Reuse Strategy	Channel Degradation Mixed Load Shale Reaches	Channel Changes Weired Reaches	Tidal Channel Changes Reaches	Stormwater Runoff
Fundamental Hydrological Monitoring																													
Weired Shale Reaches Flows																													
Sandstone Reaches Flows																													
Dams Inflows																													
Tributary Flows																													
Ecological and Physical Monitoring																													
Cold Water Releases																													
Reduced Connectivity-Natural Barriers																													
Critical Habitat Contraction																													
General Water Quality																													
Macrophytes																													
Altered Biotic Communities - Reaches 1-13																													
Recreational Fish																													
Altered Biotic Communities - Reaches 14-24																													
Commercial Fish																													
Connectivity - Woronora																													
Stratification in Pools																										uk		uk	
Reduced Flushing, Scouring																													
Iron and Aluminium in Releases																													
Riparian Vegetation																													
Iron Rich Groundwater Inflows																													

Table C3 (continued): Summary of Linkages between Components of the Monitoring Program

Monitoring Program Components that Link to Primary Component	Component of Monitoring Program (Primary): Fundamental Hydrological Monitoring				Ecological and Physical Monitoring															Ancillary Monitoring									
	Weired Shale Reaches Flows	Sandstone Realhces Flows	Dam Inflows	Tributary Flows	Cold Water Releases	Reduced Connectivity-Natural Barriers	Critical Habitat Contraction	General Water Quality	Macrophytes	Altered Biotic Communities - Reaches 1-13	Recreational Fish	Altered Biotic Communities - Reaches 14-24	Commercial Fish	Connectivity - Woronora	Stratification in Pools	Reduced Flushing, Scouring	Iron and Aluminium in Releases	Riparian Vegetation	Iron Rich Groundwater Inflows	Water Quality - Effluent Reuse Strategy	Water Quality Weir Pools	Soil Sustainability - Effluent Reuse Strategy	Inter-basin Transfers of Fish	Connectivity/Fishways - Weirs /dams	Groundwater Sustainability - Effluent Reuse Strategy	Channel Degradation Mixed Load Shale Reaches	Channel Changes Weired Reaches	Tidal Channel Changes Reaches	Stormwater Runoff
Ancillary Monitoring																													
Water Quality - Effluent Reuse Strategy						Weak	Weak		Strong	Weak	Weak		Strong			Weak							Weak	Weak			Medium		
Water Quality Weir Pools						Weak	Weak		Strong	Weak	Weak		Strong			Weak				Strong			Weak	Strong			Strong		
Soil Sustainability - Effluent Reuse Strategy						Weak	Weak		Weak							Weak				Strong			Weak	Weak					
Interbasin Transfers of Fish						Weak	Strong									Weak								Weak					
Connectivity/Fishways - Weirs/Dams						Strong	Strong		Weak							Weak							Medium				Strong		
Groundwater Sustainability - Effluent Reuse Strategy						Weak	Weak		Medium							Weak				Strong			Weak	Weak					
Channel Degradation Mixed Load Shale Reaches						Weak	Weak		Strong							Weak							Weak	Weak					Strong
Channel Changes Weired Reaches						Weak	Weak		Strong							Weak							Weak	Weak					Medium
Tidal Channel Changes Reaches						Weak	Weak		Strong							Weak							Weak	Weak					Medium
Stormwater Runoff						Weak	Weak		Strong							Weak		Medium					Weak	Weak		Medium	Medium	Medium	

Strong Linkage ie directly related, provides key information relevant to interpretation

Medium Linkage ie indirectly related, provide some key information relevant to interpretation

Weak Linkage ie indirectly related, provides some information relevant to interpretation

uk Potential Linkage but strength unknown at this time

Decision-making, Costs, Trade-offs and Risks

(Adapted from Downes et al. 2002)

There are generally three purposes for the development and implementation of an environmental monitoring program:

1. To assess the ecological state of ecosystems
2. To assess whether regulated performance criteria have been achieved or exceeded
3. To detect and assess the results of human activities

Downes et al. (2002) divide the third type of monitoring program into those that seek to detect environmental impacts (ie. deleterious environmental consequences) and those that try to evaluate rehabilitation and restoration activities (ie. activities that try to improve ecosystem health). The implementation of an environmental flow regime (EFR) is a type of river restoration activity and hence the monitoring program developed to assess its outcomes will attempt to answer the question: "has the environmental flow regime, and associated other management activities, improved aquatic ecosystem health?" This form of question is in fact a form of scientific hypothesis. Stated formally as a scientific null hypothesis this can be put "The implementation of and environmental flow regime, and associated management activities, will have no environmental benefits". Hypothesis testing is a fundamental component of the modern scientific method, but it is more commonly incorporated in controlled experiments than in monitoring programs (eg., Havens and Aumen 2000, Chessman and Jones 2001). The development of a monitoring program to determine the environmental benefits of an environmental flow regime in the Hawkesbury-Nepean River system was based upon rigorous scientific principals and methods.

Monitoring through an adaptive management process is essential to inform river managers whether changes to the environment have occurred as a result of management actions. Monitoring to assess human activities on the environment can take two forms, firstly evaluating detrimental impacts (ie. impact assessment), for example determining the effects of pollution, and secondly, testing the benefits of restoration programs, for example the implementation of environmental flows in regulated rivers. Monitoring for both detrimental and beneficial effects of river management is superficially similar. However, monitoring for restoration differs in that a target or reference condition is required in order to test whether detected changes are in the right direction and of the correct magnitude (Underwood, 1997; Grayson et al., 1999).

The general aim of river restoration is to improve aquatic ecosystem health. The definition of what constitutes a healthy river is the source of debate amongst ecologists. River health can be considered a measurable physical state equated with 'naturalness'. This means that river health is the degree of similarity to an un-impacted river of the same type, particularly in terms of its biological diversity and ecological functioning (Schofield and Davies, 1996). In contrast, Norris and Hawkins (2000) suggested that river health is simply 'shorthand for good condition' and Suter (1993) thought river health was 'a metaphor, not an observable property'. Nevertheless, an aquatic ecosystem is made up of a variety of different types of biota, their habitats and the processes that link them. Therefore a monitoring program that attempts to measure aquatic ecosystem health generally has to be multi-faceted.

There are many papers that relate experimental design to the development of ecological monitoring programs (eg. Cairns, 1979; Fairweather, 1991; Faith et al., 1991; El-Shaarawi, 1993; Downes et al., 2002). These papers generally provide scientific procedures that can be applied in developing a monitoring program, but do not provide a systematic procedure. ANZECC/ARMCANZ (2000) is the only reference cited that provides a comprehensive outline for the development of a monitoring program. Downes et al. (2002) provide details on important issues that need to be addressed in a monitoring program while not providing a detailed process. There are few examples of "real-life" attempts to put these scientific principles into practice and those that are available (see ANZECC/ARMCANZ, 2000) are related to environmental impacts, not restoration activities. The monitoring program developed for the Hawkesbury-Nepean River system was a combination of the general process outlined by ANZECC/ARMCANZ (2000) and the important scientific considerations provided by Downes et al. (2002).

Making decisions based upon results of monitoring program

By using rigorous scientific principals and methods, the decision to determine if the EFR has improved river health will be based upon the testing of the null hypothesis "The implementation of an environmental flow regime, and associated management activities, will have no environmental benefits". There are four possible outcomes to the testing of the null hypothesis to determine any potential benefits in any decision process using monitoring framework. There are two correct decisions, either there has been an improvement in the environment as a result of the EFR or there has not been an ecological benefit. However, there can also be two possible errors in this decision making process. The environment has actually improved but the monitoring program failed to detect any improvement (a Type I error) or the results of the monitoring suggest that the environment has actually improved, but in reality there has been no ecological improvement (a Type II error) – see Table C4. The errors arise because decisions arise about the truth or otherwise of the null hypotheses about unknown population parameters from imperfect samples.

Table C4: Possible outcomes of decisions based upon results of a monitoring program
(Adapted from Fairweather 1991)

Real State of Nature	Prediction or results of monitoring study	
	Improvement	**No improvement**
Improvement	Correct	Type II error (β)
No improvement	Type I error (α)	Correct

It is a convention in many disciplines, including ecology, to fix the probability of a Type I error (α) at .05 or 5% ie. there is a 1 in 20 chance that we conclude an environmental benefit from EFR when in fact there is none. This can be restated that there is a 95% chance that the monitoring program concludes that there has been an improvement in aquatic ecosystem health as a result of the EFR and in reality there is one. The convention of setting α at such a low value reflects the concerns of scientists about incorrectly concluding an effect of an experimental treatment when none exists. An incorrect conclusion can have large economic or other consequences, for example indicating that a drug has no side effects when in fact is causes deformities in babies. The probability of a Type II error can only be calculated for specific alternative hypotheses (ie. effect sizes). For example what is the probability of not rejecting the Ho (no change as a result of the EFR) if there really is 50% change in the number of macroinvertebrate taxa.

An issue then is the balance of these two types of error when testing the null hypothesis that the restoration activity has had no effect on the environment. There are two constraints to determining this balance. The first is that it is relatively easy to set the level of Type 1 errors in advance with the significance level of the experiment (α) but harder to set the level of a Type II error (β) because the probability of this error depends upon the expected size of the environmental change. The second constraint is that for given values of all other components of a monitoring program such as effect size, sample size and variability between sampling units where the probabilities of the two types of error are inversely related. The decision-making framework must provide a reasonable and flexible balance between Type I and Type II errors. In monitoring programs designed to detect environmental restoration the relative seriousness of making each type of error is probably different from most traditional areas of science.

For example, failure to detect a real environmental change (Type II error) might be considered a more serious error than incorrectly rejecting the null hypothesis of no benefit (a Type I error). The former may result in continued environmental improvement until the benefit is detected, with the resulting increased costs of engineering modification to dams to provide larger or more diverse EFRs and costs associated with decreased supply of water for human purposes. In contrast, the latter error is more precautionary of the human uses with the likelihood of no further benefit or reduced benefit occurring. In practice monitoring programs examining for restoration benefits that set α at 0.05 (5%) will have a high probability of a Type II error that there really has not been a benefit of the EFR.

The consequences of making each type of error are also different depending on vested interests of those involved with the rehabilitation activity. It is advantageous for individuals or groups interested in environmental issues to reduce the probability of a Type I error ie. the monitoring results indicate that there in an ecological improvement when in reality there has been no change. In contrast, organisations involved with the supply of water and with the potential economic losses associated with the introduction of an environmental flow are likely to wish to minimise the probability of a Type II error. For example, if the monitoring results indicate that there is no ecological improvement, when in fact there has been a benefit from an EFR (a Type II error), then at a review stage it is likely that more water would be allocated to the EFR. There may also be further economic costs with the potential for further engineering modification to dams to pass a greater range or volumes of water for EFR.

Conventional practice, for both science in general and for monitoring in particular, is to fix the chance of finding a significant result when there is not really one (a Type I error (α)) at 0.05 and therefore let β (and power) vary depending upon effect size. Downes et al. (2002) suggest that monitoring to detect impacts in freshwaters environments, rather than ecological improvement as in the case of an EFR, has low power to detect changes that could be considered ecologically important, because sample sizes are normally too small to account for the large variability that occurs among sampling units of most biological variables. Therefore, monitoring programs that are designed using conventional practices to determine ecological improvement as a result of rehabilitation or restoration activities are likely to have a low power and therefore a low chance of showing a benefit when in fact there has been an ecological improvement as a result of the EFR. In contrast, the variability of some physico-chemical variables may be less than biological data and thus monitoring designs may have higher power to detect their changes.

Setting α, by conventional practice, at a low level implies that Type I errors are more important than Type II errors. In the case of monitoring programs to detect environmental impacts, this favours the proponents of the human activity rather than the environment (Keough and Mapstone 1995). However, in the case of the human activity restoring river flows, releasing an EFR, setting α at 0.05 will result in the environment being favoured over those individuals and organisations that provide for human uses. In this instance the burden or onus of proof (Constable 1991) of the benefits or not of an EFR is left to organisations which supply or use water because the results of the monitoring program are unlikely to falsely show an improvement the environment but are more often likely to miss improvements because of low power and hence high Type II error rates.

The conflicting consequences of potential errors in decision making based upon hypothesis driven experimental design makes it important that river managers and other stake holders are involved in the design of the monitoring program. Gaining the involvement of all stakeholders in decisions regarding the probabilities of making correct decisions is essential because it is they who will be responsible for the consequences of the success or failure of the implemented environmental flows. However, much of the basic information needed to calculate the probabilities of the various types of decision errors for each high priority issue was not currently available for the Forum or IEP.

Without the measures of spatial and temporal variability of most ecological indicators the IEP could not proceed, in the majority of cases, to fully assess the various effect sizes that may be seen from the proposed environmental flow regime. The information that was available to define effect sizes and estimate variability and therefore to estimate the management decision errors differed vastly between the high priority issues. Where there were no data available for a high priority issue pre-monitoring investigations have been identified and where spatial and temporal information was available, these concepts have been developed as far as possible. Decisions regarding weighting or balancing management decision errors will need to take place at a later review stage when all the pre-monitoring investigations have taken place.

Fundamental Hydrological Monitoring

Hydrological monitoring is required to:

- provide information on inflows to dams and flows in tributaries which will be used to set environmental flows and underpin daily operations of river regulation structures
- provide input to hydrologic models which will be used to estimate flows for a range of scenarios
- provide information on hydrologic parameters which can be linked to ecologic responses and assist in understanding the behaviour of the river ecology.
- provide information to assist in water quality monitoring.

The hydrologic monitoring will be linked to hydrologic models, which will enable flow conditions and hydrologic parameters to be estimated for a range of different scenarios including:

- natural conditions;
- current (interim environmental flows) conditions;
- future (recommended environmental flows) conditions.

Monitoring of Weired Shale Reaches Below the Dams

Issue

Discharge measurements are fundamental to the delivery of environmental flows and to all other monitoring in such reaches.

Location

Reaches 15, 17 and 21. Fundamentally, the Nepean River from Menangle Weir to Yarramundi, except for sandstone reaches at Bents Gorge and the Warragamba/Nepean river confluence.

Pre-monitoring investigations

Flow gauges are required at regular distances along the Nepean River in order to monitor the passage of environmental flow releases to ensure that they are not be captured by extractors. Gauges already exist on Menangle Weir, Camden Weir, Mt Hunter Weir, Wallacia Weir, Penrith Weir and Yarramundi, which is probably sufficient for this purpose. However, the existing gauges are not suitable for accurately measuring low flows, which are essential for monitoring environmental flows.

Pre-monitoring investigations are required to establish the most suitable approach to measuring low flows. Two approaches that are likely to be suitable for the weirs are:

- Modify the weirs to incorporate a notch that will permit accurate measurement of low flows.
- Incorporate flow measuring devices into the valves/gates[1] that are to be installed at each weir, to permit the passage of environmental flows.

Measurement of low flows at Yarramundi may prove to be problematic because of an unstable control.

Pre-monitoring investigations will also be required to determine contemporary channel dimensions at locations where monitoring sites for ecological and water-quality observations are needed, so that hydraulic parameters can be computed (width, depth, velocity etc.). Discharges at these sites can be inferred from the adjacent flow gauging stations.

Variables

The stream flow, water quality and ecologic monitoring sites will measure the following hydrologic parameters:

- Discharge
- Channel cross sections (including widths, depths and areas)
- Stage heights
- Velocities

General approach

The existing weirs will need to be modified to enable accurate measurement of low flows (to within $\pm$ 10%). Telemetry equipment should be installed to permit flow data to be transmitted to a central operations centre. Flow gauging stations will need to be rated at regular intervals.

Additional gauging is likely to be required at Yarramundi due to its unstable control.

Surveys are needed at sites where water quality and ecological monitoring is likely to require cross sectional information. Suitable numerical models should be established to provide information on the hydraulic properties of the channel at these sites.

Statistical analysis

Data will be used to check delivery of environmental flows plus tributary inputs and to undertake

[1] The costs for flow measuring devices associated with valves/gates are not included in the monitoring program, but are included as part of the Forum's recommended capital works.

fundamental hydrologic, hydraulic and associated modelling with respect to water-quality and ecological monitoring programs.

Statistical analysis is generally applied to the results of monitoring programs that are based on sampling of a portion of the population to establish whether differences in measured parameters at different sites or for different time frames are statistically significant. However, statistical analysis is not applicable to hydrologic monitoring. Monitoring will provide a continuous record of flows at key sites under the prevailing operating rules. Hydrologic models will then be utilised to provide reliable estimates of what flows would have occurred under different scenarios such as natural conditions or with interim environmental flows. The differences in flow between different environmental release scenarios are readily estimated by adjusting the release rules in the hydrologic models.

Response time

This will be immediate upon installation of new gauges and rating of all sites.

Cross sections and other dimensional data collection should be collected within the first 6 months of the commencement of the monitoring program

Management interaction

The main management function here will be the delivery of the correct environmental flows to sites downstream of weirs (at suitable temperatures). This will be part of the licence requirements with management responsibilities for SCA to DIPNR.

Monitoring the Sandstone Reaches Downstream of Dams

Issue

Discharge measurements are fundamental to the delivery of environmental flows and provide key inputs to ecological and water quality monitoring.

Location

Reaches 3, 4, 8, 9, 10, 11, 12, 13, 14, 16, 18, 19 and 20. Fundamentally, these are the reaches immediately downstream of the dams, plus small sections of the Nepean River below Campbells Crossing and Wallacia.

Pre-monitoring Investigations

SCA currently operate the so-called gauging weirs downstream of Nepean, Cordeaux, Cataract and Avon Dams (remove the so-called gauging weirs). Pheasants Nest, Broughtons Pass and Maldon Weirs have also been rated and can be used to measure flows. However, none of these sites is suitable for measuring low flows. Pre-monitoring investigations are required to ascertain how best to measure low flows. It is likely that the most suitable arrangement will be to install gauging equipment on the outlets to the dams and the valves/gates that are to be installed on the weirs to permit passage of environmental flows.

Pre-monitoring investigations will also be required to determine contemporary channel dimensions at locations where monitoring sites for ecological and water-quality observations are needed, so that hydraulic parameters can be computed (depth, velocity etc.). Discharges at these sites can be inferred from the adjacent flow gauging stations.

Variables

The stream flow gauging sites will monitor the following hydrologic parameters:

- Discharge
- Channel cross sections (including widths, depths and areas)
- Stage heights
- Velocities.

General approach

The existing weirs will need to be modified to enable accurate measurement of low flows (to within ± 10%). Telemetry equipment should be installed to permit flow data to be transmitted to a central operations centre. Flow gauging stations will need to be rated at regular intervals.

Surveys are needed at sites where water quality and ecological monitoring is likely to require cross sectional information. Suitable numerical models should be established to provide information on the hydraulic properties of the channel at these sites.

Statistical analyses

Not required. Hydrologic models will be applied to estimate flows and hydrologic parameters for other scenarios.

Response time

This is immediate, upon installation of new gauges and rating of all sites.

Cross sections and other dimensional data collection should be collected within the first 6 months of the commencement of the monitoring program.

Management interaction

The main management function here will be the delivery of the correct environmental flows to the downstream channels. This will be part of the licence conditions. Site monitoring will assess effectiveness of environmental flows. In such relatively pristine areas both will be part of SCA concern with DIPNR supervision.

Monitoring Dam Inflows

Issue

Knowledge of dam inflows and tributary flows underpins the environmental flow program, as knowledge of these flows is required to:

- calculate the appropriate daily environmental flow releases at any given time; and,
- assist in the understanding of the links between flow and river health.

Location

The catchments of all dams.

Pre-monitoring investigations

Existing stream flow gauges measure approximately 80% of the inflows to Warragamba Dam, 85% of the inflows to Tallowa Dam, 70% of the inflows to Nepean Dam, and 14% of the inflows to Cataract Dam. There are no stream flow gauges on the inflow streams to the Avon, Cordeaux or Woronora Dams. Additionally only a small proportion of the tributary catchments downstream of the dams are gauged.

With the current arrangements it is possible to derive reliable estimates of daily inflows to Tallowa, Warragamba and Nepean Dams, which would form the basis of estimates for environmental flow releases. However, it is not possible to provide accurate estimates of daily inflows to Avon, Cordeaux, Cataract or Woronora Dams. Knowledge of tributary flows is also scarce. It will therefore be necessary to upgrade the gauging network and devise a methodology for estimating ungauged flows.

In an ideal situation, estimates of daily dam inflows would primarily be based on stream flow gaugings, with the ungauged flows representing a relatively small proportion of the total flows. In this situation any errors involved in estimating the ungauged flows would be relatively unimportant. Unfortunately, there are many inflow streams to Avon, Cordeaux, Cataract and Woronora Dams and it is not practical to gauge such a large number of streams, partly because of poor access and partly because of the lack of suitable gauging sites.[1]

SCA has recently completed a study which identified additional sites suitable for measuring inflows to Avon, Cordeaux, Cataract and Woronora Dams. Details are:

- Avon: Two new sites covering 12% of the total catchment.
- Cordeaux: Three new sites covering 34% of the total catchment.
- Cataract: One new site bringing the gauged portion of the total catchment to 21%.
- Woronora: Two new sites covering 34% of the total catchment.

The SCA intends to install gauging stations at these sites, which will help to improve the accuracy of inflow estimates. However, a substantial portion of the dam inflows remains ungauged and will need to be estimated.

Similarly there are many tributaries in the Nepean River downstream of the dams. Gauging stations are located on the following tributaries:

- Stonequarry Creek
- Matahil Creek (downstream West Camden STP)
- Erskine Creek
- Glenbrook Creek
- Grose River
- Redbank Creek (downstream of North Richmond STP)
- South Creek
- Eastern Creek
- Cattai Creek
- Colo River etc

[1] A suitable gauging site must have a stable cross section (not subject to scour and deposition) and should have a predictable relationship between flow depth and discharge.

Many tributaries remain ungauged and it is not practical to install gauges on all of them. Therefore a significant portion of the tributary flows will need to be estimated.

The pre-monitoring investigations should establish the best approach for estimating the ungauged flows. The two most appropriate approaches are likely to be:

1. Hydrologic modelling:

   Establish and calibrate rainfall-runoff models of all relevant catchments, using data from the gauged streams for calibration. The models can then be used to estimate runoff in the ungauged catchments on a daily basis.

2. Proportioning recorded flows:

   Estimate the inflows in the ungauged streams by applying a multiplier to the flows recorded at nearby hydrologically similar catchments, using the following formula:

   $$Q_{ug} = Q_g \times A_{ug}/A_g \times R_{ug}/R_g$$

   Where:
   Q_{ug} = Discharge in ungauged catchment
   Q_g = Discharge in gauged catchment
   A_{ug} = Catchment area of ungauged catchment
   A_g = Catchment area of gauged catchment
   R_{ug} = Catchment Average Rainfall in ungauged catchment
   R_g = Catchment Average Rainfall in gauged catchment

   Essentially this formula calculates the flow for the ungauged catchment by taking the flow in the gauged catchment and adjusting to account for differences in catchment area and mean daily rainfall on a proportional basis. The underlying assumption is that the two catchments have a similar hydrologic response to rainfall. In the Upper Nepean catchment this assumption will hold as long as the catchments have similar geological and relief characteristics.

   The mean daily rainfall for each catchment would need to be calculated based on the recorded daily values. A GIS based program can be set up to generate a daily isohyetal map and to compute average catchment rainfalls.

   The advantage of this approach is that it is mathematically very simple and can be readily automated. In this application it is believed that the adjoining catchments will have very similar hydrologic properties and the method will be very reliable. Studies carried out by the Department of Land and Water Conservation (now DIPNR) have shown that catchments in the Hawkesbury-Nepean River system can be divided into groups that display similar hydrologic properties ie. rainfall generates a similar flow response (DLWC, 1999a: 1999b). The studies investigated a broad group of factors, which may influence hydrologic response including topography, slope, geology, soil properties, mean annual rainfall and elevation. The key parameter was found to be the catchment geology with the two predominant types being sandstone and shale.

The hydrologic modelling approach is more sophisticated and requires considerably more resources. The proportional method is much simpler and may yield results that are just as reliable as the modelled results, provided suitable relationships can be established between the recorded and unrecorded streams.

In order to estimate stream flows using proportional or rainfall runoff models it is necessary to have reliable information on daily catchment rainfall. The Upper Nepean catchments are unusual in that they exhibit very strong spatial variations in rainfall. Typically rainfall is high on the eastern catchment boundary (which follows the top of the escarpment) and decreases rapidly with distance away from the escarpment. There is currently a very good distribution of rainfall gauges, sufficient to describe the spatial distribution in daily rainfall. However, only a few of these stations are telemetered and it will be necessary to install telemetry equipment for forecasting purposes. A number of these stations will also need to be converted from daily read stations to continuous recording stations.

Variables

The stream flow and rainfall gauging sites will monitor:

- Channel cross sections
- Stage heights
- Velocities
- Rainfalls.

General approach

The existing and newly established gauging stations will be used to directly measure as much of the inflow as practical, on a daily basis. These stations will need to be connected to a central control centre and the recorded daily discharges used to estimate the required environmental flow releases at each dam and weir. Either a rainfall runoff model or proportional model should be used to estimate inflows for the ungauged catchments.

Response time

The pre-monitoring investigations should commence as soon as possible to allow the new gauging stations to be installed and rated in readiness for the implementation of environmental flows.

Management interaction

The main management function will be the delivery of the correct environmental flow by operation of outlet structures installed at the dams and weirs. Fundamental hydrological monitoring should be managed by SCA and DIPNR (water supply dams, diversion weirs and compensation weirs). Servicing and the repair of breakdowns should be managed by the same agencies.

It is assumed that the existing rainfall-gauging network is adequate, except for the need to install telemetry equipment and convert to continuous recording devices.

Monitoring of Tributary Flows

Issue

Provision of estimates of Hawkesbury-Nepean River tributary flows so that the portion of tributary flows, which are to be preserved as an environmental flow regime, can be calculated.

Location

Reaches 13 to 27.

These include all major tributaries downstream of the dams and particularly those in areas where extractions are significant, such as Menangle to Wallacia and Penrith to Cattai.

Pre-monitoring investigations

Pre-monitoring investigations should assess whether additional stream flow gauging stations are required to enhance the monitoring of tributary flows. For cost estimating purposes it has been assumed that there would be a need for four additional stations.

Variables

The variables to be monitored are as follows:

- Water levels at weirs
- Discharges at weirs
- Discharges or estimates thereof in tributaries
- Temperature (water quality monitoring)
- Conductivity (water quality monitoring).

It should be noted that this monitoring program makes no provision for monitoring of irrigation and industrial extractions. It is assumed that these will be monitored by DIPNR.

General approach

Water levels and discharges in gauged tributaries (and estimates for ungauged tributaries) and at the weirs will be monitored. The information will be used to adjust outlet valves in order to release the correct environmental flow on a daily basis. The monitoring system will need to be linked via telemetry to a command centre.

Irrigation and industrial extractions should be monitored to ensure compliance with licence conditions, but these considered to be outside the scope of this program.

Response time

Monitoring equipment should be installed and estimating techniques should be in place in sufficient time to allow implementation of environmental flows.

Management interaction

The main management functions will be:

- the delivery of the correct environmental flow by operation of outlet structures installed at the weirs based on in-river flows and tributary gaugings or estimates; and
- confirmation that irrigation extractions are in compliance with licence conditions.

It is expected that this monitoring will be managed by SCA and DIPNR. Servicing and the repair of breakdowns should be managed by the same agencies.

Ecological and Physical Monitoring

Cold Water Releases from Dams

Issue

The temperature of water released from dams is potentially significantly lower than ambient surface water temperatures of both inflow waters to the dam and of surface water within the dam proper.

Hypothesis

The introduction of an environmental flow regime downstream of Tallowa Dam, the upper Nepean dams, Warragamba Dam and Woronora Dam consisting of releases made via a multi-level off-take will lead to a significant increase in the temperature of waters released from the dam relative to those released under current arrangements. It is predicted, therefore, that that there will be no significant difference between surface waters temperatures adjacent to the dam offtakes and those immediately downstream of the dams under the proposed environmental flow regime.

Location

Reaches 1, 8, 9, 10, 11, 12, 13, 14, 15, 19, 20 and 21

Variables

- Depth (as necessary)
- Discharge/Flow (accurate and daily) to describe temporal patterns in water temperatures
- Rainfall as an explanatory variable
- Temperature measurement of dam surface waters
- Temperature measurement of receiving waters immediately downstream of the dams
- Time & date, site/location

General approach

Daily surface water temperatures to be measured in a dam and immediately downstream of that dam together with the continuation of existing temperature gauges in the Hawkesbury-Nepean River system.

Field sampling design

Surface water temperature is currently measured in most dams via the ResMan thermistor system. These thermistors are located within the general vicinity of the dam wall. Where surface water temperatures are not currently measured near the dam wall then this will need to be implemented. Surface water temperatures should also be measured immediately downstream of the dam wall at a convenient location away from the influence of the discharge valve and at a time interval consistent with the within-dam measurements. The existing temperature gauging network in the Hawkesbury-Nepean system should also be maintained for modelling and other data interpretation purposes.

Statistical analysis

Paired Students T-test or ANOVA of water temperature data collected within and downstream of the dams. Graphical models could also be used to reveal 'lag' effects in response that may not be evident from the paired t-tests. While the paired tests will illustrate immediate differences, lagged responses should be investigated by correlative analyses and lag-step regressions to explore these relationships.

Response time

Real time intervention.

Management interaction

Where the temperature difference between the surface waters of a dam and surface waters downstream of that dam are statistically significant and this difference is > $2^{o}C$, a change in offtake management is recommended to minimise the difference.

Reduced Connectivity – Natural Barriers

Issue

Reduced flows over riffles or riffle-like habitats have decreased connectivity for mobile aquatic fauna along the river and at the interface between the river and estuary.

Connectivity issues can vary in relation to a number of factors (eg. reach geomorphology and the character of the hydrological impact) and some variation is found in different river reaches.

Hypotheses

Reaches 1, 3, 4 and 22

The recommended environmental flow regimes will increase the duration and frequency of 'open-passage' flows (towards levels that occurred under natural conditions) thus increasing the connectivity for mobile fauna along the rivers.

Reaches 8, 9, 10, 11, 12 and 13

The recommended environmental flow regimes, including contingent flows specific for the spawning movements of the Macquarie perch, will increase the duration and frequency of 'open-passage' flows (towards levels that occurred under natural conditions) thus increasing the connectivity for mobile fauna along the rivers.

River-estuary reach interfaces 1:2, 4:5 and 22:23

The recommended environmental flow regimes will increase the duration and frequency of 'open-passage' flows (towards levels that occurred under natural conditions) thus increasing the connectivity for mobile fauna between the rivers and their upper estuaries.

Location

River reaches and river-estuary reach interfaces that are likely to have been substantially impacted by reduced connectivity are:

- Reach 1: Reduced flows[1] over riffles along the reach have reduced the connectivity for mobile fauna during lower-flow periods;
- Reach 3, 4, 9, 12, 13 and 22: Reduced flows over riffle-like habitats along the reach have reduced the connectivity for mobile aquatic fauna;
- Reaches 8, 10 and 11: Reduced flows over riffle-like habitats along the reach have reduced the connectivity for mobile aquatic fauna when bulk-waters are not being transferred;
- Reach interface 4:5: Reduced flows over the tidal-barrier riffle-like habitat have reduced the connectivity for mobile aquatic fauna between the estuary and the river upstream; and
- Reach interfaces 1:2 and 22:23: Reduced flows and changed morphology of the river channel over the tidal-barrier riffle have reduced the connectivity for mobile aquatic fauna between the estuary and the river upstream.

Pre-monitoring investigations

To obtain prerequisite information, the following physical-habitat analysis should be undertaken along these river reaches, and river-estuary reach interfaces:

- using 'best available' hydraulic passage criteria, and following general methods described by Grant and Bishop (1998), identify likely critical fish-passage flow thresholds (a minimum of five flows over a representative set of riffles, riffle-like habitats and tidal-barrier riffles).

[1] Flows can be substantially reduced during periods when water is transferred from Tallowa Dam up to either the upper Nepean Dams or Warragamba Dam. Currently this occurs irregularly (once every 6-10 years), however, this is likely to increase greatly in the future under the influence of climate change (ie. heading into a drought-dominated regime) and Sydney's increased water consumption due to population growth.

In the process of developing monitoring activities associated with the connectivity issue, it was initially planned that the above 'working' thresholds would be subject to biological verification as follows:

- examine the veracity of the hydraulic passage criteria by undertaking paired-day directional fish sampling (eg. fyke netting) immediately upstream then downstream of representative riffles, riffle-like habitats and tidal barrier riffles.

The subsequent verified or altered thresholds would then be termed 'refined' thresholds. A higher confidence would arise from monitoring results dependent on these. Given high costs associated with the biological-verification process, the derivation of refined thresholds is not currently recommended.

Variables

- Critical 'working' flow thresholds for fish passage;
- Hourly-average-flow data at the representative riffles, riffle-like structures and tidal barrier riffles for critical fish passage flow thresholds assessments;
- Predicted daily-average-flow data at the representative riffles, riffle-like structures and tidal barrier riffles for the natural condition, before the recommended environmental flows and actual daily average flow data after the introduction of the recommended environmental flow regimes; and

If the biological-verification process had been recommended, the variables would have been:

- critical 'refined' flow thresholds for fish passage
- the abundance and diversity of fish species.

General approach

Pre-monitoring investigations will establish critical 'working' fish passage flow thresholds for riffles, riffle-like structures and tidal barrier riffles. If the biological-verification process had been recommended, these thresholds would be verified by paired-day directional fish sampling.

Monitoring will require an assessment of the number of days per year when fish passage would be classified as 'open' (ie. days when flows > critical fish passage flow threshold). This assessment would be based on river-flow gauging data. The results would be given a context in relation to the before-environmental-flow condition (% gain) and the natural condition (% shortfall). Before environmental and natural condition flows would need to be modelled and be based on dam inflows/outflows. This work could not proceed until the critical fish passage flow thresholds are identified during pre-monitoring investigations. There should be a number of flow thresholds identified, as relevant to different groups of species and life-history stages.

Field sampling design

Critical fish passage flow threshold assessment should be undertaken as per Grant and Bishop (1998).

Statistical analyses

The significance of differences in the occurrences under the environmental flow condition should be tested separately for the before-environmental flow conditions and natural condition pairs in relation to the null hypothesis that there are no differences between the conditions in the ratio of open-passage days versus closed-passage days. Differences in ratios should be tested with a parametric frequency-analysis procedure such as a Chi-squared test. The ratio should be calculated for the whole year as well as being separated for important migration periods.

Response time

Two years after the commencement of the critical fish passage flow threshold pre-monitoring.

Management interaction

During the course of environmental flow option development process the possible ecological significance of hydrological impacts was partitioned as follows:

- >30% (duration of flows above the threshold flow) shift from natural = high impact
- 10-30% shift from natural = moderate impact
- <10% = low impact

It is proposed that these ecological-significance thresholds be used to trigger adaptive-management actions as follows:

- there is a high-priority need to supplement environmental flows (eg. by altering transparency/translucency settings) if after two years the duration of 'open-passage' days under the environmental-flow condition is:
  - 30-100% less than what would be expected under natural conditions, and
- there is a medium-priority need to supplement environmental flows if after two years the duration of 'open-passage' days under the environmental-flow condition is:
  - 10-30% less than what would be expected under natural conditions.

In both of these cases the deviation from the before-environmental flow condition should be reported to provide an indication of what improvements have occurred.

Critical Habitat Contraction

Issue

Flow regulation has reduced the availability of critical physical habitat associated with higher water velocities (for example riffles, or riffle-like habitats).

> **Hypotheses**
>
> ***Reaches 1, 3 and 4***
>
> The recommended environmental flow regime will increase the duration and frequency that riffle habitats are expanded (towards levels that occurred under natural conditions) and this will increase the abundance of dependent biota and diversity.
>
> ***Reaches 8, 9, 10, 11, 12 and 13***
>
> The introduction of the recommended environmental flow regime, including specific contingent flows to protect spawning/recruitment opportunities of the Macquarie perch, will increase the duration and frequency that riffle-like habitats are expanded (towards levels that occurred under natural conditions) and this will increase the abundance and diversity of dependent biota.

Location

Reaches 1, 3, 4, 8, 9, 10, 11, 12 and 13 are likely to have been substantially impacted by such habitat contraction.

Pre-monitoring investigations

To obtain prerequisite information, the following physical-habitat analysis should be undertaken along the river reaches:

- using 'best available' hydraulic criteria, and following general methods described by Grant and Bishop (1998), identify likely critical riffle-area flow thresholds over a representative set of riffles or riffle-like habitats (a minimum of five flows over the riffles or riffle-like habitats)

In the process of developing monitoring activities associated with the habitat contraction issue, it was initially planned that the above 'working' thresholds would be subject to biological verification as follows:

- validate the hydraulic criteria by, for example, determining how well the criteria 'captures' elevated invertebrate biomass and diversity across a strategic set of riffles or riffle-like habitats.

The subsequent verified or altered thresholds would then be termed 'refined' thresholds. A higher confidence would arise from monitoring results dependent on these. Given high costs associated with the biological-verification process, the derivation of refined thresholds is not currently recommended.

The pilot/reconnaissance surveys for fish-community investigations would include logistics, method comparisons, variance estimation and subsequently power analysis to determine replication levels).

In relation to the physical-habitat analysis, this work is related to the connectivity issue (ie. reduced fish passage over riffles or riffle-like habitats) as both involve the measurement of physical-habitat features. Accordingly, fieldwork would simultaneously encompass both issues. The distribution of riffle-like habitats was identified for Reaches 3 and 4 during the longitudinal habitat survey undertaken by Patterson Britton (2002).

Variables

- Critical riffle-area flow thresholds over a representative set of riffles or riffle-like habitats;
- Fish community and population descriptors with emphasis on riffle and riffle-like dependant fish species:
  - Community-level variables: number of species, compositional structure, and the proportional abundance of riffle(-like)-dependant species (particularly Macquarie perch, but also a number of eleotrid taxa); and

  – Population-level variables: abundance of Macquarie perch, abundance of young-of-year Macquarie perch, size-structure of Macquarie perch; abundance of other riffle(-like)-dependent species;

- Hourly-average-flow data at the representative riffles, or riffle-like habitats, when flow thresholds are being investigated;
- Daily-average-flow data in all river/creek systems in which fish communities are to be sampled in the pilot/reconnaissance surveys (for use in the interpretative phase; Reaches 8-10-11 and 9-12-13 only);
- Daily-average-flow data at the representative riffles, or riffle-like habitats, during environmental flow releases;
- Predicted daily-average-flow data at the representative riffles, or riffle-like habitats, for the condition without environmental flows;
- Predicted daily-average-flow data at the representative riffles, or riffle-like habitats, for the natural condition; and
- Daily-average-flow data in all river systems in which fish communities are to be sampled (for use in the interpretative phase; Reaches 8-10-11 and 9-12-13 only).

General approach

- **Physical-habitat component**

  Simple reporting of the number of days per year, under the environmental-flow condition, that riffle area, or riffle-like area, would be classified as 'above the rapid-area-loss state' (ie. days when flows > critical riffle-area flow thresholds). This would be based on river-flow gauging data. The results would be given a context in relation to the before-environmental-flow condition (% gain) and the natural condition (% shortfall).

  Before-environmental and natural condition flows would need to be modelled and be based on dam inflows/outflows. This work could not proceed until the 'working'-flow threshold was identified during pre-monitoring investigations.

- **Fish community component**

  Fish inhabiting pools are targeted, although fish with riffle and riffle-like habitat dependence at some stage of their life-cycle are focused upon.

  Reconnaissance/pilot surveys are initially required to determine:

  - accessibility constraints and logistics
  - habitat availability at sites and the identification of meso- and/or microhabitats to be selected for standardised sampling
  - sample method selection
  - identification of key environmental covariates
  - selection of reference locations and consideration of their independence
  - initial estimation of within-site, between-site and between-location variability so that a suitable replication level can be determined through power analyses

  There appears to be three possible methods by which fish communities could be surveyed. The advantages and disadvantages of these are summarised in Table C5 below. As a part of the pilot surveying, it is proposed that these sampling methods be compared at a readily-accessible site. From this comparison the most suitable method(s) will be chosen.

Table C5: Three possible fish sampling methods - advantages and disadvantages

Possible Methods	Advantages	Disadvantages
Direct observation at night with an underwater spotlight (from an inflatable or canoe)	• high ease and safe access to sites even over rough terrain (gear not cumbersome) • no risk of electrocution if workers stumble when sampling • large areas may be surveyed (particularly along the margins of deeper pools) • observations are readily standardised • the riffle-dependent Macquarie perch, a listed threatened species, is readily observable with this method (used by J. Sammut and W. Erskine below Pheasants Nest Weir, by K. Bishop below Maldon Weir in the upper Nepean and in the lower Wollondilly River, and by J Harris and K. Bishop in the Kangaroo River) • the method is non-destructive • sampling efficiency is likely to be good as water clarity is typically high (during low flows), and because fish move from concealment during the night • has been used successfully by Bishop (1997) to characterise fish communities in the Holsworthy Military Area during 1996 (the Military Area contains expanses of rough, precipitous terrain, much like that which occurs within SCA lands downstream of the upper Nepean dams and weirs)	• some gudgeon species can not be identified to species level • size structure needs to be estimated • greater risks as work is undertaken at night • may be susceptible to reduction in water clarity
Fyke netting	• can be set and taken up during daylight hours • species-level identifications are possible and size structure assessment can be based on measurements • observations are readily standardised • have been used over an extended period to monitor Macquarie perch populations within the ACT (ten overnight sets being the standard sampling effort); accordingly, data collected in the upper Nepean River system may readily be compared to that collected in the ACT (valuable frame of reference)	• risk of fish mortality due to the presence of eels • requires two trips to the sampling sites (gear setting in the evening and gear pickup in the morning) • could be restrictive in terms of sites that can be accessed and the size of the area that can be fished (due to the cumbersome nature of sampling equipment given steep access routes, boulder-strewn, rough terrain)

Table C5 continued: Three possible fish sampling methods - advantages and disadvantages

Possible methods	Advantages	Disadvantages
Electrofishing	• standard fisheries practice • can be undertaken during the day • species-level identifications are possible and size structure assessment can be based on measurements • observations are readily standardised	• recent experience in the upper Nepean system has already shown (eg. late-2002 Ecology Lab investigations in relation to Upper-Nepean bulk-water transfers) that backpack electrofishing yields very small numbers of fish • backpack electrofishing is very restrictive (in terms of sites that can be accessed and the size of the area that can be fished) due to cumbersome nature of sampling and protection equipment; this is especially the case in the upper Nepean system given steep access routes, boulder-strewn, rough terrain, and the occurrence of pools with depths greater than one metre • boat electrofishing is also very restrictive for the reasons given above (except for pool-depth limitations); this may be overcome to some extent by helicopter lifts but this would extremely expensive and involve grave risks in narrow gorge country • electrofishing could be destructive, to fish, crustaceans and platypus

Field sampling design

For Reaches 8, 10 and 11 a balanced MBARI(P) design (an extension of the 'MBACI[P]' design referred to by Downes *et al.* [2002]; reference 'R' replaces control 'C') would be possible for this investigation given that many impacted and reference locations are potentially available (*Impacted*: below Cataract, Cordeaux and Nepean Dams; *Reference*: possibly Wongawilli[1], Wollandoola, Lizard, Donalds Castle, and Glenbrook Creeks). Without estimates of variance, a prerequisite for power analyses, it is difficult know the level of replication needed in time and space. In relation to time (fixed factor), possibly three years of twice-yearly sampling (spring and autumn) would be required in the before and after phases (ie. 3x2 + 3x2 = 12 samples in all). In relation to space (random factor), possibly three sites would be required in each location and possibly 20 samples would be taken in each site.

For reaches 9, 12 and 13 an <u>un</u>balanced MBARI(P) design (an extension of the 'MBACI[P]' design referred to by Downes *et al.* [2002]; reference 'R' replaces control 'C') would be possible for this investigation given that impacted locations are very different[2], and hence have to be examined separately, and many reference locations are potentially available (possibly Wongawilli, Wollandoola, Lizard, Donalds Castle, Glenbrook and Erskine Creeks).

Without estimates of variance, a prerequisite for power analyses, it is difficult to know the level of replication needed in time and space. In relation to time (fixed factor), possibly three years of twice-yearly sampling (spring and autumn) would be required in the before and after phases (ie. 3x2+ 3x2 = 12 sampling occasions in all). In relation to space (random factor), possibly three sites would be required in each location and possibly 20 samples would be taken in each site.

Statistical analysis

- **<u>Physical-habitat component</u>**

  The significance of differences in the occurrences should be tested separately for the before-environmental and natural condition pairs in relation to the null hypothesis that there are no differences between the conditions in the ratio of above-rapid-area-loss days versus within-rapid-area-loss days.

  This should be tested with a parametric frequency-analysis procedure such as a Chi-squared test. The ratio should be calculated for the whole year as well as being separated for important periods when riffles or riffle-like areas are heavily utilised by aquatic fauna. For example. in spring/summer riffles or riffle-like areas are used for spawning by some fish species and they provide an important supply of invertebrate food for developing juvenile fish.

- **<u>Fish community component</u>**

  For the univariate data (ie. *community-level variables*: number of species, and the proportional abundance of riffle and riffle-like dependant species; *population-level variables*: abundance of Macquarie perch, abundance of young-of-year Macquarie perch, abundance of other riffle and riffle-like dependent species) a two-factor[3] ANOVA should be used[4]. For the multivariate data (ie.

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[1] It is highly likely that fish communities in this location are independent from those in the Cordeaux River given precipitous terrain in the creeks lower reaches (ie. a barrier to fish movements). However, this location may become problematic in the longer-term due to impacts arising from long-wall coal mining.

[2] Reach 9 (Avon River below Avon Dam) is unique as it currently does not have any environmental flow releases. Reach 13 (Nepean River below Pheasants Nest Weir) is quite different from Reach 12 (Cataract River below Broughtons pass Weir) because fish communities do not contain a large predacious catadromous fish species (ie. Australian bass), a result of the presence Maldon Weir wall which acts an insurmountable barrier to upstream-moving fish. In this context, Reach 12 would be best compared with Erskine and Glenbrook Creeks given the potential presence of Australian bass in these systems.

[3] For interpretation of differences, two extra factors (making four factors in total) could be examined: times and sites within locations.

[4] A minimum effect size would be 30% of the reference-location means.

c*ommunity-level variables*: compositional structure; p*opulation-level variables*: size-structure of Macquarie perch) distance-based linear modelling (Anderson 2001) should be used.

In relation to Reaches 9-12-13, analyses should be undertaken separately for each impacted location. One analysis is appropriate for Reaches 8-10-11.

Response time

For physical habitat analysis two years after the commencement of the 'working' threshold pre-monitoring investigations (ie. at their completion; this assumes that hydrological data and modelling is underway within one year after the commencement).

For fish community and population descriptors 6-10 years[1] once pilot/reconnaissance investigations are completed.

Management interaction

- **Physical-habitat component**

  It is proposed that for these ecological-significance thresholds the trigger adaptive-management actions are:

  - there is a high-priority need to supplement environmental flows (eg. by altering transparency/translucency settings) if after two years the duration of '*above-rapid-area-loss*' days under the environmental-flow condition is:
    - 30-100% less than what would be expected under natural conditions, and
  - there is a medium-priority need to supplement environmental flows if after two years the duration of '*above-rapid-area-loss*' days under the environmental-flow condition is:
    - 10-30% less than what would be expected under natural conditions

  In both of these cases the deviation from the before-environmental flow condition should be reported to provide an indication of what improvements have occurred.

- **Fish community component**

  For community and population descriptors it is proposed that the following findings would trigger adaptive-management actions:

  - there is a high-priority need to supplement environmental flows in a particular reach if, by the end of the investigation, 4 or more of the 6 variables are 30-100% less than the respective reference-location means[2], and
  - there is a medium-priority need to supplement environmental flows in a particular reach if, by the end of the investigation, 4 or more of the 6 variables are 10-30% less than the respective reference-location means.[3]

[1] The shorter period (ie. six years) would be possible if climatic conditions were stable across the 'before' and 'after' phases of the investigation.
[2] The analytical methodology for this is yet to be determined.
[3] Again, the analytical methodology for this is yet to be determined. In respect to species richness, these effect sizes (ie. 10-30% of reference) may be unrealistic given that only seven species of fish may be present in some locations.

General Water Quality Downstream of Dams

Issue

Waters released from dams can impact on downstream receiving water quality. To ensure that these water releases are of satisfactory quality, routine monitoring immediately downstream of the dams is required.

Hypothesis

The introduction of an environmental flow regime downstream of Tallowa, Nepean, Cordeaux, Avon, Cataract and Warragamba Dams, consisting of translucent and transparent flow releases made via multi-level off-takes, will ensure that the receiving water quality is maintained at a high level. It is predicted that the quality of surface waters downstream of these dams will not differ significantly from surface water quality within the dam.

Location

Reaches 1, 8, 9, 10, 11 and 19.

Variables

Refer SCA routine monitoring program for site E851. Variables of interest to this hypothesis include:

- Algal Counts
- Algal Identification
- Alkalinity
- Ammoniacal Nitrogen
- Oxidised Nitrogen
- Total Kjeldahl Nitrogen
- Total Nitrogen
- Biological Oxygen Demand (5days)
- Chlorophyll a
- Dissolved Organic Carbon
- Total Organic Carbon
- Dissolved Oxygen
- Electrical Conductivity
- Filterable Aluminium
- Total Aluminium
- Filterable Iron
- Total Iron
- Filterable Manganese
- Filterable Phosphorus
- Total Phosphorus
- Major ions
- pH
- Phaeophytin
- Reactive Silica
- Suspended Solids
- Total Manganese
- Turbidity

General approach

Routine water quality monitoring before and after the introduction of environmental flows.

Field sampling design

Routine sub-surface collection of water quality samples and field physico-chemical measurements using standard field and laboratory QA/QC methods and procedures.

Statistical analysis

Trend analysis (GLM) to examine water quality before (3-5 years) and after the introduction of the recommended environmental flows.

Response time

For Tallowa Dam, approximately two years after the introduction of environmental flows. The other dams will require a longer period of data collection before sufficient data become available for trend analysis.

Management interaction

Ability to assess performance of operational aspects of environmental flow releases and allow for continual improvement in associated practices and procedures. Data will also be useful as explanatory variables for ecological studies.

Loss of Native Aquatic Macrophytes and Excessive Growth of Exotic Aquatic Macrophytes

Issue

Loss of native aquatic macrophytes and the impacts of excessive growth of exotic aquatic macrophytes.

Hypotheses

Reaches 14, 15, 16, 17, 18, 19, 20 ,21, 22, 23, 24 and 25

Increased flow variability as a result of implementation of the recommended environmental flow regime (including contingent flows specific for the management of *Egeria densa* and passage of environmental flows through the Penrith Weir in low flow conditions) combined with the Forum's effluent reuse strategy will provide conditions less suitable for the growth of exotic macrophytes and enhance the diversity and abundance of native species.

Reaches 22. 23, 24 and 25

Implementation of the recommended environmental flow regime and the Forum's effluent reuse strategy such that excessive growth of *Egeria densa* is reduced, will: reduce the damage caused to river infrastructure during medium to high flows as a result of the sheer biomass (weight) *of Egeria densa* transported during such flows; reduce the damage caused to the riparian zone during medium to high flows by reducing the amount transported to the riparian zone; and increase the river amenity as reduced beds of *Egeria densa* will enhance the River as a recreational area.

Reaches 14, 15, 17, 22 and 23

Implementation of the recommended environmental flow regimes, including a contingent flows, will not increase the distribution and abundance of Alligator Weed compared to that which occurs under the current flow rules.

Reaches 24 and 25

Increase in the variability of flows as a result of implementation of an environmental flow strategy combined with the Forum's effluent reuse strategy will increase the upstream extent of marine/estuarine species (eg. seagrasses and mangroves) and decrease the distribution of fresh/brackish water species (eg. *Vallisneria* sp., *Phragmites* sp.) as total flows during dry periods will be reduced thus allowing the salinity structure to increase its upstream extent.

Location

Reaches 14, 15, 16,17, 18, 19, 20, 21, 22, 23, 24 and 25

Pre-monitoring investigations

Prior to the start of the monitoring program for aquatic macrophytes, macrophyte populations in the Hawkesbury-Nepean River between the Cataract River Junction and Wisemans Ferry should be mapped using aerial photography interpretation and ground truthing (transects across the river channel every 200-500 m).

This information will then be used to identify the best sites for the monitoring program and to provide information on the extent of macrophytes beds and exotic macrophytes in the Hawkesbury-Nepean River.

The mapping of the macrophytes beds as should be repeated every five years to help monitor changes in the distribution of macrophytes (especially exotic species).

Variables

- Community composition of emergent, floating and submerged macrophyte beds;
- Species richness;

- Native and exotic species cover and abundance using the modified Domin-Krajina cover abundance scale;
- Dominant species;
- Water quality variables including temperature, salinity, turbidity, photosynthetically available radiation (PAR), nutrients, dissolved oxygen, conductivity, pH, metal concentrations;
- Daily discharge or accurate estimates of flow and flow velocity at all sampling sites; and,
- General site information such as substrate, surrounding land use, channel depth, channel shape (see site sketch map and scoring of physical characteristics).

General approach

Monitoring the long term composition of macrophyte beds at a number of sites is to occur biannually during spring and late summer, such that any changes in bed composition and abundance can be correlated to changes in hydrology, geomorphology and water quality. Data will be collected before and after implementation of the recommended environmental flow regimes and the Forum's Effluent Reuse Strategy. Data will be analysed such that trends between and within sites over time can be detected.

It is also recommended that monitoring occurs during/after extreme events such as high flows/floods and increased salinity intrusion during prolonged dry periods. Monitoring of high flow/flood events would provide information on the size of flow required to transport significant amounts of *Egeria densa* downstream and how quickly beds are able to respond to such disturbances. This information would can then be used to assess the requirements for and success of contingent flows for *Egeria densa* and any management program for *Egeria densa* and *Elodea canadensis*. Similarly, during and following extreme dry events, additional monitoring may be warranted to document the effects of increased salinity on the distribution and abundance of aquatic and emergent macrophytes.

As mentioned above, the mapping of the macrophytes beds as outlined in pre-monitoring investigations should be repeated every five years to help monitor changes in the distribution of macrophytes (especially exotic species).

Field sampling design

The sampling design outlined below is based on methodology developed by the United Kingdom's Environmental Change Network for the long-term monitoring of macrophytes in rivers and streams (Scott et al. 2002). In addition to detecting the effects of gross changes in water quality and factors such as flooding and weed management/removal, this methodology aims to detect and interpret the more subtle signs of change that may arise from diffuse sources of pollution or climatic change.

A total of eight sites have been chosen to monitor macrophytes of the Hawkesbury-Nepean River system with two locations per site (Table C6). The sites and locations have been chosen based on the current knowledge of macrophytes within the Hawkesbury-Nepean River system. Sites and their locations may need to be modified prior to starting the monitoring program based on the outcomes of the macrophyte mapping exercise to be undertaken as part of the pre-monitoring investigations.

Vegetation types (emergent, floating and submerged) to be monitored at each site are indicated in Table C6 based on the known present issues and relevant hypothesis for each reach. Thus submerged macrophytes are to be monitored at all sites, as *Egeria densa* and *Elodea canadensis* occur in all reaches nominated. Where submerged plants are monitored, evidence of its transportation (floating mats, wrack) should be noted. Floating plants are to be monitored in reaches where they are known to be a problem and where Alligator Weed presents a risk to agricultural and turf industries. Monitoring of emergent plants has been recommended in the tidal reaches such that changes in distribution that may be a result of changes in salinity can be detected.

Table C6: Sites and locations recommended for the macrophyte monitoring program based on the current knowledge of macrophyte distribution within the Hawkesbury-Nepean and Shoalhaven Rivers

Monitoring Locations	Reach No.	Vegetation Type to be Monitored		
		Emergent	Floating	Submerged
Nepean River upstream of Menangle Weir (Site 1)	14		✓	✓
Nepean River downstream of Menangle Weir (Site 1)	15		✓	✓
Nepean River at Camden (Site 2)	15		✓	✓
Nepean River downstream of Mt Hunter Rivulet (Site 2)	15		✓	✓
Nepean River at Warragamba River confluence (Site 3)	18/19			✓
Nepean River at Erskine Creek* (Site 3)	20			✓
Nepean River at Glenbrook Creek* (Site 4)	21			✓
Nepean River at upstream of Penrith Weir* (Site 4)	21			✓
Nepean River at Smith St* (Site 5)	22		✓	✓
Nepean River at Yarramundi* (Site 5)	22		✓	✓
Hawkesbury River at Richmond Bridge* (Site 6)	23		✓	✓
Hawkesbury River at Freemans Reach (Site 6)	23		✓	✓
Hawkesbury River Wilberforce* (Site 7)	24	✓		✓
Hawkesbury River at Sackville* (Site 7)	24	✓		✓
Hawkesbury River at Leets Vale* (Site 8)	25	✓		✓
Hawkesbury River upstream of Wisemans Ferry (Site 8)	25	✓		✓

***** denotes previously monitored sites

Each location is to be sampled biannually in spring (during growth season) and late summer (at end of the growth season). In subsequent years, sampling should occur at the same time or as close as possible, dependent on river flows. River flows should be around normal (baseflow), ie. not during high flows or floods. Where locations are within the tidal reaches of the Hawkesbury River, sampling should occur as close as possible to low tide (±2 hrs) on a neap tide. Water quality parameters are to be measured at each sampling site using electronic meters and/or estimated from nearby water quality sampling sites that form part of this monitoring program.

At each location the macrophyte survey will cover a 100 m length of channel, with this 100 m length divided into ten 10 m sections extending bank to bank. For each sampling period, five of the ten sections will be randomly chosen for investigation. Dependent upon the macrophyte type, each section is to be further divided into zones based on distance from shore or depth (see Table C7 for definition of sampling zones by macrophyte type). Thus for a single section, there is a maximum of four possible zones for floating and submerged macrophytes, and two for emergent vegetation. The positions of each location and sections will remain fixed each year, however zone boundaries will be reconsidered each time to take into account changes in channel shape and water level.

Table C7: Sampling zones for emergent, floating and submerged macrophytes

Vegetation Type	Sampling zone
Emergent Vegetation	All per bank
Floating Macrophytes	<1 m from shore
	>1 m from shore to edge of bed or middle of the river
Submerged Macrophytes	0 – 1 m depth (at base flow)
	>1 m depth to edge of bed or middle of the river (at base flow)

In each section, the presence of dominant species of emergent, floating and submerged macrophytes (macrophyte types to be sampled at each location as outlined in Table C6) are to be recorded for each sampling zone by moving in a zig-zag manner across the section. In addition, the overall cover/abundance of emergent, floating and submerged macrophytes for each sampling zone is to be estimated using randomly placed quadrates (Table C8) and based on the modified Domin-Krajina cover abundance scale outlined in Table C9. For each quadrat, macrophyte health is also to be scored in terms of poor, moderate or good. The number of randomly placed quadrats to be used to assess species presence, cover/abundance and health for emergent, floating and submerged macrophytes is outlined in Table C8.

Table C8: Number of quadrates to be used per sampling zones for emergent, floating and submerged macrophytes

Vegetation Type	Number of Quadrats	Quadrat Size
Emergent Vegetation	5	1 m x 1 m
Floating Macrophytes	10	0.2 m x 0.2 m
Submerged Macrophytes	10	0.2 m x 0.2 m

Table C9: Modified Domin-Krajina cover abundance scale for estimating macrophyte cover and abundance

Domin-Krajina Scale	% cover
+	<<<1 (solitary, insignificant cover)
1	<<1 (seldom, insignificant cover)
2	<1
3	1-5
4	5-10
5	10-25
6	25-33
7	33-50
8	50-75
9	>75 but less than complete cover
10	~100

In addition to the above, the following data will be recorded at each site:

Location sketch map: this should be made for the entire 100 m length and show in the broadest terms the general physical character of each location including: width of channel, shading (position and type), main macrophyte stands, extent and type of riparian vegetation, adjacent land use and evidence of transportation of aquatic macrophytes. In addition, the location sketch map should be used to show the location from where photographs are taken;

Scoring of physical characteristics (to be recorded for each of the five 10 m sections investigated): width of each zone, maximum depth, sediment/substrate type, habitat (slack, fast flowing, open channel, velocity/zone, shading (percent of section/zone in each of three categories (based on when the sun is overhead) – none, broken and dense), water clarity (percent in each of three categories – clear, cloudy and turbid), and bank stability (percentage in each of four categories – solid/firm, stable, unstable and soft/sinking);

Photographic records: photographs should betaken of the main macrophyte beds within the 100 m section, with the photographic point recorded on the site sketch map. In addition, photo should be taken of any evidence of macrophyte transportation.

Water quality: as well as using the results of the water quality monitoring program the following water quality parameters should be recorded for each section/zone, with three replicate recording for each parameter: pH, PAR, temperature, salinity, dissolved oxygen, turbidity.

Statistical analysis

General (for each location):

- Total number of species for each sampling zone, section and location;
- Average number of species per sampling zone calculated by mean species number for over the five sections;
- Average cover per species for each zone calculated by taking the mid point value of the range and determining the mean over the five sections; and
- Average frequency per species for each zone is the mean percentage of sections within which each species was observed

Distribution of species along the River (graphical):

- Total number of species versus location
- Cover of species versus location
- Frequency of species versus location

Temporal distribution of species/location (graphical):

- Total number of species versus time
- Cover of species versus time
- Frequency of species versus time

Trend analysis can be used to determine whether macrophyte communities change in response to changes in water quality and hydrology. Data to be analysed are to be grouped into sites with each of the two locations acting as a replicate. Each site will then be crossed with time.

Step trend analyses can be used to determine whether defined (known) changes in water quality and hydrology (ie implementation of the recommended environmental flow regime resulted in immediate incremental changes in macrophytes. Step trends can be tested for using the seasonal Wilcoxon-Mann-Whitney test (if data seasonal) or Kruskal-Wallis multiple comparison test. Following step trend analysis, data can be then tested for monotonic trends or gradual changes following changes in hydrology and water quality. Seasonal data can be tested for monotonic trends using the seasonal Kendall test. Data without a seasonal trend can be tested for monotonic trends using the Mann-Kendall test.

Potential changes in community composition are to be analysed using distance-based general linear modelling based upon an ANOVA experimental design as outlined below (Table C10).

Table C10: Components of variation for ANOVA

Source of Variation	Designation
Spatial variation	
Site – S	Fixed
Locations within Site – L(S)	Fixed
Section/Sampling Zone within Location – Z(L(S))	Random

Temporal variation	
Before-After – B	Fixed
Time within Before-After – T(B)	Fixed
Section/Sampling Zone x Before-After - Z(L(S))B	Random
Section/Sampling Zone x Time - Z(L(S))T(B)	Random

The inferential level of the analysis of these hypotheses is medium-low as there are no reference sites and the ability to specifically say that any changes in variables was only due to the implementation of environmental flows and the Forum's effluent reuse strategy is low because other unrelated changes in catchment conditions may have also changed over time.

Response time

As macrophytes are able to grow under a wide range of conditions, changes (trends) in their abundance and composition are usually detected over longer periods (years) rather than in the short term (months). Exceptions to these are when conditions are change such that the macrophytes are subject to extreme environmental conditions (eg salinities > 5 ppt, high flows), in which case rapid responses can occur ie loss/death of macrophytes. When assessing changes in macrophyte communities, any changes (trends) should also be considered in relation to channel changes and water quality, as well as changes in flows.

The monitoring program for aquatic macrophytes should start approximately three - five years prior to the environmental flow release.

Management interaction

The monitoring program will provide evaluations of any increase in abundance and distribution of native and exotic macrophyte species and the success of any control programs implemented for exotic species.

If the statistical analyses show that there is a no change or a significant increase in exotic macrophytes species over time then the recommended environmental flows and the Forum's effluent reuse strategy can be deemed to be insufficient to reduce the loss of native macrophytes and that both schemes need to be enhanced. However, if a significant increase in the distribution and abundance of exotic species occurs, additional management of the exotic species should be undertaken to reduce its continued spread. Given the growth rates of the exotic species under favourable conditions, this response time should be no greater than one year.

If the statistical analyses show that there is a significant decrease in exotic macrophytes species over time then the recommended environmental flows and the Forum's effluent reuse strategy can be deemed to be sufficient to reduce the loss of native macrophytes and will need to be continued to manage the growth of exotic species. At this point the use of contingent flows to help manage exotic macrophytes, in particular *Egeria densa*, can be stopped. However, should subsequent monitoring show an increase in the distribution of exotic macrophytes, the use of contingent flows to help manage *Egeria densa* should be re-introduced.

Where there is a significant increase in the cover and abundance of *Egeria densa* over time then the recommended environmental flows and the Forum's effluent reuse strategy can be deemed to be insufficient to reduce the excessive growth of *Egeria densa* and that both schemes need to be enhanced. Alternatively where a significant increase in the distribution and abundance of *Egeria densa* occurs, further management of *Egeria densa* should be undertaken to reduce its continued spread. Given the growth rates of the exotic species under favourable conditions, this response time should be no greater than one year.

If the monitoring program showed that there is a significant increase in distribution and abundance of Alligator Weed as a result of implementation of recommended environmental flows then these flows need to be reduced and additional management is required to control the distribution of Alligator Weed.

If the statistical analyses showed that there is a significant increase in the downstream extent of freshwater/brackish macrophytes species over time during dry periods then the recommended environmental flows and the Forum's effluent reuse strategy can be deemed not to reduce total flows during dry periods. Both schemes would need to be modified such that the salinity structure is able to increase its upstream extent in dry periods.

Altered Biotic Communities – Upper Nepean, Woronora and Shoalhaven Rivers

Issue

Modified river hydrology has changed fluvial habitat dynamics (eg. through habitat expansion and contraction, increased retention times, reduced flushing, etc) and resulted in the loss of biodiversity (eg. pollution-sensitive fauna) and the alteration of the structure of aquatic communities.

Hypothesis

The implementation of an environmental flow regime with transparent/translucent components, will restore flow-associated habitats and therefore increase the number of aquatic biota taxa at impacted sites, and restore macroinvertebrate community structure.

Location

Reaches 1, 3, 4, 8, 9, 10, 11, 12 and 13.

Pre-monitoring investigations

None

Variables

- The number of invertebrate genera and morpho-species in pool edge, pool rock and riffle-like habitats where they exist.
- The SIGNAL biotic index for edge, pool rock and riffle-like habitats.
- The SIGNAL-DAM biotic index for edge, pool rock and riffle-like habitats
- AusRivAS O/E biotic index based upon the SCA AusRivAS predictive model for edge, and riffle-like habitats.
- Site and water quality information required to run AusRivAS predictive models
- Community composition based upon Bray-Curtis dissimilarity values of macroinvertebrate genera in edge, pool rock and riffle-like habitats.
- Periphyton/diatom indices.
- Fish community structure
- Water quality variables including temperature, nutrients, dissolved oxygen, conductivity, pH, metal concentrations and other water quality parameters to be measured at each sampling site using electronic meters or be able to be estimated from nearby sampling sites or measured in another part of the monitoring program.
- Daily discharge or accurate estimates of flows at all sampling sites.

Periphyton and diatoms are not included as part of this issue as it was considered that the relevant indices were not at a stage of development to clearly and reliably determine or show ecosystem health.

General approach

Rapid assessment sampling of macroinvertebrates in aquatic habitats at impact and reference sites sampled in spring.

Field sampling design

Sampling for macroinvertebrates should take place using the rapid assessment sampling based upon existing protocols. The AusRivAS sampling protocols have only been developed for riffle and edge habitats. Sydney Water has rapid assessment sampling protocols for edge, riffle and pool rock habitats. The AusRivAS and Sydney Water sampling protocols for edge habitats are superficially similar. However, it is suggested that the AusRivAS protocols should be used in preference to Sydney Water's protocols for edge and riffle habitats. Sampling should only take place in the spring season.

It is recommended that the current sampling conducted by the SCA be continued (see Growns and Growns 2001, Australian Water Quality Centre 2002). The number of reference sites in the current sampling is supported by power analyses (see Appendix C3). However, the following reference sites should cease to be sampled, Kowmung and Goondarin, because catchment area of Kowmung is too big to allow for comparison of the number of taxa in the smaller upper-Nepean streams and Goondarin has been severely affected by sedimentation. The sites suggested by in Dames and Moore's (1997) 'Woronora River Reference Streams – Pilot Study' should be examined for their suitability for additional reference sites.

Statistical analysis

The data will be analysed using a Multiple Before-After-Reference-Impact (MBARI) design for the number of genera and morpho-species in each habitat type and the SIGNAL and O/E indices, with data collected before and after the introduction of the recommended environmental flows. The specific design will follow the MBACI design of Downes *et al*. (2002), Tables 7.4 and 7.5. The potential change in community composition will be analysed using distance-based general linear modelling (DISTLM) based upon the MBARI experimental design. The design of the DISTLM procedure can be found in Anderson (2000).

The inferential level of the analysis of this hypothesis is high due to the inclusion of reference sites in the experimental design.

Response time

Based upon literature reviews and the potential high dispersal rates of invertebrates from nearby areas, the response of invertebrates should be within approximately one year from the introduction of environmental flows. However, the full recovery of the invertebrate communities may take several years due to the long-life cycles (2-3 years) of some species and potential low dispersal rates.

Management interaction

If no statistically significant improvement has been found in either the number of genera in particular habitats, the SIGNAL biotic index or community composition 5 years after the implementation of the environmental flows in the regulated reaches compared with reference sites then the environmental flows can be deemed to be not sufficient to improve aquatic ecosystem health and the recommended environmental flow regime needs to be greatly enhanced.

If a statistically significant change is shown for one, two or three of either the number of genera, SIGNAL index in any habitat or community structure in the regulated river reaches compared with reference sites then the recommended environmental flow regime can be deemed to have partially improved aquatic ecosystem health and the recommended environmental flow regime needs to be improved.

If all univariate and multivariate variables show a significant change and the average values of all biotic indices become not significantly different from references sites then the recommended environmental flow regime(s) have improved aquatic ecosystem health and no change is required to them.

Reduced Recreational Fish Catches

Issue

There is a strong relationship between river flows and catches recreational catches of Australian bass (Growns 2003). Reduced freshwater flows due to river regulation has resulted in lower catches of Australian bass.

Hypothesis

The implementation of an environmental flow regime will restore a more natural flow regime and therefore increase the potential for recruitment and survival of Australian bass, resulting in greater recreational catches.

Location

Reaches 1 2.1, 3, 4, 5 and 14 to 25

Pre-monitoring investigations

None

Variables

- The percentage of young of year Australian bass caught in each year during 6-monthly Basscatch events.
- Catch per unit effort of Australian bass caught in Basscatch events.

General approach

Continue 6-monthly BassCatch events in the Hawkesbury-Nepean and Shoalhaven River systems but with additional support from this monitoring program to ensure the program continues and extended to the Woronora River system.

Field sampling design

The format of the Basscatch events should continue as it is.

Statistical analysis

Analysis of variance or general linear modelling, with appropriate error distributions, to test the hypothesis that the mean of two variables will significantly increase following the implementation of environmental flows in all three river systems. The inferential ability of the analysis of this hypothesis is low because of the lack of information of what natural or reference conditions for the catch per unit effort and percentage of young-of-year Australian Bass.

Response time

Based upon current analysis response should be within one or two years, particularly if an annual median flow of greater than 200 ML/d is achieved by the recommended environmental flow regime.

Management interaction

If no statistically significant change has been found between the relationships flow regime and either the annual percentage of young-of-year Australian bass number or the catch per unit effort 5 years after the implementation of the environmental flows, then the environmental flows can be deemed to be not sufficient to improve aquatic ecosystem health and the recommended environmental flow regime(s) needs to be greatly enhanced. If a statistically significant change is either shown for the annual percentage of young-of-year Australian bass number or the catch per unit effort then the recommended environmental flow regime(s) can be deemed to have partially improved aquatic ecosystem health and the recommended environmental flow regime(s) need to be improved. If all univariate variables show a significant increase then the recommended environmental flow regime(s) have improved aquatic ecosystem health and no change is required to them.

Altered Biotic Communities – Middle and Lower Nepean and Hawkesbury Rivers

Issue

The discharge of treated sewage effluent has caused significant changes to the biota of the River.

Hypothesis

The implementation of an environmental flow regime with transparent/translucent components, and the Forum's effluent reuse strategy will restore flow-associated habitats and improve water quality and therefore increase the number of aquatic biota taxa at impacted sites, and restore fish and macroinvertebrate community structure.

Location

Reaches 14 to 24

Pre-monitoring investigations

Additional analysis of current macroinvertebrate data, in addition to SIGNAL-G biotic index, collected by Sydney Water upstream and downstream of sewage effluent inputs to evaluate other potential impacts of current effluent management. The additional analysis should evaluate the effects of sewage inputs on the number of macroinvertebrate taxa and community structure.

Variables

- The number of invertebrate genera and morpho-species in edge, riffle, macrophyte, and pool-rock habitats where they exist.
- The SIGNAL-SEW biotic index.
- O/E AusRivAS biotic index based upon the NSW model for riffle and edge habitats
- Macroinvertebrate community composition

Periphyton and diatoms are not included as part of this issue as it was considered that the relevant indices were not at a stage of development to clearly and reliably determine or show ecosystem health.

General approach

Annual rapid assessment sampling of macroinvertebrates in aquatic habitats at selected sites in the main channel of the Hawkesbury-Nepean River in spring.

Field sampling design

Sampling for macroinvertebrates should take place using the rapid assessment sampling based upon existing protocols. The AusRivAS sampling protocols have only been developed for riffle and edge habitats. Sydney Water has rapid assessment sampling protocols for edge, macrophyte, riffle and pool rock habitats. The AusRivAS and Sydney Water sampling protocols for edge habitats are superficially similar. However, it is suggested that the Sydney Water protocols should be used in preference to AusRivAS protocols for edge and riffle habitats because this would ensure that current information collected by Sydney Water could be used in future analyses.

The selection of sites to be examined will depend on whether the pre-monitoring investigation demonstrates convincing evidence of an impact of the current sewage effluent disposal into the Hawkesbury-Nepean River on macroinvertebrate communities. The SIGNAL-G biotic index, that is current used to evaluate sewage effluent, suggests that effluent disposal has minimal impact on macroinvertebrates.

If following the pre-monitoring investigation sewage effluent is shown to have an impact on macroinvertebrates then sites should be located at areas upstream and downstream of the discharge of sewage effluent as they are current sampled for Sydney Water Corporation's Environmental Indicators

Compliance reporting. This will allow an evaluation of the benefits of the implementation of recommended environmental flows separately to the implementation of recommended environmental flows in addition to the reduction in effluent discharge through the Forum's effluent reuse strategy.

If the pre-monitoring investigation determines that there is no affect of sewage effluent on either the number of taxa or macroinvertebrate community structure then sites can be located anywhere along these reaches. Sites that are recommended for sampling for each result of the pre-monitoring investigation are given in Table C11. All these sites have been sampled previously in programs run by Sydney Water. The actual number of sampling sites will need to be determined through power analyses of existing data.

Table C11: Recommended Sampling Sites for Altered Biotic Communities

Site No.	Site Name	Sites with riffle habitats	Currently sampled
N92	Nepean River at Maldon Weir	X	Yes
N91	Nepean River at Maldon Bridge	X	Yes
N89	Nepean River at Douglas Park Crossing		
N85	Nepean River at Menangle Bridge	X	
N80	Nepean River at Cowpasture Bridge		
N78	Nepean River at Macquarie Grove Road		Yes
N75	Nepean River at Sharpes Weir		Yes
N72	Nepean River at Cobbitty Weir		
N682	Nepean River at Bents Basin	X	
N67	Nepean River at Wallacia Bridge		
N57	Nepean River at Penrith Weir	X	Yes
N53	Nepean River at BMG causeway	X	Yes
N48	Nepean River at Smith Street Bridge	X	Yes
N44	Nepean River at Yarramundi Bridge	X	
N42	Hawkesbury River at North Richmond		Yes
N40	Hawkesbury River downstream Nth Richmond WTP		Yes
N38	Hawkesbury River at Windsor Bridge		Yes
N35	Hawkesbury River at Wilberforce		Yes
N26	Hawkesbury River at Sackville Ferry		Yes

In addition to the sites currently being sampled by Sydney Water, it is recommended that sites N85 (Menangle Bridge), N682 (Bent's Basin) and N44 (Yarramundi) also be sampled as these site contain riffle habitats. It is the fauna in riffle habitats that are more likely to show environmental benefits of an EFR because of the role in water flow in creating microhabitats.

Statistical analysis

The evaluation of this hypothesis can take two forms, depending upon the results of the pre-monitoring investigation.

The effect of the EFR on univariate indices should be determined with intervention analysis with the onset of EFR and the Forum's effluent reuse strategy classified as the intervention. If the pre-monitoring investigation indicates that the current sewage effluent discharge into the Hawkesbury-Nepean River system does not affect community composition structure or the number of taxa then all sites sampled can be used as replicates in the intervention analysis. However, should the pre-monitoring investigation determine impacts of sewage effluent then two site types should be considered in the intervention analysis. These two types of sites include sites upstream of points of sewage effluent discharge and sites immediately downstream of these points. An interaction between the before and after the recommended environmental flow regime and location of sites in relation to sewage effluent discharge points would test if these two site types reacted differently to the implementation of the recommended environmental flow regime and the effluent reuse strategy. Note that a two-way ANOVA with the factors, affected by and not affected by sewage and, before and after the recommended environmental flow regime, cannot be used to analyse this data because the will be no "after" samples affected by sewage effluent.

The inferential level of this analysis is low, ie. the ability to specifically say that any changes in variables was only due to the changes in the recommended environmental flow regime and the effluent reuse strategy is low because other changes in catchment conditions not related to the recommended environmental flow regime and the effluent reuse strategy may have also changed over time.

Response time

Because of other confounding factors, eg. stormwater and diffuse source pollution the response time for macroinvertebrates is unknown. However, it can be expected that some form of response may be detected one to two years following significant improvement in water quality at sites downstream of point source inputs.

Management interaction

If no statistically significant change (ie. no change over time or downstream sites remain not similar to upstream sites) has been found in either the number of genera in particular habitats, the SIGNAL biotic index or community composition 5 years after the implementation of the environmental flows and effluent management strategy, then the environmental flows can be deemed to be not sufficient to improve aquatic ecosystem health and the EFR(s) needs to be greatly enhanced. If a statistically significant change is shown for one or two of either the number of genera, SIGNAL index in any habitat or community structure then the EFR(s) can be deemed to have partially improved aquatic ecosystem health and the EFR(s) need to be improved. If all univariate and multivariate variables show a significant change and become like the reference sites then the EFR(s) have improved aquatic ecosystem health and no change is required to them.

Reduced Commercial Fish Catches

Issue

There is also a strong relationship between river discharges and commercial catches of prawns and other fish species (Growns and Gray 2003). River regulation is also likely to have reduced estuarine productivity due to decreased inflows to estuaries.

Hypothesis

The implementation of an environmental flow regime will restore a more natural flow regime and therefore increase estuarine productivity and larger catches of some fish species.

Location

Reaches 2.1, 2.2, 25, 26 and 27

Pre-monitoring investigations

None

Variables

The monthly commercial catch of the dominant fish and invertebrate species in the Hawkesbury and Shoalhaven Rivers.

General approach

Continue to use the commercial catch system of New South Wales Fisheries. However, in order to be more useful the catch information system needs to be able to precisely link what fishing methods were used to catch school prawns in order that catch per unit effort data can be generated.

Field sampling design

None

Statistical analysis

Analysis of variance or general linear modelling, with appropriate error distributions, to test the hypothesis that the mean monthly catch of dominant fish species will significantly increase following the implementation of environmental flows.

Response time

For some fish and invertebrate species a response may occur within one year. However, species with long life cycles may not show a response in less than two years.

Management interaction

If no statistically significant change has been found between the relationships flow regime and any commercial fish species 5 years after the implementation of the environmental flows, then the environmental flows can be deemed to be not sufficient to improve aquatic ecosystem health and the recommended environmental flow regime(s) needs to be greatly enhanced.

If a statistically significant change is shown for several fish species then the recommended environmental flow regime(s) can be deemed to have partially improved aquatic ecosystem health and the recommended environmental flow regime(s) need to be improved.

If all fish and invertebrate species previously shown to have a positive relationship with river flows show an increase change in there relationships with the introduction of an recommended environmental flow regime, then the recommended environmental flow regime(s) have improved aquatic ecosystem health and no change is required to them.

Connectivity investigations – managing flows for fish passage in the Woronora River

Issue

The HRC recommended 800 ML/d (over 3 days) environmental release to provide passage opportunities for diadromous fish species which have entered the system. If the species are not in the system in substantial numbers, then little environmental benefit will arise from such releases. To avoid such low-benefit outcomes, it is recommended not to make releases when diadromous fish numbers are low. It follows that the monitoring of the abundance of diadromous fish in the system will provide vital information for the management of the releases.

Location

Reaches 3, 4 and 5.

Pre-monitoring investigations

Pre-monitoring for the Woronora River system includes:

- pilot/reconnaissance surveys for the monitoring of movement 'pulses' of diadromous fish species (includes logistics, method comparisons, developing a sufficient understanding of movement dynamics);
- further hydrological analyses to verify the findings of Patterson Britton (2002) concerning the identification of flow ranges downstream of Woronora Dam that have been impacted by dam.

These pilot/reconnaissance/ surveys are initially required to determine:

- accessibility constraints and logistics;
- develop a good understanding of the fish-movement dynamics of the system;
- habitat availability at sites and the identification of meso- and/or microhabitats to be selected for standardised sampling;
- sample method selection;
- identification of key environmental covariates; and
- initial estimation of within-site variability so that a suitable replication level can be determined.

Diadromous species inhabiting pools and open-long channels should be targeted.

Variables

- daily-average-flow data at the representative riffle-like habitats when pilot/reconnaissance surveys are underway.
- Population descriptors (distribution and abundance data, separated for adults, juveniles and young-of-year) with emphasis on diadromous fish species, particularly the Australian bass[1].

General approach

The adaptive management of the environmental-flow-regime downstream of Woronora Dam is hamstrung given a premature commencement of the Healthy Rivers Commission (HRC) recommended regime. For many components of the ecosystem this early start has meant that there are negligible baseline data available to utilise when determining the regime's effectiveness. This situation is probably worst for the fish component. This is most regrettable given that fish are an important candidate for environmental-flows monitoring because:

[1] Bass are an ideal target fish species because they are the species most vulnerable to connectivity losses. This is because of their need to utilise the river during one part of their life-cycle (which is dependent on long-distance migrations from the estuary), their large body size (hence they are first affected by flow reductions over shallows), their inability to move around obstacles out of the water (species such as eels and some gudgeon and galaxiid species have this ability), and their presence in the Woronora system. Additionally, they have high recreational value.

- they (larger species particularly) are both greatly and first to be limited in their movements by reduced water levels through shallow habitats such as riffles and runs (connectivity issue)
- high-magnitude flow releases are required from Woronora Dam annually (HRC 2001) and one of their intended functions is the provision of fish passage along the river (connectivity issue again)
- larger fish species, unlike, for example, virtually all macroinvertebrates[1], are likely to be strongly responsive to the two key hydraulic variables - water depth and water velocity

This situation could be remedied by curtailing the regime for a period to allow the collection of the necessary baseline data. To avoid this, and to not compromise the adaptive management to an unacceptable degree, the Independent Expert Panel recommends that pre-monitoring investigations[2] be activated promptly so that associated hydrological-surrogate monitoring can commence as soon as possible.

However, it would still be desirable to determine how fish communities in the river are responding to the regime. Additionally, it would be greatly beneficial to have pertinent information available to manage the high-magnitude flow releases[3]. Of particular interest in this context is whether or not diadromous fish species have entered the system from estuary. If they have not entered the system there would be only be small environmental benefits arising from the considerable quantity of water released (ie. passage opportunities would be enhanced but few fish would be present to take advantage of it!).

Accordingly, it is recommended that the abundance of diadromous fish species be strategically monitored in the Woronora River system to provide pertinent data for the management of high-magnitude flow releases. It is recognised that these data will have some use in assessing the effectiveness of the overall environmental flow regime.

Recreational-angler captures (as per the Anglers-Catch Database approach described by the Cooperative Research Centre for Freshwater Ecology (CRCFE) (1999) would be the ideal sampling method because costs would quite low and it provides a means of engaging the local community in the monitoring. Other advantages include:

- sampling effort can be high (at low cost) as large numbers of anglers can be made available
- it has apparently been successfully used by NSW Fisheries in coastal rivers of NSW, particularly with the diadromous Australian bass being a target species
- NSW Fisheries state that they have developed effective working protocols
- high ease of access to remote sites, even over rough terrain (anglers enter by foot with non-bulky gear)
- results can be compared to the same type of surveying being undertaken in the Hawkesbury-Nepean system to detect responses to environmental flows (see Issue ‘recreational catches of bass’ for that system).

This technique could be partially standardised by engaging say 5 recreational anglers to spend one-day fishing in separate pools (thalweg of pool > 1 m) within a given area. Anglers would record fish species identity, numbers and measure lengths.

However, there remains some risk that results could be ambiguous given that catches may be difficult to standardise in relation to differences in anglers’ techniques and equipment, and time-to-time differences in the catchability of fish (ie. particularly in relation to variation in feeding behaviour and activity). An additional problem is that anglers seldom capture young-of-year bass, or even juveniles a year or so older. Information on the distribution and abundance of such young fish would be, in part, important in determining whether there was a need to release fish-passage flows in the system.

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[1] Macroinvertebrates are generally much less sensitive to water depth changes given that they generally have body depths <1mm, while larger fish commonly have body depths up to 200-300mm.

[2] The investigations aim to determine ‘working’ flow thresholds for fish passage, riffle-like areas, stratification and algal scouring/flushing.

[3] HRC (2001) recommended an annual 3-day 800 ML/d release. However, hydrological modelling data provided by Patterson Britton (2002) indicated that such a release would be poorly targeted given that flows of this magnitude appear to be unaffected by Woronora Dam. Flows in the range of 30-150 ML/d appear to be substantially affected by the dam and these flows are likely to be important for fish passage along the river (Patterson Britton 2002).

Given the above disadvantages, it is obvious that there is a need to test the reliability of recreational anglers captures using 'in parallel' well-standardised surveying techniques. Additionally, given that angler's seldom catch young bass, it would be necessary to complement the work of angler's by using surveying techniques which target young bass. If a suitably straight-forward complementary technique was tested, and found to be effective, it could then be handed over to angler's after a training period, and with some supervision. This would be an ideal outcome.

Two surveying techniques used by Bishop (1993) in the Woronora River system are obvious candidates for examination given their:

- straight-forward nature (based on standardised observation which was faciliated by high water clarity),
- high cost-effectiveness,
- non-destructive nature (ie. observations only), and
- ease of access to remote sites even over rough terrain (accessing by foot with non-bulky gear)

The first technique, recording fish, particularly Australian bass, by day by visual observation using polarising glasses, could most easily be handed over to anglers and is likely to be by far the most cost-effective as up to five sites could be examined within one day by two workers. Bishop (1993) recorded considerable numbers of Australian bass along the system with this technique and there were clear longitudinal trends in numbers and the distribution of size classes. Australian bass less than 100 mm LCF were easily observed. This technique could readily be standardised by making say 5-minute observations (recording fish species identity, numbers and estimating lengths) at ten separate spots along the banks of pools (thalweg of pool at spot > 1 m, but < 2 m) in a given area. The technique standardised in this way is henceforth referred to as 'daytime spot (DS) observations', or 'DS observations'.

The second technique, recording fish at night with the aid of an underwater spotlight, is less readily handed over to anglers and is likely to be less cost-effective as only two adjacent sites could be examined within one night by two workers. However, it has the advantages that it will detect fish that were within cover during the day, and that results can be compared to the same type of surveying which is recommended to be undertaken[1] in the upper Nepean system to detect responses to environmental flows. The technique would be standardised by making observations (again recording fish species identity, numbers and estimating lengths) along say twenty separate ten-metre lengths of pool bank (depth one metre out from bank: ~0.5-2.0 m) in a given area. The technique standardised in this way is henceforth referred to as 'night-time transect (NT) observations', or 'NT observations'.

Field sampling design

Initially, in the form of an extended pilot survey over two years, it is proposed that the above three sampling methods be undertaken simultaneously at the full range of sites so to:

- develop a good understanding of the fish-movement dynamics of the system, and
- ascertain the utility of the methods/sites/sampling-times and identify redundant components, or components which require refinement

From this work the most suitable method(s) will be chosen for the ongoing monitoring.

Sampling should be undertaken twice yearly in the following periods so to provide pertinent information for the management of the release of fish-passage flows:

- *Early-mid summer:*
  - relevant to the upstream movement of adult and juvenile Australian bass, common jollytail, striped gudgeons and flatheaded gudgeons; and
  - relevant to the downstream movement of freshwater mullet.
- *Autumn to early winter:*
  - relevant to the downstream movement of adult Australian bass and common jollytails; and

[1] A number of techniques will be examined in that system during pilot/reconnaissance surveys. It is highly likely that this technique will be an important component of the monitoring.

– relevant to the upstream movement of freshwater mullet.

Sampling should be undertaken within a longitudinal arrangement of zones/areas as detailed in Table C12. These have been strategically selected in relation to key fish-passage barriers identified by Patterson and Britton (2002).

Table C12: Temporal, Spatial and Methodological Components of the Initial Phase of Fish Sampling in the Woronora System: Provision of Pertinent Data for the Management of Fish-Passage-Flow Releases

Sampling Zones	**Sampling Areas** (naming follows Patterson Britton [2002])	**Sampling** Early-mid summer (upstream movement of adult and juvenile Australian bass, common jollytail, striped gudgeons and flatheaded gudgeons; downstream movement of freshwater mullet)	 Autumn to early winter (downstream movement of adult Australian bass and common jollytails; upstream movement of freshwater mullet)
Barriers upstream ('U1'): passage opens ~30 & 150 ML/d (downstr. Friarbird), and ~ 200 ML/d barriers (downstr. Boobera); 1 km long section			
Zone 1 (3 km long section)	Lake Eckersley; 20-30 ML/d barriers upstream of the lake	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.
Barriers '1-2': passage opens ~50,90 & 250 ML/d; 2 km long section			
Zone 2 (6 km long section)	Area 2A: pools starting approx. 2 kms downstream of Lake Eckersley (ie. downstream of Site D = below No-name Pool #9)	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.
	many ~20-30 ML/d barriers; 3.5 km long section		
	Area 2B: pools near Heathcote Rd.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.
	many ~20-30 ML/d barriers; 2.5 km long section		
	Area 2C: within 'Sabugal' Pool	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.
Barrier '2-3': passage opens ~800 ML/d (one cascade)			
Zone 3	Area 3A: downstream of the downstream end of 'Sabugal' Pool to the Needles causeway	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.
	causeway barrier		
	Area 3B: downstream of the Needles Causeway (ie. the upper estuary)	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.	▪ 5 recreational anglers/ 1day ▪ 10x DS obs. & 20x10m NT obs.

Statistical analysis

Knowledge of the position of 'pulses' of fish moving along the river, particularly in relation to the location of key passage obstacles, is the key information required for management. Graphical presentation of longitudinal trends in abundance, separated in respect to species and possibly size class, would provide such information. Workers with considerable experience in fish-movement dynamics would be best able to interpret such presentations. A guideline for identifying a movement pulse could be that the abundance in a particular area/zone is more than say four fold that recorded in adjacent areas/zones.

Response time

Once the two-year pilot/reconnaissance investigations are completed, or if fortunate, after the first year of these investigations.

Management interaction

Without a good understanding of the fish-movement dynamics of the system, which can only be gained from the pilot/reconnaissance survey, it is difficult to be very specific regarding management interactions, ie. directions to transmit naturally-occurring fish-passage flows. However, tentative guidelines are provided below (note that flow values may be substantially revised following physical-habitat pre-monitoring investigations) in Table C13 below.

Table C13: Tentative Guidelines for the Transmission of Naturally-Occurring Fish-Passage Flows.

Arising from early-mid summer observations:	Arising from autumn to early winter observations:
Upstream-travelling 'movement pulse' (UMP) only within Zone 3: • no transmissions required unless a sufficiently large flow occurs to allow passage for at least half-day over Barrier 2-3 (assumed to ~800 ML/d); if this occurs it is assumed that the UMP is then in Zone 2 • the ~800 ML/d flow for Barrier 2-3 should not be transmitted because it is assumed that the hydrological analyses of PatBrit are correct – this will be tested	not applicable (already at downstream end)
UMP only within Area 2C: • transmit >30 ML/d flows for up to 6 days (then see Area 2A)	Downstream-travelling 'movement pulse' (DMP) only within Area 2C: • transmit ~800 ML/d for up to ½ day
UMP only within Area 2B: • transmit >30 ML/d flows for up to 4 days (then see Area 2A)	DMP only within Area 2B: • transmit >30 ML/d flows for up to 2 days (then see Area 2C)
UMP only within Area 2A: • transmit one day of >100 ML/d flow then one day of >250 ML/d flow (then see Zone 1)	DMP only within Area 2A: • transmit >30 ML/d flows for up to 4 days (then see Area 2C)
UMP only within Zone 1: • transmit >30 ML/d flows for up to 3 days then one day of > 200 ML/d	DMP only within Zone 1: • transmit 2 days of 30 ML/d, then 1 day of >250 ML/d, then up to 6 days of >30 ML/d (then see Area 2C); for DMPs upstream of this commence with 1 day 200 ML/d

Areas, zones and barriers were identified within Table C12; PatBrit = Patterson Britton (2002)

Note that the above releases would not be required if spills, or the translucent-component of the environmental-flow regime, satisfy the above directions.

Stratification of Natural Pools

Issue

Stratification can have significant impacts on both water quality and pool dependent biota.

> **Hypothesis**
>
> The introduction of the recommended environmental flow regime downstream of Tallowa, Nepean, Cordeaux, Avon and Cataract Dams will lead to the decreased frequency and shorter duration of thermal and oxygen stratification in natural pools and less frequent poor water quality at depth**.**

For the purposes of this hypothesis, thermal and oxygen stratification and the occurrence of associated poor water quality with depth is defined as a change in temperature with depth of > 2°C and/or the reduction in dissolved oxygen concentrations > 2 $mg.L^{-1}$.

Location

Reaches 1, 8, 9, 10, 11, 12, 13 and 14.

Pre-monitoring investigations

The extent of river regulation induced thermal stratification of natural pools in the Nepean, Shoalhaven and Woronora River systems is unknown and as such it is necessary to undertake a pre-monitoring investigation to establish the frequency, duration and magnitude of thermal stratification in natural pools. This study should be undertaken during summer and carried out in the first instance in one of these systems (eg. the Nepean downstream of Pheasants Nest weir) to determine the scale of this issue. The results of this investigation should then be used to determine whether further monitoring of stratification of natural pools is warranted.

There is an assumption that thermal stratification is a reliable indicator of oxygen stratification. Given that oxygen stratification can occur without temperature differences, there is a need to investigate the reliability of this assumption during the course of the pre-monitoring investigation. This can be undertaken be either the deployment of an oxygen probe or by profiling during field visits

Variables

- Depth (from thermistor chain);
- Discharge/Flow (accurate and daily);
- Dissolved Oxygen (profiled through depth if permanent deployment not feasible; initial focus will be to examine the assumption that thermal stratification is a reliable indicator of oxygen stratification);
- Pool bathymetry;
- Pool dimensions including length, width and depth;
- Rainfall as explanatory variable;
- Solar radiation;
- Temperature (via thermistor chain – one per pool); and
- Time & date (from thermistor data).
- Wind speed?

General approach

The pre-monitoring investigation should examine 2 pools in the Nepean River system downstream of Pheasants Nest weir to efficiently determine the relationship between flow and natural pool stratification under the existing environmental flow regime. The variables and field sampling design should be the same as those recommended for the long-term monitoring strategy.

If pool stratification is found to occur for extended periods under the current environmental flow regime, an extended program to investigate the relationship between the recommended environmental flow regimes and pool stratification is warranted. Under these circumstances four pools (two within each of the Shoalhaven and Nepean River systems, chosen to represent typical pool sizes for each system) should then be monitored 2 years before and 2 years after the introduction of the recommended environmental flows. This should be undertaken during the period October to March each year. Frequency (how often), duration (how long) and magnitude (difference between surface and bottom temperatures and dissolved oxygen) of stratification events should be assessed for each pool.

Field sampling design

General dimensions of the pools including lengths, widths and depths should be determined. Pool bathymetry should be assessed for modelling purposes. A thermistor chain should be deployed in each pool in September/October each year. Thermistors should be maintained and data down-loaded at regular intervals. During field visits at approximately three weekly intervals, profiling of the water column for dissolved oxygen, pH, salinity and turbidity should be carried out.

Statistical analysis

Impacts of environmental flows on the frequency, magnitude and duration of thermal (and oxygen) stratification should be determined via field observations and examination of the relationship between flow thresholds and destratification. There is a high level of confidence that a change in the frequency, magnitude and duration of thermal (and oxygen) stratification in natural pools downstream of the dams is due to environmental flows. Accurate flow gauging is essential to interpret the data.

Response time

Within two years of the introduction of environmental flows although the pre-monitoring investigation may reveal that stratification of natural pools is not of major concern.

Management interaction

Flow thresholds need to be determined to identify translucent/transparent triggers needed to minimise the frequency and duration of regulation-induced stratification events for typical pools. An understanding of these flow thresholds can then inform the adaptive management process.

Reduced Flushing, Scouring and Conditioning

Issue

Reduced duration and frequency of flushing/scouring/conditioning flows, together with increased nutrient concentrations (particularly downstream of the Bargo River confluence), have resulted in *i)* a build up of algal[1]/detrital material in shallow habitats[2], and *ii)* a reduction in the conditioning[3] of stony-bed areas).

Hypotheses

The introduction of the recommended environmental flow regime, including specific contingent flushing/scouring flows, will increase the duration and frequency that shallow habitats are scoured/flushed (towards levels that occurred under natural conditions), and this will increase habitat quality, by regularly removing excessive accumulations of algal/detrital material.

The introduction of a translucent/transparent environmental flow regime, including specific contingent flushing/scouring flows, will increase the duration and frequency that stony beds are conditioned (towards levels that occurred under natural conditions), and this will increase habitat quality, particularly within the interstitial spaces of the beds.

Locations

River reaches that are likely to have been substantially impacted by the build up of algal/detrital material in shallows are 3, 4, 9, 12 and 13.

River reaches that are likely to have been substantially impacted by the reduced stony-bed conditioning are 3, 4, 8, 9, 10, 11, 12 and 13.

Pre-monitoring investigations

To confirm that the reduction of flushing/scouring flows, and the associated buildup of algal/detrital materials, is an important environmental issue, it would be prudent in summer months to undertake a spatial assessment of the abundance of algal/detrital material downstream of the dams/weirs and in appropriate reference areas. An elevated abundance below the dams/weirs, in comparison to the reference areas, would provide evidence that the issue is ecologically significant. This examination should additionally include an examination of hydrological modelling data (a re-examination in the case of the Woronora system) to determine the likelihood that dam operations have substantially reduced the duration and frequency of effective flushing/scouring flows.

To obtain fundamental information regarding reduced stony bed conditioning, hydrological modelling data should be examined (a re-examination in the case of the Woronora system) to determine the likelihood that dam operations have substantially reduced the duration and frequency of effective conditioning flows. If the hydrological analyses clearly suggests that dam operations have impacted conditioning flows, then it will be necessary to identify likely critical flow thresholds for conditioning stony-bed areas. Pilot studies should also examine the level of resolution on the thresholds. To do this, power analyses on the gathered turbidity data would be required.

Variables

- Benthic algae

[1] Primarily diatomaceous coatings and filamentous-greens.
[2] The shallows of key interest are those associated with biological-important areas, particularly riffle-like habitats.
[3] *Conditioning* is the removal of accumulations of fine organic material from interstitial spaces of the stony beds by the flow-driven 'turning over' of the beds. The beds of key interest are those associated with biological-important areas, particularly riffle-like habitats.

- Critical thresholds for scouring algae in shallow water
- Daily-average-flow data in all river systems in which investigations are undertaken (for use in the interpretative phase);
- Complete set of hydrological-model inputs necessary for the examination of modelling undertaken;
- Daily-average-flow data at the representative shallows during recommended environmental flow releases;
- Predicted daily-average-flow data at the representative shallows for the state without environmental flows;
- Predicted daily-average-flow data at the representative shallows for the natural condition;
- Critical stony bed conditioning thresholds;
- Ten-minute-average-flow data at the selected stony beds when ‘working’ and ‘refined’ flow thresholds are being investigated;
- Daily-average-flow data in all river/creek systems in which investigations are undertaken (for use in the interpretative phase);
- Complete set of hydrological-model inputs necessary for the examination of modelling undertaken.
- Daily-average-flow data at the representative stony-beds during environmental flow releases;
- Predicted daily-average-flow data at the representative stony-beds for the state without environmental flows; and
- Predicted daily-average-flow data at the representative stony-beds for the natural condition.

General approach

Following the pre-monitoring investigation for scouring algal and stony bed conditioning flow thresholds, the general approach involves simple reporting of the number of days per year, under the environmental-flow (EF) state, that scouring algae in shallows and stony bed conditioning would be classified as having occurred (ie. days when flows > scouring algal and stony bed conditioning flow thresholds). These would be based on river-flow gauging data. The results would be given a context in relation to the before-environmental-flow state (% gain) and the natural condition (% shortfall). Before-environment and natural condition flows would need to be modelled and be based on dam inflows/outflows.

Field sampling design

Walker *et al.* (2003) identified two flow ranges within which two dominant types of algal/detrital material would be scoured free in riffle-like areas (stream width = 15 m) following ~ 6 hrs exposure to the flow:

- medium-strength algae: 120-190 ML/d (midpoint 155 ML/d)
- higher-strength algae: 690-860 ML/d (midpoint 775 ML/d)

Even though the algal-detrital work was restricted to below the upper-Nepean dams (as opposed to below the upper-Nepean diversion weirs or within the Woronora system), it is recommended that the midpoints of the ranges (adjusted for representative stream widths) be used as critical flow thresholds for flushing/scouring algal/detrital material in shallows. Strategic observations should then be made before and after flushing/scouring contingent-flow releases on the abundance of algal/detrital material in a set of critical riffle-like habitats. Ascertain the effectiveness of the releases and upgrade the flow thresholds as necessary.

To identify likely critical flow thresholds for conditioning stony-bed areas and following observations in NSWDPWS (2000), it appears that these would be best determined by manipulating flows beneath the dams and continually recording turbidity (alternatively suspended solids concentration) upstream and downstream of bed areas which are downstream of large pools. Flows should be stepped up and each step should last at least 6 hrs (0-100 ML/d – steps of 10 ML/d, 100-200 ML/d – steps 25 ML/d, 200-300 ML/d – steps 50 ML/d, 300-1000 ML/d – steps 100 ML/d; 1000-1400 ML/d – steps 200 ML/d). A rapid increase in turbidity would indicate a critical threshold for the entrainment of detritus/fines. A number of thresholds may be identified – surface coatings would have the lowest threshold, while deeply-deposited material would have the highest. A rapid decrease in turbidity would indicate that the supply of material had been exhausted. This information would be valuable in determining the most effective length of conditioning flows. Given differences in river gradient, this would have to be undertaken in the Cordeaux River and either the Nepean, Cataract or Woronora Rivers.

Statistical analyses

For each reach, the significance of differences in the occurrences should be tested separately for the before-environmental and natural conditions pairs in relation to the null hypothesis that there are no differences between the states in the ratio scouring-algae-in-shallows and stony bed conditioning days versus non-scouring and non-conditioning days.

This should be tested with a parametric frequency-analysis procedure such as a Chi-squared test. The ratio should be calculated for the whole year as well as being separated for biologically-important periods such as spring and early summer.

Response time

The response time for algal/detrital scouring will be two years after environmental flows commence algal/detrital scouring thresholds have already been identified by Walker *et al.* [2003]); assuming that hydrological data and modelling is underway at the commencement).

For stony bed conditioning the response time will be one year after the commencement of the stony bed conditioning flow threshold pre-monitoring investigations (ie. at their completion; this assumes that the environmental-flow regime had been running for two years and that the necessary hydrological data-gathering and modelling was simultaneously underway).

Management interaction

It is proposed that these ecological-significance thresholds be used to trigger adaptive-management actions for algal/detrital scouring and stony bed conditioning flows:

- there is a high-priority need to supplement environmental flows (eg. by altering transparency/translucency settings) in a particular reach if after two years the duration of 'scouring-algae-in-shallows' days under the environmental-flow condition is:
  - 30-100% less than what would be expected under natural conditions; and
- there is a medium-priority need to supplement environmental flows in a particular reach if after two years the duration 'scouring-algae-in-shallows' days under the environmental-flow condition is:
  - 10-30% less than what would be expected under natural conditions.

In both of these cases the deviation from the before-environmental-flow state should be reported to provide an indication of what improvements have occurred.

Elevated Iron and Aluminium Concentrations in Discharge Waters

Issue

Stratification of the water column in the dam can lead to the release of iron and aluminium from bottom sediments into the water column which, if released, can lead to elevated iron concentrations in downstream receiving waters and elevated aluminium concentrations coupled with low pH can be toxic to fish.

Hypothesis

The introduction of an environmental flow regime downstream of Tallowa Dam, consisting of translucent and transparent flow releases of surface waters made via a multi-level off-take, will lead to a significant decrease in the surface area covered by iron precipitate and associated iron-oxidising bacteria. Significant improvements in water quality will also be realised with respect to total and filterable aluminium concentrations in downstream receiving waters particularly during dry weather.

Location

Reach 1

Pre-monitoring Investigation

An investigation is required to establish the exact design of the photo-quadrat monitoring program including the statistical analysis of the resultant incidence-area data.

Variables

- Area affected by iron precipitate downstream of Tallowa Dam.
- Filterable Iron
- Total Iron
- Filterable Aluminium
- Total Aluminium

General approach

Photo transects of iron precipitate plus routine monitoring of water quality through time will be used to demonstrate reductions in iron precipitate and iron and aluminium concentrations downstream of the dam following the introduction of environmental flows.

Field sampling design

Photo transects undertaken on an annual basis for a minimum of two years before and after the introduction of the recommended environmental flows. While the following design is suggested, a pre-monitoring investigation is needed to establish the exact sampling design. Four fixed transects, each approximately 100 m apart should be established across the river channel commencing immediately downstream of the dam. These should extend from bank to bank and include heavily impacted sites. Eight photo-quadrats (1m x 1m) should be photographed haphazardly along each transect on each bank. Photos should be taken from a set height eg. 1.5m. These photos should be visually assessed for the incidence of iron precipitate on an appropriate rating scale. Incidence by area curves should then be established and assessed through time.

In addition, the ongoing collection of monthly surface water quality samples for total and filterable iron and aluminium analysis should be carried out at SCA site E851 (see *General Water Quality Downstream of Dam,* above, for further details).

Statistical analysis

The percentage of the area covered by iron precipitate before and after the introduction of the recommended environmental flows should be carried out via the statistical analyses of the incidence-area curves.

Trend analysis (GLM) should be used to examine the relationship between water quality with respect to iron and aluminium concentrations through time (before and after the introduction of recommended environmental flows).

There is a high level of confidence that changes in water quality and the area affected by iron precipitate is due to the introduction of the recommended environmental flows via a multi-level offtake at Tallowa Dam.

Response time

It is anticipated that a significant reduction in the area covered by iron precipitate will occur over the course of a period of approximately two years after the introduction of environmental flows. Changes in the concentration of iron and aluminium in discharge waters, however, will occur immediately the discharge water is sourced from above the thermocline and discharged via a multi-level offtake.

Management interaction

Improvements in water quality due to the introduction of transparent and translucent environmental flows via a multi-level off-take can be assessed and used to inform the adaptive management process.

Encroachment of Riparian Vegetation

Issue

Riparian vegetation and terrestrial weeds encroaching on the river channel as a result of low flows.

> **Hypothesis**
>
> Increase in flow variability as a result of implementation of the recommended environmental flow regimes will reduce the encroachment of riparian vegetation and weeds into the river channel by more frequently providing medium to high flows and reducing the frequency of very low flows will help to scour vegetation from the channel and/or disrupt its growth.

Location

Reaches 3, 4, 9, 11 and 12.

Pre-monitoring Investigations

Determination of Reference and Impact Sites is required. Reference sites should be located in similar areas, geomorphically and climatically, with no anthropogenic impacts to the Impact sites. In addition, the channel dimensions should be comparable to that of Impact sites. Once suitable Reference and Impact sites have been determined, a preliminary study of the riparian vegetation should be undertaken.

Determine suitable Reference and Impact sites (see Site Location for recommendations for site location).

As it is thought that riparian vegetation would have occurred within the river channels under natural conditions, this study will determine whether there is actually a significant difference between the vegetation of Impact sites compared with Reference sites. If an Impact site is determined not to be significantly different to that of the Reference sites, then there is to be no further study/monitoring of this site as it will be considered similar to natural. If the Impact site is significantly different, then monitoring (as detailed below) is to be carried out.

Determination of the channel shape at sites to be monitored, such that the effect of changes in flow (flow velocity, magnitude, depth), and hence vegetation can be understood.

Variables

- Community composition of riparian vegetation;
- Species richness;
- Native and exotic species cover and abundance using the modified Braun-Blanquet cover abundance scale;
- Dominant species;
- Daily discharge or accurate estimates of flow, flow depth and flow velocity at all sampling sites; and
- General site information such as sediment/substrate type, surrounding land use, channel shape.

General approach

Monitoring the long term composition of riparian vegetation at a number of fixed locations (sites), such that any changes in composition and abundance can be correlated to changes in hydrology. Data will be collected annually in spring, before and after implementation of environmental flows at impact and reference sites. Data will be analysed such that changes in community composition detected.

Field sampling design

Potential reference sites include O'Hares and Punchbowl Creeks, however the final reference sites should be determined during the pre-monitoring investigations. It is expected that there will be at least two reference locations.

A total of eight sites have been chosen to monitor encroachment of riparian vegetation within the Woronora and upper Nepean River systems, with two locations per site (Table C14). The sites and locations have been chosen based on the current knowledge of riparian vegetation within these systems. The exact locality of sites will be determined as part of the pre-monitoring investigations.

Table C14: Sites recommended for the riparian vegetation monitoring program based on the current knowledge of riparian vegetation within the Upper Nepean and Woronora Systems.

Monitoring Localities	Reach No.
Woronora River at Eckersley's Crossing*	3
Woronora River at Heathcote Creek Junction*	4
Nepean River downstream of Avon Dam Weir – site 1	9
Nepean River downstream of Avon Dam Weir – site 2	9
Nepean River downstream of Pheasants Nest Weir – site 1	11
Nepean River downstream of Pheasants Nest Weir – site 2	11
Nepean River downstream of Broughtons Pass Weir – site 1	12
Nepean River downstream of Broughtons Pass Weir – site 1	12

* indicates previous data available

Sampling is to be undertaken annually in late spring/early summer, to maximise the detection of any cryptic species.

The riparian vegetation sampling will be undertaken at two locations within each site, with three floristic zones at each location:

1. Centre of river channel (including area of permanently flowing water)
2. Channel edge
3. Bank edge

In each zone, three permanent plots (30 m x 5 m) will be located, with their long axes parallel to the river channel. Within each permanent plot, nine 1 m x 1 m sub-plots will be systematically placed, with one in each corner, one in the middle of each side and one in the middle (Figure C1).

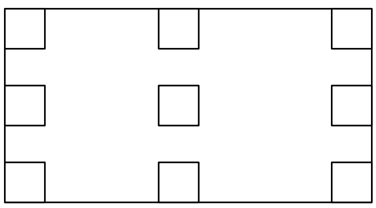

Figure C1: Configuration of sub-plots within permanent quadrat

All terrestrial and emergent plant species growing in or extending over each permanent plot are to be recorded and assigned a visually assessed cover/abundance value based on the modified Braun-Blanquet scale (Table C15).

Within each sub-plot all terrestrial and emergent plant species and their cover/abundance are to be visually estimated using the same modified Braun-Blanquet scale. This will allow a more quantitative measure of the presence of each species in each permanent plot (ie. a score out of nine) as well as providing a median cover/abundance value to be calculated.

Table C15: Modified Braun-Blanquet scale to be used to estimate the cover/abundance of riparian vegetation

Braun-Blanquet Scale	% cover
1	<5
2	5-25
3	25-50
4	50-75
5	75-100

Statistical analysis

Each site/zone is to be described by the total list of plants found recorded within it. This list is then to be used to create two data sets, the first allocating each species a percent frequency for the proportion of that site/zones quadrats in which it was recorded, and the second being the median cover value from the quadrats in which it was found.

The data for these reaches will then be analysed using a Multiple Before-After-Reference-Impact (MBARI) design for the number of species, percent frequency and median cover value in each zone, with data collected before and after the introduction of environmental flows (as summarised in Table C16). Potential changes in community composition will be analysed using distance-based general linear modelling based upon the MBARI experimental design.

Table C16: Components of variation for ANOVA

Source of Variation	Designation
Spatial variation	
Impact-Control Reference - CR	Fixed
Site within Impact- Reference Control – S(RC)	Fixed
Location within Site – L(S(RC))	Fixed
Temporal variation	
Before-After - B	Fixed
Times within Before-After – T(B)	Fixed
Impact-Control x Before-After - RCB	Fixed
Impact-Control x Times - RC T(B)	Fixed
Location x Before-After - L(S(RC))B	Fixed
Location x Time - L(S(RC))T(B)	Fixed

The inferential level of the analysis of this hypothesis is high due to the inclusion of reference sites in the experimental design.

Response time

As riparian vegetation is able to grow under a wide range of conditions, changes (trends) in their abundance and composition are usually detected over longer periods (years) rather than in the short term (months). An exceptions to this is when riparian vegetation is subject to high flows such that vegetation from within the river channel is scoured. Changes are likely to occur over a decadal time scale.

The monitoring program for aquatic macrophytes should start approximately three years prior to the environmental flow release.

Management interaction

If the statistical analyses show that there is a significant increase or no change in riparian vegetation and/or terrestrial weeds within the river channel at Impact sites and that the Impact sites are still significantly different to Reference sites then environmental flows can be deemed to be insufficient to reduce the encroachment of riparian vegetation and terrestrial weeds into the river channel.

If Impact sites are shown not to be significantly different to Reference sites, then monitoring should be discontinued at these sites as it will be deemed that environmental flows are sufficient to reduce the encroachment of riparian vegetation and terrestrial weeds into the river channel and that these sites are similar to natural. However, should the environmental flow be reduced, then monitoring should continue at these sites.

Iron-rich Groundwater Inflows Downstream of Avon and Cataract Dams

Issue

A combination of decreased surface flows and reduced scouring and flushing flows has lead to a substantial increase in the occurrence of iron precipitate and iron-oxidising bacteria downstream of Avon and Cataract Dams.

> **Hypothesis**
>
> The introduction of an environmental flow regime downstream of Avon and Cataract Dams, consisting of translucent and transparent flow releases made via a multi-level off-take, will lead to a significant decrease in the surface area covered by iron precipitate and associated iron-oxidising bacteria in the reaches immediately downstream of Avon dam and in the Cataract River downstream of Broughtons Pass weir.

Location

Reaches 9 and 12

Pre-monitoring Investigation

An investigation is required to establish the exact design of the photo-quadrat monitoring program including the identification of appropriate sites and the statistical analysis of data.

Variables

Photographs of the area affected by iron precipitate downstream of Avon Dam and Broughtons Pass weir before and after the introduction of environmental flows. Accurate flow gauging information is essential for this study.

General approach

Photo-transects to be monitored for a minimum of two years before and after the introduction of environmental flows.

Field sampling design

Photo transects undertaken for a minimum of two times per year for a minimum of two years before and after the introduction of the recommended environmental flows in the Avon and Cataract Rivers. While the following design is suggested, a pre-monitoring investigation is needed to establish the exact sampling design. Four fixed 25m transects, in each of two relevant locations (including heavily impacted sites) in each system should be established across the river channel. Four photo-quadrats (1m x 1m) should be photographed haphazardly along each transect. Photos should be taken from a set height eg. 1.5m. These photos should be visually assessed for the incidence of iron precipitate on an appropriate rating scale. Incidence by area curves should then be established and assessed through time.

Statistical analysis

The percentage of the area covered by iron precipitate before and after the introduction of environmental flows should be carried out via the statistical analyses of the incidence-area curves. There is a high level of confidence that a reduction in the area affected by iron precipitate and iron-oxidising bacteria is due to the release of transparent and translucent environmental flows.

Response time

Approximately two years after the introduction of environmental flows.

Management interaction

The role of transparent flows and translucent scouring and flushing flows in maintaining habitat quality will be assessed. This information can then be used in the adaptive management process in terms of assessing both transparent and translucent components of the flow regime and their efficacy in maintaining/improving habitat quality downstream of Avon and Cataract dams.

Ancillary Monitoring

General Water Quality Associated with the Forum's Effluent Reuse Strategy

Issue

Point and diffuse sources of pollution have resulted in poor water quality in the river system resulting in algal blooms and the excessive growth of exotic macrophytes. In the estuary, the longitudinal excursion of the salinity profile has been impacted by a combination of regulated flows and the discharge of sewage effluent from South Creek.

Hypothesis

The implementation of the Forum's effluent reuse strategy will reduce point source nutrient inputs during low flows and combined with an environmental flow regime will reduce concentrations of nutrients in the water column of the mainstream Hawkesbury River and will make conditions less conducive to the formation of cyanobacterial blooms.

Location

Reaches 23, 24 and 25

Variables

Refer to current SCA routine monitoring at site N35. Water quality variables include:

- Turbidity
- pH
- Temperature
- Conductivity/salinity
- Dissolved Oxygen
- Biochemical Oxygen Demand (5days)
- Dissolved Organic Carbon
- Total Organic Carbon
- Suspended Solids
- Filterable Phosphorus
- Total Phosphorus
- Ammoniacal Nitrogen
- Oxidised Nitrogen
- Total Kjeldahl Nitrogen
- Total Nitrogen
- Reactive Silica
- Chlorophyll *a*
- Phaeophytin
- Major ions
- Algal Identification
- Algal Counts

General approach

Routine water quality samples will be collected at fortnightly intervals during October to March each year and at monthly intervals during the remainder of the year. This should be undertaken for a minimum period of two years before and two years after the introduction of environmental flows and the implementation of the Forum's effluent reuse strategy in the South Creek catchment.

Field sampling design

Single surface water quality samples plus field physico-chemical measurements should be taken at each site using standard field QA/QC procedures. Samples for algal identification and counts and chlorophyll-*a* should be collected using an integrated depth sampler capable of sampling to a depth of 3m. Five random replicate integrated depth samples should be taken at each site to provide a composite algal sample. From the composite sample a single sample for each of algal counts and identification and chlorophyll-*a* should be drawn. Sampling sites should include Cattai National Park (formerly Cattai State Recreation Area), Wilberforce Reach, Sackville Ferry, Lower Portland and Wisemans Ferry.

Statistical analysis

Trend or intervention analysis should be used to determine water quality trends through time for sites at which sufficient temporal data is available. There is a high level of confidence that changes in water quality and cyanobacterial populations are due to the implementation of the effluent management strategy combined with translucent and transparent environmental flows.

The relationship between salinity structure of the estuary and the occurrence will also be examined.

Response time

Two years after the introduction of environmental flows and the Forum's effluent reuse strategy.

Management interaction

The resultant data will indicate the combined effects of the Forum's effluent reuse strategy and environmental flows on water quality. This information can then be used to determine the need for further management intervention with respect to effluent reuse, stormwater management and the occurrence of algal blooms.

Water Quality in Deep Weir Pools Associated With the Forum's Effluent Reuse Strategy and Weir Management

Issue

A combination of altered/regulated flows and irrigation extractions have the potential to cause stratification in deep weir pools and, in addition, the river may cease to flow immediately downstream.

Hypothesis

The introduction of the recommended environmental flow regime downstream of Nepean, Cordeaux, Cataract and Avon Dams combined with the Forum's effluent reuse strategy and weir management, will lead to the decreased frequency of thermal (and oxygen) stratification and algal blooms in deep weir pools and less frequent hostile water quality at depth, particularly during periods of low flow.

Location

Reaches: 14, 15 and 17

Variables

- Time and date (from thermistor data)
- Temperature (via thermistor chain – possibly 2 required)
- Depth (from thermistor chain)
- Dissolved Oxygen (profiled through depth if permanent deployment not feasible)
- Discharge/Flow (accurate and daily)
- Rainfall as explanatory variable
- Weir pool dimensions including length, width & depth
- Weir pool bathymetry
  - Turbidity
  - pH
  - Electrical conductivity
  - Dissolved oxygen
  - Suspended Solids
  - Filterable Phosphorus
  - Total Phosphorus
  - Ammoniacal Nitrogen
  - Oxidised Nitrogen
  - Total Kjeldahl Nitrogen
  - Total Nitrogen
  - Reactive Silica
  - Chlorophyll a
  - Phaeophytin
  - Algal counts
  - Algal identification

General approach

Impacts of environmental flows on the frequency, magnitude and duration of thermal stratification in Sharpes and Maldon weir pools will be determined via field observations. The relationship between flow and destratification will be examined and the occurrence of the flow threshold before and after the introduction of environmental flows will be assessed. The overall effect of environmental flows, effluent and weirs management on water quality within these weir pools will be examined.

Field sampling design

Sharpes Weir (SCA N75) and Maldon Weir (SCA N92) pools should be monitored for a minimum 2 years before and after the introduction of environmental flows.

A thermistor chain should be deployed in each pool from October to March each year. Accurate flow gauging is essential to interpret the data. Thermistors should be maintained and data downloaded at regular intervals. During field visits, profiling of the water column for dissolved oxygen, pH, salinity and turbidity should be carried out.

Single surface water quality samples plus field physico-chemical measurements should be taken at each site each month using standard field QA/QC procedures. Samples for algal identification and counts and chlorophyll-*a* should be collected using an integrated depth sampler capable of sampling to a depth of 3m. Five random replicate integrated depth samples should be taken to provide a composite sample. From the composite sample a single sample for each of algal counts and identification and chlorophyll-*a* should be drawn.

Statistical analysis

Frequency (how often), duration (how long) and magnitude (sum of the daily differences between surface and bottom temperatures) of stratification events by location. There is a high level of confidence that a change in the frequency, magnitude and duration of thermal stratification is due to environmental flows and the weirs management strategy. There is also a high level of confidence that a change in water quality is due to a combination of environmental flows and the implementation of the effluent management strategy.

Trend analysis (GLM) of water quality variables.

Response time

Two years after the introduction of environmental flows, the integrated effluent and weirs management strategies.

Management interaction

The resultant data will indicate the combined effects of integrated effluent management, weirs management and environmental flows on water quality. This information can then be used for further management intervention with respect to water quality in these reaches of the river.

Soil Sustainability Associated with the Forum's Effluent Reuse Strategy

Issue

Productivity of crops and pastures could be impacted through changes in soil salinity levels or other soil qualities that impact on plant productivity.

Hypothesis

Changing from river water to effluent irrigation will not lead to an increase in soil salinity and sodicity which could lead directly or indirectly to a lowering of plant productivity. Saline soils will not lower plant productivity particularly where sensitive horticultural plants are grown. Sodicity will not degrade soil structure in clay soils leading to reduced plant growth. Poor soil structure could also impact on machinery access, result in pugging of grazing pastures, animal health problems and plant disease problems.

Location

Reaches 15, 17, 23, 24 and 25

Pre-monitoring investigations

Pre scheme and post scheme monitoring is essential to assess the sustainability of the scheme, provide user confidence and to provide a feedback mechanism to allow improvements should aspects of the scheme cause concern.

Establishment of any effluent irrigation scheme would require identification of participating farms. During this process it will be possible to gain a range of data about farms that express an intention to switch from river to effluent irrigation. Such data would include (but may not be limited to) size of farm, range of land use activities, rate of production for each activity, current irrigation strategy. It may be possible to also obtain more sensitive financial data in an appropriate manner.

Soil types, crop types and crop management systems over the reclaimed water irrigation area should be collated.

Variables

- Soil landscape
- Soil type
- Crop type
- Crop management system (fertiliser use, number of crops)
- Irrigation management system - daily usage
- Potential evapotranspiration as explanatory variable
- Soil properties (soil moisture, pH, salinity, sodicity, and nutrients) with depth
- Effluent quality including pathogens, BOD, pH, heavy metals, pesticides and nutrients
- Daily rainfall as explanatory variable.

General approach

The proposed methodology for monitoring soil sustainability is to select three reclaimed water irrigated and three river water irrigated controls for each major land use included in the scheme. The farms would be selected from a review of properties participating in the scheme as well as properties that have decided not to be included in the scheme (for the non-effluent irrigation controls). The farms would be paired based on land use type, geographic proximity, predominant soil types and property size.

Intensive sampling and observations would occur on the participating farms. It is envisaged that the monitoring program would start approximately 12 months prior to scheme commencement in order to obtain baseline data. A person responsible for collecting and analyzing all the monitoring data is needed.

Details of farm management will need to be kept so that the influence of management practices on results can be clearly identified

Field sampling design

Soil properties such as pH salinity and sodicity will be monitored at regular intervals and at regular depths. The frequency of soil sampling sites will depend on the land use and management system, but at least three soil profiles should be sampled within one land management unit with a maximum of five soil sample profiles per hectare. Salinity should be monitored at monthly intervals to show how salinity is impacted by rainfall variability. pH and sodicity can be monitored at yearly intervals. Depths should be 0-10 cm, 10-20 cm and 20-40 cm.

Daily rainfall data, effluent usage, application rates of fertiliser, cultivation and harvesting events will need to be monitored.

Statistical analysis

The impacts of effluent irrigation on soil salinity and sodicity will be assessed. The analysis will need to show how other factors such as rainfall and crop management influence these. The impact of soil salinity and sodicity on plant productivity will also need to be established.

Response time

Within two years of the introduction of effluent salinity and sodicity impacts and trends should become apparent.

Management interaction

The data collected will be used to monitor soil sustainability and to inform farm management practices such as effluent application rates.

Inter-catchment Transfer of Fish via Glenquarry Cut

Issue

Continued inter-catchment transfers of water (eg. Shoalhaven to Wingecarribee, and Wingecarribee to Nepean) will increase the likelihood that aquatic and riparian biota will be translocated between river basins.

Hypothesis

The installation of an exclusion device on the Glenquarry Cut Canal will halt the establishment of alien fish species, and the Shoalhaven River (SR) Macquarie perch, in the river systems upstream of the Nepean Dam, thereby maintaining the viability of the Nepean River (NR) Macquarie perch populations, and other native fish populations, therein.

Location

Reach 7

Pre-monitoring investigations

To obtain prerequisite information for the monitoring program, the following should be undertaken:

1. Before installing the exclusion device, and given that fish surveying has not been undertaken in the area for almost ten years, it would be prudent to determine whether or not alien fish species, or the Shoalhaven River Macquarie perch, have recently arrived in the Nepean Dam and the main trunk streams entering the dam (ie. the Nepean River and the Burke River). Similarly, it would be prudent to determine the viability of populations of the Nepean River (NR) Macquarie perch in the area. If aliens are present, and/or the NR Macquarie perch populations are not viable, then there is little point in installing the device. To provide confidence in the findings, four seasonal samples should be taken over one year at 9 sites: 3 in the dam, 3 in the Nepean River and 3 in the Burke River. To allow data to be compared with the monitoring data, the sampling methods should follow that to be used in the ongoing monitoring (which should ideally follow the environmental-flow fish-community monitoring protocols to be used in Reaches 8, 10 & 11, and Reaches 9, 12 & 13).
2. Pilot/reconnaissance surveys for ongoing monitoring (fish-community investigations: method selection, determining variability and subsequent power analysis to determine replication levels).

Variables

The variables are fish community/population descriptors with emphasis on alien fish species and the NR and SR Macquarie perch.

- *Community-level variables*: the proportional abundance of alien species and the Macquarie perch (MP).
- *Population-level variables*: abundance of MP, abundance of young-of-year MP, size-structure of MP; abundance of alien species.

General approach

Reconnaissance/pilot surveys are initially required to determine:

- accessibility constraints and logistics
- habitat availability at sites and the identification of meso- and/or microhabitats to be selected for standardised sampling
- sample method selection
- identification of key environmental covariates
- selection of reference locations and consideration of their independence

- initial estimation of within-site, between-site and between-location variability so that a suitable replication level can be determined through power analyses

Field sampling design

As much as possible sampling methods should follow the environmental-flow fish-community monitoring protocols to be used in Reaches 8, 10 & 11, and Reaches 9, 12 & 13. It is likely that these protocols will primarily rely on the use of night-underwater spotlighting (from a light inflatable dinghy or canoe) as a means of surveying fish communities. However, it is recognised that some additional capture methods (eg. bait traps, netting and electrofishing) may be necessary when investigating the occurrence of alien fish species.

Without estimates of variance, a prerequisite for power analyses, it is difficult to know the level of replication needed in time and space. Routine sampling upstream of the Nepean Dam could involve twice-yearly sampling (spring and autumn) at the following three locations:

- the Nepean River,
- the Burke River, and
- within the Nepean Dam.

Possibly three sites would be required in each location and 20 samples would be taken in each site. Because alien taxa, or the SR Macquarie perch, may appear after inter-catchment transfers of water, sampling would need to intensify about the transfer events as follows: one sample immediately before a transfer, then samples 1 week, 1 month, 6 months and 1 year after the transfer.

Focus on alien species and SR Macquarie perch: No sophisticated design or statistical analyses are required for this component of the investigation given that just an influx of alien taxa or the SR Macquarie perch, is to be detected. Accordingly, no reference locations are required for comparison. The routine monitoring will provide information on the background condition and reveal if alien taxa, or the SR Macquarie perch, are introduced via means other than inter-catchment transfers.

Focus on NR Macquarie perch: A reasonably sophisticated design is required for this component of the investigation given that population characteristics may vary in relation to natural processes. Accordingly, reference locations are required to judge the ecological significance of changes through time. It is recommended that the reference sites to be used in the environmental-flow fish-community monitoring in Reaches 8, 10 & 11, and Reaches 9, 12 & 13, be also used in the present investigation.

An unbalanced MBARI(P) design (an extension of the 'MBACI[P]' design referred to by Downes *et al.* [2002]; reference 'R' replaces control 'C') would be possible for this investigation given that one impacted and many reference locations are potentially available (*Impacted*: Nepean and Burke Rivers combined; *Reference*: possibly Wongawilli, Wollandoola, Lizard, Donalds Castle Creeks).

Statistical analysis

For the univariate data (ie. c*ommunity-level variables*: the proportional abundance of Macquarie perch; *population-level variables*: abundance of MP, abundance of young-of-year MP) a two-factor[1] ANOVA should be used[2]. For the multivariate data (ie. p*opulation-level variables*: size-structure of MP) distance-based linear modelling (Anderson 2001) should be used.

Response time

It is possible that alien species could be detected in less than one year if they are introduced during inter-catchment water transfers. Deleterious impacts on Macquarie perch populations could possibly detected within 1 to 5 years after alien species have obtained access to the rivers upstream of the Nepean Dam.

Management interaction

[1] For interpretation of differences, two extra factors (making four factors in total) could be examined: times and sites within locations.
[2] A minimum effect size would be 30% of the reference-location means.

It is proposed that the following findings would trigger adaptive-management actions:

- there remains a **high-priority** need to maintain the exclusion device if alien species, or the SN Macquarie perch, are not detected upstream of the dam and the NR Macquarie perch populations remain viable.
- there remains a **medium-priority** need to maintain the device if alien species, or the SR Macquarie perch, are detected upstream of the dam and the NR Macquarie perch populations remain viable.
- there remains a **low-priority** need to maintain the device if alien species, or the SR Macquarie perch, are detected upstream of the dam and the NR Macquarie perch populations become unviable.

Lack of Connectivity – Diversion and Gauging Weirs

Issue

Lack of connectivity due to the absence of fishways on diversion weirs and gauging weirs.

Hypothesis

The installation of fishways on the upper-Nepean weirs will result in increased connectivity for mobile fauna along the river. That is, the fishways to be installed will be effective.

Location

Reaches 8, 9, 10, 11, 12 and 13

Pre-monitoring investigations

To obtain prerequisite information for the monitoring program the following should be undertaken:

- Pilot/reconnaissance surveys for fish-movement-flux monitoring (includes logistics, the selection of representative/key fishways for monitoring, method comparisons, variance estimation and subsequently power analysis to determine replication levels.
- Estimates of the fish-movement-upstream-flux flux are made (by either direct or indirect methods) downstream and upstream of the selected fishways. These estimates are then used to estimate success rates of upstream passage (success = effective). Because fish with different swimming abilities may have different success rates, there should be a clear partitioning between strong-swimming species and weak-swimming species.
- Inspection of the installed fishways in order to determine appropriate multi-dimensional maintenance scores and protocols.

Variables

- fish-movement-flux.
- p*opulation-level fluxes as follows*: upstream flux of selected weak-swimming species, size-structure of flux of selected weak-swimming species, upstream flux of selected strong-swimming species, size-structure of flux of selected strong-swimming species. It is important that the Macquarie perch (likely to be a strong-swimming species) is one of the targeted species.
- surveillance of fishway maintenance.
- multi-dimensional maintenance scores recorded during monthly 'no warning' inspections of the fishways.
- daily-average-flow data at the selected fishways (for use in the interpretative phase).

General approach

- **Fish-movement flux component**

  Reconnaissance/pilot surveys are initially required to determine which fishways should be monitored. It is recommended that at least two are chosen and the selection criteria should include the following factors:

  - *importance*, as judged by the extent of passage severance (ie. length of river isolated), particularly in relation to the distribution of habitats critical to the Macquarie perch
  - *representativeness*, ie. whether an 'effective' finding at a particular fishway would mean that all other fishways would be classed as effective (eg. if a long fishway was considered to be effective, then it may be assumed that short fishways would also be effective)
  - accessibility constraints

Given that the fishways have not been designed as yet, it is strongly recommended that the selected fishways be constructed to include upstream and downstream trapping chambers. These chambers, when strategically sampled with directional sampling gear, would provide a very efficient means of obtaining estimates of the upstream (and downstream) movement flux of fish.

Once such fishways are constructed, it will be possible to determine the following as a part of pilot/reconnaissance surveys:

- identification of key environmental covariates
- initial estimation of movement-flux variability over time, within particular flow ranges, so that a suitable replication level can be determined through power analyses

If fishways without trapping chambers are constructed, then pilot/reconnaissance surveys would additionally need to determine:

- accessibility constraints and logistics (upstream and downstream of the selected fishways)
- habitat availability upstream and downstream of the fishway (eg. the location of steep water-velocity gradients plus the positioning of riffles)
- sample method selection

- **Fishway maintenance component**

  Once the fishways are installed the details of the scoring system will be determined. The inspections are on a 'no warning' basis in order to ensure that the general operational condition is effectively captured by the scoring system. There may be a case that inspections should intensify during the spring to early-summer period when upstream fish movement activity is at a peak for the greatest number of species. All fishways should be inspected, rather than just representative/key fishways.

Field sampling design

- **Fish-movement flux component**

  The effectiveness of the fishway will be judged by comparing upstream flux rates to downstream flux rates. This should be done on a paired-day basis (sampling below the fishway commences first). Each day should be partitioned in relation to time of day as follows: day, dusk, night and dawn. Comparisons should be done on a per-species basis covering a range of species' swimming abilities. Observations should be focussed on the spring to early-summer period when upstream fish movement activity is at a peak for a large number of species.

  Without estimates of variance, a prerequisite for power analyses, it is difficult to know the level of replication needed in time to adequately represent passage-success rates for a particular flow range. At this stage, and as based on the practicality of a 5-day working week, it is recommended that two paired days (4 sampling days)[1] be the basic sampling unit per flow range.

  Observations should be made over a range of flows so that it can be determined if effectiveness varies in relation to flow. It is recommended that the above sampling units be undertaken at the twenty 5%ile flow ranges that cover the full range of flow conditions (ie. from the 100-95%ile range to the 5-0%ile range). It is recognised that there may be problems sampling the movement fluxes during the higher flow ranges.

[1] Four paired days (and thus a total of eight sampling days) would normally be required in the case of the upper Nepean fishways because downstream sampling could interfere with upstream sampling (thus sampling can not occur simultaneously), a consequence of sampling being undertaken within the space-restricted fishway. To avoid the additional high costs associated with this number of sampling days, it is recommended that instead two paired days (4 sampling days) be used, but within these days observations are replicated per time of day so to enable statistical comparisons between sets of days.

Statistical analysis

- **Fish-movement flux component**

  For the univariate data (i.e *population-level variables*: flux of a range of species) a paired t-test should be used to test whether or not the upstream movement is => 95% of the downstream movement flux (sample size = 4). For the multivariate data (ie. *population-level variables*: size-structure of a range of species) distance-based linear modelling (Anderson 2001) should be used to investigate whether particular size classes of fish are not obtaining access to the top of the fishway.

- **Fishway maintenance component**

  For fishway maintenance surveillance only yearly summary statistics need to be calculated.

Response time

- **Fish-movement flux component**

  The determination of fishway effectiveness is dependent on the availability of flow ranges for examination. If the complete range of flows were available in a week-by-week sequence, then forty weeks could be required for the fieldwork (assuming that two teams are available to work on the two selected fishways). However, flows are rarely available in such a sequence and this timing ignores the time needed for data analysis and interpretation.

  It is crudely estimated that a period of 4-5 years would be required to assess the fishways across a full range of flows. However, an assessment of one flow range may take only one-two months. If it is shown that the fishways were not effective for that particular flow, then a case can be made very early on that the fishways should be modified.

- **Fishway maintenance component**

  Feedback on fishway maintenance could be as early as one month. Otherwise yearly when findings are summarised in a standard reporting format.

Management interaction

- **Fish-movement flux component**

  A finding that the fishways were *effective* for a particular flow range would arise from the following result:

  - more than 95% of all fish species and individuals attempting to negotiate the barrier actually succeeds in doing so (this follows the first criteria for an effective fishway given by Mallen-Cooper [1992])

  If after the examination of twenty flow ranges, the fishways were classed as *effective* for >=95% of the ranges (>=19 out of 20), then the fishways would be considered to effective in an overall sense (this follows the second criteria for an effective fishway given by Mallen-Cooper [1992], ie. "…..and operates in at least 95% of the prevailing flow conditions"). Accordingly, no modifications to the fishways would be considered necessary.

  However, if two of the twenty flow ranges examined resulted in the fishways being classed as *ineffective* (ie. 10% of the flow ranges ineffective, or at most 90% effective), then modifications to the fishways would be considered necessary. This may become apparent as early as after the examination of the second flow range, or as late as after the examination of the twentieth flow range. If such a finding occurs early within the investigation it would be prudent to replicate the examination of the flow range so to increase surety. Other confounding factors would also need to be checked, eg. level of maintenance, problems in getting a reliable flux estimate in the river downstream of the weir.

- **Fishway maintenance component**

  When poor maintenance is reported management responds by ordering more effective maintenance.

Groundwater Sustainability associated with the Forum's Effluent Reuse Strategy

Issue

Contaminants in effluent could leach into local groundwater tables thereby impacting directly on groundwater and indirectly on the river through shallow connections between ground and surface waters.

Hypothesis

The use of effluent for irrigated agriculture will not lead changes in groundwater quality.

Location

Reaches 15, 17, 23, 24 and 25

Pre-monitoring investigations

Collation of information on soil types, crop types and crop management systems over the effluent irrigation area as described above for *Soil sustainability associated with the Forum's Effluent Reuse Strategy*.

Existing groundwater bores will be assessed for their utility in this monitoring program. New groundwater bores will be established if necessary. These will be located in areas affected by irrigation and in areas that are not. Groundwater bores will be established in areas of high risk where the groundwater is closest to the soil surface or where there are obvious interconnections between groundwater and river.

Groundwater quality should be assessed on a quarterly basis for one year prior to commencement.

Variables

- Soil landscape
- Soil type
- Crop type
- Crop management system (fertiliser use, number of crops)
- Irrigation management system - daily usage
- Potential evapotranspiration as explanatory variable
- Soil properties (soil moisture, pH, salinity, sodicity, and nutrients) with depth
- Daily rainfall as explanatory variable.
- Existing groundwater height, flow patterns and quality eg nutrients, heavy metals and pesticides
- Effluent quality including pathogens, BOD, pH, heavy metals, pesticides and nutrients

General approach

The monitoring of groundwater quality will be undertaken at 6 monthly intervals following the pre-monitoring investigation. Standard groundwater monitoring protocols should be followed.

Field sampling design

Groundwater height, flow pattern and quality will assessed at putatively impacted and non-impacted locations.

Statistical analysis

Changes in soil groundwater height, flow patterns and quality will be assessed. These analyses will include other factors such as rainfall and crop type.

Response time

Within two years of the introduction of effluent salinity and sodicity impacts and trends should become apparent in areas with shallow groundwater tables.

Management interaction

Where irrigation is shown to be impacting on groundwater, management responses may include lowering the irrigation and fertiliser rates.

Effectiveness of Tallowa Dam Fish Lift

Issue

Lack of connectivity due to the absence of a fishway at Tallowa Dam.

Hypothesis

The installation of a fishway at Tallowa Dam will result in increased connectivity for mobile fauna along the river. That is, the fishway to be installed will be effective.

Location

Reach 1

Pre-monitoring investigations

To obtain prerequisite information for the monitoring program the following should be undertaken:

- Pilot/reconnaissance surveys for fish-movement-flux monitoring (includes logistics, method comparisons, variance estimation and subsequently power analysis to determine replication levels)
- An examination of the adequacy of NSW Fisheries' existing baseline data, for assessing the effectiveness of the proposed Tallowa Dam fish lift, revealed that there are major problems associated with design, appropriateness of focus, power and cost/delay consequences (see Table C17). To determine whether it is worthwhile to pursue monitoring in the form which created the baseline data (termed 'baseline-utilisation monitoring'), it is necessary to undertake power analyses to identify the necessary number of replicates needed to detect effect sizes of 30% and 10% change. From this the need for more 'before-fishway-condition' replicates will be ascertained. Once this is known cost/delay consequences can be determined.
- Inspection of the installed fish-lift in order to determine appropriate multi-dimensional maintenance scores and protocols

Estimates of the flux are made (by either direct or indirect methods) downstream and upstream of the fish lift. These estimates are then used to estimate success rates of upstream passage (success = effective). Because fish with different swimming abilities may have different success rates, there should be a clear partitioning between strong-swimming species and weak-swimming species.

Variables

- generally fish-movement-fluxes
- *population-level fluxes as follows*: upstream flux of selected weak-swimming species, size-structure of flux of selected weak-swimming species, upstream flux of selected strong-swimming species, size-structure of flux of selected strong-swimming species.
- baseline-utilisation monitoring - this approach ensures that previous efforts to gather baseline data are not entirely wasted. No detail is given here on the monitoring as it is prudent to await a decision (arising from the pre-monitoring investigations) on whether it is worthwhile pursuing this monitoring component.
- surveillance of fish lift maintenance:
- multi-dimensional maintenance scores recorded during monthly 'no warning' inspections of the fish lift.

TABLE C17: An examination of the adequacy of existing baseline data for assessing the effectiveness of the proposed Tallowa Dam fish lift.

In order to i) characterise the impact of Tallowa Dam on fish communities, and ii) develop a baseline data-set useful in assessing the effectiveness of a possible fishway on the dam, Gehrke *et al.* (2001) collected four fish samples over two years (autumn and spring in each year; assumed to be independent replicates) at twelve sites within the Shoalhaven River catchment. These sites can be considered to be distributed within the following two 'treatment' locations:

- a location where emigration (ie. as mediated by upstream movements) from the estuary and the lower river is not blocked by the dam, ie. a 'reference' location: Gehrke *et al.* sampled 3 sites in such a location, all of which were downstream of the dam, and
- a location where emigration from the estuary and the lower river is blocked by the dam, ie. an '*impacted*' location: Gehrke *et al.* sampled 9 sites within such a location, all of which were upstream of the dam (4 within Lake Yarrunga, and 5 upstream of the lake)

As fish can readily move between sites (indeed the effects of fish movements are of key interest) it follows that the sites within each treatment can not be considered to be independent. Therefore the sites cannot be considered to be replicate locations, but rather, subsamples which should be combined during analysis to provide a better estimate of the mean. Accordingly, a BARIP design (an extension of the 'BACIP' design referred to by Downes *et al.* [2002]; reference 'R' replaces control 'C') is the only impact-assessment design possible if the baseline data-set of Gehrke *et al.* is to be utilised (ie. only one impacted and one reference location are potentially available). However, there is some reservation that even this design is possible given that, after the installation of fish lift, the treatments will not be independent as fish will be moving from the 'reference' to the 'impacted' (as a result abundances will fall in the 'reference' and rise in the 'impacted').

With the combining of site data within treatments, the existing 'before-fishway' condition data has only 4 replicate observations (2 season x 2 years). It is highly likely that this will considerably restrict the power of statistical analyses which compare before-after and upstream-downstream conditions. This would particularly be the case if the same effort was invested (ie. n = 4) to characterise the 'after-fishway' condition. Power analyses should be undertaken to determine the necessary number of replicates to detect effect sizes of 30% and 10% change. It may be found that more 'before-fishway' condition replicates are required and this would delay installation of the fish lift. There is a cost disadvantage involved as well. This is additionally pertinent if a considerable number (ie. > 4) of 'after-fishway' condition replicates are also required.

Accordingly, if the baseline data-set is to be utilised, there appears to be major problems associated with design, power and cost/delay consequences. A possibly more significant problem arises from the poor focus ('indirectness') of the observations made within the baseline study. Quoting Mallen-Cooper (1992), Gehrke *et al.* (2001) highlighted the following:

"Effective fishways are defined as being able to pass at least 95% of all fish species and individuals attempting to negotiate the barrier, and operate in at least 95% of the prevailing flow conditions"

Following this definition, it is clear that the most direct and efficient way of assessing fishway effectiveness is the comparison of estimates of:

- the number of individuals/species approaching the fishway (ie. measurements of the upstream-movement flux), and
- the number of individuals/species successfully negotiating the fishway (ie. measurements of the movement flux through the fishway)

The observations made by Gerhke *et al*. (2001), which are essentially measures of abundance of fish at sites remote from the dam, clearly provide quite a 'blunt' tool in assessing fishway effectiveness[1]. Even though the abundances at the sites may eventually reflect the effectiveness of the fish lift, there are likely to be considerable time lags and a large number of site-specific confounding factors.

[1] It is recognised that Gerhke *et al*. (2001) primarily aimed to characterise the impact of Tallowa Dam on fish communities so to determine the level of need for a fishway. In doing this it was not necessary to characterise the movement flux approaching the dam – it was stunningly obvious that virtually all the movement flux was stalled at the base of the dam! However, for the development of an assessment strategy, it would have been important to investigate the movement-flux dynamics, particularly in relation to changes in flows.

General approach

For the assessment of fish-lift effectiveness, reconnaissance/pilot surveys are initially required to determine:

- accessibility constraints and logistics (down river and within the fish-lift portage container)
- habitat availability down river (the location of steep water-velocity gradients plus the positioning of riffles)
- sample method selection
- identification of key environmental covariates
- initial estimation of movement-flux variability over time, within particular flow ranges, so that a suitable replication level can be determined through power analyses

Once the fish lift is installed the details of the fish-lift maintenance scoring system will be determined. The inspections are on a ‘no warning’ basis in order to ensure that the general operational condition is effectively captured by the scoring system. There may be a case that inspections should intensify during the spring to early-summer period when upstream fish movement activity is at a peak for a large number of species.

Field sampling design re fish-lift effectiveness

The effectiveness of the fish lift will be judged by comparing upstream flux rates (ie. as measured at the top of the dam within the fish-lift portage container) to downstream flux rates (ie. as measured in the river immediately downstream of the dam). This should be done on a paired-day basis (sampling below the dam commences first). Comparisons should be done on a per-species basis covering a range of species’ swimming abilities (weak swimmers such as empire gudgeons to strong swimmers such as Australian bass).

Both weak- and strong-swimming species should be sampled at the upstream end from within the fish-lift portage container. At the downstream end, ie. within the river immediately downstream of the dam, but upstream of the first riffle, the weak-swimming species should be sample by directional sampling equipment such as fyke nets set within steep velocity gradients in the littoral zone. The strong-swimming species could be collected by non-directional sampling gear (eg. gillnets or electrofisher) below the dam, then tagged and released. Their proportional occurrence within the fish-lift portage container would then be of key interest (eg. if 90% of tagged fish occurred in the portage container then 90% effectiveness/success would be indicated).

Observations should be made over a range of flows so that it can be determined if effectiveness varies in relation to flow. It may be necessary to superimpose on this a range of temperature (and possibly water quality) differentials between dam-spill waters and valve-discharge waters. Observations should be focussed on the spring to early-summer period when upstream fish movement activity is at a peak for a large number of species.

Without estimates of variance, a prerequisite for power analyses, it is difficult to know the level of replication needed in time to adequately represent passage-success rates for a particular flow range. At this stage, and as based on the practicality of a 5-day working week, it is recommended that four paired days[1] be the basic sampling unit per flow range. Each day should be partitioned in relation to time of day as follows: day, dusk, night and dawn.

It is recommended that such sampling units be undertaken at the twenty 5%ile flow ranges that cover the full range of flow conditions (ie. from the 100-95%ile range to the 5-0%ile range). It is recognised that there may be problems sampling the downstream movement flux during the higher flow ranges. Note that some flow ranges may need to be repeated in order to investigate the impact of water temperature or water quality differentials.

[1] A total of only four sampling days are required because downstream sampling is unlikely to interfere with upstream sampling (thus sampling can occur simultaneously), a result of the buffering effect introduced by the presence of a large pool immediately downstream of the fish lift.

Statistical analysis

For the univariate data (ie. *population-level variables*: flux of a range of species) a paired t-test should be used to test whether or not the upstream movement flux is => 95% of the downstream movement flux (sample size = 4). For the multivariate data (ie. p*opulation-level variables*: size-structure of a range of species) distance-based linear modelling (Anderson 2001) should be used to investigate whether particular size classes of fish are not obtaining access to the fish-lift portage container.

For fish lift maintenance surveillance only yearly summary statistics need to be calculated.

Response time

The determination of fish-lift effectiveness is dependent on the availability of flow ranges for examination. If the complete range of flows were available in a week-by-week sequence, then twenty weeks could be required for the fieldwork. However, flows are rarely available in such a sequence and this timing ignores the time needed for data analysis and interpretation.

It is crudely estimated that a period of 2-3 years would be required to assess the fish lift across a full range of flows. However, an assessment of one flow range may take only one month. If it is shown that the fish lift was not effective for that particular flow, then a case can be made very early on that the fish lift should be modified.

Feedback on fish lift maintenance could be as early as one month. Otherwise, yearly, when findings are summarised in a standard reporting format.

Management interaction

A finding that the fish lift was *effective* for a particular flow range would arise from the following result:

- more than 95% of all fish species and individuals attempting to negotiate the barrier actually succeeds in doing so (this follows the first criteria for an effective fishway given by Mallen-Cooper [1992])

If after the examination of twenty flow ranges, the fish lift was classed as *effective* for >=95% of the ranges (>=19 out of 20), then the fish lift would be considered to effective in an overall sense (this follows the second criteria for an effective fishway given by Mallen-Cooper [1992], ie. "…..and operates in at least 95% of the prevailing flow conditions"). Accordingly, no modifications to the fish lift would be considered necessary.

However, if two of the twenty flow ranges examined resulted in the fish lift being classed as *in**effective* (ie. 10% of the flow ranges ineffective, or at most 90% effective), then modifications to the fish lift would be considered necessary. This may become apparent as early as after the examination of the second flow range, or as late as after the examination of the twentieth flow range. If such a finding occurs early within the investigation it would be prudent to replicate the examination of the flow range so to increase surety. Other confounding factors would also need to be checked, eg. level of maintenance, water quality differentials between spill water and valve-release water, problems in getting a reliable flux estimate in the river downstream of the dam.

When poor maintenance is reported management responds by ordering more effective maintenance.

Consideration management response to 'baseline-utilisation monitoring' depends on the outcomes of power analyses (see Pre-monitoring investigations above).

Channel Degradation in the Mixed-Load Shale Reach Downstream of Penrith Weir

Issue

Channel degradation between Penrith Weir and the Grose River has resulted from the past management of the river.

Location

Reach 22

Pre-monitoring investigations

There is a need to determine contemporary channel dimensions:

- to establish what changes have occurred;
- to assess the impacts of such changes on hydraulics and flow behaviour;
- to assess how such changes might influence environmental flows;
- to assess how contingent flows might behave, particularly in the removal of exotic plant life; and
- to determine the impacts of the magnitude and frequency of spills on surcharging.

Existing data on channel surveys should be brought together to produce a database and to show degradation through time. Information on extractions from the channel, adjacent chutes and floodplains should be gathered to work out the volume of extracted material. This should be compared with channel losses to establish additional erosion or accretion.

Variables

- Channel widths at low flows and bankfull discharge
- Channel depths, including maximum, at low and bankfull levels
- Cross-section areas at both levels
- Channel capacities at bankfull
- Velocities, mean and maximum for environmental, contingent and flood flows
- Stream power, derived

All of these at sites which “pick out” pools and riffles

General approach

This is a reach where there have been some previous surveys but there has been little collation of material. This could be done from earlier surveys (partial) and from an air photographic base, where photographs taken at different times can be used to catalogue change through time.

To determine the influences of environmental flows through these greatly increase cross-section areas undertake surveys of 12 estimated cross sections and 14 enlarged cross sections.

Field sampling

This 18.9 km (5.6% of the total channel length) reach of channel is poorly known and field assessments are needed to establish a survey network. Preliminary echo-sounding runs would be useful but they would not be easy in this unweired reach with shallow, modified, mixed-load riffles making traversing difficult.

Statistical analysis

Standard channel change assessment.

Response time

Most of the changes in this reach have occurred post 1946 (Warragamba concrete aggregate came from the southern part of this reach). Most of the enlargement changes are associated with the removal of aggregate and have thus occurred over a few decades. In this mixed-load, unweired environment, responses to flows are slower than in the upstream sandbed channels because higher thresholds of motion for the coarser materials prevail. Thus future changes in a drought dominated climate may be slow, except in times of big floods.

Management interaction

This is a complex reach: subject to sewage treatment plant inputs (Penrith and Winmalee), formerly suspected ground-water losses (Penrith Lakes), polluted through-flow inputs (Penrith Lakes), diffuse source inputs (Penrith and Emu Plains), with proliferation of *Egeria densa*, and losses to irrigation. Channel enlargement has reduced the scouring impacts of recent low flows and will probably adversely impact on the effectiveness of environmental flows. Part of the reach may eventually need re-engineering with berms to create a smaller, more efficient channel, to increase the effectiveness of environmental flows, to help with fish passage and perhaps to restrict the growth of exotic vegetation. Thus there is a need for management to know what is happening to the channel through time to evaluate, amongst other things, the effects of environmental flows and potential management options.

Connectivity - Penrith Weir Fishway

Issue

Poor maintenance of the fishway at Penrith Weir

> **Hypothesis**
>
> Monitoring the maintenance of the Penrith Weir fishway, and the subsequent reporting of results to the responsible Government body, will result in more effective maintenance of the fishway.

Location

Reach 22

Pre-monitoring investigations

The inspection of the fishway in order to determine appropriate multi-dimensional maintenance scores and protocols should be undertaken.

Variables

- Surveillance of fishway maintenance
- Multi-dimensional maintenance scores recorded during monthly 'no warning' inspections of the fishway.
- Daily-average-flow data from weir (for use in the interpretative phase).

General approach

Once the fishway is inspected the details of the scoring system will be determined. The inspections are on a 'no warning' basis in order to ensure that the general operational condition is effectively captured by the scoring system. There may be a case that inspections should intensify during the spring to early-summer period when upstream fish movement activity is at a peak for the greatest number of species.

Statistical analysis

Only yearly summary statistics need to be calculated. Maintenance scores will also be plotted through time in order to determine if maintenance improves as maintenance-monitoring progresses.

Response time

Feedback could be as early as one month. Otherwise yearly when findings are summarised in a standard reporting format.

Management interaction

When poor maintenance is reported management responds by ordering more effective maintenance. If management does not order more effective maintenance then institutional arrangements need to be examined.

Channel Changes in Weired Reaches

Issue

Channel changes in weired reaches need to be resurveyed for management and interpretation of other monitoring relating to weir pools

Location

Reaches 14, 15, 17, 20 and 21

Pre-monitoring investigations

All previous surveys need to be found and put into a database, which will then allow changes to be analysed in temporal sequences. Echo-sounding traverses will be required to show which areas might need priority status in resurveys.. Knowledge of extractions from company records would form the basis of reconciling extractions with net degradation (sediment budget).

Variables

- Channel widths at stepped water levels (at weir crests) and at bankfull for cross sections (banktop to banktop)
- Mean and maximum depths at water level and bankfull stages
- Cross section areas at both levels
- Channel slope at water level and bankfull stages
- Channel capacities at weir crests and at bankfull (derived from slope, mean hydraulic depth and roughness)
- Bankfull capacities for flood frequency determination
- Long profile (thalweg) depths from echo-sounding traverses

General approach

Cross sections should be located every 100 to 500 m, depending on channel conditions. Each end of cross sections should be marked (monumented), so that subsequent surveys can be made at the same section. Benchmarks and a surveying network should be established for height control of each section, as well as for water level and banktop determination. Long profiles will be important in areas where weirs have failed because the gradients will be steeper than before failure and sediment will be more mobile in lengthened weir compartments.

Clearly priorities will prevail. The highest priority will be where there are weirs to be removed. In such cases, weirs ponds upstream and downstream of the structure will need to be carefully surveyed to get base-line conditions established before removal. In very low flow conditions changes will occur only slowly but the passage of spills with higher velocities and a steeper gradient between the upstream surviving weir and the one beyond the removed weir will allow the reworking of bed sandy sediments more quickly. Scour holes downstream of the removed weir will be infilled from sediment upstream. Its source areas will be steeper than in the downstream pond because the backwater gradient from the next weir downstream will remain much the same. Surviving dredging holes in the upper or lower weir ponds will be slowly or quickly infilled, depending on the magnitude of spills and their energy. The loss of such holes may well remove sources for safe irrigation pumping and will be a source of concern to riparian landowners.

Lower priorities will exist where there are no plans to remove weirs but where two adjacent weirs have failed (Bergins and Thurns), there should be some surveying to ascertain changes and adjustments, which have been going on since their failure. Their ultimate removal or re-establishment will also require baseline data.

The total of 75 km represents much work and a large budget, especially if 4 cross sections were done for each km (300). However some reaches could be put into low priority status immediately. Reaches 14 and 20 (25 km) are in sandstone gorges and there would be no great urgencies here, particularly because the weirs involved are unlikely to be removed (Menangle and Penrith). Channel changes in Reach 21 were determined in some detail in 1980s (Warner, 1987; 1994). This has not been subject to extraction but changed regimes plus the influences of Warragamba Dam and those of the nearby Glenbrook delta combined to effect channel changes. There has also been the invasion of exotic macrophytes into this reach. In 1987 41 cross sections were resurveyed from about 0.5 km above Cobbitty Bridge to about 2 km downstream of Sharpes weir (Erskine and Green, 2000), a distance of about 3.5 km (every 85 m on average). This study was specifically designed to study the effects of aggregate dredging.

Such studies reduce the total length nearly another 9 km or 34 km in all where lower priorities exist. This is about 45% of the total.

Field sampling design

Echo-sounding runs should be used to determine where cross sections should be located. Prior to survey, it would be useful to establish a surveying network for height determination and channel location.

Statistical analysis

Surveys will need to be compared with earlier surveys. These will be cruder until resurveys take place at exactly the same sections, but general changes in channel dimensions and changes in the location of holes can be worked out. In some cases it may be necessary to determine whether or not the changes are significant.

Response times

These will be governed in reality by the time between surveys, which will provide mean rate of change over the interval of time, although significant changes can occur with the passage of a high flow event. Changes occur following large events generally but the chances of surveying before and after them are usually remote. Since these channels are sand bed forms, thresholds of motion will soon be exceeded by flows any where near 1 m/s. This information will be crucial to deliberations on the removal or modification of weirs in these reaches.

Survey data can be fed into established databases and comparisons should then be possible over different periods. In the case of weir removals, there may be a requirement for impact assessment, in which case there would need to be surveys before and after the removal. Subsequent surveys would test such assertions and would be best timed after moderate to large events.

Management interaction

Although weirs were set up to protect the rights of riparian landowners, they have subsequently caused all sorts of problems. Problems have been associated with channel infill with sand from upstream, its subsequent removal (and much more as well), creating the large channel, its stratification pools, as well as bank modification and attempts at rehabilitation. The channel has a mobile sand bed, which is currently constrained and compartmentalized by weirs. Adjacent to it are the first densely settled parts of the valley with water losses to irrigation extractions and gains from polluted sewage treatment plant and diffuse sources.

These are reaches where the management function of valley floor is complex and where there is a need to be aware of channel changes and their implications for ecosystems. Management will be dealing with conflicts in the these reaches and will need to know the value of understanding adjustments in the conduit, which may affect the proper transmission of proposed environmental flows and their impacts on fish, bugs and water quality

Tidal Channel Changes in the Hawkesbury River

Issue

The impact of channel changes in the tidal reaches of the Hawkesbury River is unclear. Resurveys may be necessary to assess these impacts and for other purposes such as water quality, hydraulic and hydrological modelling.

Location

Reaches 23, 24, 25, 26 and 27

Pre-monitoring investigations

Relocate the NSW PWD cross sections surveyed in the 1970s and 1980s

Collate data (19^{th} Century surveys of Gowland and Josephson; Captain Cook Cruise echo-sounding runs; SKM photogrammetric studies; Sydney University surveys; Sydney Water and other consultants' studies) into a useable database.

Variables

- Channel widths at bankfull and at 0 m AHD
- Channel depths at bankfull and at survey datum (0mAHD)
- Bankfull and sub-tidal cross-section areas
- Average depths for bankfull and sub-tidal levels
- Depths and widths at ISLW (Indian Springs Low Water) are useful in working out sub-tidal capacities.

General approach

Resurvey cross sections on a needs basis for modelling and the interpretation of other monitoring.

Field sampling design

Echo-sounding traverses to establish areas of greatest change and to select sample sites to be resurveyed.

Statistical analysis

Standard channel change assessment.

Response time

Immediate once surveying is complete and assessment against historical data is completed.

Management interaction

The upper part of the tidal reaches is probably the second most degraded reach of the river, with channel changes, diffuse and point source inputs and large irrigation extractions. Perhaps the Inter-Agency Modelling Committee or a catchment management authority needs to take ownership of the data, to create ongoing databases, and to manage them effectively and to use them for modelling purposes. Too much time is wasted in finding material from diverse and often incomplete sources.

Stormwater Runoff

Issues

In order to protect the recommended environmental flows the impacts of stormwater runoff in the catchment needs to be assessed.

Location

Reaches: 4, 5, and 13 to 27

General Approach

An assessment of the improvement in water quality associated with the incorporation of water sensitive urban design into new urban areas. It is envisaged that the approach will involve the collation of existing information on water quality, hydrology, land use and other catchment features for use in an appropriate model.

Field sampling design

Council and Sydney Water Corporation's sites would need to be seen to work out where and what kinds of monitoring were in place and how this would affect any modelling.

Management interaction

Improved management of stormwater runoff is urgently required to protect water quality and environmental flows.

Appendix C1 - Salinity-Driven Contraction of Fish-Nursery Habitat in the Upper Estuary

As discussed in Part B (Reach 2.1), this issue is not considered a high priority, although this status is marginal. Consequently, details of investigations needed to address this issue are given below.

Issue

Reduced flows during low-flow periods have increased salinity in the upper estuary and this has led to contractions in fish-nursery habitat (= freshwater-associated aquatic plants).

The potential consequences of this are:

- upstream shift and overall loss of freshwater-associated submerged, emergent vegetation (this is the fish-nursery habitat)
- upstream shift and overall loss of vegetation-dependent fauna
- up-river and within-estuary reductions in the abundance of diadromous fish species which utilise the vegetation as nursery and or feeding areas
- up-river and within-estuary reductions in recreational and commercial fish species which utilise the vegetation as nursery and or feeding

Hypothesis

Translucent/transparent environmental flows will increase the duration that beds of aquatic vegetation in upper estuary reaches are protected from salt-driven losses (towards levels that occurred under natural conditions), and this will increase and maintain the abundance of dependent fauna.

Location

The river (estuary) reach that is likely to have been substantially impacted by such habitat contraction is Reach 2.1 (Shoalhaven River[1] estuary: Burrier to Nowra bridge)

The potential for such habitat contraction needs to be assessed (by a reconnaissance survey) in Reach 5 (Woronora River estuary: The Needles to Georges River confluence)

Pre-monitoring investigations

To obtain fundamental prerequisite information, the following should be undertaken:

1. pilot/reconnaissance surveys for the assessment of either the relevance of the issue (Reach 5), or the needs regarding logistics and methodology (Reach 2.1)
2. Specific to Reach 2.1 at this stage: By examining[2] the association between estuary inflows and losses in the area of beds of freshwater-associated aquatic plants, identify inflows (magnitude

[1] Flows can be substantially reduced during periods when bulk-water is transferred from Lake Yarrunga up to either the upper Nepean Dams or Warragamba Dam. Currently this occurs irregularly (once every 6-10 years), however, this is likely to increase greatly in the future under the influence of climate change (ie. heading into a drought-dominated regime) and Sydney's increased water consumption due to population growth. Flows are further reduced by extractions at Burrier by Shoalhaven Water.

[2] To be in a position to 'pickup' losses in vegetation through sequential sub-reaches, it is tentatively recommended that bed-width measurements (done separately for different species) be made along transects spaced 100 m apart, from 0 to at least 12 kilometres downstream of the tidal limit near Burrier. This should be done on low tides and will take approx. three days on each surveying occasion. Sampling intensity should be high (say monthly) in periods leading into droughts, and/or intense periods of water extraction, as bed losses occur in these times. Outside these periods, ie. when recovery is occurring, sampling intensity can be considerably lower (say every 2-3 months). Data from these latter periods provides information on bed

and duration) which are linked with plant losses in a longitudinal series of sub-reaches (these are 'working' sub-reach inflow thresholds).

3. Specific to Reach 2.1 at this stage: Replicate observations on the association between estuary inflows and losses in the area of beds of freshwater-associated aquatic plants, and if necessary refine inflows (magnitude and duration) which are linked with plant losses in a longitudinal series of sub-reaches (these are 'refined' sub-reach inflow thresholds).

Monitoring program

The following details of the monitoring program apply only to Reach 2.1 at this stage.

Variable(s)1 (based on 'working' sub-reach thresholds):

The duration of flows greater than the determined 'working' sub-reach inflow thresholds

- **General approach**

  Simple reporting of the number of days per year, under the environmental-flow (EF) condition, that sub-reaches would be classified as not being within a 'plant-bed-loss' state (i.e. days when inflows > 'working' sub-reach inflow threshold). This would be based on river-flow gauging data. The results would be given a context in relation to the before-environmental-flow (BEF) condition (% gain) and the natural (NAT) condition (% shortfall). BEF- and NAT-condition flows would need to be modelled and be based on dam inflows/outflows. This work could not proceed until the 'working' sub-reach inflow thresholds were identified.

- **Statistical analysis**

  The significance of differences in the occurrences should be tested separately for the EF-BEF and EF-NAT pairs in relation to the following specific null hypothesis:

  > *There are no differences between the conditions in the ratio of 'not-within-plant-bed-loss' days versus 'within-plant-bed-loss' days.*

  This should be tested with a parametric frequency-analysis procedure such as a Chi-squared test. The ratios for key sub-reaches should be calculated for the whole year as well as being separated for important periods when plant beds are heavily utilised by aquatic fauna, such as spring and summer.

Variable(s) 2 (based on 'refined' sub-reach thresholds):

The duration of flows greater than the determined 'refined' sub-reach inflow threshold.

- **General approach**

  As per Variable(s)1 above ('working' sub-reach inflow threshold, instead dependant on the 'refined' threshold).

- **Statistical analysis**

  As per Variable(s)1 above ('working' sub-reach threshold, instead dependant on the 'refined' threshold).

Management interaction (Reach 2.1 only at this stage)

- **Variable(s)1 (based on 'working' sub-reach thresholds)**

  During the course of environmental-flow-option-development process the possible ecological significance of hydrological impacts was partitioned as follows:

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resilience, and a 'running base' from which losses can be assessed. Confounding factors, eg. losses due to flood scouring, can also be identified by maintaining such a base.

- >30% shift from natural = high impact
- 10-30% shift from natural = moderate impact
- <10% = low impact

It is proposed that these ecological-significance thresholds be used to trigger adaptive-management actions as follows:

- there is a **high-priority** need to supplement environmental flows (eg. by altering transparency/translucency settings) if after two years the duration of 'not-within-plant-bed-loss' days in key sub-reaches under the environmental-flow condition is:
  - ✓ 30-100% less than what would be expected under natural conditions, and
- there is a **medium-priority** need to supplement environmental flows if after two years the duration of 'not-within-plant-bed-loss' days in key sub-reaches under the environmental-flow condition is:
  - ✓ 10-30% less than what would be expected under natural conditions

In both of these cases the deviation from the before-environmental flow condition should be reported to provide an indication of what improvements have occurred.

Response time: Possibly four years after the commencement of the 'working' threshold pre-monitoring investigation (ie. at its completion; this assumes that hydrological data and modelling has been underway for two years). If an intense drought occurs early in the period the response time could be as low as 2 years.

- **Variable(s)2 (based on 'refined' sub-reach thresholds)**

  Details as per 'Variable(s)1' above (ie. as based on the 'working' sub-reach inflow thresholds). However the 'need priority' is greater because a higher level of certainty is involved, a result of 'refined' rather than 'working' thresholds being used.

  Response time: 2 to 4 years after the commencement of the 'refined' pre-monitoring investigations (2 years if an intense droughts occurs early in the period).

Links to other issues

The monitoring of 'pulses' of moving fish in the Woronora system (Connectivity Issue, Reaches 3-4-5) may reflect impacts associated with this issue.

Summary of hydrological data needs

- **Pre-monitoring investigations**
  - daily-average-inflow data in the Reaches 2.1 and 5 during pilot/reconnaissance surveys (for use in the interpretative phase)
  - daily-average-inflow data when 'working' and 'refined' inflow thresholds are being investigated (only Reach 2.1)
- **Routine monitoring (only Reach 2.1)**
  - daily-average-inflow data a during environmental flow releases (ie. EF condition)
  - predicted daily-average-inflow data for the condition without environmental flows (ie. BEF condition)
  - predicted daily-average-inflow data for the natural condition (ie. NAT condition)

Appendix C2 - Links between high priority issues selected for monitoring and the impact mechanisms identified in the rivers reaches assessment

Within the river reaches assessment[1], a series of impact mechanisms were identified and given a likely-intensity rating per river reach. The mechanisms were partitioned as follows:

- Flow-alteration impact mechanisms in rivers.
- Flow-alteration impact mechanisms in estuaries.
- Dam-induced water quality alteration impact mechanisms.
- Anthropogenic non-flow impact mechanisms.

Links between the more significant of these mechanisms (specifically, those mechanisms with two or more reaches having a moderate or high likely-intensity rating) and the high-priority monitoring components are given in Tables C2-1 to C2-4. The strengths of the links can be summarised as follows:

- **Flow-alteration impact mechanisms in rivers**

  High priority monitoring component links to these mechanisms are shown in Table C2-1. Eighty-seven percent of the mechanisms have strong links to the monitoring components. This coverage is provided by nine monitoring components. The remaining mechanisms have medium to weak links and the coverage is provided by four monitoring components.

- **Flow-alteration impact mechanisms in estuaries**

  High priority monitoring-component links to these mechanisms are shown in Table C2-2. Sixty-four percent of the mechanisms have strong links to the monitoring components. This coverage is provided by seven monitoring components. The remaining mechanisms have medium to weak links and the coverage is provided by five monitoring components.

- **Dam-induced water quality alteration impact mechanisms**

  High priority monitoring-component links to these mechanisms are shown in Table C2-3. Eighty percent of the mechanisms have strong links to the monitoring components. This coverage is provided by four monitoring components. The remaining mechanism has medium to weak links and the coverage is provided by eleven monitoring components.

- **Anthropogenic non-flow impact mechanisms**

  High priority monitoring-component links to these mechanisms are shown in Table C2-4. Forty-eight percent of the mechanisms have strong links to the monitoring components. This coverage is provided by twelve monitoring components. The remaining mechanisms have medium to weak links and the coverage is provided by sixteen monitoring components.

Key to Tables C2-1 to C2-4

Reach impact mechanisms:

- LOW: Impact mechanisms relevant to low-magnitude flows
- M/H: Impact mechanisms relevant to moderate to high-magnitude flows
- ALL: Impact mechanisms relevant to flows of all magnitudes

(blue)	Strong link, ie. directly relevant with the mechanisms being directly measured.
(red)	Medium link, ie. indirectly relevant but providing key information for
(yellow)	Weak link, ie. indirectly relevant but providing some information for

[1] *River Reaches Assessment*; Microsoft Access Database, Expert Panel, March 2004

Table C2-1: Flow-alteration impact mechanisms in rivers: links with high-priority monitoring components. See IEP (2002a) for full details of the mechanisms.

High Priority Monitoring Components	Reach impact mechanisms														
	LOW: Longitudinal connectivity	LOW: Connectivity with estuary	LOW: Hostile water quality at depth	LOW: Contraction of critical habitat	LOW: Suspension and transportation	LOW: Aggravation of pollution	LOW: Water heating	LOW: Pool retention time	M/H: Bed flushing	M/H: Longitudinal connectivity	M/H: Dispersal of alien plants	M/H: Hostile water quality at depth	ALL: Flow variability	ALL: Rate of discharge increase	ALL: Rate of discharge decrease
Fundamental Hydrological															
Monitoring of shale and sandstone reaches below the dams	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Blue	Blue	Blue
Monitoring dam inflows	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Monitoring tributary flows	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Blue	Blue	Blue
Ecological and Physical															
Cold water releases from dams															
Reduced connectivity-natural barriers	Blue	Blue								Blue					
Contraction of critical habitat				Blue											
General water quality downstream of dams			Blue			Blue	Blue	Blue							
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes											Red	Blue			
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers			Yellow	Yellow									Red		
Reduced recreational fish catches	Yellow	Yellow													
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers			Yellow	Yellow									Red		
Reduced commercial fish catches	Yellow	Yellow													
Connectivity investigations – managing flows for fish passage in the Woronora River	Blue	Blue								Blue					
Stratification of natural pools			Blue			Red	Red	Yellow				Blue			
Reduced flushing, scouring and conditioning of habitat									Blue						
Elevated iron and aluminium concentrations in discharge waters from dams															
Encroachment of riparian vegetation on channels													Red		
Iron-rich groundwater inflows downstream of Avon and Cataract Dams						Red									
Ancillary															
General water quality associated with the Forum's Effluent Reuse Strategy															
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management															
Soil sustainability associated with the Forum's Effluent Reuse Strategy															
Inter-catchment transfer of fish via Glenquarry Cut															
Lack of connectivity – diversion and gauging weirs	Red	Red								Red					
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy															
Effectiveness of Tallowa Dam fish lift	Red	Red								Red					
Channel degradation in the mixed-load shale reach downstream of Penrith Weir															
Connectivity - Penrith Weir fishway	Red	Red								Red					
Channel changes in weired reaches															
Tidal channel changes in the Hawkesbury River															
Stormwater runoff															

Table C2-2: Flow-alteration impact mechanisms in estuaries: links with high-priority monitoring components. See IEP (2002a) for full details of the mechanisms.

High Priority Monitoring Components	Reach impact mechanisms										
	LOW: elevated salinity affecting	LOW: Elevated salinity affecting flora	LOW: Aggravation of pollution	LOW: Retention times	M/H: Estuary bed flushing	M/H: Suspension and transportation	M/H: Dispersal of alien plants	M/H: Hostile water quality at depth	M/H: Connectivity to river	ALL: Salinity structure variability	ALL: Establishment of macrophytes
Fundamental Hydrological											
Monitoring of shale and sandstone reaches below the dams											
Monitoring dam inflows											
Monitoring tributary flows											
Ecological and Physical											
Cold water releases from dams											
Reduced connectivity-natural barriers											
Contraction of critical habitat											
General water quality downstream of dams											
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes											
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers											
Reduced recreational fish catches											
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers											
Reduced commercial fish catches											
Connectivity investigations – managing flows for fish passage in the Woronora River											
Stratification of natural pools											
Reduced flushing, scouring and conditioning of habitat											
Elevated iron and aluminium concentrations in discharge waters from dams											
Encroachment of riparian vegetation on channels											
Iron-rich groundwater inflows downstream of Avon and Cataract Dams											
Ancillary											
General water quality associated with the Forum's Effluent Reuse Strategy											
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management											
Soil sustainability associated with the Forum's Effluent Reuse Strategy											
Inter-catchment transfer of fish via Glenquarry Cut											
Lack of connectivity – diversion and gauging weirs											
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy											
Effectiveness of Tallowa Dam fish lift											
Channel degradation in the mixed-load shale reach downstream of Penrith Weir											
Connectivity - Penrith Weir fishway											
Channel changes in weired reaches											
Tidal channel changes in the Hawkesbury River											
Stormwater runoff											

Table C2-3: Dam-induced water quality alteration impact mechanisms: links with high-priority monitoring components. See IEP (2002a) for full details of the mechanisms.

High Priority Monitoring Components	Reach impact mechanisms				
	Altered temperature regime	Altered nutrient regime	Toxic material release	Reduced organic material inputs	Reduced sediment inputs
Fundamental Hydrological					
Monitoring of shale and sandstone reaches below the dams					
Monitoring dam inflows					
Monitoring tributary flows					
Ecological and Physical					
Cold water releases from dams					
Reduced connectivity-natural barriers					
Contraction of critical habitat					
General water quality downstream of dams					
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes					
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers					
Reduced recreational fish catches					
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers					
Reduced commercial fish catches					
Connectivity investigations – managing flows for fish passage in the Woronora River					
Stratification of natural pools					
Reduced flushing, scouring and conditioning of habitat					
Elevated iron and aluminium concentrations in discharge waters from dams					
Encroachment of riparian vegetation on channels					
Iron-rich groundwater inflows downstream of Avon and Cataract Dams					
Ancillary					
General water quality associated with the Forum's Effluent Reuse Strategy					
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management					
Soil sustainability associated with the Forum's Effluent Reuse Strategy					
Inter-catchment transfer of fish via Glenquarry Cut					
Lack of connectivity – diversion and gauging weirs					
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy					
Effectiveness of Tallowa Dam fish lift					
Channel degradation in the mixed-load shale reach downstream of Penrith Weir					
Connectivity - Penrith Weir fishway					
Channel changes in weired reaches					
Tidal channel changes in the Hawkesbury River					
Stormwater runoff					

Table C2-4: Anthropogenic non-flow impact mechanisms: links with high-priority monitoring components. See IEP (2002a) for full details of the mechanisms.

High Priority Monitoring Components	Reach impact mechanisms																									
	Weir evaporation	Weir sedimentation	Water quality & weirs	Habitat and weirs	Passage blocks	Water extraction	Water releases	Saline groundwater	Channel widening	Channel deepening	Flood mitigation works	Fauna harvesting	Recreational vehicle impacts	Riparian damage	Alien pest plants	Alien pest animals	Hormone inputs	Nutrient inputs	Organic inputs	Pathogen inputs	Immunosuppressants	Toxic material inputs	Bedload inputs	Suspended load inputs	Transfer of biota
Fundamental Hydrological																										
Monitoring of shale and sandstone reaches below the dams																									
Monitoring dam inflows																									
Monitoring tributary flows																									
Ecological and Physical																									
Cold water releases from dams																									
Reduced connectivity-natural barriers																									
Contraction of critical habitat																									
General water quality downstream of																									
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes																									
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers																									
Reduced recreational fish catches																									
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers																									
Reduced commercial fish catches																									
Connectivity investigations – managing flows for fish passage in the Woronora River																									
Stratification of natural pools																									
Reduced flushing, scouring and conditioning of habitat																									
Elevated iron and aluminium concentrations in discharge waters from dams																									
Encroachment of riparian vegetation on channels																									
Iron-rich groundwater inflows downstream of Avon and Cataract Dams																									
Ancillary																									
General water quality associated with the Forum's Effluent Reuse Strategy																									
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management																									
Soil sustainability associated with the Forum's Effluent Reuse Strategy																									
Inter-catchment transfer of fish via Glenquarry Cut																									
Lack of connectivity – diversion and gauging weirs																									
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy																									
Effectiveness of Tallowa Dam fish lift																									
Channel degradation in the mixed-load shale reach downstream of Penrith Weir																									
Connectivity - Penrith Weir fishway																									
Channel changes in weired reaches																									
Tidal channel changes in the Hawkesbury River																									

Stormwater runoff																									

Appendix C3 - Power Analysis for Issue on Altered Biotic Communities

Environmental impact assessment and monitoring can be regarded as attempts to test the null hypothesis that some human action has not caused a change in the environment (Fairweather 1991). Therefore, the aim of a monitoring program should be to detect a change, if one really exists, by optimising the sampling program to be able to detect changes through time. A linear regression of estimated abundance against time is commonly used to evaluate if populations are increasing or decreasing or are responding to environmental change. However, analysis of trends through time are often confounded in that change can also be brought about by factors other than natural resource management. The inclusion of reference sites allows for greater inferential ability of the study design. Although there are several obvious ways to increase the power of an monitoring program eg. by increasing the number of replicated sampling sites or increase the length of the sampling program, some factors such as the rate of change and the degree of natural variation are beyond human control.

Under a hypothesis-testing framework two conclusions may be drawn from any monitoring program; there has been, or has not been, a change over time in the abundance of the population. However, it is possible that these conclusions may be right or wrong. When a statistical test fails to correctly determine any real change it is termed a Type I error and when the test indicates a trend in population has occurred when there really has been no change over time, it is termed a Type II error. The frequency or probability of making a Type I error, or significance level, is often denoted by α and is conventionally set at 0.05 (ie. an error is made one in twenty times). The probability of committing a Type II error is denoted by β and has a value that is generally not specified nor known. The power of a statistical test is defined as $1-\beta$; ie., power is the probability of rejecting the null hypothesis when it is in fact false and should be rejected (Zar 1984). In the analysis of a trend in the abundance of an animal populations over time, the power of the test is the probability of correctly concluding that a trend in the data exists (Hatfield et al. 1996).

Power analyses can be undertaken either before (a priori) or after (a posteriori) a statistical test has been done. Statistical power analysis conducted a priori is most valuable in the design or planning phases of research efforts (Steidl *et al.* 1997). Prospective power analyses can help determine the resources that may need to be applied to a monitoring program by estimating the number of samples necessary to achieve a high probability of detecting biologically significant effects. Retrospective power analyses are normally carried out for different reasons and have been advocated as a method to increase information about hypothesis tests that were not rejected. Retrospective power analysis can be used effectively to estimate the number of samples or effect size that would have been necessary for a completed study to have rejected a specific null hypothesis.

The aim of this study was to determine the number of reference sites that would enable a high probability of detecting ecological benefits of the introduction of environmental flows.

Methods

The macroinvertebrate data used for this project was collected by Growns and Growns (2001). Twenty three sites were sampled on five occasions in spring and autumn between 1995 and 1997. The number of genera and morphospecies (hereafter just genera) of macroinvertebrates inhabiting riffles was found to have decreased by 40% compared to nearby reference sites. Power analyses were conducted using simulations of the data to generate alternative hypotheses.

The following procedure was used

1. For each trial, the number of riffle genera was obtained from a set number of reference sites drawn randomly, with replacement, from the original data set. Data were drawn to simulate five years of data collected before the implementation of EFR and five years of data collected following EFR at each reference site.
2. For each trial, the number of riffle genera was obtained from a set number of impact sites drawn randomly, with replacement, from the original data set. Data were drawn to simulate five years of data collected at one impact site prior to the implementation of EFR.

3. Data were again drawn randomly from the impact sites to simulate five years of post implementation of EFR. The number of riffle genera for each impact site was multiplied by a specified rate of change to simulate partial recovery of the number of genera.
4. Data were analysed using a multiple-before-after-reference-impact (MBARI) statistical model according to Downes et al (2002) in the SAS software package using Proc Mixed. A change in the number of riffle genera was accepted to be significant if the probability of the interaction between before/after reference/impact was less than 0.1.
5. This process was repeated 1000 times for the number of reference sites of less than or equal to 20 and 300 times if the number of reference sites was greater than 20. Fewer repetitions were conducted for trials involving greater than 20 sites because of large computational times. The proportion of the trials in which the interaction between before/after reference/impact was significantly different from zero was taken as the estimate of power. This value indicted how often a monitoring program would correctly detect a significant increase for each combination of number of reference sites and rates of increase.

The number of reference sites tested was 4, 8, 10, 12, 16, 20, 24, 28, 30 and 34. The rates of change tested were 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, and 1.7. Note that a rate of change of 1.7 is equivalent to returning the number of riffle genera at impact sites to reference conditions.

The analysis described above assumed that each impact site would be evaluated separately against a set of reference sites. However, it is possible that three impact sites might be included in any future analysis as there are currently three impact sites affected by bulk water transfers (Cataract, Cordeaux and Nepean Rivers) and potentially three impact sites not affected by bulk water transfers (Avon, downstream of Pheasants Nest and Broughtons Pass weirs). In order to examine the advantages of considering groups of sites a separate analysis of 8, 10, 12, 14 and 16 reference sites and rates of change of 1.4, 1.5, 1.6 and 1.7 was conducted using the framework described above.

These analysis assumes that the spatial variation and temporal variation among reference sites and among impacted sites are equal over the five sampling occasions and over the study area. Growns and Growns (2001) found no significant difference in the number of riffle genera over time or among reference sites.

Results

The power of the MBARI design to detect changes in the number of riffle genera with one impact site generally increased with increasing number of reference sites and increasing rates of change (Figure C3-1). However, the probability of detecting a 1.1 rate of change decreased with increasing number of reference sites. Only the rate of change of 1.7 reached a probability of detecting change of 0.8 with 16 reference sites. However, there was not a consistent increase in power with increasing number of reference sites with a 1.7 rate of change above 6 sites. In general, an asymptote is evident at approximately 12 sites for the majority of different rates of change where increasing the number of reference provides no great increase in the power of the MBARI.

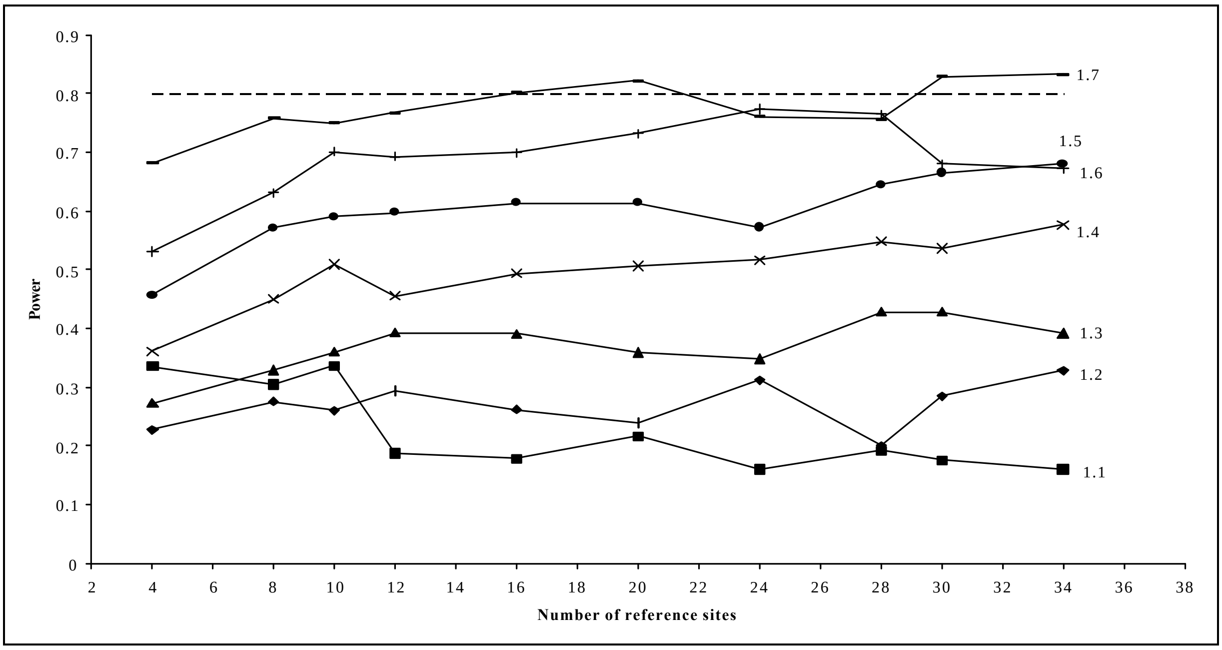

Figure C3-1: Statistical power for different rates of change to detect changes in the number of riffle genera in an MBARI statistical design comparing numbers of reference sites with one impact site. The lines for each rate of change are indicated at the end of the series.

When three impact sites are considered in the MBARI design, there is a substantial increase in power, for the same rates of change and number of sites as for a one-impact site design (Figure C3-2). For example, the power of the MBARI design with one impact site and three impact sites for a 1.5 rate of change with eight reference sites are 0.57 and 0.83, respectively. Similarly to the power analysis using one impact site, there appears to be an asymptote at approximately 10 to 12 reference sites where there appears to be no increase in power with increasing number of reference sites.

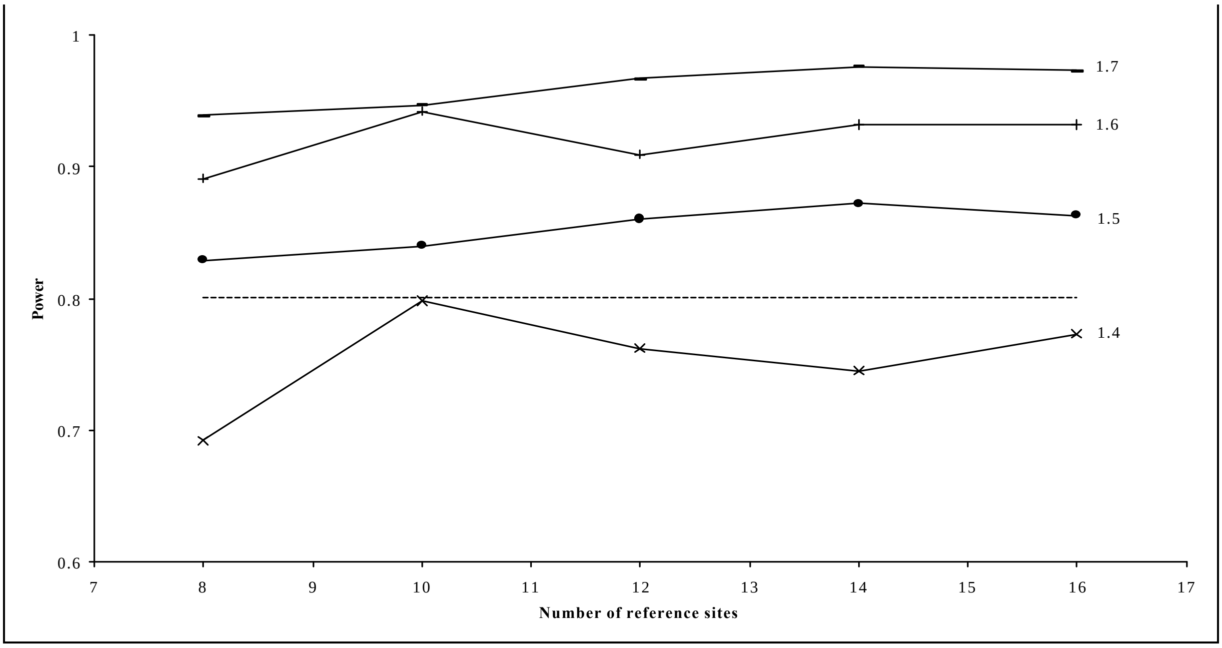

Figure C3-2: Statistical power for different rates of change to detect changes in the number of riffle genera in an MBARI statistical design comparing numbers of reference sites with three impact sites. The lines for each rate of change are indicated at the end of the series.

Discussion

Downes et al. (2002) indicate for an MBARI type of statistical analysis, increasing the number of reference of impact sites is usually the most efficient way to increase power, and therefore the ability of the statistical test to detect change. The evaluation of the power of the study design to detect changes in the number of riffle genera suggests that approximately 12 reference sites would be cost effective for the monitoring design. Increasing the number of reference sites above 12 does not appear to greatly increase the power of the statistical design.

Two other ways to potentially increase power of a test are to increase the number of years sampling takes place or to take sub-samples at each reference and impact site (Downes et al. 2002). However, when planning for an a priori monitoring program to support an adaptive management process, a fixed period of time before and after the implementation has to be evaluated because reviews of the management action, in this case the introduction of environmental flows, is normally set in legislation or licensing arrangements. Therefore, increasing statistical power by increasing the length of time sampling takes place is not always an option.

Downes et al. (2002) suggest that having sub-samples at each reference or impact site can indirectly increase the power of an MBARI design by removing small scale spatial variation and the improvements will be greatest where variation is large. However, this aspect was not evaluated in this study. It should be noted that increasing the sub-samples taken within each reference or impact location will dramatically increase the costs of the monitoring program. For example, increasing the number of sub-samples at each site from one to two will effectively double the cost of the monitoring program. Downes et al. (2002) suggest that if a monitoring program is financially constrained any increase in sampling effort within sites is difficult to justify and in such circumstances the study designer should maximise the number of sites and minimise the number of sub-samples.

Due to limited time this study only examined the ability to a MBARI design to detect changes in the number of riffle genera. The monitoring program for environmental flows in the upper Nepean River system will also use other biotic variables to examine changes to ecosystem health. The additional recommended variables included number of genera in pool rocks, the SIGNAL and SIGNAL-DAM biotic indices, AusRivAS O/E scores and macroinvertebrate community structure (see Part C “Altered Biotic Communities - Upper Nepean, Woronora and Shoalhaven Rivers”). Some or all of these indices may have different spatial and temporal variability than the number of riffle genera and therefore may require a greater or lesser number of reference sites to be able to detect a change at impact sites. Until further power analyses are done on these indices it is recommended that the decision on the number of reference sites be based upon the ability of the MBARI model to detect changes in the number of riffle genera.

PART D: SOCIAL, ECONOMIC, CULTURAL AND HERITAGE MONITORING PROGRAM

Introduction

Effective monitoring of the social, economic, cultural and heritage (SECH) issues associated with environmental flows are a crucial component of the integrated monitoring process. Improved environmental and SECH outcomes will be dependant upon a number of influencing factors, including the way that flows are provided and the consequences of river management decisions for various government, commercial and public interest groups. It is essential that there be high levels of public participation on the monitoring program as a whole. The processes associated with social and economic impact assessment and monitoring provide a sound basis for a framework that links the monitoring program to decision making in a complex and changing institutional context.

The Hawkesbury–Nepean catchment is characterised by a diverse number of communities. The river provides water to an expanding urban population, with rural residential development increasing along the riverine corridor. Primary and agricultural industries rely significantly on the river, as do tourism and water based recreational activities. Cultural and heritage values are attached to specific Aboriginal and non-Aboriginal sites and the river landscape as a whole. The adjacent Shoalhaven, Woronora and Wingecaribee catchments also need to be considered.

In addition to the diversity of stakeholders, there is the added complexity of multiple government agencies with responsibilities over different aspects of river and catchment management. Furthermore, many agencies are currently undergoing change under the State Government's new direction for natural resources management.

This part of the Report presents the social, economic cultural and heritage components of the monitoring program for the Hawkesbury–Nepean River. It is intended as a guide to the social scientists and decision makers who will be responsible for the design and implementation of SECH monitoring.

The SECH component is designed to evaluate social change associated with environmental flows and related river management strategies. Successful SECH monitoring will be enhanced by providing information and community education about environmental flows and encouraging strong community engagement in monitoring change. These forms of participation combined with the regular reporting of information and responsiveness of decision-making will promote ownership and encourage the early resolution of potential conflicts. These outcomes are not the direct responsibility of SECH monitoring, but fall within the brief of other initiatives implemented by agencies such as the DEC, SCA and DIPNR.

This Part of the report deals with the following:

- Research methodology used to develop the proposed program, describing the literature reviews, workshops, preliminary consultations and stakeholder surveys. The themes and preliminary findings drawn from this research that have been incorporated into the design of the monitoring component are discussed.
- Overview of SECH issues in the catchment.
- Program design and each of the four phases of program implementation.
- SECH program detailing each SECH issue (including existing programs and options for how future monitoring could occur), indicating likely river stakeholders who would need to participate in the processes.
- Case studies and tables that summarise and present additional information.

Table D1 summarises the high priority issues which are the subject of the detailed monitoring design in this Part.

Table D1: High Priority Issues within Reaches – Social, Economic, Cultural and Heritage

High Priority Issues	Reach or Reach Group (a)																			
	Shoalhaven			Woronora			Wingecarri-bee River		Nepean								Hawkesbury			
	1	2.1	2.2	3	4	5	6.1	6.2	7	8 10 11	9 12 13	14	15 17	16 18 19	20 21	22	23	24	25	26 27
Social and Cultural Values																				
Social values																				
Heritage values																				
Aboriginal values																				
Institutional performance																				
Land and River Activities - existing																				
Irrigation extraction				tbd	tbd	tbd	tbd	tbd												
Industrial extraction				tbd	tbd	tbd	tbd	tbd												
Riparian extraction				tbd	tbd	tbd	tbd	tbd												
Commercial fishery activities				tbd	tbd	tbd	tbd	tbd												
Recreational fishing				tbd	tbd	tbd	tbd	tbd												
Recreational amenity				tbd	tbd	tbd	tbd	tbd												
River-related tourism				tbd	tbd	tbd	tbd	tbd												
Land use and land management																				
Land and River Activities – following implementation of recommended environmental flow regimes																				
Environmental flow releases from dams				tbd	tbd	tbd	tbd	tbd												
Demand management – urban consumers				tbd	tbd	tbd	tbd	tbd												
Demand management – river extractors				tbd	tbd	tbd	tbd	tbd												
Changes to the level of reliability for urban consumers				tbd	tbd	tbd	tbd	tbd												
Modifications to the access conditions for river extractors				tbd	tbd	tbd	tbd	tbd												
Inter-catchment transfers				tbd	tbd	tbd	tbd	tbd												
Stormwater management				tbd	tbd	tbd	tbd	tbd												
Effluent reuse strategy				tbd	tbd	tbd	tbd	tbd												
Weir management				tbd	tbd	tbd	tbd	tbd												

a Reaches and reach groups as defined by the Expert Panel – refer Table B1 in Part B of the Monitoring Program report.
b These issues are discussed in this report but as they apply to Sydney water customers, they do not affect the river reaches directly.
c tbd = Investigation to be done.

d High priority issues identified: SECH co-ordinator to develop the initial public participation process in conjunction with stakeholders No high priority issues identified

Methodology

This section sets out the key concepts used to inform the development of the SECH component, the methods used and preliminary findings drawn from this initial research. The SECH monitoring component was developed by the Institute for Sustainable Futures (the Institute) and Biosis Research (SECH advisers), in collaboration with the Independent Expert Panel on Environmental Flows (the Expert Panel). Robert Bell, an Indigenous representative on the Forum, provided feedback and advice on specific Aboriginal cultural heritage issues and contributed to the overall program design.

The approach is informed by literature relating to: social impact assessment and social monitoring, with special attention give to participatory approaches to assessment and decision-making.

The catchments are complex and cross numerous boundaries; of local government, State agencies and management structures. Clear monitoring roles are required for all those with responsibilities within the catchment. Because of the number of river management strategies, the nature and extent of likely impacts and the expression of those impacts across jurisdictions and geographical boundaries, no single local entity or State agency has the information needed for quality monitoring. Consequently, SECH monitoring often requires a conscious measure of inter-agency and/or multi-agency cooperation (Carley, 1985, 301). The roles and management responsibilities of various bodies, groups and communities need clearly defining. In addition, the cumulative nature of change and the diversity of the stakeholders, means that responsibility for identified impacts is not easily allocated to individual agencies. The monitoring program should be directly linked with stakeholders and decision-making to assist managing the uncertainty of impacts and benefits.

River Stakeholders and Decision Making

Throughout this report, the term ‘river stakeholders’ refers to all organisations likely to have an interest in changes to the river and/or in the implementation of river management strategies. River stakeholders include Commonwealth, State and Local government agencies, corporations and industry associations, local community groups and local geographically and culturally defined communities. A number of these are presented in Table D1 below.

Whilst the SECH monitoring component is designed to cover the Hawkesbury–Nepean catchment area, the pre-monitoring investigations must include consultation with stakeholders in the Shoalhaven, Woronora and Wingecarribee catchments.

Table D2: Summary of River Stakeholders in the Hawkesbury Nepean, Shoalhaven, and Woronora catchments[1]

Government			Non-Government and Quasi-Government Organisations	
Commonwealth	**State**	**Local**	**Corporations, Industry Groups and Boards, etc.**	**Non-Government Organisations and Community Groups**
Two commonwealth departments have an interest in this matter: ▪ Department of the Environment and Heritage (Environment Australia) ▪ Department of Agriculture, Fisheries and Forestry	▪ Department of Infrastructure, Planning and Natural Resources (formerly DLWC) ▪ Department of Local Government ▪ NSW Department of Environment and Conservation ▪ Healthy Rivers Commission ▪ Ministry of Energy and Utilities ▪ Independent Pricing and Regulatory Tribunal ▪ National Parks and Wildlife Service ▪ NSW Agriculture ▪ NSW Rural Assistance Authority ▪ Sydney Catchment Authority ▪ NSW Fisheries	The following councils border the Hawkesbury-Nepean River: ▪ Camden ▪ Baulkham Hills ▪ Blue Mountains ▪ Hawkesbury ▪ Hornsby ▪ Penrith ▪ Wollondilly Water transfers may also occur within the municipal boundaries of Wollongong and Wingecarribee Councils, which contain the Nepean, Avon, Cordeaux and Cataract Dams	Corporations: ▪ Sydney Water Corporation ▪ Delta Electricity Industry Groups eg.: ▪ NSW Seafood Industry Council ▪ Crushed Stone and Sand Association ▪ Tourism Industry Association Decision-making Bodies eg.: ▪ Water CEOs Task Force ▪ Catchment Management Authority Initiatives: ▪ Farming for the Future ▪ Waterwise ▪ WaterwatchNSW/ Streamwatch	▪ Hawkesbury Nepean Catchment Foundation ▪ Nature Conservation Council ▪ Native Title Holders ▪ NSW Water Ski Association ▪ Recreational Fishing Association ▪ Upper Nepean Water Users Association ▪ Local History Groups ▪ Hawkesbury Trawl Association ▪ General Public

Stakeholders and communities can and should play a critical role in both SECH and environmental monitoring. It is proposed that as part of the monitoring program a new decision-making forum be established. This would provide the linking and communication flows between the information collected and generated by the Integrated Water Management Framework, the newly established Hawkesbury-Nepean Catchment Management Authority and other relevant stakeholders. This report is unable to provide the terms of reference, budget and role of the proposed committee, however, it is essential that these issues be addressed promptly by the newly formed Catchment Management Authority.

The public participation in this initial phase was constrained by a number of factors. These relate to the limited time available for consultation and hence a limited capacity to identify and access stakeholder groups. The SECH advisers were also constrained by the preliminary nature of the proposal. While environmental flows are the primary change expected, a number of policy interventions to facilitate flows are proposed, including for example, effluent reuse for irrigation and demand management for domestic and commercial water users. The scale and number of proposals involved, combined with some uncertainty regarding implementation, meant that identifying likely impacts was difficult. Moreover, there was uncertainty about the amount of funding that would be available for the program. Given these constraints, consultations were limited and preliminary. Stakeholders were identified largely from membership in the Hawkesbury–Nepean Management Forum. Workshops were conducted with members of the Forum but should not be seen to substitute for a full scoping of issues with all stakeholders.

[1] The Hawkesbury Nepean Foundation holds a list of the numerous community and other groups that should be included in a consideration of the stakeholders. The lists in Table D1 are indicative rather than exhaustive.

Methods

A number of information sources informed the design of the SECH monitoring component. These included literature reviews, documentation from workshops and consultations, Forum and Expert Panel deliberations and stakeholder surveys. Workshops and regular communication with the Expert Panel aimed to integrate the SECH and environmental components of the monitoring program. Forum deliberations included contributions by Forum representatives in monitoring workshops, attendance at selected meetings and the Minutes of all Forum meetings. In addition, general advice on a monitoring program for the Hawkesbury–Nepean catchment was sought from professionals with expertise in social and economic impact assessment and monitoring.

In summary, the following methods were used:

- Literature reviews
- Workshops and consultations
- Stakeholder surveys

Literature/document reviews

A number of literature searches were undertaken. This included literature relating specifically to the relevant catchments and that relating more generally to social impact assessment and monitoring in the context of river management.

In 2002, the Forum commissioned a literature review on social and economic activities in the Hawkesbury–Nepean catchment. This review identified a number of impacts these activities were having on river conditions and in turn, how these activities may be affected by changing river conditions. The literature review is part of a discussion paper “The socio-economic value of environmental flows in the Hawkesbury-Nepean” (Vecellio & White, 2002). The review examined existing literature on the environmental impacts of social and economic activities, other publicly available literature about social and economic activities and some informal contact with agency staff. The review found the available literature to be of variable quality and currency and identified a number of major gaps in knowledge about the catchments.

Information on existing stakeholder activities and associated economic values at the catchment level can be found in this discussion paper. Many of the identified knowledge gaps are accounted for in the baseline data requirements of the SECH monitoring component, described later in this report.

Proceedings of Forum meetings and workshops provided information about the significant issues from the perspective of Forum members. The proceedings also provided information about river management strategies being considered for recommendation. (Some of the key proceedings are the Forum Meetings of 15 October 2001 and 11 March 2002, the Forum Workshop 24-25 July 2002, Forum Meeting 3 February 2003, Forum Meeting 28 April 2003 and Forum Workshop 26–27 May 2003.)

The Social Impact Assessment (SIA) literature was key in shaping the program design. SIA is a process of predicting, interpreting and monitoring the consequences for social conditions and individuals’ wellbeing, which result from development activities. This includes policies and programs. Social impacts to be assessed may involve changes to a community regarding their way of life, economy, culture, community, political systems, environment, health and wellbeing, personal and property rights and fears and aspirations. An SIA will normally identify the following:

- relevant stakeholders likely to be affected
- likely or probable impacts on these stakeholders
- strategies to optimise these impacts, and
- strategies to mitigate or avoid these impacts

Guidelines have been prepared for SIA in NSW for River, Groundwater and Water Management Committees (Independent Advisory Committee on Socio-Economic Analysis, 1998) and internationally (ISCPSIA, 1994). Also, see Vanclay (2003) for recent discussion of SIA in relation to principles of sustainable development.

Demand for and development of SIA has occurred because of concerns about the process of social change. SIA is intended to explicate significant factors and present preferences and aspirations relating to the future. It can also be used as a process to highlight value choices, increase public involvement and efficacy and give more democratic direction to a development process. See Craig (1990) for the reasons why SIA has developed.

Public participation in decision-making is a central to many practitioners of SIA. There is some debate on this point as studies are "polarised between approaches that emphasise the technical collection of primarily quantitative data with which to objectively determine the nature of impacts, versus approaches that emphasise the facilitation of community participation and empowerment in planning and decision-making" (Lockie et al. 1999). The approach we have adopted here is a balance between more technical forms of data collection and a commitment to community participation. Burdge and Vanclay (1995) discuss factors contributing to the success of SIA and there are specific discussions of SIA in relation to the water industry (Seebohm 1997, Lockie et al. 1999).

Literature concerning monitoring was also consulted. Monitoring is described as:

> …*systematic collection and organisation of information, used to improve the decision-making process—either indirectly by informing the public, or directly a feedback tool designed for policy development, program evaluation (or adaptive management)—so that policies and decisions are responsive to changes that are both anticipated and unforeseen* (Carley 1985).

The types of monitoring can vary depending on its purpose. Carley (1985) outlines seven types. These range from monitoring compliance with operating procedures at a specific site, to monitoring a wide variety of cumulative impacts occurring over an entire region. Different types of monitoring may be incorporated in one program, depending on the issues to be monitored.

Monitoring SECH issues in the Hawkesbury–Nepean River needs to include a combination of monitoring for project-specific impact management and cumulative impact monitoring. The former usually involves establishing a group to regularly assess a range of impacts associated with a project and the latter monitors SECH impacts resulting from broader factors. In contrast, hydrological and ecological monitoring of environmental flows is largely experimental and seeks to test specific predictions and hypotheses about environmental causes and effects. This type of monitoring is less suited to SECH issues in a large catchment with complex social and economic conditions.

When conducting impact assessments, social and economic monitoring is usually developed at a later stage and a number of steps tend to precede monitoring. According to US guidelines, (ICGPSIA 1994), the first step is to scope the range of likely, significant impacts, by consulting all potentially affected people. Subsequent steps include a baseline assessment of existing conditions, determining the significance of potential impacts to the community and developing mitigation strategies (ICGPSIA 1994). The significance of impacts cannot be determined in isolation from the views and experience of affected stakeholders. The level of significance depends upon a number of factors, including the responses and attitudes of affected parties to the impact (ICGPSIA 1994) and the availability of shared decision-making processes to manage impacts (Krawetz et al. 1987). Other criteria for determining the significance of impacts include the distribution of costs and benefits to various groups, the number of people who are affected and the presence or absence of controversy over the issue (ICGPSIA 1994). Public participation extends beyond initial scoping of issues to ongoing monitoring and decision-making. A number of case studies demonstrate methods for achieving effective public participation are attached (see Appendix D1).

Finally, the cultural and heritage literature search included material on heritage assessments incorporating both Aboriginal and non-Aboriginal heritage issues in the catchment and in relation to monitoring and river management.

Workshops and consultations

A number of informal workshops were held during the course of designing the program. These workshops did not aim to include all relevant stakeholders. These involved the following groups:

- SECH advisers only
- SECH advisers with environmental advisers on the Expert Panel
- Expert Panel with the Forum representatives

- SECH advisers with Indigenous communities.

The SECH advisers were involved in three specific workshops aimed to establish a common framework within which to consider social, economic, cultural and heritage issues. There were a number of Joint workshops, meetings and personal communications between SECH advisers and the Expert panel that aimed to integrate the different disciplines. There were also a series of field trips to identify river sites.

The Expert Panel regularly met with Forum members to discuss issues around monitoring environmental flows. Recommendations by members of the Forum and also in response to stakeholder surveys, meetings were also held with representatives from Western Sydney Regional Organisation of Councils (WSROC) and DIPNR in relation to the Integrated Water Monitoring Framework (IWMF). These discussions sought to ascertain the extent of monitoring activities already taking place and potential roles for future bodies.

A workshop and information session was held to inform local Aboriginal Land Councils of the Forum's work. At this workshop, it was agreed that consultation would occur through a representative on the Forum. Robert Bell undertook this role and provided advice and feedback about the design of the SECH monitoring component. The SECH advisers also relied upon unpublished reports that documented extensive consultation with Aboriginal people in the catchment. (Kenney & Richardson 2002, Kenney, 2002).

Stakeholder surveys

SECH advisers conducted (telephone) open-ended surveys with planning and natural resource agencies and identified stakeholders. These stakeholders were initially identified based on Forum membership. An appropriate contact was identified for each stakeholder represented on the Forum, for example, the appropriate manager of a relevant unit or department. Initial contact was by email and followed up with a telephone call. Individuals nominated by the initial representative were contacted to provide additional useful or new information. Follow-up telephone interviews were conducted with some participants.

The survey sought to establish knowledge and experience on previously unidentified impacts, existing infrastructure and additional needs for SECH monitoring and co-ordination to be identified.

Participants were asked about:

- social, economic, cultural and heritage issues that should be monitored;
- ways in which SECH and environmental monitoring could be integrated and linked in an adaptive management system;
- current and past collection of social, economic, cultural and heritage information relating to river communities;
- the kind of monitoring program required for the river, in relation to environmental flows; and
- any barriers to monitoring impacts and suggestions to overcome these barriers.

Because of the constraints identified earlier, the range of stakeholders surveyed was limited. For example, geographically defined residential communities and broader recreational interests were not included[1].

Results

Workshops with indigenous communities

Indigenous communities specified they did not require extensive consultation; particularly once regular attendance at the Forum by an Indigenous representative was underway. Agreements were reached on two major issues. The final recommendations of the Forum concerning environmental flows would be communicated to Aboriginal communities in a summary newsletter-style report in plain English. In addition, it was agreed that all relevant Aboriginal communities could have an active role in any monitoring associated with environmental flows.

[1] A representative from the Department of Tourism was contacted for the survey but did not respond.

This consultation with Indigenous communities highlighted the importance of ensuring that the SECH component enabled ongoing consultation with Indigenous communities, taking into account past and existing work of government agencies in a catchment area. For example, the Indigenous communities of the Sydney catchment were consulted in the development of the Sustaining the Catchments Regional Environmental Plan (PlanningNSW and SCA 2002). Previous experience has demonstrated that this may facilitate Indigenous people developing stronger relationships with researchers and increase the level of trust. It is desirable that consultation be coordinated where possible so as not to draw unnecessarily on community resources.

Stakeholder surveys

Of the 23 organisations contacted[1], there were responses from representatives of eighteen organisations. A little less than two thirds of these responding organisations (61%) were Government bodies and the remainder from non-government bodies. Table D3 has a full list of organisations that were contacted and which responded.

Table D3: Organisations contacted

No	Organisation approached	Responded
1	NSW Department of Agriculture (NSW Ag)	Y
2	NSW Department of Land and Water Conservation, now Department of Infrastructure, Planning and Natural Resources (DIPNR)	Y
3	PlanningNSW, now Department of Infrastructure, Planning and Natural Resources (DIPNR)	Y
4	Fisheries NSW (Fisheries)	Y
5	NSW National Parks and Wildlife Service (NPWS), now NSW Department of Environment and Conservation (DEC)	N
6	Western Sydney Regional Organisation of Councils (WSROC)	Y
7	Macarthur Regional Organisation of Councils (MACROC)	Y
8	Sydney Catchment Authority	N
9	Sydney Water Corporation (Sydney Water)	Y
10	Environmental Protection Authority (EPA), now NSW Department of Environment and Conservation (DEC)	Y
11	NSW Department of Health (NSW Health)	Y
12	NSW Local Government Association	N
13	NSW Premier's Department	Y
14	Upper Nepean Water Users' Association	Y
15	Lower Nepean Water Users' Association	Y
16	Nature Conservation Council (NCC)	Y
17	NSW Seafood Industry Council	Y
18	NSW Fishing Club Association	Y
19	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Y
20	Hawkesbury–Nepean Catchment Management Foundation (HNCMF)	Y
21	Hawkesbury Trawl Association	Y
22	UWS Tourism	N

[1] Nine of these organisations were non-government bodies with an interest in the river or the associated catchments.

The main themes to emerge from the survey were:

- scope and purpose
- costs
- data co-ordination
- community engagement
- institutional roles

Scope and purpose of SECH monitoring

Most stakeholders noted that it would be desirable to have clarity about the purpose or goal of the program. It was commonly observed that information being monitored should be easily accessible and engage the community as well as being fed back meaningfully for management and decision-making. The challenge this presents is that although monitoring should capture the complexities of a catchment area sufficiently for the purposes of decision-making, it should be simple enough to be readily accessible and informative to a diverse group. This group includes not only managers and policy makers but also those communities relying on and affected by the river, including Aboriginal communities.

Most stakeholders indicated that monitoring should be clearly defined and that for each element of a monitoring program, the scope of work should be clear. It was pointed out that monitoring should be sufficiently rigorous to engender confidence in decision-makers. Therefore, a protocol that is clear, well defined and transparent is essential. Concern was expressed about the difficulty of demonstrating that any measured or perceived social and economic change in affected communities could be directly attributed to environmental flows. It was suggested that governments might be reluctant to commit or invest in any monitoring program that did not provide specific evidence of benefits attributable to environmental flows. It was suggested that the model adopted for (SECH) monitoring should be sufficiently long term - at least 10 years - to measure benefits.

Nevertheless, it was noted that the purpose of the monitoring program is not confined to demonstrating the benefits of environmental flows. Other goals identified are that:

- it guides future management decisions specifically around environmental flows—for example by presenting comparative scenarios to enable choices between options; and
- it guides broader catchment management decisions in relation to physical, environmental and social and economic planning; and
- it monitors planning and monitoring trends in community sustainability (environment, social, economic and cultural).

Another concern was that the program be sufficiently sensitive to the spatial variations of the region being monitored. For example, the program would need to differentiate between:

- the region above and below the Warragamba dam wall (above is ‘extensive farming’ ie. grazing pastures, whereas below the wall is ‘intensive farming’ ie. horticulture of vegetables); and
- the region above and below Spencer is significantly different for the fishing communities.

Cost of monitoring

Funding was recognised as an issue and some suggested that monitoring programs are considered expensive, but overall they agreed the program should happen. Duplication is to be avoided where possible, for example by utilising the existing monitoring of urban demand management by Sydney Water. In particular, it was suggested that monitoring ‘ancillary issues’, such as the Forum’s recommended effluent reuse schemes and catchment transfers should not incur excessive expenditure. A suggested potential funding source is the proposed ‘Healthy River Surcharge’.

Data coordination

Data management and integration were currently seen as barriers to effective monitoring of SECH impacts because:

- information is fragmented between agencies and councils;
- information being collected is stored and used for different purposes;
- information being collected is of variable quality and reliability;
- geographical boundaries of the information collected are not consistent – some agencies use ABS Statistical Local Areas, others use Local Government Areas and the Department of Health uses Area Health Services boundaries;
- information is often collected as a one-off exercise with little collected on a regular basis;
- institutional barriers make it difficult for information to be released or shared.

It was suggested that the use of written agreements around use and sharing of information between agencies could be developed, such as for the Integrated Water Monitoring Framework (IWMF) (described further in Part E *Administration and Management*).

Community engagement

Community participation in the SECH monitoring component was considered critical by a number of Government agency representatives. It was emphasised that a program aiming to monitor these kinds of impacts needs to meaningfully engage the community as a basic prerequisite. Community participation in monitoring was seen to include the conduct of the monitoring itself and it was suggested that local government provides a locus for community engagement. In contrast, another Government agency representative merely required that monitoring information be 'publicly available'.

Some non-government stakeholders expressed a strong desire for community participation in monitoring. Participation was seen as a means of empowerment and a basis for negotiating potential cross-cultural conflicts. There was a sense of frustration about access to information in the current environment. This was seen to be alleviated somewhat if participation in a Monitoring Program allowed affected communities access to previously unavailable information.

Several stakeholders saw community engagement as a challenge for the monitoring program. It was seen to be critical to demonstrate that participation in monitoring could make a difference to the success of environmental flows. Concerns were raised that public perceptions about river health may not be based on fact or contextual information. The difficulty of attributing these perceptions to environmental flows, as opposed to other factors, was acknowledged. It was suggested that public participation in monitoring is an important educative tool about the outcomes of environmental flows.

Institutional roles in monitoring

Government as well as non-government stakeholders discussed the roles and responsibilities of agencies in monitoring. An integrated, coordinated effort involving a number of Government agencies (eg. DIPNR and NPWS) was seen to be important. It was seen as important that inter-agency partnerships did not lead individual actors avoiding their responsibilities.

Another concern was the ability to maintain long-term monitoring in the context of ongoing institutional change, elections, changes in Ministers, government restructures and policy changes. This was seen to be exacerbated by inconsistencies in both content and timing of policy implementation at Commonwealth and State levels.

A significant amount of research has informed the SECH monitoring component. Some consultation has occurred and sources of available base line data identified. However, the review cannot be described as comprehensive or sufficient for the purposes of commencing the monitoring phase of the program. The SECH design is based on a preliminary scoping of potential impacts drawing on the research undertaken. The detailed design can only be determined with comprehensive and continuing involvement of river stakeholders and local communities. They must be involved in the process of refining the objectives of SECH monitoring, negotiating the relative significance of issues and impacts to be monitored, specifying their information needs and reviewing communication processes and other service delivery options (eg. community education and dispute identification and referral). The recommended pre-monitoring investigations in the initial phases of the Monitoring Program aim to achieve this level of stakeholder involvement.

SECH Issues in the Catchment

The Hawkesbury-Nepean catchment is a vast and diverse region, populated by over 650,000 people and covering 22,000 square kilometres. The cultural diversity of the catchment is indicated by the fact that over 15% of its inhabitants speak a language other than English (HNCMT 2000). An estimated 80–90% of the catchment's market gardens are operated by people from non-English speaking backgrounds (Parker 2000). The largest non-English speaking background groups in the catchment are Chinese, Filipino, Italian and Arabic (HNCMT 2000).

The following geographic framework was developed to summarise the reaches information provided in Part B, where these issues are described in more detail (across the catchment). The framework is based on three broad geographical divisions:

- Upper Nepean and Warragamba reaches above Warragamba River confluence (Reaches 8–19)
- Reaches downstream of Warragamba River confluence (Reaches 20–27)
- Shoalhaven reaches downstream of Tallowa Dam (Reaches 1–2.2)

Each of these is described below, together with a preliminary analysis of the SECH issues that may be significant. They are also discussed in the SECH Program section of this Part of the report. References to the information sources are provided in Appendix D2.

SECH issues in the Woronora and Wingecarribee catchments have not been assessed and the summary of SECH issues in the Shoalhaven catchment is preliminary. For these three catchments, pre-monitoring investigations are essential and must be done with the full involvement of river stakeholders.

Upper Nepean and Warragamba reaches above Warragamba River confluence (Reaches 8–19)

These reaches contain substantial water extraction activities. Irrigation extraction is concentrated in the reaches below Maldon Weir, often drawing from the many Upper Nepean compensation weirs. In addition, there are unknown numbers of riparian extractors, and a number of industrial operations also extract water. Recreational fishing is a significant activity at various points along these reaches. Other river based recreational activities are popular at sites such as Wallacia and Bents Basin and further upstream to Camden. Land-based recreation occurs further upstream as far as Douglas Park. The recreational amenity and cultural heritage values of the river are enhanced by some of the weirs and dams. Together with the river's aesthetic values, recreational amenity contributes significantly to tourism visitation rates in the region.

There are heritage listed agricultural and rural properties with state heritage protection such as Camden Park, Brownlow Hill Estate and Camelot/Kirkham, which reflect the early European settlement of these areas. The Aboriginal cultural heritage in these upper reaches includes rock art sites, middens and stone artefact scatters. All of these sites are often found in association with water, on riverbanks and on rocks exposed to water. The rock art sites are predominantly found on the soft sandstone exposures of the Sydney-Hawkesbury ridges. This type of sandstone is quite susceptible to weathering. It is therefore imperative to ensure that all steps are taken to preserve any known rock art sites.

Reaches downstream of Warragamba River confluence (Reaches 20–27)

All the social and economic activities described above continue along the Hawkesbury–Nepean River below Warragamba dam. Many agricultural operations rely upon STP discharges to maintain sufficient base flows during dry seasons. The Penrith Lakes Scheme will also extract significant quantities of water and returns most of this water further downstream. Commercial fishers operate in the estuarine reaches of the river, including oyster farming and prawn trawling. Recreational fishing is a significant activity along both the freshwater and estuarine reaches. Other river based recreational activities are popular. Between Windsor and Wiseman's Ferry, motor boating and water skiing are the most popular water based activities. The estuarine reaches below Wiseman's Ferry are most commonly used for fishing, cruising, canoeing and sightseeing.

The numerous cultural and heritage sites downstream of Warragamba dam include more weirs, bridges, ferries, punt crossings, protected geological areas, the Penrith Rowing course, mills, early homesteads, cable ferries and various riverine structures associated with settlement of areas such as piers, jetty, boatsheds, submerged historical sites and protected areas of foreshore. The Aboriginal sites include middens, stone scatters, art sites and obviously the value of the river as part of a living cultural landscape.

Shoalhaven reaches downstream of Tallowa Dam (Reaches 1–2.2)

The Shoalhaven River supplies water to its own catchment, with communities and issues that are unique. A Monitoring Program that includes the Shoalhaven River would need to be based on a full scoping of the issues affecting all stakeholders and communities in that catchment. Because catchment transfers create a particular relationship between the Shoalhaven and the Hawkesbury–Nepean, it is essential that communication and cooperative processes be established between relevant Shoalhaven and Hawkesbury–Nepean stakeholders for SECH monitoring to cover the two catchments. Inequity may arise or be seen to arise when catchment transfers occur if the Shoalhaven is experiencing restrictions and Sydney is not.

The new regime of dam releases for the Shoalhaven catchment is planned to commence relatively early in the environmental flow regime. Therefore, the required communication, participation and education processes should commence in the Shoalhaven as one of the early components of the Establishment Phase, continuing into the Pre-Monitoring Phase. Ongoing involvement of Shoalhaven river stakeholders is essential.

The SECH advisers' brief did not extend to a detailed consideration of the Shoalhaven catchment. The issues, concerns and activities outlined below are based on stakeholder and community views reported in the Inquiry into the Shoalhaven River held by the Healthy Rivers Commission (HRC 1998).

- Equity between Shoalhaven and Sydney Water users;
- Degraded native vegetation and weed infestation along riparian corridors caused by farming practices and unfenced livestock;
- The numerous government and community processes currently in operation and their seeming lack of coordination or integration. A particular theme has been distrust between levels of government (and) within the State-level, where roles and responsibilities of each agency are not well understood;
- Poorly managed on-site sewage disposal systems on local waterways;
- A need to integrate floodplain or estuary management;
- Specific regions on the River have high aesthetic and conservation value and should be protected;
- Agricultural activity in the catchment is concentrated around Kangaroo Valley and the Berry area. Along the Shoalhaven River itself, below Tallowa Dam there are relatively smaller levels of irrigation extraction, continuing into non-tidal estuarine tributaries. Improved pasture and horticulture are the main uses for water extracted from the River;
- Subdivision of land for rural residential use is increasing. Rural residential development growth is greatest in the Berry area and Kangaroo Valley. However, there is rural residential development further south, which would be affected by conditions in the Shoalhaven River;
- There is an important commercial fishery and aquaculture industry, supporting a wide variety of fish habitats and species. The main river downstream of Tallowa Dam is an important fish habitat. Recreational fishing is a popular use of the River;
- The Shoalhaven estuary is a popular location for motor boating, water skiing and jet skiing and tourism is a significant industry.

In addition to these social and economic issues, Aboriginal and non-Aboriginal historical cultural heritage issues are present in the Shoalhaven reaches. As with the Hawkesbury-Nepean, the Aboriginal sites include middens, stone scatter sites and rock art sites. The non-Aboriginal historical heritage includes evidence of settlement by European people, for example industrial sites, jetties, punts, bridges and homesteads.

Program Design

The overall objectives of the Forum and the brief provided to the expert panel have guided the design of the SECH component. It is anticipated that over time, policy changes and improved knowledge will need to be accommodated within the overall framework. The program requires participation and advice from relevant government agencies to incorporate the experiences of past and existing programs. The program should provide for coordinated whole of government participation and must accommodate the shifting nature of the institutional arrangements characteristic of these catchments, where agencies are likely to change roles and priorities. This part of the report presents an overview of the framework used to present the SECH issues. The framework is then described in more detail, the priorities are discussed and the stages of implementation are presented.

The monitoring phase involves three strands of monitoring. The monitoring phase of the SECH monitoring component involves three strands of monitoring. These strands are:

1. Regular Monitoring
2. Specific Monitoring
3. Open-Ended Monitoring

Regular monitoring collects core information about SECH impacts associated with longer-term changes to river conditions because of environmental flows. Specific monitoring focuses on shorter-term impacts that may arise during implementation of key river management strategies to provide and protect environmental flows. Open-ended monitoring does not occur regularly, nor does it respond to specific events. Instead, it scans widely for river information from various external sources, such as the media, local newspapers and newsletters by relevant community groups. One of the aims of open-ended monitoring is the early identification of cumulative and/or unanticipated impacts.

While the three strands are distinct, the distinction is not rigid. They complement each other and issues are likely to move from one strand to the other depending on their significance, longevity, geographical distribution and range of stakeholders affected.

Specific monitoring and open-ended monitoring are likely to be the most important strands of the SECH monitoring.program. Open-ended monitoring involves new infrastructure to capture unanticipated impacts as they arise and improve channels of communication with all stakeholders. Specific monitoring targets those issues that are expected to arise during the implementation of river management strategies and have the greatest potential for controversy. By contrast, regular monitoring evaluates the beneficial impacts of environmental flows in the longer-term. A lower risk is associated with failing to adequately monitor beneficial impacts, than failing to adequately monitor adverse and unanticipated impacts. Hence, limited funding should be targeted to ensure that both specific and open-ended monitoring elements are sufficiently resourced.

The design of the SECH component incorporates a phase during which the objectives of the monitoring program are reviewed and agreed by stakeholders. The nature of the agreed objectives will affect the kind of monitoring to be developed. Different stakeholders are likely to have a variety of views on what SECH monitoring is designed to achieve. For river management authorities, a likely objective of SECH monitoring would be to provide accurate and timely information for decision-making; however, the specific objectives preferred within and between each body may vary. Moreover, the objectives of monitoring for river-reliant communities and industries and non-government organisations may be quite different again. These may revolve around engagement in river issues, being able to effectively influence decision-making about the river and ensuring that there is a level of accountability about management of river issues. Different objectives would need to be captured by a comprehensive scoping of stakeholder issues and subsequent negotiation.

Framework of Issues

This research has identified key social, economic, cultural and heritage issues that are likely to be impacted by the implementation of river management strategies and subsequent changes to river conditions, 'the SECH issues'. This section describes these SECH issues. The analysis focuses on the Hawkesbury–Nepean catchment, but touches upon the Shoalhaven catchment, because of the relationship between the two. It is important to note that the identification of the issues is preliminary and subject to ongoing review as part of the adaptive management process.

Two types of issue have been identified. Firstly, eight issues related to the ongoing impacts of changing river conditions on SECH issues. These are likely to require 'regular monitoring' i.e. monitoring on an ongoing basis, beyond the early implementation stages of any river management strategies. These SECH issues are:

- Social and cultural values
- Institutional performance
- Industrial and irrigation extraction
- Riparian extraction
- Commercial fishery activities
- Recreational fishing
- Recreational amenity and river tourism
- Land use and land management

Secondly, nine issues related to the SECH impacts of implementing specific river management strategies were identified. These are likely to require 'specific monitoring' in the earlier stages of strategy implementation. They are identified by the name of the corresponding river management strategy:

- Environmental flow releases from dams
- Demand management – urban consumers
- Demand management – river extractors
- Changes to the level of reliability – urban consumers
- Modifications to access conditions – river extractors
- Catchment transfers
- Stormwater management
- Effluent management schemes
- Weir management

Priorities

All the issues identified in this report are important for inclusion in the SECH monitoring Program. Preliminary priorities have been allocated and are outlined below. These must be seen as provisional, and subject to revision following the pre-monitoring investigations.

As discussed earlier in this section, the two strands of specific and open-ended monitoring are higher in risk and therefore these issues are a higher priority.

More specific priorities were identified within each of the issues. These have been identified in response to the stakeholder survey and from the relevant literature. Some were included based on the judgement of the SECH advisors and the Expert Panel. Feedback from the Forum on initial drafts of this report further influenced the selection of priorities. The priorities are summarised in the following section (*The SECH Program*, Tables D4 and D5).

The tables include a column to indicate whether a priority area is being monitored at present. Further information about the existing data available for each of the priorities can be obtained by reference to Appendix D2: Data Sources. A column in each of the tables indicates where negotiation with government and non-government stakeholders is required to establish new monitoring activities or to improve existing monitoring for the purposes of SECH issues as they related to environmental flows.

SECH Monitoring Implementation

The SECH monitoring is designed to occur over four phases: Establishment, Pre-Monitoring, Monitoring and Audit and Review. The design provides a general framework with ample scope for flexibility and refinement. SECH monitoring requires responsiveness to changing circumstances and information requirements for both river management authorities and stakeholders.

Each phase of the program is described below. In addition, several appendices have been included.

- Appendix D3: Implementation Schedule

  This sets out each phase and breaks them down into likely tasks, together with anticipated timeframes for completion, and overlap in terms of relationships between each phase, seeking to represent the principles of adaptive management.

- Appendix D4: Implementation Budget

  This provides a table of the anticipated budget implications of SECH monitoring, together with the anticipated timeframes associated with them.

- Appendix D5: Summary of SECH Program

  This sets out the three strands of monitoring, by reference to each SECH issue, as a key framework for the program's design.

Establishment Phase

The first phase of the SECH monitoring will establish the required funding and institutional arrangements. Funding is required for a SECH co-ordinator with dedicated responsibility for developing and conducting SECH monitoring.

During the Establishment Phase, the SECH co-ordinator would establish their operational capacities and reporting and accountability structures, including levels of autonomy and authority. The SECH co-ordinator would establish initial processes to communicate and form relationships with key river stakeholders and relevant decision-making bodies. This would include the development of a stakeholder committee under the auspices of the Hawkesbury-Nepean River Management Authority The SECH co-ordinator would also develop the initial public participation process in conjunction with the integrated community awareness program recommended by the Forum[1].

It is envisaged that the SECH co-ordinator will be integrated within the existing infrastructure of the Integrated Water Monitoring Framework (IWMF). This would build on the IWMF model of brokering information from a number of agencies. The Framework co-ordinates collaboration and information sharing in water monitoring activities of all stakeholders in the Hawkesbury-Nepean River Catchment (Mann et al. 2002). It will be necessary at this stage to implement processes for the effective integration of social sciences and other forms of knowledge, such as local community knowledge. The challenges of effectively integrating the social sciences into natural resource agencies and the integration of local and expert knowledge into decision making are discussed further in part E.

Funding and administrative arrangements for a sustainable river fund would also be negotiated during the establishment phase. The proposed fund would be administered to assist river stakeholders to participate in monitoring. The importance of providing resources to facilitate the involvement of local residents and users of the river is affirmed by the social and economic assessment guidelines developed by the Independent Advisory Committee on Social and Economic Analysis (IACSEA 1998, 16).

The sustainable river fund would provide opportunities for community groups and other stakeholders to conduct monitoring activities relating to environmental flows. Reports from these projects would provide

[1] This program is intended to provide community engagement and awareness, in relation to environmental flows and sustainable water management. It is also intended to establish the values, aspirations and needs of river stakeholders. (Hawkesbury-Nepean River Management Forum (2003). *Water and Sydney's Future. Balancing the values of our rivers and the economy. Extract: Draft Summary and Recommendations.* Report from the Hawkesbury-Nepean River Management Forum, Draft version 11 November 2003).

documentation of community interests and priorities. Local community groups (including Aboriginal communities) are in a good position to assess the impacts of changing river conditions for their members. Some government stakeholders would also access the fund, particularly local councils. Specific projects to be negotiated would include those described under each of the SECH issues below[1]. Guidelines and assessment processes for the sustainable river fund would be negotiated during the Pre-Monitoring Phase below.

During the Establishment Phase, it may also be appropriate to commence developing the new infrastructure required for the open-ended strand of SECH monitoring (detailed in the next Section on the SECH Program). However, specific decisions regarding timing and implementation details would be determined in this phase. In addition, the detailed specifications of the open-ended monitoring strand would emerge from the pre-monitoring investigations described below.

Pre-monitoring Phase

Following the Establishment Phase, the SECH co-ordinator will be in a position to undertake the Pre-Monitoring Phase. A number of steps must be completed to enable the full commencement of SECH monitoring. However, certain elements of SECH monitoring can commence earlier than others, and there is overlap between the end of the Pre-monitoring Phase and the Monitoring Phase.

The pre-monitoring phase should have four objectives:

- refine the direction and detailed design of the SECH monitoring
- address knowledge gaps in required baseline data,
- conduct negotiations to utilise and modify existing infrastructure,
- implement new programs and infrastructure.

Different bodies will have primary responsibility for these objectives. The first objective is to be met by specific pre-monitoring investigations co-ordinate d by the SECH co-ordinator. These investigations should be closely linked to the proposed integrated community awareness program. The second objective will be partially met by these investigations, but will largely need to be negotiated with agencies responsible for the catchment. The third and fourth objectives require ongoing collaboration with agencies and other river stakeholders. These objectives would need to be reviewed and agreed by the key river stakeholders as part of the initial engagement and public participation process. This is critical to securing a shared sense of ownership and investment in securing the success of the SECH monitoring.

It is likely that a number of key tasks will need to be undertaken during the Pre-Monitoring Phase. These are:

- Pre-monitoring investigations
- Negotiating collection of required baseline data
- Reviewing existing programs and negotiating modifications and data coordination

- **Pre-monitoring investigations**

  Social and economic pre-monitoring investigations in relation to environmental flows are particularly crucial for the Shoalhaven, Woronora and Wingecarribee catchments, since these catchments have not been examined in detail by the present project. These investigations include a number of key elements. Firstly, a process of stakeholder analysis is required to identify all relevant stakeholders, understand the aspirations and concerns of various stakeholders in relation to the river, and identify opportunities and strategies for increasing stakeholder participation in monitoring.

  Public participation is necessary to obtain agreement on objectives of SECH monitoring, relative significance of issues and impacts to be monitored, specific information needs, meaningful indicators, communication processes and other service delivery options (eg. community education and dispute identification and referral). The first round of river workshops would focus on these

[1] Further suggestions include training and development programs conducted by Indigenous organisations, research into the cultural meaning of the river for NESB users and outreach initiatives with riparian landholders.

requirements. The river workshops process is described in the following section. The first round of submissions from stakeholders would also provide relevant information. To inform their submissions, river stakeholders would be encouraged to conduct internal discussions about preferences relating to the points above.

Public participation would also be used to refine and determine the relative significance of various impacts in the predictive assessments of SECH impacts associated with environmental flows. In particular, distribution of potential impacts amongst stakeholders, which can raise inequity or perceptions of inequity, would be examined through participatory processes.

The pre-monitoring investigations would also contribute to understanding the changing status of social and economic conditions across the catchment, including sources of change and the capacity for communities to undergo further change. This would assist the collection of baseline data for the SECH monitoring (see below).

Cultural and heritage pre-monitoring investigations would aim to identify recorded and potential Aboriginal and non-Aboriginal historical and archaeological material (including submerged sites) by field survey, in order to assess the cultural and heritage significance of the sites most likely to be affected by environmental flows. They would also involve consultation with the community (eg. Aboriginal organisations and local historical societies) to ascertain their views on the cultural and heritage values. The following would need to be carried out:

- conduct detailed background investigations into previous studies in the region and particularly the study area;
- identify all known and potential archaeological sites within the study area;
- produce a predictive model for site locations, densities, types and chronologies that might be expected to occur within the study area;
- carry out a suitable field survey to sample recorded and potential Aboriginal and historical sites;
- produce a statement identifying the heritage significance of the study area;
- consult with the appropriate local non-Aboriginal and Aboriginal community representatives including Native Title claimants;
- submit realistic recommendations and safeguards that will ensure compliance with statutory and non statutory obligations and the protection of significant components of the archaeological resource if they are likely to be affected by environmental flows; and
- prepare a report to meet the National Parks and Wildlife guidelines for archaeological survey reporting and the guidelines of the NSW Heritage Office so that they have access to the data.

Addressing baseline data gaps

Some baseline data relevant to catchment-wide processes will be collected as part of the investigations described above. There are further baseline data requirements in relation to particular SECH issues and programs to fulfil these would need to be negotiated with agencies. Other river stakeholder groups would also be involved in collecting baseline data, by conducting research with their members. The collection processes may be developed using existing agency expertise and by reference to existing guidelines. The costs would be established in consultation with the relevant agencies.

The following baseline data would be high priority:

- Level of participation, including tourist participation, in various river-based recreational activities;
- Economic activity associated with recreational and tourism activities
- Current patterns of irrigation water use from various sources and irrigation methods (including unlicensed irrigators);

- The extent and growth of rural residential development and use of the river;
- Economic viability of commercial fishers and individual operators;
- Current values and concerns amongst local stakeholders and communities (including Aboriginal communities) and stakeholders in relation to the river and environmental flows.

A baseline survey of cultural heritage sites in the river reaches will also need to be done. Field methods involving riverbank based surveys and inspections from the river in some areas will be required to accurately determine the cultural heritage site types present. Baseline site conditions would be required to monitor direct impacts on the sites as a result of environmental flows. The workshops and consultation with community groups will provide input into the social significance of sites recorded during the surveys.

Reviewing existing programs and negotiating modifications and data coordination

The SECH co-ordinator would review data collected by existing programs (including those identified in this Report) and evaluate them for quality and relevance to river stakeholders and adaptive management. This review would also identify and evaluate existing programs that cover the Shoalhaven, Woronora and Wingecarribee catchments.

The review of existing programs would be undertaken drawing on the findings in this Report. Details of existing programs are set out in the SECH program organised in reference to each SECH issue. Using already available data reduces duplication, capitalises on existing infrastructure, with a view to reducing costs, and encourages opportunities for sharing information across agencies. Furthermore, it is important to coordinate programs with consultative processes so that communities are not ‘over-consulted’.

It is important to acknowledge that monitoring or collection of economic and social information relevant to management of the Catchment is in the early stages. For example, the CSIRO Audit of the Sydney Catchments indicated that comprehensive social and economic information on the catchment, either quantitative or qualitative, is rarely collected (CSIRO 2001). Moreover, information collected by existing programs is not directly related to environmental flows and associated SECH issues. Appendix D5 contains a list of existing programs and Appendix D2 a list of data sources.

Information appears to be fragmented, project and agency-specific, and poorly linked between agencies, rendering use by other agencies difficult. Existing programs do not always collect information along similar geographical boundaries; some use local government boundaries, which are similar to but inconsistent with the SLAs (Statistical Local Areas) used by the ABS. The Department of Health uses Area Health Service boundaries, which again do not conform to LGA or SLA boundaries. In addition, most information is not collected on a regular basis for monitoring. The information that is collected regularly is reported at different frequencies and at different times during the year.

The consequences for the design of the SECH monitoring are that while a number of existing programs could be adapted to be more relevant, there is also a need to develop a number of new programs for the specific information required.

The SECH co-ordinator would need to negotiate with agencies modifications to existing programs. This might include what data to collect, how data can be modified to suit changing management requirements, determining new data to be collected and by whom, and to negotiate data sharing arrangements. Negotiations with agencies potentially involved in SECH monitoring will need to take into account the following considerations:

- the agency’s jurisdiction and functional responsibilities (Carley, 1985, 300-301);
- whether the agency has sufficient resources (technical expertise and financial resources) to match the responsibility expected of it (Leistritz & Chase, 1982, 333-349);
- the agency’s role in implementing particular river management strategies;
- existing involvement by the agency in monitoring programs; and
- existing information sharing agreements between agencies.

This would require further examination of the costs expected by agencies to modify their data collection programs or participate in data sharing arrangements. During negotiations about data sharing and coordination, the commitment of participating agencies is likely to be based upon an understanding of reciprocal benefits arising from the SECH monitoring. One benefit for participating agencies is access to a wider and more co-ordinate d set of data on SECH impacts arising in the catchment. Another benefit will be greater input into decision-making processes.

Managing data obtained through participating agencies would be achieved by utilising existing systems where possible. The Hawkesbury–Nepean Integrated Data Management System (HN IDMS) is a key component of the IWMF. It is a web-based application with a user-friendly interface, which allows users to request and retrieve information about water quality (Boey & Mann 2003). This system has potential to be extended and further developed to integrate the regular monitoring of SECH impacts. Alternatively, a similar model with the capacity to interface may be considered. HN IDMS can produce requested reports and present maps, tables and graphs. It is intended that all monitoring activities conducted by State and local government agencies and other organisations in the Catchment be registered with HN IDMS.

Establishing the SECH co-ordinator will require some time. Before the SECH co-ordinator is established, river stakeholder groups are able to contribute to the Pre-monitoring Phase in a number of ways. Accordingly, there is an overlap between these two phases of SECH monitoring (as shown in the Implementation Schedule located at Appendix D3). Suggestions for stakeholder involvement in the Pre-Monitoring Phase before the establishment of the SECH co-ordinator include:

- Review their own data collection processes in light of the preliminary issues identified in this Report;
- Review their own un-utilised monitoring capacity, in terms of potential for new or modified monitoring programs to address preliminary issues identified in this Report;
- Report their data collection programs not identified in this Report or un-utilised monitoring capacity to the Hawkesbury Nepean Catchment Management Authority (HNCMA) and DIPNR;

Monitoring Phase

Following the completion of key tasks associated with the Pre-Monitoring Phase, the SECH co-ordinator would be responsible for coordinating the monitoring phase. In light of the broad range of SECH issues that are likely to need monitoring, a significant proportion of the SECH monitoring processes will be managed and implemented by river stakeholders, particularly government and non-government bodies. The sustainable river fund for example would support relevant bodies to undertake some of these activities. Note that some elements of the monitoring phase may be able to commence before the completion of the pre-monitoring phase.

The primary objective of the SECH monitoring is to evaluate the performance of environmental flows and other river management strategies. Apart from satisfying this formal program requirement, effective reporting of monitoring findings is likely to have additional positive consequences for local communities, such as improved community education and earlier avoidance of potential conflicts. Community education initiatives that communicate information about environmental flows and changes to the river will benefit from much of the information obtained through the Integrated Monitoring Program. Community research on the Upper Nepean weirs conducted by the Institute found that people have very different understandings of environmental flows and the characteristics of the river. Participants across all groups requested information on a broad range of issues affecting the river (Cheney et al. 2003). The need for better delivery of information to the community, preferably through face-to-face meetings, was reiterated in telephone surveys conducted by the SECH advisers. Indeed, if participants are not adequately informed about the topics on which they are questioned, particularly in terms of quality assurance, the successful operation of the SECH monitoring will be hindered.

Often, the early provision of information from a credible independent source — such as the SECH co-ordinator — is sufficient to resolve disputes (West, 1991, 210). This can avoid conflicts at a later stage when they are more intractable and costly for the affected parties. Thus, the capacity for *ad hoc* reporting of monitoring findings is required to respond to information requests by river stakeholders who are well placed to identify areas of concern. For affected parties, access to appropriate methods and expertise to deal with potential issues is likely to improve both the decision-making process and outcomes of adaptive management (Willetts et al. 2003). The SECH co-ordinator would be responsible for providing appropriate information about the specific issues involved and potential avenues for resolving disputes. Disputes that require formal resolution processes will be referred by SECH co-ordinator to more appropriate bodies such as agency-specific dispute resolution services. For example, bodies such as Sydney Water are required to provide an external dispute resolution service that is regularly audited.

The monitoring phase involves three distinct but inter-related strands of monitoring. Issues are likely to move from one strand to the other depending on their significance, longevity, geographical distribution, and range of stakeholders affected. These strands are:

1. Regular Monitoring
2. Specific Monitoring
3. Open-Ended Monitoring

Regular monitoring collects core information about SECH impacts associated with longer-term changes to river conditions as a result of environmental flows. Specific monitoring focuses on shorter-term impacts that may arise during implementation of key river management strategies to provide and protect environmental flows. Open-ended monitoring does not occur regularly, nor does it respond to specific events. Instead, it scans widely for river information from various external sources, such as the media, local newspapers, and newsletters by relevant community groups. One of the aims of open-ended monitoring is to identify cumulative and/or unanticipated impacts early. Open-ended monitoring also has the capacity to improve channels of communication with all stakeholders.

Specific monitoring targets those issues expected to arise during the implementation of river management strategies and have the greatest potential for controversy. By contrast, regular monitoring evaluates the beneficial impacts of environmental flows in the longer-term. A lower risk is associated with failing to adequately monitor beneficial impacts, than failing to adequately monitor adverse and unanticipated impacts. Hence, funding should be targeted to ensure that specific and open-ended monitoring are both sufficiently resourced.

The three strands of the SECH monitoring are summarised in Appendix D5 and outlined in detail later in this report. Appendix D5 lists the various SECH issues, summarises the existing and new programs within SECH monitoring and indicates which of the three strands of SECH monitoring (regular, specific or open-ended) are associated with the various SECH issues.

The section 'SECH Program' in this report provides a detailed description of each strand of monitoring (regular, specific and open-ended). By reference to each strand, there is an analysis of each relevant SECH issue, including a description of existing monitoring programs and data collection processes, a proposed approach to monitoring that SECH issue, including methods and case.

This section is a crucial briefing document for the SECH co-ordinator, as it captures the detail of the findings from the research undertaken in the development of the SECH monitoring. However, once again, it is important to note that consistent with the principles of adaptive management, the SECH co-ordinator will need to ensure that there is ongoing stakeholder engagement in the review and implementation of monitoring programs regarding the SECH issues, as well as an operational capacity to respond to findings and events associated with the Audit and Review Phase.

Audit and Review Phase

The Water Management Act 2000 (NSW) requires DIPNR to review Water Management Plans every five years[1], and requires a panel[2] to audit the Plan. Given the scope of the SECH issues identified, the processes stipulated in the current Act may be insufficient to manage the SECH monitoring required (White et al. 2003). The terms of the review and audit, with the objectives for SECH monitoring, may also be negotiated by relevant stakeholders at the Pre-Monitoring Phase. The outcomes of these negotiations may then be adopted. SECH monitoring for catchment management needs to be sufficiently responsive to changing circumstances, and also be an information tool for river management

[1] s.43(2), WMA.
[2] s44, WMA.

authorities and stakeholders. This flexibility requires that the objectives of the SECH monitoring be periodically reviewed and renegotiated by river stakeholders.

The Natural Resources Commission may have a role in periodic audits of the SECH monitoring and reporting to Parliament in relation to the effectiveness of the Integrated Monitoring Program. This would fit within its high-level independent auditing function for the entire Hawkesbury–Nepean Catchment Area. An inquiry of the SECH monitoring would assess the rigour of the monitoring process and establish whether its findings are sufficiently supported. To enable such an inquiry to occur, the processes and primary data utilised to generate findings must be documented throughout.

The SECH monitoring was designed to incorporate a range of research methods including participatory approaches. These different approaches require appropriate methods of evaluation.

Technical approaches typically involve larger scale studies involving quantitative data, such as indicators of economic performance, customer preferences, or attitudinal surveys. The rigour of data collected using these approaches may be affected by the representativeness of the participants from whom data is being collected. To a limited extent, it also depends on how reliable the data is – for example, replicability of results. Depending on the nature of the data collected, and the kind of evaluation, a range of statistical tests may be employed. These tests have the aim of determining whether changes found are statistically significant, and whether these changes could be attributed to policies that have been implemented. For example, surveys of irrigators being supplied with treated effluent may be found to change over time. The statistical tests appropriate for assessing whether an observed change is significant and may be attributed to use of effluent, depend on the following:

- the kind of questions being asked;
- the nature of the data, and data relating to other factors agreed by stakeholders as also being relevant to attitudes toward the use of treated effluent (for example, economic performance of farms using effluent, cost considerations);
- whether the data was provided by a sample that has been randomly selected from a normal population of irrigators.

These are issues that have yet to be determined by the SECH co-ordinator in consultation with stakeholders (see Pre-Monitoring Phase), and to be considered in the analyses and reporting of the SECH monitoring.

Findings from participatory approaches tend to be qualitative in nature, and evaluated normatively. In participatory approaches to monitoring, the rigour and quality of the findings are driven by considerations around how “goodness” or “trustworthiness” is being judged (Pretty, 1994; Marshall, 1990; Krawetz et al. 1987). The major criteria used to evaluate these include the following:

- the extent to which perspectives of significance from different stakeholders, captured by different methods, compare and confirm each other (triangulation);
- the extent to which different stakeholder perspectives have been captured;
- the extent to which participants know about the relevant issues, and the resulting degree of empowerment this engenders;
- the extent to which there is engagement with stakeholders to build a level of trust in which participants and their local context are valued;
- the extent to which participant stakeholders are able to review the interpretations made of their own input, provide feedback so that monitoring processes are continually improved (participant checking); and
- the extent to which the monitoring is focused on appropriate goals and objectives, and the degree to which these goals and objectives are achieved.

Based on these criteria, there are a number of further approaches to assess the rigour of qualitative findings obtained through the SECH monitoring. Through a peer review process the findings of the SECH monitoring may be investigated and reviewed by qualified social scientists not directly involved in the program and who understand the value of participatory and deliberative research methods. Their role includes thoroughly exploring the assumptions and methods of the monitoring and ensuring these are made explicit where possible. Publication of these assumptions and methods assists decision makers and stakeholders to evaluate the assessment of impacts (ICGPSIA 1994). Feedback about the

SECH monitoring is also required from river stakeholders to enable continuous improvement. “Participant checking” allows stakeholders who have participated in the monitoring to review the interpretations drawn from their input and ensure these are fair.

In addition, the SECH co-ordinator will be responsible for early reporting and feedback of data and findings and recommending modifications to data needs where required. It is anticipated that the findings of SECH monitoring will be reported in a timely fashion, in a number of formats easily accessible for the various different stakeholders, with different information needs. Particular river stakeholders are likely to have specific information needs that can be negotiated, and reporting could be tailored so that each group receives detailed information about their area of interest. Reporting key findings and interpretations can be done through the following, depending on the purpose and intended audience:

- fact sheets (could be produced in a number of languages);
- newsletters – in particular the DIPNR newsletter “The Source”;
- user-friendly web pages (the multimedia issues register, as part of the open-ended monitoring would provide regular publication of issues);
- summary documents.

SECH Program

This section provides a detailed description of each strand of monitoring (regular, specific and open-ended). There is an analysis of each SECH issue with reference to each strand and including a description of existing monitoring programs and data collection processes, a proposed approach to monitoring each SECH issue, with methodologies and case studies where available.

This is a crucial briefing document for the SECH co-ordinator, as it captures the detail of the findings from the research undertaken in the development of the SECH monitoring component. However, once again, it is important to note that consistent with the principles of adaptive management, the SECH co-ordinator will need to ensure an ongoing stakeholder engagement in the review and implementation of monitoring SECH issues, as well as an operational capacity to respond to findings and events associated with the Audit and Review Phase.

This section describes the proposed SECH monitoring component by grouping types of SECH issues with each of the three strands of monitoring. This will help the co-ordinator to negotiate the specific arrangements required for different types of monitoring.

Three stands of monitoring have been identified:

1. Ongoing SECH impacts arising from changing river conditions, which are likely to require **'regular monitoring'**, ie. monitoring on an ongoing basis beyond the early implementation stages of river management strategies;
2. SECH impacts from implementing specific river management strategies, which are likely to require **'specific monitoring'** in the earlier stages strategy implementation; and
3. SECH issues related to the conditions of the river or catchment management in general, (not directly related to environmental flows), which are likely to require **'open-ended monitoring'** to take into account the emergence of unanticipated issues.[1]

This section separately addresses each of the types of monitoring (regular, specific and open-ended).

Regular Monitoring

This section describes existing monitoring programs and proposed regular SECH monitoring, which addresses each of the following issues:

- Social and cultural values
- Institutional performance

[1] With time these issues may be included in the regular and specific strands of SECH monitoring.

- Land and river activities – existing.

The regular monitoring strand of the SECH monitoring component collects core information about SECH impacts from the viewpoint of river stakeholders. It addresses SECH impacts associated with longer-term changes to river conditions as a result of environmental flows. Overall, these changes are expected to benefit most stakeholders. It is important, however, to recognise that the significance of longer-term changes to river conditions will be equally influenced by the way in which these changes are managed and communicated. The regular monitoring strand includes a periodic cycle of formal submissions from all river stakeholders, river workshops and the synthesis and interpretation of existing data by the proposed Environmental Flows Management Committee (EFMC) of the HNCMA (see Part E of this report).

Within each SECH issues, priorities for regular monitoring were identified, however, these must be considered preliminary and subject to revision as a result of the pre-monitoring investigations. These priority areas are listed in Table D4.

Table D4: Identified priorities for regular monitoring within each SECH issue

SECH Issues	Identified priorities for regular monitoring	Exists	TBN*
Social and cultural values	▪ Residents' sense of place		✓
	▪ Aesthetic values		✓
	▪ Appreciation of the river	✓	✓
	▪ Cultural values		✓
	▪ Heritage values.		✓
Water extraction	▪ The reliability of river water available for extraction		✓
	▪ Changes in farm productivity	✓	✓
	▪ Types of crops grown as a result of changed access to river water from environmental flows	✓	✓
	▪ The characteristics of discharges to the river from agricultural and industrial operations.	?	?
Riparian extraction	▪ Number of riparian landholders, their extraction volumes, and their views about changing river conditions.		✓
Commercial fishery activities	▪ Catch weights and economic valuation for various types of fishery resources	✓	
	▪ Economic viability of commercial fishers and individual operators		✓
	▪ Commercial fishers' effort expended on different species and sections of the river		✓
	▪ Navigability of the river.		✓
Recreational fishing	▪ Level of participation in recreational fishing	✓	✓
	▪ Catch quantities for various types of fish	✓	✓
	▪ Economic activity associated with recreational fishing.	✓	✓
Recreational amenity and river tourism	▪ Level of participation, including tourist participation, in various river-based recreational activities		✓
	▪ Economic activity associated with recreational and tourism activities	✓	✓
	▪ Changes in river conditions affecting recreational and tourism activities.		✓
Land use and land management	▪ Urban growth patterns	✓	
	▪ Changes in existing land uses	✓	
	▪ The distribution of extractive industries.	✓	
Institutional performance	▪ Inter-agency coordination and accountability in river management and monitoring		✓
	▪ Public awareness of agency responsibilities and level of trust in government institutions		✓
	▪ Opportunities for public involvement in decision-making		✓
	▪ Voluntary activities related to the river environment.		✓

* TBN = To be negotiated

Social and cultural values

People from different river stakeholder groups will have diverse social and cultural values, depending on where, when and how they relate to the river. Social values refer to people's feelings, attitudes, aspirations and judgements about the river. Cultural values are part of these social values. Values about the river influence the extent to which people interpret change in river conditions as being significantly beneficial or adverse. Values influence people's acceptance of change and their willingness or ability to adapt to new conditions brought about by change.

It is important to acknowledge that SECH impacts from changed river conditions depend upon complex, dynamic inter-relationships. This complexity means that as well as changes in the river environment, other factors like attitudes towards government and interactions with other river stakeholders will be influential. Past interaction with the river and aspirations for the future of the river are important in determining how changes are interpreted.

Monitoring social and cultural values relating to the river should be done regularly, so monitoring objectives and management approaches continue to reflect stakeholder aspirations. Identified priorities for monitoring people's values in relation to the river include:

- Residents' sense of place
- Aesthetic values
- Appreciation of the river
- Cultural values
- Heritage values.

Sense of place refers to how residents feel about their local area and the river as a part the local community's identity. Sense of place could be affected by changes to the river environment, such as changed recreational amenity, modification of weirs, changes in aesthetic values or changes in water quality.

Aesthetic values relate to the sensory appeal, primarily visual, of the river surroundings for recreation and lifestyle activities. It includes changes both to the river and to pools, by structures such as weirs. It includes the sound and odour of the river and may be affected by algal blooms, the colour and turbidity of the water, the visibility of submerged objects during low flows, polluting discharges and stagnation in sections of the river.

Appreciation of the river refers both to people's values regarding the river ecosystem in its own right and to their values about the role it plays in social and economic activities. Often there is some tension between these types of value and different individuals may hold both to varying degrees. A relationship is likely to exist between an individual's appreciation of the river and their knowledge of and views about environmental flows.

Cultural values are those that people hold for sites and places associated with the river relating to their way of life. Cultural value is a dynamic component of the spiritual, social, historic and aesthetic values that all people hold for their environment and for places within that environment. Cultural heritage significance means aesthetic, historic, scientific or social value or even a special value for future generations of Australians, as well as the present community (Australia ICOMOS 1999). In other words, the significance of places depends on the value that people give to a place. It is likely to change over time and be influenced by other aspects of social value that are more immediately visible, such as aesthetic value.

Heritage sites and places, both terrestrial and underwater and Aboriginal and non-Aboriginal, are present throughout the Hawkesbury–Nepean region and are ascribed value by people. Heritage places (or sites) can provide us with important information about past lifestyles and cultural changes that occurred along the river. Preserving and enhancing these important and non-renewable resources is encouraged. Changes in river conditions, particularly in terms of salinity, may have an impact on some heritage sites by increasing their rate of deterioration. This applies particularly to submerged sites of cultural heritage significance, which are already subject to a constant process of deterioration from being in water. Many heritage sites are unlikely to be adversely affected, but baseline assessment and monitoring will confirm this.

Integral to understanding Aboriginal value concerning the river is that it is part of a living cultural landscape that is both physical and spiritual. The river is viewed as part of an environment encompassing complementary environmental, social, cultural, spiritual and economic objectives. Relationship to the environment is very important in terms of understanding Aboriginal belief systems. Aboriginal knowledge is embedded in cultural and spiritual explanations and symbols that manifest as "sites" (that may included archaeological remains) and places within the environment. Any changes to the river are considered to have some cultural impact. However, it is essential to understand that the value Aboriginal people may hold for areas within the catchment may go beyond the physical remains of activity. Therefore, although many Aboriginal sites have been destroyed and land use activities in various parts of the catchment have been substantial, the significance of the area in terms of Aboriginal values remains relatively high.

Existing programs – social and cultural values

Local councils are required to collect information about environmental issues as part of their local State of the Environment (SoE) reporting obligations. This includes a requirement for comprehensive consultation with the local community in the production of the reports. A State of the Environment Reporting Manual was developed by the Hawkesbury–Nepean Catchment Management Trust to guide councils in collecting and reporting information to meet their SoE reporting requirements (HNCMT 1998).

An example of the SoE reporting process is that conducted by the Western Sydney Region of Councils (WSROC), which is responsible for producing a Regional State of the Environment (RSoE) report every four years. The 2000 report was produced by WSROC in collaboration with a number of other organisations, including the Regional Integrated Monitoring Centre (RIMC) at the University of Western Sydney.

The RIMC conducted workshops with a wide range of local community groups. The workshops explored social values and community wellbeing in relation to the environment and made use of community aspirations to develop a shared vision for the future of the region. Workshops were held at locations appropriate for each local group. For example, the workshop for people with rural interests was held at Western Sydney markets early in the morning.

This consultation process increased the level of meaningful community engagement in SoE related monitoring. Community and other interest groups agreed to undertake some monitoring. The report recommended that in order for this to be effective, groups should be supported through a public education program and community capacity building.

A number of past and existing research programs have provided information about values in relation to the river. In 2001, the Sydney Catchment Authority (SCA) commissioned a survey of residents living within the Sydney water catchment (Urbis Keys Young 2001), which assessed awareness and attitudes towards water quality, the cost of water, catchment health and catchment protection issues.

The Sydney Water Corporation customer research program conducts annual and ad hoc surveys of customers about water supply issues. This research has included questions about perceptions of water quality in the Hawkesbury–Nepean River.

Every three years, the EPA conducts a state-wide survey, “Who cares about the environment?” of people’s attitudes toward environmental issues. It includes questions relating to river conditions. The results are reported in the EPA’s State of the Environment reports and can be disaggregated to show Sydney residents’ responses.

In terms of cultural heritage, there are no known programs monitoring Aboriginal or non-Aboriginal places and sites (including underwater sites) in a co-ordinated and integrated way, although assessing likely heritage impacts, both direct and indirect, is required under State legislation. The NSW Heritage Office is the State government body responsible for protecting non-Aboriginal heritage places in New South Wales, including buildings, gardens, shipwrecks and historic archaeological sites. The NSW Heritage Council, through the Heritage Office, administers the *Heritage Act 1977* and has detailed criteria for assessing cultural heritage significance. These criteria are divided into two categories, the nature of significance and comparative significance. Heritage significance is a term is used to describe an item’s value in heritage terms. An important component of heritage significance assessments is understanding that community values change over time concerning what is considered to have heritage value. The heritage values of a site or place are broadly defined as the “aesthetic, historic, scientific or social values for past, present or future generations” (Marquis-Kyle and Walker 1992). This means a place can have different levels of heritage value and significance to different groups of people.

In the past, assessments of non-Aboriginal historical places in NSW have not been particularly rigorous in considering social and cultural values (apart from Conservation Management Plans for specific places). Sites and places are usually identified by studies carried out in response to impact assessments for specific projects. The purpose of these assessments are likely to have been different to that which would be required for evaluating environmental flow impacts.

In general, the Aboriginal heritage assessment process includes:

- consulting with Aboriginal people holding cultural knowledge or responsibilities for country in which the flows will occur;
- identifying Aboriginal heritage values associated with the affected area through written and oral research and field investigations;
- understanding the significance of identified Aboriginal heritage values;
- assessing the impact of the proposal on Aboriginal objects and Aboriginal places;
- describing and justifying the proposed outcomes and alternatives;
- reporting on the Aboriginal heritage impact assessment process and its findings (NSW NPWS 2003, p9).

Proposed SECH monitoring: social and cultural values

Local governments are recognised by communities as the key face of government; for many, local councils are the main source of community building and linkage. Councils conduct surveys of communities for a number of purposes, one of which is to inform strategic, regional and social planning. As such, local government is well placed to play a key role in the monitoring program, particularly through its capacity to engage with local communities.

Potential exists for a comprehensive approach linked to the current local and regional SoE reporting process, for instance by extending the community workshop process conducted by RIMC. The process could be co-ordinated with the other four regional organisations of councils (WSROC and MACROC being two of these) covering the Hawkesbury–Nepean catchment. The community-based indicators developed through the RIMC community workshops could be expanded to include indicators reflecting values about changing river conditions, perhaps for each region to retain local differences in river aspirations. In addition, the SoE Reporting Manual might be updated to advise relevant councils how to report on community values about the river and environmental flows.

A new program of specialised river workshops is recommended for river stakeholders and members of the public. These workshops would collect and inform people's views and values about the river and environmental flows. This is a form of deliberative research, involving not only information collection but also providing information and opportunities for different views and interpretations of a problem to be considered (Willetts et al. 2003). Separate workshops could be co-ordinated in a number of ways: by each local government area, for each major stakeholder group across the catchment, or a combination of these groupings. The RIMC community workshops had a regional approach, involving participants from each interest group. Local councils, local community groups, river stakeholders or an external consultant could carry out the planning and implementation of workshops.

Existing programs should be retained and enhanced. Local government survey processes could be modified to include questions about people's values in relation to the river, where appropriate. Both the SCA survey and the Sydney Water customer preferences research could include additional questions relating specifically to environmental flows and the value people place on them. They might adopt more deliberative approaches by providing more information and opportunities for different views and interpretations of the problem to be considered (Willetts et al. 2003). The SCA survey would need to be conducted regularly and be extended to the entire Hawkesbury–Nepean catchment below the dams. In negotiating information sharing arrangements, other agencies may take on responsibility for administering this survey. In addition, the EPA's survey of community attitudes towards environmental issues could include specific questions about people's values in relation to the river environment, river management and changing river conditions.

The physical monitoring of the targeted areas of Aboriginal and non-Aboriginal heritage sites would be most effective on a three year inspection basis. One example would be a rotating inspection of heritage sites beginning with the reaches above Warragamba Dam one year, the sites below Warragamba the following year and the Shoalhaven the next. A three-year rolling inspection program allows time to collect data regarding any changes to the river and to specific sites most likely to be impacted.

In addition, annual consultations regarding cultural heritage values would include Aboriginal communities and other non-Aboriginal groups such as organised historical societies. The process for consulting Aboriginal communities needs to ensure that relevant groups are included, as there is a wide variety of active Aboriginal communities with interests in the river. The consultation needs to encompass the concept of the river and places as being part of a living cultural landscape and not just focus on physical sites, although those are an important aspect.

The annual consultation process would include a workshop regarding any changes and to receive feedback on any issues and questions the groups might have. Annual newsletters to update stakeholders on significant changes noted during the physical monitoring investigations would complement the workshops.

Institutional performance

Institutional performance relates to how people view the quality of river management and broader decision-making processes. There is evidence that river stakeholders in the catchment are dissatisfied with the performance of government institutions in managing the river as an ecosystem and a natural resource. It is argued that there is excessive fragmentation and overlap of responsibilities amongst different agencies. Consequently, members of the public do not know who is responsible for what aspects of the catchment and there is mistrust of government and frustration about the lack of a genuine say in government decisions. The relationship between government agencies and community organisations is sometimes fraught.

The public needs opportunities to participate in, or contribute to, decision-making processes affecting the river and the catchment. Public participation initiatives will need to continue and their quality from the perspective of participants needs to be monitored. The 2001 CSIRO Audit of the catchment concluded that "there does not appear to have been a systematic framework for evaluating public involvement" and notes that at present "most of this public involvement has been stakeholder-based rather than comprehensively attempting to include the wider community" (CSIRO 2001). Broad public support is required for the successful implementation of river management strategies.

In addition, consultation with Aboriginal groups needs to be thorough, consistent and to involve all groups with a cultural interest in the area. There needs to be an acknowledgment that Aboriginal interest in the management of the river is not restricted to physical sites but encompasses social, environmental, cultural and economic issues around the river.

There are a large number of community-based groups in the catchment working on issues related to the river. They form an important part of the institutional arrangements for the catchment, aiming to involve the community in actively taking steps to improve the river environment. The CSIRO audit suggested, "an overall evaluation of voluntary catchment management activities should be started, at least before the next audit".

New institutional arrangements for providing and protecting environmental flows are expected to improve inter-agency coordination and community involvement. Part of these arrangements will include the management of an Integrated Monitoring Program. The level of participation by the community in the Integrated Monitoring Program should be evaluated, including the appropriateness of Aboriginal representation.

All river stakeholders and local communities are likely to have an interest in monitoring institutional performance issues. At this stage, four priorities for monitoring institutional performance are apparent:

- inter-agency coordination and accountability in river management and monitoring;
- public awareness of agency responsibilities and level of trust in government institutions;
- opportunities for public involvement in decision-making;
- voluntary activities related to the river environment.

Existing programs: institutional performance

The 2001 CSIRO audit of the Sydney drinking water supply catchments convened a Community Audit Reference Panel (CARP) to capture stakeholders' views on catchment management. In a preliminary exercise, the CARP completed the Self-Help Evaluation Framework (SHEF), which identified a number of concerns. These included the lack of accessible information and understanding about current social and economic conditions in the catchment, the commitment of local people to catchment management and the lack of clear links and agreed roles and procedures amongst Government departments and other stakeholders in the catchment.

In 2001, the SCA commissioned a community survey of residents of the Sydney water catchment (Urbis Keys Young 2001) and in 2002, a similar survey was conducted with Sydney metropolitan area residents (Urbis Keys Young 2002). Both surveys included questions relating to public knowledge of regulation and agency accountabilities. They found that about two thirds of respondents could not identify any controls or regulations protecting water quality in the Sydney water catchment area. When asked to nominate which organisations are mainly responsible for protecting water quality in the catchment area, only 12 per cent of metropolitan respondents and 18 per cent of catchment area respondents mentioned the Sydney Catchment Authority. Sydney residents were most likely to mention Sydney Water, while catchment area residents were most likely to mention local councils.

Sydney Water's customer research program has included questions about public knowledge of agency accountabilities and has found that public knowledge is very limited about agency accountabilities for sewerage, waterways, stormwater and environmental flows in the Hawkesbury–Nepean catchment. In particular, there appears to be no public knowledge about which agencies would be responsible for environmental flows (Roseth 2003).

Proposed SECH monitoring: institutional performance

Inter-agency coordination and accountability for river and catchment management should be regularly monitored by the HNCMA–EFMC and may well be audited independently by another body. Monitoring may include completion of surveys by agency representatives as a self-evaluation exercise. The content and format would need to be negotiated by the HNCMA–EFMC with input from the agencies. In addition, other community groups and stakeholder groups not represented on the HNCMA–EFMC could be individually surveyed.

To monitor the public's awareness and perception of agency responsibilities and their trust in government institutions, large-scale surveys are preferable. Some existing programs could be modified in so they are more relevant to this task. Both the SCA survey and the Sydney Water customer preferences research could include additional questions relating specifically to levels of trust in government institutions involved in environmental flows or catchment management. As discussed under regular monitoring of values, the SCA survey would need to become a regular mechanism and be extended to fully cover the Hawkesbury–Nepean catchments below the dams. Other agencies may be involved in negotiations to take on responsibility for extending the existing survey.

The quality of individual opportunities for public involvement in decision-making is most appropriately evaluated by focusing on participants' own reflections about these processes. The overall adequacy of opportunities for public involvement could be assessed as part of the survey on inter-agency co-ordination discussed above.

Evaluating voluntary activities related to the river environment from the perspective of participants requires a new process. Community organisations using volunteers would be well placed to conduct this monitoring. A funding program would need to be made available to these organisations to report on participation levels and the degree of empowerment and satisfaction reported by people who participate in these activities.

Land and river activities - existing

This section describes existing and proposed SECH monitoring of the following existing land and river activities:

- Irrigation and Industrial Extraction
- Riparian Extraction
- Commercial Fishery activities
- Recreational Fishing
- Recreational Amenity and River-related Tourism
- Land Use and Land Management

As some of the activities can be monitored concurrently, irrigation extraction and industrial extraction are considered jointly, as are recreational amenity and river-related tourism.

Irrigation and industrial extraction

Agricultural activities along the river include vegetable growing, plant nurseries, turf farming, orchards and dairy pasture. Irrigators depend upon a sufficient availability of water for their crops throughout the year. However, reliance on water is highest during hot dry seasons, just when the river is at its lowest level.

Changes to the river – in particular changes to the available water within it – have consequences for irrigators' crop choices, crop yields and financial performance. Many irrigators associate reliable water supply with the viability of their livelihood (Cheney et al. 2003). Other impacts may arise, such as the historical or cultural significance farmers associate with certain crops.

The reliability and volume of water available for irrigation extraction may be affected by variable dam releases. Other influencing factors include the quantity of sewage effluent discharged to the river, the availability of recycled effluent and the presence of weirs in the upper Nepean, which are regarded by many irrigators as being responsible for providing secure water. Many other pressures unrelated to the river affect the performance and viability of agricultural enterprises and this broader context needs to be considered when interpreting monitored information.

Major stakeholders with an interest in monitoring irrigation extraction include water user groups, NSW Agriculture, DIPNR and individual irrigators (both licensed and unlicensed).

Industrial operations relying on river water extraction may be affected by changes to reliability of supply and associated river hydrology and water quality. These changes are most apparent during dry seasons, when reductions in base river flows could adversely affect their operations, unless alternative supplies are available. Ready availability and the price of alternative supplies will affect the way in which these changes are perceived.

In the Penrith Lakes Scheme, a series of artificial lakes provides recreational amenity and residential development opportunities. When fully operational it may extract 26,000 ML/a from the Hawkesbury–Nepean, returning most of it further downstream. A highly variable flow regime will affect the Scheme's ability to extract water, since pumping can only occur during periods of moderate to high river flow.

All forms of water extraction have potential consequences for river conditions. Extractions may modify river hydrology, especially during low flow periods. In dry conditions extractions may further exacerbate anthropogenic impacts such as riverbank erosion. The amount and quality of agricultural run-off released to the river is affected by factors such as riparian vegetation, irrigation practices and the use of fire in agricultural practices. In the case of industrial operations, returned water discharges pollutants into the river. In addition, agricultural run-off can affect water quality and silting of the river, especially during wet seasons.

There has been no input from industry associations about which SECH aspects associated with environmental flows are important to them. It is important to engage with this group to understand their priorities for monitoring. At this stage, identified priorities for monitoring SECH issues associated with river water extractions are:

- the reliability of river water available for extraction;
- changes in farm productivity;
- types of crops grown as a result of changed access to river water from environmental flows; and
- the characteristics of discharges to the river from agricultural and industrial operations.

Existing programs: irrigation extraction

DIPNR is currently negotiating a MOU with water user groups to install metering of water extraction by licensed irrigators. The program will result in limited monitoring.

Information relevant to farm productivity is not collected by any one agency and is fragmented. Information directly or indirectly associated with crop yields and farm performance is collected by three major agencies: the Australian Bureau of Statistics (ABS), NSW Agriculture and Australian Bureau of

Agricultural and Resource Economics (ABARE) and DIPNR. The ABS collects, every five years, information on regional irrigated agricultural production. The ABS Irrigation Statistics Catalogue includes data on production area, crop types (including pasture/livestock production) and agricultural yield. However, the CSIRO Audit of Sydney's drinking water supply catchments found that inconsistencies between catchment and administrative boundaries made the collection of economic indicators from sources such as ABS difficult (CSIRO 2001). Further difficulties in using ABS data for monitoring farm productivity are that the ABS only surveys irrigated farms that are larger than 20 hectares, only documents certain types of land use (for example, turf farming is not measured) and only records the dominant land use for each farm.

NSW Agriculture (in collaboration with DIPNR) annually collects financial data related to irrigated production. In addition, the ABARE Irrigated Farm Survey periodically collects detailed whole-of-farm performance and social data. ABARE utilises a range of survey methods including face-to-face, mail or telephone surveys. This data may be purchased from ABARE and the cost depends on specific data requirements.

In unregulated river systems such as the Hawkesbury–Nepean, the number of irrigation enterprises using the river is difficult to estimate. In 1998, NSW Agriculture conducted a desktop study, *Sydney–South Coast Region Irrigation Profile*, to summarise the information available on irrigation activities in the region (NSW Ag 2001; NSW Ag 2001b). The study concluded, "a more comprehensive and consistent approach to the collection of irrigation statistics is needed". It found that basic information about the irrigation industry in the Hawkesbury–Nepean and Shoalhaven catchments is poor, with significant gaps in the information available on irrigation methods. Yields from irrigated crops and estimates of the economic value of irrigated agriculture varied widely.

Information about the price of water licences is available from DIPNR. Where water licence trading schemes are in place, Land and Property Information (LPI) captures all water licence transfer deals on a regular basis. Details captured include: names, location, licence number, purchase price, mortgage, volume and water source. In particular, changes in the unit price ($/ML) of water access licences transferred are likely to be relevant for the SECH monitoring component and indirectly reflect the movement of water to higher value uses.

Existing Programs: industrial extraction

There do not appear to be any programs directly monitoring industrial extraction of river water.

Proposed SECH monitoring: irrigation and industrial extraction

Baseline data is needed on current patterns of water use from different sources such as town water, groundwater and irrigation methods (including unlicensed irrigators). As well, data on the cost of water from these sources is important.

The programs described above, including the metering of licensed extraction, are relevant and should continue. Farm productivity, production areas and the types of crops grown can be assessed at a regional scale using data from ABS, ABARE and NSW Agriculture. Modifications to these programs may be negotiated to obtain more detailed data at various scales.

A new program is required to monitor water extraction from the river. It is important to collect information on irrigation methods used. Water user groups may play an important role in monitoring through surveys or workshops with their members. Water user groups may collaborate with other stakeholders to design and implement the surveys or workshops. Additional measures would need to be taken for irrigators not belonging to the water user groups. The research could collect additional information about costs associated with water use from various sources. Water user groups and industry associations would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Assessment of inequity amongst river extractors is critical. The existing water user groups provide a good forum for discussion about the distribution of impacts amongst irrigators. Additional measures would need to be taken to involve irrigators not part of the water user groups.

Riparian extraction

Riparian landholders have an attachment to the river as an immediate feature of their domestic environment, contributing to sense of place, visual appeal and lifestyle choice. They are entitled to extract water without a licence for non-potable domestic use, such as for stock, gardening or hobby farming.

The quantity and distribution of extractions by riparian landholders is currently unknown, however, there are major concerns about such river extraction. These concerns relate to the way that basic landholder rights to extract water without a licence multiply on subdivision of riverfront land. Increasing rural residential development can involve clearing of riparian vegetation and other land management practices that affect river conditions. While the number of riparian landholders is currently unknown, increasing rural residential subdivision of riverfront properties implies that their numbers are increasing. They are expected to have an interest in environmental flows.

Some factors influencing the relationship between riparian landholders and the river include the availability of water for pumping, the quality of the water, the presence of algal blooms and the aesthetic and recreational values of the river. This stakeholder group enjoys basic landholder rights and will be concerned about any changes to their licence exemption status. Other stakeholders likely to have an interest in monitoring riparian extraction include DIPNR, local councils and the building and development industry. Identified priorities for monitoring are the number of riparian landholders, their extraction volumes and their views about changing river conditions.

Existing programs: riparian extraction

Riparian extraction from the river is not currently monitored. Baseline data on the extent and growth of rural residential development and use of the river appears to be absent.

Proposed SECH monitoring: riparian extraction

It is important to engage with this group to understand how these landholders might participate in the SECH program. The river workshops described under “Social and Cultural Values” provide an ideal opportunity to ascertain the views of riparian landholders. Baseline data on the current number of riparian landholders, their extraction volumes and purpose of extraction might be collected by DIPNR. However, what should be monitored and how it should be monitored will need to be negotiated with affected parties, with the HNCMA–EFMC to facilitate negotiations. This is likely to be a very sensitive issue.

Commercial fishery activities

Commercial fishery operators rely on an abundance of fishery resources within the river. They rely on the river’s estuarine reaches primarily for the purposes of fishing, prawn trawling and oyster farming.

Fish, oysters and prawns are highly sensitive to altered water quality in estuarine reaches. Changes to the estuary affect commercial ocean fish landings, since about 70 per cent of marine species are estuary dependent at some stage of their lifecycle. The estuary is a rich source of food, not only for riverine inhabitants, but also for ocean fish.

Concern about pollution levels and algal blooms can reduce consumer confidence in fishery products. Transient weeds or riverbed siltation can reduce river navigability for commercial fishers. It is expected that environmental flow releases will have long-term beneficial effects on water quality in the estuarine reaches.

Freshwater reaches are important for the movement and breeding of fish. Fish rely on the effectiveness of weir fishways and adequate flows over riffle zones in these reaches. Environmental flows are expected to increase the passage of flows over riffle zones.

Major stakeholders with an interest in the monitoring of commercial fishery issues include commercial fishing associations, stakeholder forums and NSW Fisheries. Currently identified priorities for monitoring are:

- catch weights and economic valuation for various types of fishery resources;
- economic viability of commercial fishers and individual operators;
- commercial fishers' effort expended on different species and sections of the river; and
- navigability of the river.

Existing programs: commercial fishery activities

NSW Fisheries carried out a consultation process with commercial fishers in 2001, as part of an Environmental Impact Assessment for the Estuary Prawn Trawl Management Strategy and the Estuary General Fishery. However, in SECH surveys of stakeholders, some commercial fishery associations expressed dissatisfaction about the consultation process. It was reported that contributions were restricted to representation on specific committees and written submissions. Overall, affected parties felt excluded, with the identification and assessment of impacts left to technical experts.

NSW Fisheries collects information annually on the five estuaries in NSW, including the Hawkesbury estuary. NSW Fisheries provides aggregate figures for the catch weights in the different sectors of the fishery industry and the number of operators on the estuary targeting different species. It reports on aquaculture activities such as oyster farming. Since March 1997, commercial fishers have been required to submit a log sheet providing information such as catches and fishing effort on a monthly basis. The information is entered onto a database managed by NSW Fisheries. NSW Fisheries estimates the economic value of the output from each of the commercial fishery industry sectors. However, these estimates are based on prices at the Sydney Fish Markets and are contested by some commercial fishery associations.

Existing forums for stakeholders to discuss issues of concern include the Estuary Prawn Trawl Management Advisory Committee, which involves industry representatives from each of the five NSW estuaries, NSW Fisheries, and other groups including recreation, conservation and Indigenous interests. A new statutory body, the Fisheries Resource Conservation and Assessment Council (FRCAC), involves peak stakeholder representatives from a number of different stakeholder interests, agencies and scientific experts. The FRCAC advises on the preparation, review and assessment of fisheries management strategies.

Proposed SECH monitoring: commercial fishery activities

Commercial fishery associations indicated in telephone surveys with the SECH group that future assessment of impacts should place more emphasis on community participation and empowerment.

New programs are required to monitor the economic viability of fishers and conduct surveys of individual commercial fishers. Commercial fishery associations may play an important role in monitoring these issues, through surveys of their members. The surveys could target the following characteristics: individual operators working above or below Spencer, targeting different species or having dual endorsements. The surveys may be designed and implemented in collaboration with other stakeholders. Commercial fishery associations would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Existing programs appear relevant and should continue. Catch weights and economic valuation of catches are reported by NSW Fisheries for the Hawkesbury estuary. This program could be adapted to include questions specific to effort expended, navigability of the river and environmental flows. In addition, the program could disaggregate data between commercial fishery above and below Spencer, because they have different target species and hours of operation. The economic valuation of catches could be updated in consultation with stakeholders. Finally, catch data could be reported relative to changes in the abundance of targeted species, changing river conditions and river management such as the Estuary Prawn Trawl Management Strategy.

Recreational fishing

Recreational fishing relies on an abundance of specific fish species, which is influenced by water quality and the capacity for fish movement and breeding. For example, the low flow-variability conditions of the current dam release regime, do not favour popular native species such as the Australian Bass. Reduced navigability due to transient weeds or riverbed siltation affects fish breeding and population.

The aesthetic value of the river and views about water quality can affect the popularity of recreational fishing. This activity contributes to people's sense of place and has cultural significance for local communities, as well as economic value for the fishers themselves and associated industries.

Environmental flow releases in combination with other river management strategies, aim to address these issues and are expected to have a beneficial impact on recreational fishing.

Major stakeholders include recreational fishing associations, NSW Fisheries, local councils and Tourism Board. Currently identified priorities for monitoring are:

- level of participation in recreational fishing;
- catch quantities for various types of fish; and
- economic activity associated with recreational fishing.

Existing programs: recreational fishing

NSW Fisheries conducted a 12-month survey of recreational fishing in NSW in 2000–2001. Most recreational fishing surveys are limited in temporal (one-off) or spatial (single lake / estuary) scales. The purpose was to obtain fisheries statistics on non-commercial components of Australian fisheries. The survey estimates the level of participation, fishing effort and catch by recreational fishers, economic activity associated with fishing and attitude of recreational fishers to prominent fisheries issues. Data were collected at national, state and regional levels.

Proposed SECH monitoring: recreational fishing

The recreational fishing survey appears to be relevant for SECH monitoring and should continue. However, the content and frequency of such a survey would need to be negotiated with NSW Fisheries and other stakeholders. Recreational fishing associations would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Recreational amenity and river tourism

Recreational amenity of an environment is likely to influence both local users and the level of tourism. These impacts are discussed together because preliminary information indicates that they have similar monitoring requirements.

Recreational amenity of the river environment contributes to many people's enjoyment and quality of life. Popular river-related recreation activities include motor boating, water skiing, recreational fishing, canoeing and swimming. Recreational amenity includes land-based uses of the river, such as bushwalking, picnicking, four-wheel driving and enjoying the river environment from parks and paths near the riverbank. In addition, local businesses providing recreational services, such as fishing shops and horse riding, benefit from the popularity of the river.

Past surveys of recreational users have indicated concerns about water quality and aesthetic values, specifically with respect to issues like sewage effluent and blue-green algae. Primary contact recreation activities like water skiing and swimming are strongly affected by water quality and algal blooms. In addition, swimming activities are adversely impacted by high turbidity and large discharges of cold water from Warragamba Dam. Secondary contact recreation activities like motor boating and canoeing are less reliant upon water quality, since the water is unlikely to be swallowed. The prevalence of transient weeds in the water may reduce the navigability of the river for motorboats. The aesthetic value of different sections of the river affects all aspects of recreational amenity, including land-based enjoyment of the river environment.

The recreational amenity and aesthetic values of the river are likely to have some effect on the number of tourists visiting the river. Tourism is popular in the Hawkesbury–Nepean and Shoalhaven catchments and contributes significantly to regional economies. Tourists participate in all river-based recreational activities and some tourist specific activities such as river cruises and houseboats. There is some evidence that widespread publicity of pollution levels in the Hawkesbury–Nepean has created an unfavourable image of river holidays in the region.

Environmental flow releases and associated river management strategies are expected to improve water quality, reduce the incidence of algal blooms and decrease the quantity of transient weeds. The new flow release regime is expected to improve the problem of large discharges of cold water from Warragamba dam, which is likely to benefit swimmers. Cultural sites are likely to benefit from environmental flows in terms of the value people may place on them when the river is perceived as healthy, particularly sites that are utilised for recreational purposes. Such changes will improve the river's aesthetic value and recreational amenity, with beneficial SECH impacts for recreational users and tourism. Improvements to the environmental condition of the river could raise its profile as a natural landmark worth visiting.

Increased recreational use of the river and associated tourism in turn, has the potential to degrade the river environment, if not carefully managed. There are a number of ways in which recreational users affect the river. Boat wash from motor boating and water skiing can accelerate bank erosion and impact on Aboriginal sites such as middens. High levels of boating activity can release chemical pollutants and some untreated sewage discharges. Off-road vehicles can erode fire trails and lead to increased turbidity and bank erosion. Some riparian and tidal foreshores have been cleared or excavated to create beaches and recreation areas. Litter is a problem associated with recreational activities.

Major stakeholders include local communities, recreational services, tourist operators and tourists. Those primarily interested in recreational amenity include recreation groups, operators of recreational activities, NSW Department of Sport & Recreation, local councils, Waterways Authority, NPWS, DIPNR and the EPA. Those interested in river tourism include tourism industry associations, Tourism NSW, ABS, local councils, Regions of Councils and the Greater Western Sydney Economic Development Board. At this stage, there has been no input from recreation or tourism groups about what aspects of monitoring are important to them and these groups should be engaged.

Identified priorities for monitoring are:

- level of participation, including tourist participation, in various river-based recreational activities;
- economic activity associated with recreational and tourism activities; and
- changes in river conditions affecting recreational and tourism activities.

Existing programs: recreational amenity

The Waterways Authority establishes and supports a number of User Groups throughout the state, including the Nepean/Hawkesbury User Group. This group consults relevant communities regularly and provides information about Waterways activities. A number of local community and industry organisations attend these meetings, as well as representatives of government services such as the police and the district health service. The meetings cover a range of concerns and river activities including motor boating, water skiing, recreational fishing and canoeing.

Recreational water quality is a component of the Integrated Water Monitoring Framework (IWMF). The Recreational Water Assessment and Management Program monitors parameters such as water quality, pH, algal and faecal coliform counts, turbidity, temperature and algal blooms. This monitoring occurs at a number of pre-determined sites on the river and the program reports on whether these sites meet the guidelines for primary and secondary contact recreation.

Statistical information about the number of people participating in river-based recreational activities on the Hawkesbury–Nepean and the economic performance of related industries appears to be very limited. The NSW Department of Sport and Recreation and the ABS do not appear to regularly collect such information at this level. Participation statistics for recreational activities are collected at the state and national levels only.

Surveys conducted by local councils to inform strategic, regional and social planning sometimes include components on recreational activities. Some industry associations and local Chambers of Commerce would collect relevant information about their members.

The NSW National Parks and Wildlife Service (NPWS) conducts periodic surveys of recreational users and estimates visitation rates for many National Parks, including several of those in the catchment. These provide a rough indication of participation in land-based recreation along the river.

Riverbank surveys have been conducted by the (then) DLWC as one-off exercises in the past, including the relative popularity of various recreational activities at different sites on the river and assessment of the problems with river conditions that are of greatest concern to recreational users.

Existing programs: river tourism

The ABS collects data on supply and demand for various types of tourism accommodation on a quarterly basis. The information is collected at the Statistical Local Area (SLA) level but could be aggregated to roughly approximate the region covered by the catchment.

Tourism NSW publishes a series of Regional Tourism Profiles biannually that provide data about the activities of domestic and international tourists. However, the Hawkesbury–Nepean catchment is largely included within the Sydney region and hence tourism data cannot be disaggregated for the catchment alone.

Proposed SECH monitoring: recreational amenity and river tourism

New programs are required to monitor the priority areas identified. As such, baseline data will be required. In monitoring the level of participation in river-related recreational activities, such as canoeing, swimming, bushwalking and picnicking, industry associations may participate through surveys or workshops with their members. The process could collect additional information, such as related levels of economic activity and changes in river conditions considered significant by recreational users. Recreation and tourist groups may collaborate with other stakeholders, such as local councils, NPWS and DIPNR to design and conduct the surveys or workshops. Recreation and tourist groups would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Existing programs described above appear relevant and should continue. The Nepean/Hawkesbury User Group offers potential as a wider forum for discussion of changes in river conditions affecting recreational activities and possibly tourism activities. It could involve a wider range of river recreation groups not currently represented. It could be a forum where levels of economic activity associated with various recreational activities are discussed. Negotiations to adapt the forum would involve the Waterways Authority as a host of meetings held by the Nepean/Hawkesbury User Group.

The coordination of existing programs needs to be negotiated by the HNCMA–EFMC with relevant agencies. Riverbank surveys could be repeated on a more regular basis by DIPNR, to obtain ongoing information about recreation activities at various popular sites on the river.

ABS statistics contain information about economic activity associated with tourism accommodation at the sub-regional level. Tourism NSW reports on the activities of tourists at the regional level. This information needs to be disaggregated at the sub-regional level. The research could be adapted to obtain further relevant data on the specific relationship between tourism activities and the river. Research into tourist activities could include their views and preferences in relation to the river's recreational amenity.

Land use and land management

Land use and management affects riparian vegetation and other river conditions such as water quality. These changes in turn can affect fishery resources, recreational amenity and aesthetic values. Land uses and zoning decisions can either reduce or enhance the beneficial impacts of environmental flows and should be monitored on a regular basis. This will assist in anticipating potential SECH impacts for future monitoring and tracking changing patterns of anthropogenic impacts.

This issue is primarily related to the zoning and use of public lands and the zoning of private lands. The nature of private land use is relevant and covered under the issues of river water extraction, riparian extraction and stormwater management. Public land use includes urban development, coal mining and sand and gravel extraction. The potential for increased stormwater runoff due to urban growth is a threat to environmental flows addressed within the specific monitoring strand. Coal mining releases polluted discharges to the river and can cause riverbed subsidence. Sand and gravel extraction from the river has significant impacts on river conditions.

Major stakeholders with an interest in monitoring land uses and management practices include water user groups, NSW Agriculture, DIPNR, environmental groups, commercial fishery associations, recreational fishing associations and individual agricultural operators. Identified priorities for monitoring include urban growth patterns, changes in existing land uses, the number of plots available for rural subdivision and trends in rural residential development and the distribution of extractive industries.

Existing programs: land use and land management

A number of existing programs are relevant. DIPNR has information about the planned and actual distribution of areas zoned for urban development and major development projects. Local councils maintain planning and development records at the local scale. The merger of PlanningNSW and DLWC into DIPNR may have benefits in terms of information sharing about rural residential developments. NSW Agriculture is involved in mapping the availability and use of land for different agricultural practices. The NSW Department of Mineral Resources has information on coal mining and extractive industries in the catchment. The RIMC is currently undertaking a project in which farmers are directly involved in mapping remnant vegetation cover on their lands and current activities undertaken.

Proposed SECH monitoring: land use and land management

Existing planning and development records and reports from DIPNR, local councils, NSW Agriculture and the NSW Department of Mineral Resources would be synthesised. Existing GIS layers would need to be collated for this purpose. Additional information produced by industry associations and universities would be included periodically. Key results of this analysis would be included in the HNCMA–EFMC's regular reporting cycle and inform advice to river management authorities. Information about land use and land management trends would improve the contextual understanding of other findings from the proposed SECH monitoring component. The HNCMA–EFMC may coordinate negotiations with the above stakeholders around data sharing or additional data collection.

Specific Monitoring

This section addresses existing monitoring programs and proposed SECH monitoring for Land and River Activities – Environmental flows, which includes each of the following issues:

- Environmental flow releases from dams
- Demand management – urban consumers
- Changes to the level of reliability – urban consumers
- Catchment transfers
- Demand management – river extractors
- Modification access conditions – river extractors
- Stormwater management
- Effluent Reuse Strategy
- Weir Management

The specific monitoring strand of the SECH monitoring component focuses on key river management strategies implemented to provide and protect environmental flows. The objective of this monitoring strand is to identify specific impacts so that appropriate optimisation strategies may be developed. That is, avoiding or mitigating adverse impacts and promoting and maximising beneficial impacts. These impacts are likely to arise in the shorter-term, compared to the longer-term impacts addressed by regular monitoring. With time, it may become apparent that some strategies are likely to generate impacts of ongoing significance. When this occurs these impacts would be incorporated into regular monitoring.

The SECH issues addressed by the specific monitoring strand may be grouped into two groups. One group of SECH issues relates to the implementation of river management strategies to secure and release environmental flows from dam storages. The other group relates to the implementation of river management strategies that occur below dam storages and generally aim to protect environmental flows once they are released. These river monitoring strategies are primarily the ‘ancillary issues’ referred to elsewhere in this report, but incorporate future management strategies. It is important to acknowledge that how these strategies are managed and communicated to river stakeholders is just as important as the specific impacts they produce.

Within each SECH issue, priorities for specific monitoring were identified based on a number of factors. These priority areas are listed in Table D5. However, the identified priorities must be considered preliminary and subject to revision as a result of the pre-monitoring investigations.

Table D5: Identified priorities for specific monitoring within each SECH issue

SECH Issues	Identified priorities for specific monitoring	Exists	TBN*
Environmental flow releases from dams	▪ The effect of timing of dam releases on prawn catches		✓
Demand management – urban consumers	▪ Urban consumers' views about changing water use patterns associated with demand management	✓	✓
	▪ Urban consumers' views about economic costs experienced in relation to demand management		✓
	▪ Urban consumers' views about the environmental benefits of increased demand management		✓
Changes to the level of reliability – urban consumers	▪ Urban consumers' views about changing water use patterns associated with lower levels of reliability	✓	✓
	▪ Urban consumers' views about economic costs they experience in relation to lower levels of reliability	✓	✓
	▪ Urban consumers' views about the environmental benefits of lower levels of reliability		✓
Catchment transfers	▪ Actual or perceived levels of inter-catchment inequity associated with catchment transfers		✓
Demand management – river extractors	▪ Changes to farming and irrigation practices required for demand management		✓
	▪ Associated changes to farm productivity	✓	✓
	▪ Ongoing and maintenance costs of demand management changes		✓
	▪ Changes to industrial operating procedures associated with demand management		✓
Modification of access conditions – river extractors	▪ Changes to farm productivity or industrial operating procedures associated with changed access conditions	✓	✓
	▪ Changes in the price of water from various sources and in the value of existing licences	✓	✓
Stormwater management	▪ The benefits for river users associated with improved water quality and recreational and aesthetic amenity	✓	✓
	▪ The views of urban residents, the building industry and irrigators about changes and costs associated with stormwater management		✓
Effluent Reuse Schemes	▪ Number of users of recycled effluent		✓
	▪ Capital and ongoing costs for recycled effluent customers		✓
	▪ Characteristics of recycled effluent (quality, volume, pressure and reliability)		✓
	▪ Health impacts for recycled effluent customers and fresh produce consumers		✓
	▪ Consumer perceptions of fresh produce grown with recycled effluent		✓
	▪ Impacts on crop choices or industrial operating procedures		✓
	▪ Impacts on farm productivity	✓	✓
	▪ Improvements in fishery resource abundance, recreational amenity and tourism associated with an effluent reuse scheme	✓	✓
Weir Management	▪ Reliability of water supply for irrigators who extract from the weir pool		✓
	▪ Irrigators' views about alternative supplies of water and any possible compensation measures		✓
	▪ Local community views about the weirs (for example, heritage values, sense of place, aesthetic values)		✓
	▪ Impacts on recreational activities associated with use of the weir pool		✓

* TBN = To be negotiated

Land and River Activities – Environmental flows

This section describes existing and proposed SECH monitoring of the following land and river activities associated with the provision of environmental flows:

- Environmental flow releases from dams
- Demand management – urban consumers
- Changes to the level of reliability – urban consumers
- Catchment transfers
- Demand management – river extractors
- Modification access conditions – river extractors
- Stormwater management
- Effluent Reuse Strategy
- Weir Management

Environmental flow releases from dams

River stakeholders and local communities have come to rely on the services or amenities provided by the existing river environment, which has been shaped by human interventions such as dams and weirs. However, people may, place value on the integrity of the river ecosystem as it was before this kind of intervention. These values about the river in its contemporary and 'natural' states may conflict.

Environmental flows include both transparency/translucency release rules and provision for contingency flows. Environmental flow releases are expected to change the hydrology and ecology of the river. In the longer-term, these changes are expected to improve river conditions and generally have beneficial impacts for river stakeholders. Stakeholders who depend upon good water quality and the abundance of fishery resources may benefit the most. The aesthetic values associated with the river are expected to improve, with fewer algal blooms and weed infestations. However, the complexity of the catchment and the number of other strategies aiming to provide and protect flows mean that it will be difficult to attribute benefits solely to flow releases from dams.

Environmental flow releases from dams could have adverse impacts in the shorter-term. The timing of dam releases, for example, could affect prawn trawlers' access to prawn stocks and reduce catch sizes. Further investigation of how substantial these impacts might be and strategies to avoid them, is required.

All river stakeholders and local communities are likely to have an interest in the monitoring of issues associated with the implementation of environmental flow dam releases. Identified priorities for monitoring are the effect of timing of dam releases on prawn catches. The longer-term beneficial impacts expected because of dam releases are accounted for in the proposed regular SECH monitoring strand.

Existing programs: environmental flow releases from dams

The monitoring of water quality according to safety guidelines is currently being carried out by the SCA. However, there do not appear to be programs directly monitoring SECH impacts associated with the implementation of environmental flow releases.

Proposed SECH monitoring: environmental flow releases from dams

Impacts arising from implementation and management of dam releases will be identified through formal submissions to the River Monitoring Group.

Demand management – urban consumers

Reductions in urban demand for water are expected to free up water available in Sydney's drinking water storages for release as environmental flows.

Continuing and increased demand management may potentially change consumers' water use patterns. If demand management is to be made mandatory, the associated capital and operating costs involved may raise concerns amongst residential and industrial consumers. Differences in demand management measures or costs experienced across groups of urban water consumers and river extractors may raise issues about equity.

Identified priorities for monitoring focus on urban consumers' views about:

- changing water use patterns associated with demand management;
- economic costs experienced in relation to demand management; and
- the environmental benefits of increased demand management.

Existing programs: demand management – urban consumers

Sydney Water investigates urban potable water consumers' views and preferences about a range of issues relating to various options for demand management initiatives. The surveys address views and preferences on issues including:

- views about existing demand management initiatives;
- support for mandatory in-door demand management initiatives, such as dual-flush toilets and water efficient showerheads;
- views about the need to save water in their area;
- rating of their own ability to save further water;
- support for the development of further demand management technology.

IPART in its mid-term review of Sydney Water's Operating Licence recommended that Sydney Water regularly report its demand management program in prescribed format. This format includes a reporting of water consumption by different urban sectors. IPART is investigating longer-term regulatory options for demand management.

Proposed SECH monitoring: demand management – urban consumers

The Sydney Water customer preference research program, coupled with its reporting requirements as stipulated by IPART, will be relevant for monitoring urban demand management. Community education is clearly seen as an important component of demand management and is likely to affect customers' views about the desirability of its impacts.

Further investigation is required to identify customer research initiatives by Shoalhaven Water in relation to demand management to decide whether modification options are relevant.

Changes to the level of reliability – urban consumers

Lower levels of reliability are expected to leave more water available for dam releases of environmental flows. Lower levels of reliability equate to more frequent periods of restriction on outdoor water use, leading to changed water-use patterns and lifestyles. Residential consumers may hold diverse view about these changes, but are likely to be influenced by how the change is communicated and managed.

Some urban consumers (for example, nurseries) require a certain level of reliability for their business operations to function. Changes to reliability may affect the price of water from alternative sources. It is therefore likely that these groups will be more sensitive to change.

Increased water use restrictions may or may not generate significant impacts over time. Variables will include the extent of change in water use patterns, the capacity of customers to adapt to the change and customers' views about the potential benefits of increased restrictions.

It is anticipated that SECH impacts related to the political consequences of decisions about reliability levels, rather than the change itself, will occur more rapidly. It is important these early impacts be anticipated and appropriately managed.

Identified priorities for monitoring focus on urban consumers' views about:

- changing water use patterns associated with lower levels of reliability;
- economic costs experienced in relation to lower levels of reliability; and
- the environmental benefits of lower levels of reliability.

Existing programs: changes to the level of reliability – urban consumers

Sydney water customer-research surveys assess urban potable water consumers' views and preferences about:

- Support for permanent water restrictions as a way to ensure future supply
- Support for various restriction options both under normal and drought conditions
- Support for price increases in water as a way to ensure future supply

IPART determines and reviews the level of reliability and price of water to be supplied by the SCA and Sydney Water. It requires Sydney Water and SCA to develop a process for assessing customer preferences in relation to reliability requirements. This process will involve community consultations about the desirability of changing reliability levels and catchment transfers in Sydney Water's end of term licence review (to be held 2004).

Proposed SECH monitoring: changes to the level of reliability – urban consumers

Sydney Water's customer research assesses industrial as well as residential views about changes to the level of reliability and resultant changes in water use patterns. This research could take into account respondents' awareness about the condition of the Hawkesbury–Nepean and their knowledge of environmental flows. It may be accompanied by deliberative methods that provide more information and opportunities for different views and interpretations of the problem to be considered (Willetts et al. 2003). Greater opportunities for participatory decision-making could be incorporated into the research process.

Catchment transfers

Catchment transfers supplement water available for dam releases and so contribute to longer-term environmental improvements associated with environmental flows in the Hawkesbury–Nepean.

Currently transfers from the Shoalhaven catchment occur in dry conditions, when Sydney's water storages are lower than 60 per cent full. As such, catchment transfers usually occur at a time when the Shoalhaven is undergoing restrictions while Sydney is not. This may cause inequity to arise or be perceived.

Apart from the potential impacts on Shoalhaven residents, the operation of catchment transfers is likely to introduce alien flora, fauna and chemical substances to the Upper Nepean. While this can be minimised using filtering devices, there is some risk of adversely affecting recreational fishers and the condition of the river.

Stakeholders likely to be interested in catchment transfers include the SCA, Sydney urban water consumers and Shoalhaven communities as well as Hawkesbury–Nepean communities. The main priority for SECH monitoring is the actual or perceived level of inter-catchment inequity associated with catchment transfers.

Existing programs: catchment transfers

There is no direct monitoring of Shoalhaven river stakeholder's views about catchment transfers. However, IPART intends to consult affected communities about water balance issues, including the issue of urban reliability and catchment transfers.

Proposed SECH monitoring: catchment transfers

The issues of catchment transfers and urban reliability of water supply are inter-related. Monitoring of both issues needs to be accompanied by sufficient information about the nature of issues and needs facing the Hawkesbury–Nepean and Shoalhaven catchments. Formal channels of communication would be required between stakeholders in the two catchments, to address issues of actual or perceived inter-catchment inequity.

Heritage assessment is required of cultural heritage places and sites regarding the construction of any infrastructure associated with the operation of catchment transfers.

Adverse impacts on recreational fishers in the Upper Nepean arising from catchment transfers would be identified in other strands of the program.

Demand management – river extractors

A high level of river extraction can significantly reduce the improvements in river conditions expected from environmental flow releases. The protection of environmental flows downstream may be assisted by demand management initiatives that seek to reduce water consumption levels by river extractors. This is achieved by increasing the efficiency of water usage through a number of mechanisms. Major river extractors include irrigators, Penrith Lakes Scheme, industrial extractors and riparian landholders.

Demand management for irrigators is expected to change farming practices, crop choices (e.g. higher value crops or those that require less water) and crop patterns (e.g. type, yield, quantity, quality). Demand management for industrial users and the Penrith Lakes scheme may affect their operations.

Adverse impacts may arise for river extractors in relation to upfront equipment costs and ongoing operational costs associated with demand management. Incentives and subsidies need to be examined to address concerns about these costs. However, if demand management subsidies or obligations are applied unevenly, inequity may arise or be seen to arise between different river extractors and between river extractors and urban water consumers. Another economic consideration for river extractors is the pricing of water, since modified pricing schedules may accompany demand management. At present, it has been argued that the low price of river water provides little incentive for river extractors to improve their water efficiency.

Demand management may hold a number of benefits for river extractors, such as improved crop yields in certain situations, reduced loss of soil nutrients due to runoff and improved effectiveness of fertiliser application. Demand management for river extractors is expected to contribute to longer-term environmental improvements associated with environmental flows, thereby generating beneficial impacts for many river stakeholders and local communities.

Identified priorities for irrigators are changed farming and irrigation practices required for demand management, associated changes to farm productivity and the ongoing and maintenance costs of demand management. For industrial extractors, currently identified priority concerns include changes to operating procedures associated with demand management and associated ongoing and maintenance costs.

Existing programs: demand management – river extractors

NSW Agriculture currently implements the WaterWise program, a voluntary initiative targeting irrigators on a farm-by-farm basis, to adopt water efficient methods of irrigation. The information being collected is on a farm-by-farm basis and stored for administrative rather than program evaluation purposes.

Proposed SECH monitoring: demand management – river extractors

The views of river extractors adopting demand management initiatives may be surveyed. Project officers interacting with participating river extractors could administer the survey. Information about the impacts of demand management for irrigators in the Hawkesbury–Nepean region already collected by NSW Agriculture for the WaterWise program may be adapted for this purpose.

Water user groups and industry associations should monitor issues associated with demand management. They would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Case Study: Target 10 Dairy Extension Program

A dairy extension project in Victoria monitored changes for individual farmers over one year. This was done by regularly recording farmers' stories about observed changes and comparing interpretations within these stories. The individual's own interpretation of observed changes was accorded priority, although reviewers provided their own interpretation. In addition, previous data was reviewed and re-interpreted in light of new data. The monitoring was dynamic and adaptive to "reflect a changing world and changing sets of perceptions" (Dart 1999).

Modifications to access conditions – river extractors

Placing restrictions on river extractions during low flow periods is expected to protect environmental flows. Enforcement of these restrictions would require all commercial river extractors to be licensed and metered. In the current regulatory regime, riparian landholders are entitled to extract river water without a licence. Consequently, restrictions or modifying access conditions for riparian landholders is more difficult.

There are number of potential adverse impacts associated with changes to access conditions for river extractors. Such changes may raise the price of alternative water supplies. The number and volume of farm dams may increase to maintain security of supply, thereby impacting on the land available for agriculture as well as land management practices. Irrigators unable to pay for alternative supplies of water could face reduced crops and even crop failure during dry seasons.

A substantial proportion of irrigators are currently unlicensed. Licensing and metering could place an additional administrative burden on farming businesses, which may be a barrier to entering or continuing business. Industrial extractors may require a certain level of reliability for their operations to function, incurring a higher price for water in order to secure this.

Identified monitoring priorities for river extractors are changes to farm productivity or industrial operating procedures associated with changed access conditions and changes in the price of water from various sources and in the value of existing licences.

Existing programs: modifications to access conditions – river extractors

Licensing arrangements can be negotiated through Water Management Committee under the Water Management Act. The committees are required to develop Water Sharing Plans, including an assessment of the potential social and economic impacts for various users. The Committees are responsible for specifying performance indicators to evaluate the success of strategies outlined in the plan. These plans will be reviewed by DIPNR on a 5-yearly basis, but may still lack sufficient responsiveness considering that the tenure of most irrigators' licences last for 15 years.

Changes to access conditions would depend upon the water sharing provisions of this plan and need to be negotiated by the appropriate bodies. Consultation with water users would be necessary to assess the potential social and economic impacts. In the Shoalhaven catchment, the Southern Water Management Committee will be responsible for developing its Water Sharing Plan.

Land and Property Information NSW collects property sales and selling prices but valuations are done every one to six years, or on an as-needs basis by government request. Annual valuations on every property in NSW are passed to NSW Treasury and this information may be made available to other agencies for a fee.

Proposed SECH monitoring: modifications to access conditions – river extractors

The existing programs appear to supply relevant data for monitoring the SECH impacts of changed access conditions. Changes to farm productivity appear to be covered by the regular monitoring of irrigators by NSW Ag, ABS and ABARE. Information about the value of water licences traded is available through the Land and Property Information register. This register provides information on the value of affected lands and economic impacts of changed access conditions.

River extractor groups would have the opportunity to make formal submissions to HNCMA–EFMC as part of its regular planning cycle.

Stormwater management

Stormwater management is expected to improve water quality, potentially leading to beneficial impacts for commercial fishery activities, recreational fishing, recreational amenity and river-related tourism. The aesthetics of the river are expected to improve, which could benefit recreational amenity and river-related tourism.

Stormwater management strategies primarily address urban and agricultural runoff and aim to manage the volume and quality of stormwater released during wet weather. These strategies may require new urban developments to utilise water sensitive designs, or retrofitting of old developments. They may require behaviour changes by urban dwellers, as well as restricting their housing choices. Building and associated industries are likely to be affected by potential regulation imposing stormwater management conditions. Irrigators may be required to minimise run-off, with potential associated costs.

Identified priorities for monitoring are:

- the benefits for river users associated with improved water quality and recreational and aesthetic amenity;
- the views of urban residents, the building industry and irrigators about changes and costs associated with stormwater management.

Existing programs: stormwater management

There are few programs concerned with people's views on stormwater management programs. Sydney Water's customer research included a survey of community views on stormwater management in 2000. It investigated customers' views about problems associated with stormwater runoff, the quality of existing stormwater management and views about agency responsibilities and spending on stormwater management. This appears to have been a one-off exercise.

Proposed SECH monitoring: stormwater management

Further investigation is required to identify stormwater management programs conducted by local councils or Regional Organisation of Councils in the Hawkesbury–Nepean catchment. They could take lead responsibility for monitoring associated changes, which may be incorporated into their social and environmental planning functions.

Sydney Water's customer research program may be expanded to surveys relevant urban areas and to investigate residents' views of any changes (behavioural or otherwise) associated with the stormwater management.

Industries adversely impacted by the implementation of stormwater management strategies would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Effluent reuse schemes

Effluent reuse schemes substitute river water with treated effluent for irrigation purposes. Consequently, water extraction from and sewage effluent discharge to, the river are expected to decrease. Effluent reuse schemes are proposed to be implemented at a number of STP sites.

The benefits of the strategy are primarily from the reduction of sewage effluent discharges to the river and resultant improvements in water quality. For river extractors the supply of recycled effluent is likely to be more reliable than the river and the nutrients contained may lead to some cost savings. Recreational activities, tourism, commercial fishery activities and recreational fishing are expected to benefit. Changed aesthetic values of the river following implementation of effluent reuse may benefit social and cultural values, recreational amenity and river-related tourism.

Effluent reuse has potential adverse impacts for affected river extractors, depending upon the costs they must bear and the characteristics of recycled effluent provided. The costs of obtaining treated effluent are expected to raise concerns if they are significantly higher than the current cost of extracting water from the river. Inequities may result if the cost of recycled effluent or other water supplies differs across extractors. These costs include not only the effluent itself but also associated equipment and required safety procedures. Increased costs may be particularly important where effluent is provided at locations where weir management results in decreased access.

The characteristics of recycled effluent relevant for river extractors include reliability, water quality, volume and pressure. An effluent reuse scheme may have adverse impacts for irrigators if certain crops cannot be grown with recycled effluent, significant changes to farming practices are required, or the long term exposure to recycled effluent causes soil to become increasingly saline or otherwise polluted. Some industrial consumers may require a high quality grade of recycled effluent for their operations. Recycled effluent characteristics are directly associated with cost, because higher grades of recycled effluent are expected to be more expensive.

Finally, consumer reaction to crops grown with recycled effluent may lead to an adverse impact for irrigators if they face lower market demand.

The identified priority areas for monitoring the implementation of an effluent reuse schemes are:

- number of users of recycled effluent
- capital and ongoing costs for recycled effluent customers;
- characteristics of recycled effluent (quality, volume, pressure and reliability);
- health impacts for recycled effluent customers and fresh produce consumers;
- consumer perceptions of fresh produce grown with recycled effluent;
- impacts on crop choices or industrial operating procedures;
- impacts on farm productivity; and
- improvements in fishery resource levels, recreational amenity and tourism associated with an effluent reuse.

Existing programs: effluent reuse

Existing ABS, ABARE and NSW Agriculture statistics address farm productivity. Beneficial impacts for recreational amenity, tourism and fishery resource levels would be monitored within the respective SECH issues listed under the regular monitoring strand.

Sydney Water customer research includes surveys assessing public knowledge of the role of recycled effluent in reducing effluent discharges to waterways and their views about using recycled water for various purposes. Recently, surveys were conducted with residents in the Rouse Hill Development Area, investigating their views of the recycled water scheme that is incorporated in the development.

The Department of Health conducts a NSW Health Survey program, to interview around 17,000 NSW residents each year. Information collected relates to public health in general and not specifically to health impacts associated with irrigation activities. Translations to other languages are available. This is relevant when considering that a significant proportion of irrigators have non-English speaking backgrounds.

Proposed SECH monitoring: effluent reuse

The implementation of effluent reuse schemes will be a complex multi-agency exercise with Sydney Water likely to be the lead agency. The Proposed SECH Monitoring would need to be coordinated by effluent reuse working group(s), comprising representatives from government and non-government stakeholders. It would provide an opportunity for discussions and negotiations to occur between these parties and for the interpretation of information and negotiations around changed or additional information requirements. The specific terms of reference for the working group would need to be negotiated between affected stakeholders and those responsible for the implementation of an effluent reuse scheme.

There are a number of agencies that would have an interest in monitoring the effluent reuse schemes. Sydney Water is required to comply with safety requirements set out under its Operating Licence and has an MOU with NSW Health for this purpose. However, the NSW Health Survey could undertake specific surveys to monitor safety guidelines and health incidents for individuals working with recycled effluent. NSW Agriculture has the capacity to assess water quality for irrigation purposes and could be involved in monitoring effluent characteristics in relation to crop needs. Research into produce grown with recycled effluent may be required, including consumer perceptions of this produce. The Sydney Water customer research program could survey users of recycled effluent and produce consumers. The content of the surveys could be negotiated with water user groups, industry associations, NSW Health, NSW Ag and DIPNR. Monitoring farm performance could rely on existing statistics collected by the ABS, ABARE and NSW Agriculture. Monitoring farm performance in relation to effluent reuse ideally requires data at the individual farm level, which may be difficult to obtain from these statistics.

Water user groups and industry associations (in collaboration with the agencies responsible for implementing an effluent reuse scheme) may play an important role in monitoring SECH impacts associated with use of recycled effluent. They could be responsible for surveying their members who are participating in the scheme. The surveys could commence during implementation and continue over time. It would be desirable for this ongoing consultation to be accompanied by information and advice at the individual farm level. Water user groups would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Weir management

The various weirs on the river vary greatly in working characteristics and states of repair. Weir management may include weir modification to ensure fish movement and passage of environmental flows, repair of weir structures and fishways, or removal.

River stakeholders value weirs for a number of reasons. Weir structures may be a feature of the local heritage that contributes to residents' sense of place. Weir pools provide greater reliability of supply for irrigators drawing from the weir pool. Weir pools are used for recreational fishing and other recreational activities.

Impacts of weir management will vary depending upon the extent of changes made and the way they are managed. Adverse impacts potentially arise if changes to the visual appearance of the weir affect the sense of place for local residents or the aesthetic value of the weir site. Weir modification may impact on the heritage significance of the weirs. Any reductions in the level of the weir pool following modification are expected to reduce the reliability of supply for irrigators extracting from the weir pool. In addition, lower weir pool levels may reduce opportunities for recreational users.

The construction or repair of fishways has long-term beneficial impacts for commercial and recreational fishers. These include improving the movement and breeding of fish in the freshwater reaches. The modification of weirs to allow increased passage of environmental flows downstream will extend the beneficial impacts of environmental flows.

Identified priority areas for monitoring SECH issues associated with the implementation of weir management include:

- reliability of water supply for irrigators who extract from the weir pool;
- irrigators' views about alternative supplies of water and any possible compensation measures;
- local community views about the weirs (for example, heritage values, sense of place, aesthetic values);
- impacts on recreational activities associated with use the weir pool.

Existing programs: weir management

There do not appear to be any programs specifically related to weir modification.

Certain weir modification projects would require an Environmental Impact Statement to be prepared. Irrigators who draw from weir pools, recreational users and the general public would have an opportunity to provide input on their views about the proposal.

Recent community research on weirs in the Upper Nepean found there were different perspectives from four main groups: general public, community groups, water users (irrigators and recreational users) and Indigenous people (Cheney et al. 2003). All of these groups requested more information about the issues involved and were concerned to be involved in decision-making about the removal or modification of weirs.

SECH monitoring: weir management

Environmental impact assessment (EIA) processes would supply some information identified as important by participants in the Weirs research. It is preferable that the EIA include a variety of mechanisms for obtaining views of stakeholders and local communities beyond legislated requirements. Information about potential impacts on heritage values would be required. This would assist the development of the proposal and the ongoing management of weirs.

Water User Groups (in collaboration with other relevant agencies) would be responsible for assessing and monitoring impacts on irrigators. Recreational user associations and fishing clubs could monitor the views of their members. All stakeholders would have the opportunity to make formal submissions to the HNCMA–EFMC as part of its regular planning cycle.

Open-ended Monitoring

The open-ended monitoring strand of the SECH monitoring component serves a number of important purposes. It is designed to capture a range of issues as they arise. They need not be directly related to environmental flows but may be related to the conditions of the river or catchment management in general. This takes into account the emergence of unanticipated issues, which with time may be included in the regular and specific strands of SECH monitoring. Open-ended monitoring contributes to an understanding of the broader catchment context. This understanding will assist interpretation of information provided by regular and specific monitoring. The open-ended strand of the SECH monitoring component provides an interactive forum for the identification of issues and ongoing communication with stakeholders about the meaning and significance of change. In this forum, interpretation is negotiated and jointly constructed by participants. A key feature of a Monitoring Program should be public accountability. Parameters around which to organise information will need to be agreed and be made publicly available so people understand the scope and purpose of open-ended monitoring. Public reporting would present information to stakeholders and the public, allowing a range of interested parties to engage with issues as they arise and monitor responses from agencies.

Potential sources of information

1. **News media record**

   This would involve the regular collection of relevant items from newspapers, television and radio programs and newsletters published by Government and non-government stakeholders (including Aboriginal groups). This could include newsletters by local community organisations and other river stakeholders.

2. **Organisational documents and research**

   This would involve the regular collection and analysis of plans, strategies, records of decisions and relevant project reports arising at the local government, State and Federal levels impacting on river conditions or the implementation of river management strategies. Publicly available research relevant to SECH issues would be reviewed and analysed to extract any information about important trends in the catchment. For example, demographic data and regional economic figures would provide a context to interpreting specific monitoring data.

3. **Multimedia issues-register**

   The multimedia issues-register would record the views and concerns of stakeholders and individuals on river changes. Contributions to the issues-register could be made by telephone, email, fax or post. It could be made publicly available through the Internet. Moderated dialogue around each of the issues raised would occur by facilitating ongoing participation of interested parties. Information requests could be submitted and responses provided by the appropriate agencies.

A similar initiative is the issues-log maintained by the Murray–Darling Basin Commission on the website of The Living Murray Project. It summarises major issues and questions emerging from community engagement activities and forums or submitted in writing, email or by telephone. The issues-log provides space for a Government response to each issue.

4. Community River fund: monitoring and evaluation

Information gathered from monitoring and evaluation activities are likely to be an important contribution to the open-ended monitoring and some of the specific monitoring associated with river management.

Conclusion

In this part of the report, SECH monitoring has been described as a component of the Integrated Monitoring Program. In particular, a description of the methodology used to design the program and the main design features.

The four phases to implementing the SECH monitoring component have been set out, namely the Establishment Phase, Pre-Monitoring Phase, Monitoring Phase and the Audit and Review Phase. At the end of this part of the report, is a series of appendices presenting this information in tables.

The implementation of the SECH component of the Integrated Monitoring Program will need to be supported by adequate and accessible long-term funding. The management arrangements to support the implementation of the SECH monitoring component are set out in Part E: Administration and Management, which deals with the management arrangements for the complete Integrated Monitoring Program.

As important as the monitoring of the social economic cultural and heritage issues are, it is worth noting that there are practical limitations to SECH monitoring in a region as large and socially diverse as the Hawkesbury–Nepean. These limitations need to be clearly understood so that expectations of the program are not unrealistic. They include:

- biophysical impacts resulting from changed flow regimes may be relatively small and not significant on a human scale;
- changes relating to environmental flows, especially SECH impacts, may take years or even decades to manifest;
- changes are interpreted significantly by some stakeholders but not by others;
- it is impossible to monitor all the dimensions of SECH impacts in such a large and diverse system, because change has a way of creating other changes;
- it is difficult to draw direct causal links between changing river conditions and SECH impacts because of broader social change processes occurring simultaneously;
- cumulative impacts are catchment or regional in scope, rather than confined to specific locations;
- there are likely to be many unanticipated impacts that arise through complex interactions of river management strategies being proposed.

These limitations are noted, but do not undermine the importance and efficacy of the proposed SECH monitoring design. They do not prevent effective SECH monitoring and management, but they do indicate the necessity to carefully link monitoring and management to environmental flows. Involving agencies, experts, Indigenous communities and the wider community at the earliest stages is critical to ensuring that the program is relevant and responsive.

Appendix D1: Case Studies

Case study: Shoalhaven Reclaimed Effluent Management Scheme (REMS)

REMS is one of Australia's largest water recycling schemes. Since 2002, four sewage treatment plants (STPs) supply irrigation water to 370 hectares of dairy farms, golf courses and sporting fields. This capacity is set to double in 2006 when two further STPs join the Scheme. According to the Shoalhaven City Council, a key success factor for REMS has been the ability to involve key stakeholders, such as user groups, in the consultative process to ensure the Scheme was tailored to their specific needs (Tomkinson 2002). The Scheme attempted to ensure this involvement from the outset. REMS was one of seven alternative wastewater management strategies originally put to the community. Community survey responses favoured land application of recycled water. Negotiations between government organisations and local communities commenced in 1989. A technical advisory group was formed to include all affected parties. After eight years of initial consultation, an EIS for the Scheme was exhibited.

Two special committees were formed to develop a Monitoring Program and obtain input from users. The Monitoring Liaison Committee (MLC) was made up of government and community representatives and oversaw a baseline-Monitoring Program and developed the ongoing integrated monitoring program. It is believed that continual liaison with users is required to ensure their needs are met and benefits flow to all stakeholders. The Monitoring Program is intended to undergo continual review and refinement through stakeholder input and operational experience. The Farm Irrigation Committee (FIC) was made up of farmers and other users of recycled water. Negotiations with users were carried out to tailor the development of the Scheme. For example, after the dairy industry was deregulated and profits dropped, the Scheme subsidised equipment costs for participating farmers and provided a free supply period. Ongoing user input into the management of the Scheme is sought through the REMS Management Advisory Board.

Case Study: Murray–Darling Basin Commission and the Living Murray Project[1]

The Murray–Darling Basin Commission is currently grappling with similar issues to those faced in the Hawkesbury–Nepean and nearby catchments. The Living Murray Project involves environmental flows and a number of other river management initiatives. The Commission seeks to assess the impacts for local communities and river stakeholders both through technical assessments of impacts and by engaging with affected parties and listening to their views and concerns.

The technical component of impact assessment was addressed by establishing an independent Social and Economic Reference Panel, made up of social science professionals. The purpose of the Panel is to advise the Commission on methods for assessing social and economic impacts and help guide the various studies and consultations undertaken. To this end, it is developing a detailed plan of information collection, analysis and consultation. Ongoing social and economic analysis is expected to inform the implementation of decisions by the Commission.

Community engagement is a critical component of the Living Murray Project. A Stakeholder Profiling Study was conducted to understand key stakeholder values that were salient to the project. This showed overwhelming support for the provision of environmental flows, but the level of support was halved if decisions about environmental flows did not involve stakeholders. The Murray–Darling Basin Commission established a number of bodies dedicated to increasing community engagement and communication between government and stakeholders. These include a three-person Independent Community Engagement Panel (ICEP), a Community Reference Panel (CRP) and a Community Advisory Committee (CAC). The ICEP observes the community engagement process and ensures that community feedback informs decision-making. The CRP provided a range of community viewpoints throughout the development of the Living Murray Project. The CAC advises the Ministerial Council and communicates the views of Basin communities.

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[1] This case study is based upon information sourced from the following documents: Murray-Darling Basin Ministerial Council 2002; MDBC 2002; MDBC 2003a; MDBC n.d.; Nancarrow & Syme (2001).

Community engagement is planned to occur over three stages. Stage 1 informed the community about the Living Murray Project and conversely enabled communities to inform the Commission about its local knowledge, values, aspirations, issues, information needs and concerns. Stage 2 involves establishing what is needed to manage and keep track of the social, cultural, economic and environmental impacts of any decision. Community engagement meetings are currently being held. Stage 3 will involve the Ministerial Council considering the outcomes of community engagement to date and negotiating details and timeframes for implementation with the community. It was expected that this process of negotiation would take up to three years.

Appendix D2: Data Sources

• Western Sydney Regional State of the Environment Report 2000 (WSROC 2000)
• Sydney Catchment Authority community awareness and attitudes surveys (Urbis Keys Young 2001; 2002).
• Department of Environment and Conservation survey "Who Cares about the Environment?" (EPA 2000)
• Sydney Water Customer Research Program (SWC 2002)
• NSW Heritage Office assessments of non-Aboriginal heritage places (NSW Heritage Office 2003)
• Western Sydney Social Profile (WSROC & UFP 2002)
• Australian Bureau of Statistics demographic data (ABS 2001; 2001b).
• NSW Department of Urban Affairs and Planning population projections for Sydney local government areas to 2021. (DUAP 1995)
• Shifting suburbs: Population Structure and Change in Greater Western Sydney (WSROC & UFP 2003).
• Council surveys of local communities to inform strategic, regional and social planning
• Australian Bureau of Statistics data on regional irrigated/ agricultural production (area, crop type and pasture/livestock production and yields) (ABS 2002b).
• Australian Bureau of Agricultural and Resource Economics – Australian Farm Surveys Report (ABARE 2002).
• NSW Agriculture – financial data related to irrigated production.
• NSW Fisheries estuary production data (NSW Fisheries 2003).
• NSW Fisheries recreational fishing survey (Henry & Lyle 2003).
• Nepean/Hawkesbury User Group minutes of meetings available from the Waterways Authority of NSW.
• Recreational Water Assessment and Management Program (Integrated Water Monitoring Framework) (Sonter et al. 2002)
• NSW National Parks and Wildlife Service – National Parks visitation rates and surveys of recreational users.
• Riverbank surveys of recreation users conducted by the (then) Department of Land and Water Conservation (Lindsay 1998; 1998b).
• Australian Bureau of Statistics Tourism Accommodation Data (ABS 2003)
• Tourism NSW Regional Tourism Profiles (Tourism NSW 2002b).
• Tourism New South Wales Estimates of tourism visits, nights and visitor expenditure (Tourism NSW 2002).
• Greater Western Sydney Economic Development Board – Economic Fact Files for Local Government Areas in the region (GWSEDB 2001).
• NSW State Government urban development projections (eg DUAP 2001)
• NSW Agriculture maps the availability and use of land for different agricultural practices (NSWAg 2002).
• Australian Bureau of Statistics – data on numbers of building approvals in different regions (ABS 2002)
• NSW Department of Mineral Resources information on coal mining and extractive industries in the catchment (Minerals 2003).
• Local council land use and development records.
• Land and Property Information NSW produces data on property sales and selling prices and annual valuations of NSW properties.
• NSW Department of Housing Rent and Sales Reports (Housing 2001).
• NSW Department of Health – NSW Health Survey Program (Williamson, Baker and Jorm (2001)).

Appendix D3: Implementation Schedule

SECH Monitoring Phases and Tasks	Monitoring tasks and activities for year 2004-2019															
	‘04	‘05	‘06	‘07	‘08	‘09	‘10	‘11	‘12	‘13	‘14	‘15	‘16	‘17	‘18	‘19
Establishment Phase and Ongoing																
Establish SECH Co-ordinator (within IWMF Group)																
Establish environmental flows committees within HN Catchment Management Authority (see Part 5)																
Establish infrastructure for open-ended monitoring																
Establish sustainable river fund																
Commence Shoalhaven communication processes																
Pre-monitoring Phase																
Conduct pre-monitoring investigations																
Negotiate collection of required baseline data																
Review quality and relevance of existing programs																
Negotiate modifications to existing programs and data coordination																
Monitoring Phase																
Conduct regular monitoring of SECH issues																
Conduct ongoing open-ended monitoring																
Conduct specific monitoring: Environmental flow releases from dams																
Conduct specific monitoring: Demand management and changes to reliability for urban consumers																
Conduct specific monitoring: Demand management and modifications to access conditions for river extractors																
Conduct specific monitoring: Catchment transfers																
Conduct specific monitoring: Stormwater management																
Conduct specific monitoring: Effluent reuse schemes																
Conduct specific monitoring: Weir management																
Audit and Review Phase																
Conduct audits and reviews of the SECH monitoring on a regular basis																

Legend:

The grey regions indicate the general boundaries of each of the four phases of the SECH monitoring: establishment, pre-monitoring, monitoring and audit & review. Note that individual tasks do not necessarily conform strictly to these boundaries. Several tasks continue throughout the duration of the SECH monitoring, beyond the phase in which they commence.

The arrows indicate the beginning and end of individual tasks. Where tasks are ongoing for the duration of the SECH monitoring, there is no closing arrow. Some tasks involve regular cycles of action, as indicated by the solid arrows. Other tasks involve actions that occur irregularly in response to other factors, and these are indicated by dotted arrows.

Appendix D4: Implementation Budget

SECH Monitoring Phases and Tasks	Pre-Monitoring • Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Establishment Phase and Ongoing (partially funded)		
SECH co-ordinator - Salary	$0	$100,000
Sustainable River Fund	*$tbd*	*$tbd*
Pre-Monitoring Phase *(unfunded)*		
Social and economic pre-monitoring investigations*[1]	*$350,000*	$0
Cultural and heritage pre-monitoring investigations*[2]	*$240,000*	$0
Monitoring Phase *(unfunded)*		
Regular monitoring – social and economic issues	$0	*$tbd*
Regular monitoring – cultural and heritage issues:	$0	*$130,000*
Audit & Review Phase *(unfunded)*		
Regular auditing and reviews of SECH monitoring	*$tbd*	*$tbd*

Notes:

At this stage it is expected that additional costs will be involved. Figures in italics represent estimated costs which have not been funded within the Integrated Monitoring Program. The symbol "tbd" indicates that costs for this task are to be determined through further negotiations with agencies and other stakeholders.

*[1] Estimates for social and economic pre-monitoring and monitoring costs are extrapolated from cost estimates provided by (then) DLWC publication by Harwood, A. (2001). *Social and Economic Analysis and Impact Assessment for Sydney South Coast Groundwater Management Plans*. Socio-Economic Services Unit, Department of Land Water Conservation, May 2001.

*[2] Estimates for cultural and heritage pre-monitoring and monitoring costs are provided by Biosis; dated Aug 18 2003. A breakdown of the pre-monitoring costs is provided below (GST not included):

Cultural and heritage issues - pre-monitoring phase	
Background research	$64,650
Targeted baseline field survey	$49,996
Consultation	$51,720
Reporting	$68,960
Total	**$235,326**

Appendix D5: SECH Program

SECH Issues	Existing Programs*	New Programs	Type of Monitoring			Socio-Econ. Pre-Monitor.	Cult. Heritage Pre-Monitor.
			Specific	Regular	Open-ended		
Social and Cultural Values	SCA; SWC; Council surveys; RSoE; SoE; DEC; Heritage	River workshops; Indigenous consultations; Heritage monitoring		✓	✓	✓	✓
Institutional Performance	SCA; SWC	Stakeholder monitoring		✓	✓	✓	
Land and River Activities - existing							
- River Water Extraction (irrigation & industrial extraction)	ABS; ABARE; NSWAg; LPI licenses; DIPNR metering	Stakeholder monitoring; Submissions		✓	✓	✓	
- Riparian Extraction		River workshops		✓	✓	✓	
- Commercial Fishery activities	NSWFisheries	Stakeholder monitoring; Submissions		✓	✓	✓	
- Recreational Fishing	Rec. Fishing Survey	Submissions		✓	✓	✓	
- Recreational Amenity and River Tourism	NHUserGroup; IWMF; NPWS; ABS; TourismNSW; Riverbank surveys	Stakeholder monitoring; Submissions		✓	✓	✓	
- Land use and land management	DIPNR; NSWAg landuse; ABS; RIMC; Minerals; Council planning			✓	✓	✓	
Land and River Activities – environmental flows							
- Environmental flow releases from dams		Submissions	✓		✓	✓	✓
- Demand management – Urban consumers	SWC		✓		✓	✓	
- Demand management – River extractors	NSWAg	Individual surveys; Stakeholder monitoring; Submissions	✓		✓	✓	
- Changes to the level of reliability for urban consumers	SWC		✓		✓	✓	
- Modifications to the access conditions for river extractors	WMC; LPI	Submissions	✓		✓	✓	
- Catchment transfers		Heritage assessment	✓		✓	✓	✓
- Stormwater management	SWC	Submissions	✓		✓	✓	
- Effluent Reuse Schemes	SWC; Health	Working Group; Stakeholder monitoring; Individual surveys; Submissions	✓		✓	✓	
- Weir Management		Stakeholder monitoring; Submissions; Heritage assessment	✓		✓	✓	✓

* See Legend overleaf for abbreviations.

Legend to Appendix D5:

The various SECH issues listed in the far left-hand column correspond to the headings utilised in this report. The next two columns summarise the existing and new programs within SECH monitoring, respectively. The following lists explain the abbreviations used.

Existing programs:

ABARE: Australian Bureau of Agricultural and Resource Economics – Irrigated Farm Survey

ABS: Australian Bureau of Statistics – data on irrigated agriculture and regional tourism

Council surveys: Local Councils – community surveys

Council planning: Local land use planning and development records.

DEC: NSW Department of Environment & Conservation – Survey of community attitudes – "Who cares about the environment?"

DIPNR: Department of Infrastructure, Planning & Natural Resources – Planned and actual urban growth and rural residential growth.

DIPNR metering: Current negotiations to install irrigation meters.

Health: NSW Department of Health – telephone health surveys

Heritage: NSW Heritage Office – non-Aboriginal heritage sites

IWMF: Integrated Water Monitoring Framework

LPI: Land & Property Information NSW – property valuations

LPI licenses: License trading and property valuation data

Minerals: NSW Department of Mineral Resources – information on extractive industries

NHUserGroup: Nepean/Hawkesbury User group

NPWS NSW National Parks and Wildlife Service – National Parks visitation rates & recreation surveys

NSW Ag: NSW Department of Agriculture – irrigated agriculture data

NSW Ag landuse: Mapping land use for agriculture.

NSWFisheries: NSW Fisheries – estuary production data

Rec. Fishing Survey: Recreational fishing survey – NSW Fisheries

RIMC: Regional Integrated Monitoring Centre – Mapping remnant vegetation on farms

Riverbank surveys: One-off recreation surveys – the (then) DLWC

RSoE: Regional State of the Environment Reporting – Local Councils and/or Regions of Councils

SCA: Sydney Catchment Authority – community awareness surveys

SOE: State of the Environment Reporting – NSW Department of Environment and Conservation

SWC: Sydney Water – customer research

TourismNSW: Tourism NSW – regional tourism profiles

WMC: Water Management Committees

WW: Waterwise program – NSW Agriculture

New monitoring programs:

Individual surveys: Surveys conducted with individual river extractors participating in demand management and effluent reuse initiatives.

Heritage monitoring: Ongoing monitoring of heritage sites and associated cultural values, in relation to changing river conditions.

Heritage assessment: Assessment of heritage sites and associated cultural values, in relation to implementing specific river management strategies.

Indigenous consultations: Consultations to focus on cultural values amongst various Aboriginal communities in relation to the river landscape.

River workshops: Community workshops to assess social, economic, cultural and heritage values in relation to the river. Estimated cost $40-$60,000 (a).

Stakeholder monitoring: Research initiatives implemented by river stakeholders. Funding may be provided under additional monitoring activities.

Submissions: Formal submission from stakeholders to the SECH co-ordinator. This can also include reporting by government agencies.

Working Group: Working Group of government and non-government stakeholders – for an effluent reuse strategy. Funding to be provided by lead agencies.

a. Based on the cost of community workshops conducted by the UWS Regional Integrated Monitoring Centre for the Regional State of the Environment Report.

PART E: ADMINISTRATION AND MANAGEMENT

Introduction

Administration and management processes need to be established to guide the monitoring program and to respond to its findings. The Expert Panel recommends the adoption of the arrangements discussed in this section although it is recognised that alternative arrangements that meet the overall aims of the program may be adopted.

The recommended management and administration arrangements accompanying the monitoring program comprise the following components:

- Adaptive management
- Institutional arrangements (and the interactions between institutions).
- River management.
- Administrative arrangements in terms of reporting, reviewing and auditing and costs and issues for future consideration.

Overall, the integrated monitoring program seeks to provide information to the groups responsible for managing the river to allow them to make informed decisions within a complex and changing context. This context is typical of natural resource management, where information and learning is evolving, thus requiring management to adapt to changing information. Within these kinds of contexts, monitoring and adaptive management are viewed as linked and essential (Allen et al, 2001). The Hawkesbury–Nepean River Management Forum recognised adaptive management (AM) as an approach that would support the implementation of a new flow regime.

Monitoring and Adaptive Management

Monitoring is fundamental to adaptive management as it provides new information from previous and current actions and it is this information that allows adaptation of management regimes.

Adaptive management has been recognised as an approach that suits ideally the circumstances of the introduction and ongoing management of the recommended environmental flows to the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers - see IEP (2002b). The adaptive management process is premised on the understanding that knowledge of the environmental, social and economic systems of a region are not always complete and that these systems are often highly dynamic. Adaptive management requires river management authorities to be flexible in their approaches to issues that are highly complex, inter-related and involve multiple stakeholders. This requires a capacity to respond to feedback and apply new learning obtained through the monitoring program to help build relationships between decision makers and stakeholders. In this process, it is expected that a level of trust will be established and general principles agreed. See Dovers (2001) for a discussion of an adaptive approach to the development of institutions for sustainability.

Many of the considerations that emerge in natural resource management disputes can be characterised as issues of choice about values and preferences. For any adaptive management framework to work, the political reality of decision making needs to be acknowledged. Such acknowledgment entails making the bargaining and negotiation process as transparent and inclusive as possible (Howitt 1989).

Public participation is emphasised at all stages of the monitoring program, including the design stage. A number of pre-monitoring investigations are proposed to ensure that necessary public participation is carried out to inform the design and direction of the program. The public participation requirements of the SECH component of the monitoring program are closely related to the integrated community awareness engagement program proposed by the Forum.

A number of processes in the SECH component have the capacity to create feedback loops between river management authorities and river stakeholders and involve interpreting information and exchanging views about the significance of various changes. Just as there are many views about what constitutes a 'healthy' river, there will be many views about the costs and benefits of changing river conditions. It is essential that communication between stakeholders and decision makers be reflected in the institutions responsible for river management.

The adaptive management process proposed for water cycle management in the Hawkesbury-Nepean, Shoalhaven and Woronora Rivers is summarised in Figure E1 which illustrates how information is used to formulate objectives. The favoured action is then implemented and subjected to monitoring. The results of the monitoring are fed back to modify management actions until the desired outcome or objective is achieved.

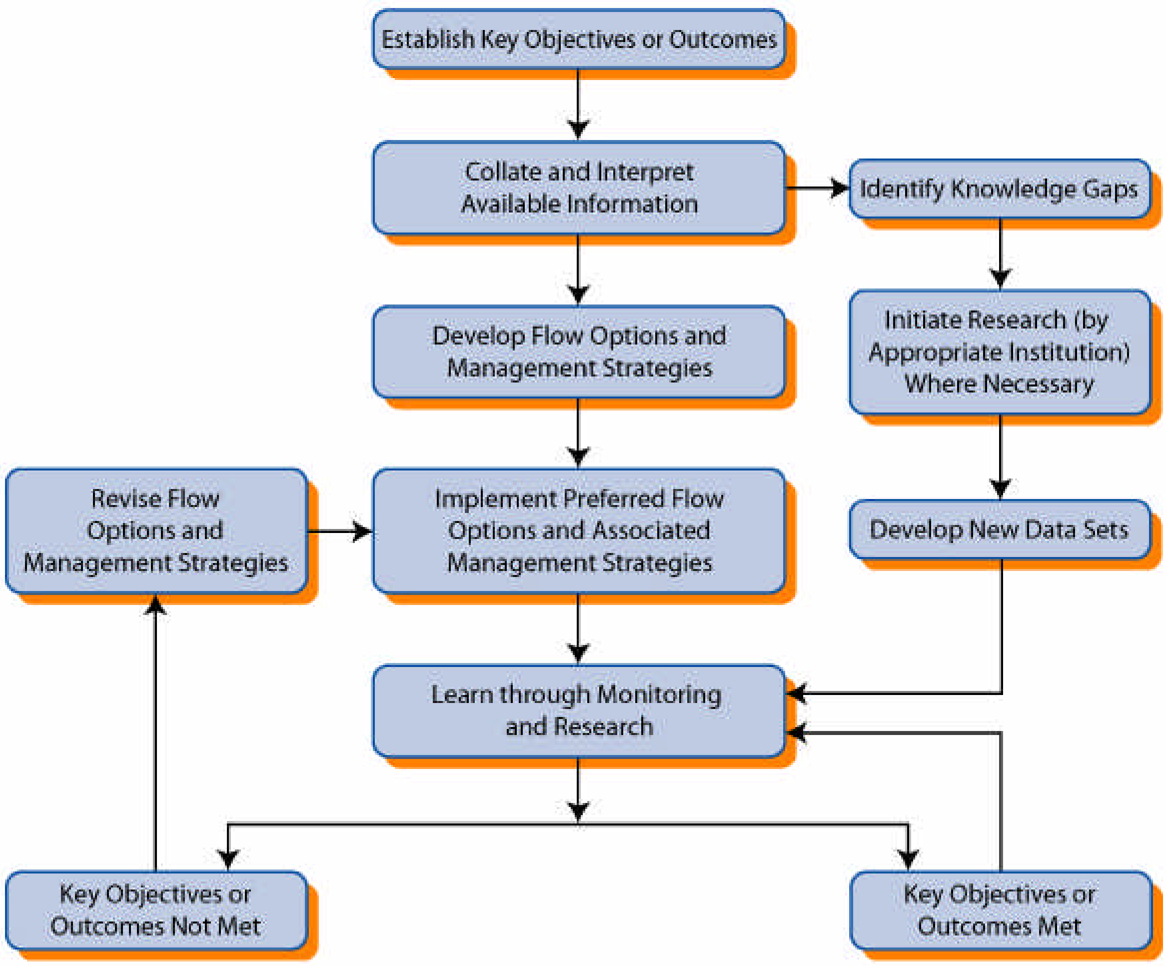

Figure E1: Adaptive Management and Environmental Flows Process

Institutional Arrangements

The recommended framework for the institutions involved in the monitoring program is shown in Figure E2. The four key groups are:

1. Hawkesbury - Nepean Catchment Management Authority (HNCMA)
2. Hawkesbury - Nepean Catchment Management Authority - Environmental Flows Management Committee (EFMC)
3. Environmental Flows Independent Technical Advisory Committee (ITAC)
4. Integrated Water Monitoring Framework Group (IWMF Group).

The recommended roles of these groups is described in the following sections.

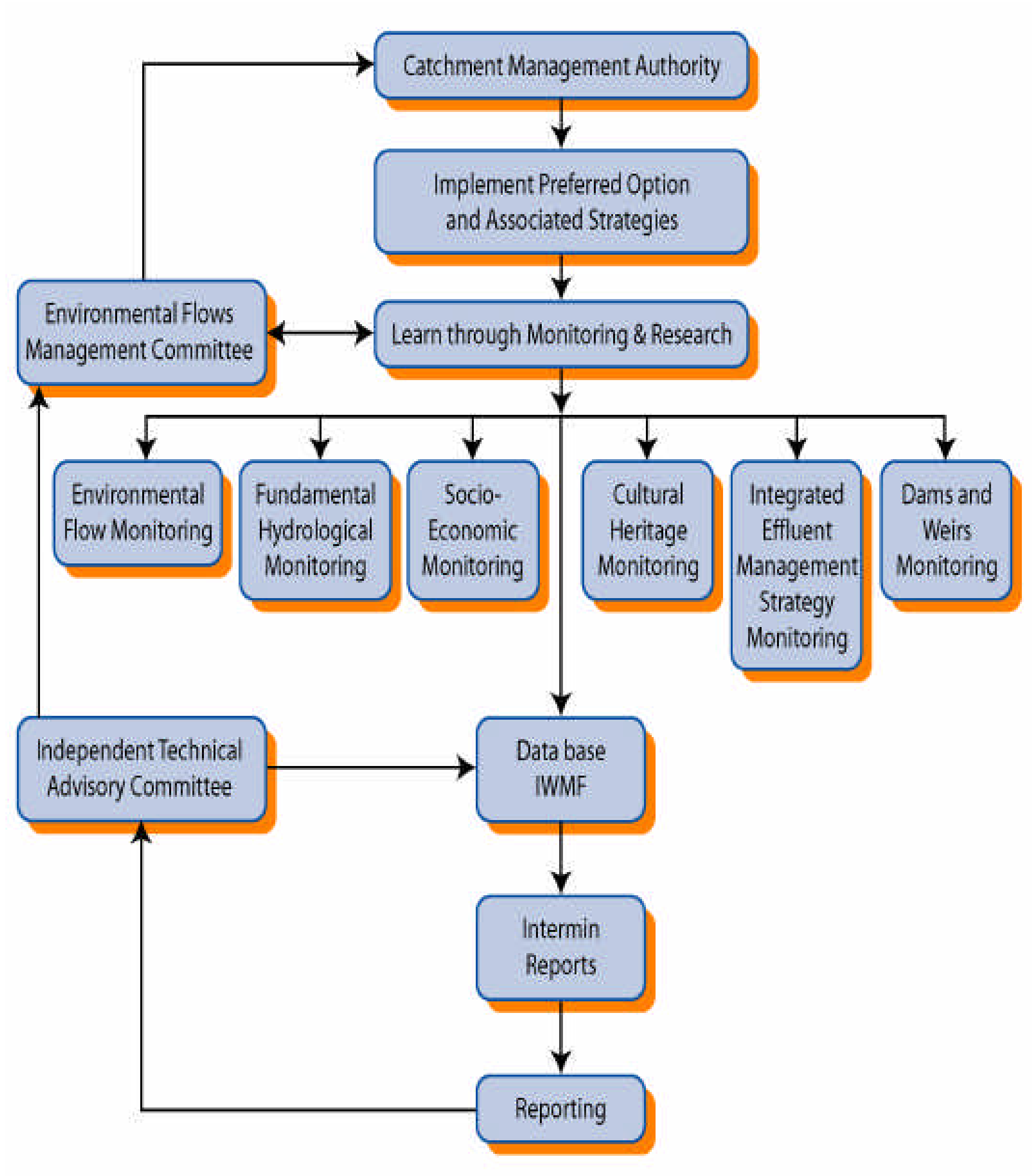

Figure E2: Recommended Framework for Monitoring Environmental Flows and Associated Activities

Hawkesbury-Nepean Catchment Management Authority (HNCMA)

The Hawkesbury-Nepean Catchment Management Authority was established in February 2004. In the context of the monitoring program, the HNCMA will:

- decide on and fund implementation of an environmental flows regime;
- receive information from the monitoring program via the relevant sub-committee; and
- report to the Minister.

Environmental Flows Management Committee (EFMC)

It is recommended that a Hawkesbury-Nepean, Shoalhaven and Woronora Inter-agency Environmental Flows Management Committee (EFMC) be established for the purposes of implementation, management and review of the monitoring. This committee would comprise key agency representatives (including

DIPNR, SCA, SWC, NSW EPA, Local Government, NSW AG, NSW Fisheries and other key stakeholders) and would be supported by an independent Environmental Flows Technical Advisory Committee (ITAC - see below). Based on advice from the ITAC the EFMC would provide advice to Government on the performance of the management regime and, where necessary, make recommendations for changes to the regime based on an integrated "levels of evidence" approach. A very good example of such an approach is the Ecosystem Health Monitoring Program which was established for the Moreton Bay region in south-east Queensland in 1999 by the Moreton Bay Waterways and Catchments Partnership. A description of the Ecosystem Health Monitoring Program is given in the introductory sections of Counihan *et al.* (2002).

Membership of the EFMC and protocols for decision-making should be clearly established at the outset.

Environmental Flows Independent Technical Advisory Committee (ITAC)

The ITAC would comprise technical experts for each major component of the overall program and would provide technical overview and independent assessment of the results of the monitoring program. The ITAC would also be responsible for providing the EFMC with technical advice on the performance of the current management regime following assessment of the results of the monitoring program. The HNCMA and the EFMC will need to determine how members of the technical committee are appointed and its terms of reference.

Integrated Water Monitoring Framework Group (IWMF Group)

Some components of the monitoring program can be managed by relevant agencies. For example, fundamental hydrological monitoring would be managed by SCA as flow and rainfall gauging is integral to their management function. While the data generated by this aspect of the program is expected to reside on the host database, in this case the SCA database, it will be extremely important to have a central facility for data management and/or processing across the entire monitoring program. The central database will facilitate various levels of reporting, communication and consultation. The central facility will contribute to ongoing community engagement.

DIPNR has an existing Integrated Water Monitoring Framework for the Hawkesbury–Nepean River (IWMF). This web-based application provides a central processing facility for a variety of summary information on water quality and is an excellent platform on which to build. It is recommended that the IWMF be enhanced to provide public access to the monitoring and adaptive management program associated with this initiative and that the existing IWMF Group would have responsibility for developing that process.

Roles

The specific role and responsibilities of each group will need to be negotiated over time. Two of the groups would consist of representatives of major stakeholders with interests in environmental flows. They would be responsible for negotiating potentially sensitive or contested interpretations of information reported by the IWMF Group, ITAC and other agencies.

Interpretation of monitoring findings is often a negotiated social process rather than data analysis by experts. This is particularly so when the purpose of monitoring is to manage SECH impacts (Krawetz et al, 1987). As previously noted, effective management of the river will rely on a transparent political process that integrates stakeholder negotiations into resource planning and decision-making (Dale, 1992). Stakeholder values and perspectives will need to be negotiated to ensure that management decisions fully consider issues of equitable distribution of impacts and explore alternative management strategies where necessary.

To carry out their functions appropriately, all of these groups will need to be adequately supported and resourced. At a minimum, this support should consist of:

- access to an experienced, credible and independent facilitator;
- access to independent experts to assist interpretation of findings; and
- appropriate administrative support.

River Management

The principles reflected by the management arrangements of the monitoring program and some of the problems that will need to be resolved are discussed briefly in the following section.

Principles

Seven major principles have been identified to guide reforms of the institutional arrangements for the river (White et al, 2003):

1. Transparent and timely accountability mechanisms
2. Effective Public Participation
3. Accessible deliberative and complaints processes
4. Independent auditing and compliance
5. Adequate and accessible long-term funding
6. State-wide high level planning and standard setting with legislative authority
7. Integration of decision making functions

Integrated monitoring

Integration in the monitoring program, especially between the SECH components and environmental components of the monitoring program, is highly desirable. It is important to recognise that this kind of integration is a major challenge (Krawetz et al. 1987). The challenges primarily arise from the divisions between disciplines engaged in social and environmental assessments. There are few methodologies that are truly interdisciplinary and there is no commonly accepted framework for assessing both social and environmental impacts.

The integration of the various components of the monitoring program has been a design of the program. For example, the reaches assessment was conducted using a shared geographical framework for both environmental and SECH issues and interactions between the two sets of issues were noted.

Ongoing integration of the monitoring program is envisaged in a number of respects including:

- Environmental monitoring will inform stakeholders to ensure they have current and relevant information
- The views and preferences that emerge from SECH monitoring may inform priorities for environmental monitoring. This process helps to refine the direction of environmental monitoring so that it provides useful information for river stakeholders (Krawetz et al. 1987, 41).
- Expansion of the existing infrastructure of the Integrated Water Monitoring Framework will require integration of various disciplines and data from a number of different agencies (IWMF).
- The IWMF will require effective integration of social science practitioners into its current culture and operations. A number of options for this change in natural resource institutions have been evaluated elsewhere (Taylor et al. 2001)

Decision making

There is a direct link between the management of the monitoring program and broader river management and decision making. Some challenges for the monitoring program are that decisions about how water is provided require action in a number of interrelated policy areas and responsibility river management is unlikely to rest with one organisation or body. Interagency and other forms of co-operation are essential. In this regard it should be expected there will be conflicts between decision-makers. (Tonn et al. 2000) To address the need to deal with conflicting preferences of both decision makers and parties affected by decisions, various approaches in decision-making will be essential.

Power relations inevitably exist between individuals and organisations and within a political context. A number of options exist (Willetts et al, 2003). Some approaches detailed below can assist in balancing power relations between parties involved in or affected by a decision.

- Participatory and deliberative approaches
- Interagency and Whole of government

- Conflict management
- Cooperative decision making
- Integrating expert and local knowledge

- **Participatory and deliberative approaches**

  There exist many types of participation and understandings of what this term means. It is therefore important that all involved in a particular participatory process understand the process being used in that particular context and both the potential for involvement and limitations of that involvement. Deliberation, by contrast, is a form of decision-making in which there is opportunity for different angles and perspectives of a problem to be considered. This usually occurs in some form of group process involving discussion and debate. Hence, many deliberative processes are also participatory processes. The decision may lie in the hands of the group deliberating or they may make a recommendation to the decision-making authority.

  Complex decisions with numerous implications for different parties benefit from involvement of either stakeholders and/or community in some form. Involvement of stakeholders and community helps ensure legitimacy and may increase acceptance of the final decision. Genuine opportunities for stakeholder and community groups to influence decisions are often limited. Although such groups are 'engaged' in the process in some way (for example, information is distributed to them and they can provide comment), they do not have extensive decision-making authority delegated to them. This may cause people to withdraw their participation or challenge the legitimacy of decisions. Improved More genuine forms of participation are seen to consist of more dynamic, interactive and deliberative processes. These differ with regard to:

  - who is involved (and how many);
  - what the purpose and intent of that involvement is; and
  - what level of decision-making authority is delegated to participants.

  Recommending an appropriate participatory process for the monitoring program therefore requires consideration of these three aspects and they will determine which type of participatory process suits the specific purpose. For examples of participatory processes that have been developed and used in different contexts are, see Carson and Gelber (2001) and Konisky and Beierle (2001). Also useful would be Bridgeman and Davis (1998), for participatory processes in Australian policy development and Petts (2001), for criteria to evaluate participatory processes

- **Inter-agency and whole-of-government decision making**

  Decisions will require whole-of-government processes or at least some collaboration between different government agencies. A number of decision will relate directly or indirectly to the policies of at the Federal and State and Local levels of Government. Whole-of-government and interagency initiatives need special forms of support and encouragement ranging from high-level sponsorship and advocacy through to new rules and dedicated funding to practical tools and training. Developing relationships is essential, however, this is time intensive and requires careful communication. Often there is no history of working together co-operatively and there is a need to clarify perceptions of the issue and whose resources should be used. These aspects are assisted by frequent, face-to-face meetings, reaching decisions by consensus whenever possible and sharing all relevant information early and continuously throughout the decision-making process. In addition, internal factors such as leadership and cohesion and external factors such as strong political support require attention. Some useful resources may be Ida (1999), for a detailed discussion of whole of government approaches, Environment Australia (2003), for a whole of government approach to sustainability, Singer (2000), for factors that promote interagency decision making, Wright (2002), for an outline of important considerations for collaborative work between agencies, and Lambright (1997), for an examination of interagency work in its political context.

- **Conflict Management**

  Conflict management is an essential element to many decision-making approaches. Decisions that involve or affect different stakeholder groups with different needs and perspectives will inevitably involve some form of dispute and compromise. Access to appropriate methods and expertise to deal with such situations is likely to improve both the decision-making process and outcome. A continuum exists from informal direct communication between parties to formal legal processes of conflict dispute. This continuum includes processes such as negotiation, facilitation, mediation, expert determination, use of an arbitrator, and court conference and litigation procedures. Facilitation and mediation are likely to be particularly useful in the context of the decisions involved in provision of environmental flows. See Devine (2000) for a comprehensive description of alternative dispute resolution methods.

- **Co-operative decision-making**

  Co-operative decision-making represents a situation where individuals (or groups) voluntarily act in a way to improve whole group outcomes. Such a scenario is in contrast to the usually predicted 'tragedy of the commons'[1] involving over-exploitation and eventual ruin of all common resources. Co-operative decision-making has the potential to reduce or remove the role played by legislation, regulation and privatisation.

  This approach is appropriate for decisions in which there are strong social consequences or competing interests for different groups affected by a decision. Co-operation requires "working together in a flexible and open manner on a sustained basis" (Holzwarth, 2002). Strong facilitation skills either within or outside the group will also be necessary to carry out the process. An essential feature of co-operative decision-making is good communication between individuals or sub-groups. A comparison of the perspectives of resource users, other direct stakeholders, researchers and policy makers on resource management, will help the various actors involved to understand each other's agenda, and will facilitate negotiations on the organisation of resource management. Useful resources for this approach include Stein and Edwards (1999), for sustainable management of common-pool resources Schmitt et al. (2000), for the conditions that support and undermine co-operative action, Burger and Gochfield (1998), for how environmental awareness affects management of common resources, and finally, Holzwarth (2002), for transparent, participatory governance in water management.

- **Integration of local and expert knowledge**

  An adaptive management regime is based on relationships between stakeholders and between people and the environment (Jiggins and Roling 2000). Monitoring for adaptive management also promotes synthesis of scientific concepts and abstractions with a layperson's understanding of their immediate contextual reality. An important ingredient will be integrating local knowledge with expert knowledge. This approach to decision-making challenges the dominant paradigm of 'expert' decision-making and looks at the importance and viable ways of integrating local knowledge into decision-making.

  Participants need access to the information and knowledge to enable them to do challenge the experts critically (Petts 2001). Decisions that have a direct impact on local communities require their views to be acknowledged and taken into account. Such integration of perspectives may make possible solutions that would otherwise be rejected if thrust upon a community without prior consultation. Indeed, the increase in understanding that results from the integration of local views may also shed light on completely new and creative solutions to the problem. Another instance when it is important to integrate local views is when risk is present in a real or perceived form. The risk management and communication literature suggest that lay people's opinions of risk often differ from those of experts.

  The ways in which local knowledge may be integrated into a decision-making approach are many and varied. It should be noted that integration of local perspectives may increase the complexity of the decision-making approach and allow conflict to rise to the surface. Conflict resolution practices

[1] "The Tragedy of the Commons," Hardin's (1968) essay, is a modern classic in environmental literature. The 'commons' refers to the common resources that are owned by everyone. The 'tragedy' occurs as the result of everyone being free to maximise one's own profit by exploiting the commons.

may then be required. Some useful resources may be Jiggins and Roling (2000), for an understanding of how local knowledge is necessary for adaptive management, Petts (2001) who discusses the necessity of including local knowledge in decision making and Konisky and Beierle (2001) for innovative public participation processes.

Stakeholders

Identification of key stakeholders in the monitoring program is a key component of a successful communications framework. A preliminary indication of stakeholders, examples of issues likely to be of interest to them and the kind of information that they are likely to require are provided below. This initial list, and the types of information provided, would be subject to regular reviews to ensure that relevance and currency is maintained.

- **General community** (including local geographical communities): trends in water quality - for example in comparison with established standards (ANZECC/ARMCANZ, 2000), health of the river system (for example the health of native fish populations), water system and usage information (for example consumption per capita).
- **Catchment stakeholders and landowners**: spatial and temporal trends in water quality - for example in comparison with established standards (ANZECC/ARMCANZ, 2000), and advice in the case of non-compliance with standards, changes to water policy or pricing and equity issues including progress with demand management initiatives.
- **Local and State Government**: water quality and river health in terms of trends and comparisons with other water bodies both within and outside of local government boundaries (for example as input to State of the Environment (SoE) Reports), raw data as well as data summaries (including demand management, integrated effluent management and the provision of environmental flows) for reports on the effectiveness of programs and policies implemented to improve or respond to environmental change, broader water reforms and water cycle management initiatives.
- **Irrigators**: general water quality, pricing issues, equity issues, contemporary hydrological (flow) information, contemporary information on effluent quality and quantity, guidance on best management practice and farm productivity and monitoring data and information.
- **Commercial Fishers**: information regarding water quality, environmental flows, policy papers and initiatives and details on the progress of the integrated effluent management strategy, information on the status and management of the exotic macrophyte *Egeria densa*, commercial fisheries statistics such as catch-per-unit-effort of the main commercial species. Generally required as summary information, primarily of a non-technical nature with some technical information on occasions.
- **Non-Government Organisations**: policy papers and initiatives, general statistics, technical and non-technical information on water quality and river health indicators, demand management targets, progress of government resource management initiatives including the integrated effluent management strategy and provision of environmental flows.
- **Researchers**: raw data or data summaries on a broad range of issues including strategic policy, social, economic, hydrology, ecology, water and soil quality.
- **Sporting Clubs and Recreational Users**: contemporary water quality, general river health and issues associated with their sport such as recreational fish catch statistics. Generally in a non-technical format.

Administrative Arrangements

As part of the monitoring program, procedures need to be considered for reporting, reviewing and auditing.

Reporting

Reporting the results of the monitoring program is fundamental to the adaptive management program. The proper reporting of results on the status of environmental, social and economic systems helps to engage managers, stakeholders and the broader community in the better management of the resource and is essential feedback to the adaptive management process.

Information needs to be reported in a timely fashion and in a number of clear and readily accessible formats. Reporting must satisfy the information needs of all participants in the monitoring program and there will therefore be a need to produce a range of reports for different river stakeholders.

ANZECC/ARMCANZ (2000) provides a framework for designing a reporting program (Figure E3).

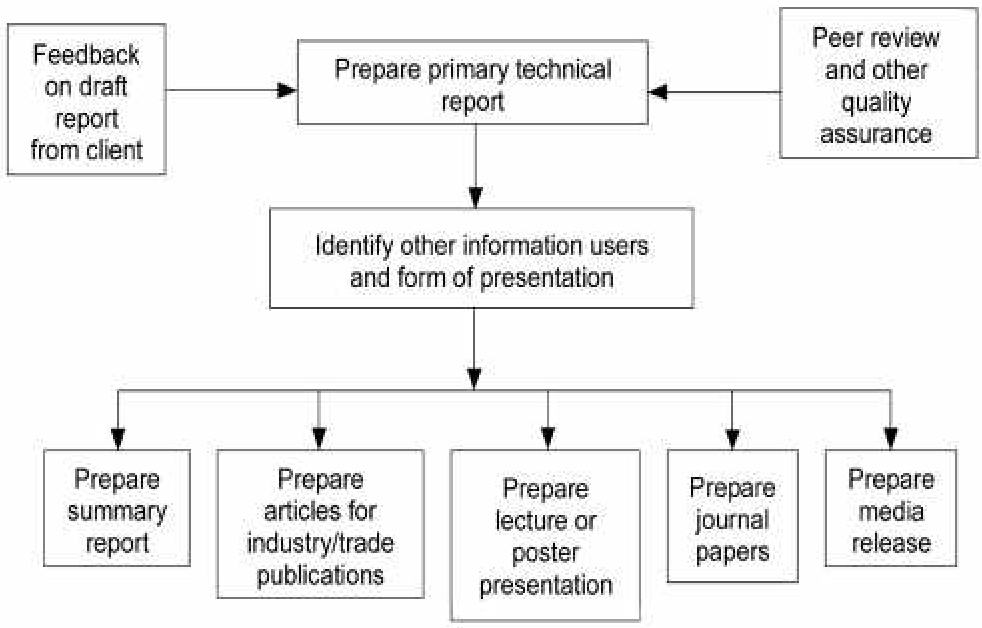

Figure E3: A framework for designing a reporting system (ANZECC/ARMCANZ, 2000)

A critical step in designing a reporting framework is the recognition that reporting relates to a broad spectrum of information users (ANZECC/ARMCANZ, 2000). Thus the identification of the stakeholders requiring information and the form of presentation that best meets their needs is a key component of a successful reporting and communications framework. A preliminary indication of the range of stakeholders and the type of information that they are most likely to be interested in are discussed above. This initial list, and the types of information provided, would be subject to regular reviews to ensure that relevance and currency is maintained.

The reviews could be undertaken via several mechanisms, and it is recommended that multiple methods are employed to facilitate contact with a variety of stakeholders. Some suggestions include:

- Drawing on information gathered through web page registration (see below) to periodically sample users, with a survey focused on the usefulness and relevance of information provided for their stakeholder group. Input on possible improvements would be sought and the feedback fed into reporting processes. This mechanism would also provide data that could be included on the web page, ensuring that the community is aware of the consultation that has occurred.
- Establishment of an informal stakeholder reference group, drawn from the key groups identified as having major information needs. This group would act as a 'test point' for the reporting framework, again ensuring that a feedback loop is built into the process.

For groups not identified at this stage, existent or emerging, who may have information needs it would be advisable to provide a series of advertisements to be distributed via mass communication channels (newspaper, radio, television). This would ensure that interested groups can gain access to information, and subsequently register their interest moving them into the ‘known’ group category. If this activity were performed at periodic intervals it would capture individuals and groups who have recently become interested and/or who are latent information users. Timing the distribution of the messages with awareness raising/ educative messages that other parts of the program may be promoting would greatly increase the effectiveness. Appropriate information materials and channels would be developed to service the needs of groups identified through this process.

Appropriately targeted information dissemination is essential to the adaptive management process. Community organisations and river stakeholders are likely to have more specific information needs that can be negotiated, and reporting would be tailored so that each group receives detailed information about their area of interest. Reporting key findings and interpretations can be done using a number of methods, depending on the purpose and intended audience. Some examples are listed below:

- **Water Management Plans**
- **Overview periodical reports**: These reports could be produced every three months and designed to provide management with an update on progress of the implementation, management, time-lines, milestones and other features of the overall program. This will allow managers insight into progress on a regular basis.
- **Technical periodical reports**: These reports could be produced every six months and be designed to provide technical readers with an update on progress of the technical program. This will allow technical readers insight into progress on a regular basis.
- **Annual reports**: This is the primary report produced in a form agreed by all parties. It should be able to be targeted at the broad cross-section of users. The report will contain full and complete details of all aspects of the study, including site locations, experimental design, executive summary, introduction, results, discussion, conclusions and recommendations for future work. It should be referenced accordingly where necessary and contain appendices providing laboratory reports, data tables and other information too detailed to include in the main body of the report. Data summaries and graphical presentations of results should be used as they significantly enhance the readability and utility of the report and are an excellent way of presenting data.
- **Web page**: Information about the program, reports and monitoring data should be made available on a dedicated web page. This is a low-cost medium for the user as well as providing relatively equitable access. Reports can include the publications produced for public audiences. Data can be supplied, most likely as summary statistics and should be accompanied where necessary with professional interpretation, as this type of information can easily be misinterpreted by users from a non-technical background. The inclusion of a registration facility on the web page would facilitate many of the other communication activities discussed throughout, and would be especially important in performing the reviews discussed above.
- **Bulletins and fact sheets**: *Ad hoc* bulletins that focus on specific issues could be developed. These may be in response to issues that are receiving increased media attention, and are consequently highly topical in the community. If these could be produced fairly quickly they could prove to be a highly effective communication medium. These could be mailed out to all those who have registered interest, and loaded to the web page. If the issue is gaining very high levels of media attention they could also be promoted through mass advertising to alert community members to where they can access. In addition, regular bulletins could be developed that provide information on results of monitoring and emerging trends. The aim of these should be to increase the community's and catchment stakeholder's awareness of current issues in the study area. Summary documents of overview and technical reports could be produced. The DIPNR newsletter *The Source* could be used as an information medium.
- **Advertisements**: As indicated above this would ensure that interested groups are able to gain access to information, and subsequently register their interest moving them into the ‘known’ group category. This activity should be performed periodically in order to capture

individuals and groups who have recently become interested and/or who are latent information users.

- **Data reports**: Data may need to be supplied weekly (or at other intervals) to operational staff, who may have operational works that are dependent on water quality results. These types of reports are unlikely to require interpretation.
- **Other reporting requirements**: There are processes that should also be implemented with respect to the monitoring program and the dissemination of information to ensure that the information is of the highest quality and is successful in reaching its target audience. These include:
  - Reporting Schedules - A schedule of reporting requirements should be devised and posted on the web-site at the start of the monitoring program and should make provision for the various types of reports at different intervals and at key milestones in the adaptive management process. The schedule would be updated regularly to reflect any changes or amendments to the schedule that may occur during operational phases.
  - Peer Review and Auditing - It is recommended that any reports distributed to the public are subject to peer review. This review could be a function of the EFTAC. External review is also recommended where additional technical expertise is required. Independent auditing of all aspects of the monitoring program is also highly desirable and ensures that appropriate QA/QC procedures and processes are in place and are being routinely implemented. Again, the EFTAC could undertake an independent audit function.

Review and auditing

Feedback from river stakeholders about the monitoring program is required to enable continuous improvement. The objectives of the program should also be periodically reviewed and renegotiated with river stakeholders.

Under the Water Management Act, the review of Water Management Plans is to be carried out by DIPNR every five years[1]. An audit panel[2] will also be appointed to audit the Plan. However the preliminary issues identified (particularly in the SECH aspects of monitoring), may be beyond the scope of this review and audit process. Terms for review and audit would be negotiated and agreed at the outset of the monitoring. Some existing evaluation frameworks would be useful for developing criteria for the terms of review. In particular, with respect to integrated catchment management (Syme et al. 1999 and to integrated resource management. (Belamy et al. 1999).

Other Issues for Future Consideration

The advantage of adaptive management approaches is the ability to incorporate additional issues over time as their significance is identified. The following have been identified by the Expert Panel as issues that may be affected by the introduction of the recommended environment flow regime and which may need to be included in monitoring at a later stage:

Reach 1

- Reduced flows over riffle or riffle-like habitats results in lowered input of dissolved oxygen into downstream pools.

Reach 2.1

- Reduced flows and water extractions during low-flows have created a salinity structure that is increased in its upstream extent and this has led to some losses in the availability of fish-nursery habitat - specifically freshwater-associated submersed plants.
- Degradation of the riparian zone caused primarily by land management practices during low flows due to increased nutrients, exotic species and recreational use of the river.

[1] s.43(2), Water Management Act 2000.
[2] s.44, Water Management Act 2000.

- *Elodea canadensis* is known to occur in the Shoalhaven River system. Currently flows in the Shoalhaven River system are sufficient to manage the growth of *Elodea canadensis*.

Reach 2.2

- Reduced flows and water extractions during low-flows have created a salinity structure that is increased in its upstream extent and this has led to some losses in the availability of fish-nursery habitat - specifically brackish-water-associated reeds.

Reach 4

- Degradation of the riparian zone caused primarily by land management practices during low flows due to increased nutrients and exotic species.

Reach 5

- Degradation of the riparian zone caused primarily by land management practices during low flows due to increased nutrients, exotic species and recreational use of the river.

Reach 6.1

- Discharge of poor water quality from Wingecarribee Reservoir including elevated nutrient concentrations, suspended solids and potential seeding of algal blooms in downstream weirs
- Diffuse sources of nutrient pollution have resulted in water quality problems. This is aggravated by a combination of altered/regulated flows and irrigation extractions particularly during dry conditions
- Reduced flows over natural barriers along the reach have reduced the connectivity for mobile aquatic fauna
- Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities
- Reduced connectivity for mobile aquatic fauna along the reach due to the presence of weirs and dams without effective fishways
- Inter-catchment translocation of aquatic and riparian biota from the Shoalhaven River system
- Degradation of the riparian zone and wetlands primarily by land management practices has been further exacerbated by altered flow regimes.
- Degradation of the riparian zone as a result of inter-catchment transfers.
- Inter-catchment translocation of aquatic and riparian biota from the Shoalhaven system.

Reach 6.2

- Reduced flows over natural barriers along the reach have reduced the connectivity for mobile aquatic fauna
- Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities
- Reduced flows over riffle or riffle-like habitats results in lowered input of dissolved oxygen into downstream pools (low; focus: upstream end of reach and attributable to evaporation from weirs and irrigation extractions).
- Inter-catchment translocation of aquatic and riparian biota from the Shoalhaven River system Inundation of critical 'dry' riparian microhabitats of vertebrates (eg. platypus burrows) during bulk-water transfers
- Degradation of the riparian zone as a result of inter-catchment transfers.
- Inundation of critical 'dry' riparian microhabitats of vertebrates
- Inter-catchment translocation of aquatic and riparian biota from the Shoalhaven system.

Reach 7

- Inundation of critical 'dry' riparian microhabitats of vertebrates (eg. platypus burrows) during bulk-water transfers
- Degradation of the riparian zone as a result of inter-catchment transfers.
- Inundation of critical 'dry' riparian microhabitats of vertebrates (eg. bird's nests and platypus burrows) during bulk water transfers.
- Inter-catchment translocation of aquatic and riparian biota from the Shoalhaven system.

Reaches 8 to 13

- Constant flows resulting in build up of filamentous algae
- Reduced connectivity for mobile aquatic fauna along the reach due to the presence of weirs and dams without effective fishways

Reaches 8, 10 and 11

- Reduced flows over riffle or riffle-like habitats results in lowered input of dissolved oxygen into downstream pools
- Unnaturally rapid changes in flows arising from bulk-water transfers can damage populations of aquatic biota and suppress their recruitment processes - sudden rises in flow: displacement and damage to fish eggs in riffle-like habitats leading to reduced reproductive success for riffle-dependent fish species, displacement of macroinvertebrates; sudden drops in flow: stranding of fauna including the desiccation of fish eggs deposited within riffle-like habitats; the threatened Macquarie perch is vulnerable in many of these respects
- Reduced frequency and duration of large flushing flows, together with increased nutrient concentrations, is likely to have led to large depositions of algal material and resulting organic detritus in deeper pools (after the material is occasionally scoured free from shallow areas), with a result that hostile water-quality conditions develop in the pools
- Reduced incidence of flushing/scouring flows, together with increased nutrient concentrations, is likely to have caused a build up of algae and detritus on shallow substrates, with a result that aquatic habitat diversity, quality and utility is diminished

Reach 9

- Reduced flows along the Avon River are likely to have caused the local extinction of platypus

Reaches 9, 12 and 13

- Reduced frequency and duration of large flushing flows, together with increased nutrient concentrations, is likely to have led to large depositions of algal material and resulting organic detritus in deeper pools (after the material is occasionally scoured free from shallow areas), with a result that hostile water-quality conditions develop in the

Reach 14

- Diffuse sources of nutrient pollution have resulted in water quality problems and excessive growth of plants, particularly exotic aquatic macrophytes. This is aggravated by a combination of altered/regulated flows and irrigation extractions particularly during dry conditions
- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.
- The impact of excessive growth of aquatic macrophytes, in particular *Elodea* on river amenity.
- Fragmentation and transportation of exotic macrophytes by river users.

Reach 15

- Reduced flows over natural barriers along the reach have reduced the connectivity for mobile aquatic fauna

- Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities
- Reduced connectivity for mobile aquatic fauna along the reach due to the presence of weirs and dams without effective fishways

Reaches 15 and 17

- Diffuse sources of nutrient pollution have resulted in water quality problems and excessive growth of plants, particularly exotic aquatic macrophytes. This is aggravated by a combination of altered/regulated flows and irrigation extractions particularly during dry conditions
- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Reaches 16, 18 and 19

- Diffuse sources of nutrient pollution have resulted in water quality problems. This is aggravated by altered/regulated flows and irrigation extractions particularly during dry conditions
- Reduced flows over natural barriers along the reach have reduced the connectivity for mobile aquatic fauna
- Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities
- Reduced flows over riffle or riffle-like habitats results in lowered input of dissolved oxygen into downstream pools
- Reduced incidence of flushing/scouring flows, together with increased nutrient concentrations, is likely to have caused a build up of algae and detritus on shallow substrates, with a result that aquatic habitat diversity, quality and utility is diminished
- Reduced incidence of flushing/scouring flows, together with increased nutrient concentrations, is likely to have reduced the conditioning of stony-bed areas, and this has led to the deterioration of interstitial aquatic habitat
- Reduced connectivity for mobile aquatic fauna along the reach due to the presence of weirs and dams without effective fishways
- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Reaches 20 and 21

- Possible hostile water quality due to stratification in the Penrith Weir pool
- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Reach 22

- Reduced flows have reduced the availability of critical physical habitat associated with higher water velocities (low; focus: remnant riffles)
- Reduced flows over riffle or riffle-like habitats results in lowered input of dissolved oxygen into downstream pools (low)
- Extractions and groundwater losses to Penrith Lakes may reduce low flows for 8 km along the main stem of the Nepean River thereby potentially reducing connectivity for mobile fauna along this section of the river
- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Reach 23

- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Reach 24

- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Reach 25

- Degradation of the riparian zone caused primarily by land management practices is exacerbated during low flows due to increased nutrients, exotic species and recreational use of the river.

Cost Estimates

The overall costs for the various components of the monitoring program approved by the Forum are shown in Table E1. These costs will be progressive expenditure that reflects the implementation program recommended by the Forum and will not be incurred, *in toto*, when the Forum's recommended environmental flow regimes are introduced.

Pre-monitoring costs includes preliminary surveys, logistics of pre-monitoring and monitoring programs, site selection, testing of selected methods, mapping and surveys, collation of information, aerial photograph analysis (including ground truthing) and database development.

Annual costs include some operational costs that may be incurred by state government agencies. For example, much of the estimated $270,000 required for annual operation of the fundamental hydrological monitoring would be an operational cost to the Sydney Catchment Authority so that the correct environmental flows can be delivered from water storages.

Table E1: Integrated Monitoring Program – Priority Components

Component of Monitoring Program	Pre-Monitoring • Costs • 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Fundamental hydrological	100,000	270,000
Ecological and physical	429,000	448,000
Ancillary	314,000	475,500
Social, economic, cultural and heritage	0	100,000
Total: Overall Program	**$843,000**	**$1,293,500**

The cost estimates in Table E1 do not cover the full program described in Parts C and D of this report. The costs reflect those components of the monitoring program approved by the Forum (see Part A) and comprise:

- All of the fundamental hydrological monitoring (Table E2);
- The top 10 ranked items of the ecological and physical component (Table E3);
- The top 6 ranked items of the ancillary component (Table E4); and
- A socio-economic monitoring component possibly based on a relatively modest increase in the costs of the existing Integrated Water Quality Management Framework (Table E5).

As noted in Part A, the Panel considers that all of the high priority studies originally identified need to be implemented to avoid compromising the adaptive management program for implementation of environmental flows. For example, the $100,000 included for SECH monitoring will not be adequate for the design of the SECH component as described in Part D of this report. It is anticipated that the initial funds will be used to employ a coordinator who will undertake a limited amount of SECH work. The coordinator will need to attract further funds or obtain the cooperation of other agencies to implement the full SECH component which relies upon a high level of involvement from stakeholders in both monitoring and decision making activities.

Table E2: Fundamental Hydrologic Monitoring

High Priority Issue	Rank	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Monitoring of weired shale reaches below the dams	1	25,000	67,500
Monitoring of sandstone reaches downstream of the dams	2	25,000	67,500
Monitoring dam inflows	3	25,000	67,500
Monitoring tributary flows	4	25,000	67,500
Total: Fundamental Hydrology		**$100,000**	**$270,000**

Table E3: Ecological and Physical Monitoring

High Priority Issue	Rank	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
Cold water releases from dams	1	0	19,000
Reduced connectivity – natural barriers	2	284,000	45,000
Contraction of critical habitat - Macquarie perch spawning/recruitment - Abundance and diversity of dependent biota	 2 4	 70,000 0	 128,000 28,000
General water quality downstream of dams	5	0	68,000
Loss of native aquatic macrophytes and excessive growth of exotic macrophytes	5	60,000	80,000
Altered biotic communities – Upper Nepean/Woronora/Shoalhaven Rivers	7	0	60,000
Reduced recreational fish catches	8	0	5,000
Altered biotic communities – Middle and lower Nepean/Hawkesbury Rivers	9	15,000	10,000
Reduced commercial fish catches	10	0	5,000
Sub-total: Items ranked 1 to 10		**$429,000**	**$448,000**
Connectivity investigations – managing flows for fish passage in the Woronora River	11	96,000	7,000
Stratification of natural pools	12	24,000	36,000
Reduced flushing, scouring and conditioning of habitat	13	98,000	21,000
Elevated iron and aluminium concentrations in discharge waters from dams	14	7,000	15,000
Encroachment of riparian vegetation on channels	15	50,000	60,000
Iron-rich groundwater inflows downstream of Avon and Cataract Dams	16	9,000	21,000
Sub-total: Items ranked 11 to 16 (not currently funded)		**$284,000**	**$160,000**
Total: Ecological and Physical		**$713,000**	**$608,000**

Table E4: Ancillary Monitoring

High Priority Issue	Rank	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
General water quality associated with the Forum's Effluent Reuse Strategy	1	0	92,000
Water quality in deep weir pools associated with the Forum's Effluent Reuse Strategy and weir management	2	0	48,000
Soil sustainability associated with the Forum's Effluent Reuse Strategy	3	100,000	85,000
Inter-catchment transfer of fish via Glenquarry Cut [a]	3	98,000	57,000
Lack of connectivity – diversion and gauging weirs	5	16,000	90,500
Groundwater sustainability associated with the Forum's Effluent Reuse Strategy	6	100,000	85,000
Sub-total: Items ranked 1 to 6		**$314,000**	**$457,500**
Effectiveness of Tallowa Dam fish lift	7	18,000	74,000
Channel degradation in the mixed-load shale reach downstream of Penrith Weir	8	88,500	0
Connectivity - Penrith Weir fishway	8	2,000	2,500
Channel changes in weired reaches	10	136,750	0
Tidal channel changes in the Hawkesbury River	11	88,000	0
Stormwater runoff	12	10,000	0
Sub-total: Items ranked 7 to 12 (not currently funded)		**$343,250**	**$76,500**
Total: Ancillary		**$657,250**	**$534,000**

a) Not required if the Forum's recommended strategy for inter-catchment transfers from the Shoalhaven is adopted.

Table E5: Social, Economic, Cultural and Heritage Monitoring

High Priority Issue	Pre-Monitoring Costs 2004-2014 ($)	Annual Monitoring Costs ($/yr)
SECH Co-ordinator (expansion of existing Integrated Water Quality Management Framework)	0	100,000
Sub-total – Initial SECH Monitoring	**$0**	**$100,000**
Sustainable River Fund	tbd	tbd
Pre-monitoring Phase - Social and Economic - Cultural and Heritage	 350,000 240,000	 0 0
Monitoring Phase - Social and Economic - Cultural and Heritage	 0 0	 tbd 130,000
Audit and Review Phase	tbd	tbd
Total: Social, Economic, Cultural, Heritage	**$tbd**	**$tbd**

tbd: To be determined. Scope of program to be developed by the SECH co-ordinator and Hawkesbury Nepean River Management Authority in consultation with stakeholders.

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