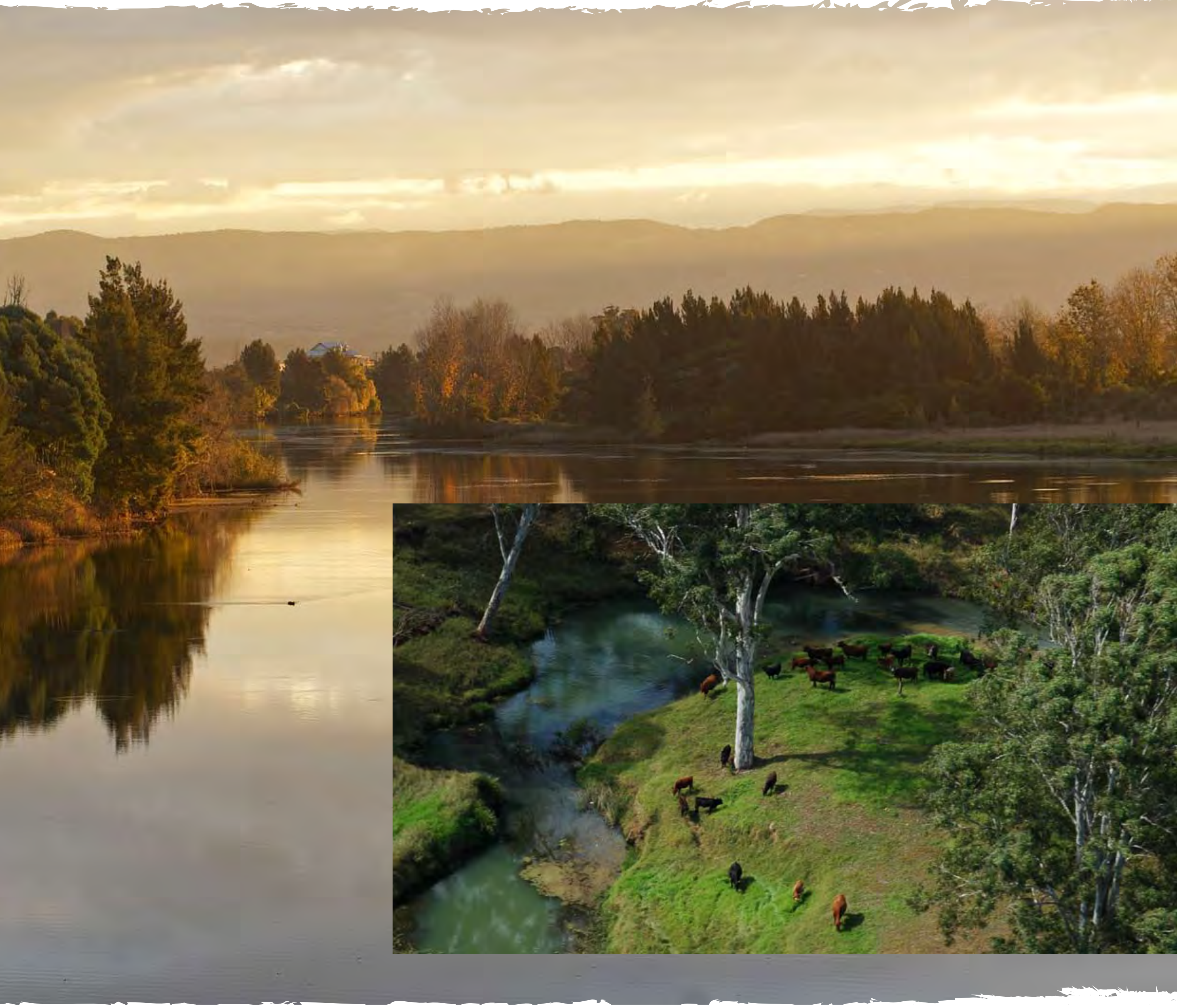

Hawkesbury-Nepean River Environmental Monitoring Program

Final Technical Report

SYDNEY CATCHMENT AUTHORITY

Department of Environment & Climate Change NSW

This project was undertaken by the Department of Environment and Climate Change with funding provided by the Sydney Catchment Authority. The project was overseen by the Hawkesbury–Nepean Environmental Monitoring Program Working Group, consisting of members of the Metropolitan Water Directorate (initially part of the Cabinet Office and later within the Department of Water and Energy), Department of Environment and Climate Change, Department of Water and Energy, Sydney Catchment Authority, Sydney Water Corporation, and Department of Primary Industries (Fisheries). Data was sourced primarily from the Sydney Catchment Authority, Sydney Water Corporation and Department of Primary Industries (Fisheries). The Department of Primary Industries (Fisheries) also undertook additional sampling of fish and macrophytes as a component of the project. In addition, an inter-agency technical peer-review group was formed to assist with ongoing scientific review of the program. All of these contributions were important for the successful completion of the project.

Cover photos:
The Hawkesbury River at Windsor; Cattle on the riverbank at South Creek
(both from Hawkesbury-Nepean Catchment Management Authority)

Published by:

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Website: www.environment.nsw.gov.au
ISBN 978-1-74232-143-1
DECC 2009/112
February 2009

Printed on paper containing 80% post consumer recycled content and 20% pulp from sustainable forest plantations.

CONTENTS: BOOKLET

CONTENTS: CD

Summary

Adaptive management requires monitoring to measure the effectiveness of previous management actions and to better focus subsequent actions. Without such monitoring there is often no measure of 'success' or 'failure' of the management action. Long-term monitoring programs are rare in an Australian and in the worldwide context. However, they are fundamental to understanding where a system currently is in terms of an underlying natural climate cycle and a range of changes made by humans in the past. They are also essential for assessing and understanding long-term trends.

Monitoring can be done at a catchment-scale level for broad strategic initiatives such as the NSW Metropolitan Water Plan (NSW Government 2006) or at a local-scale level to discriminate the specific benefits of individual initiatives. The Hawkesbury-Nepean River Environmental Monitoring Program (HN-EMP) is a long-term monitoring program operating at a catchment-scale level and enabling the broad-scale assessment of river health. It is complemented by shorter term program-specific monitoring such *as replacement flows monitoring*. The focus of this report is restricted to the broad-scale assessment of river health.

The HN-EMP has drawn together sites with a significant history of monitoring. When considered collectively, these long-term water quality monitoring sites in the Hawkesbury-Nepean have a very valuable time series of monitoring data. Many sites have been routinely monitored for water quality since the early 1980s, and the data collected at these sites represent not only a significant historic investment, but a very valuable resource in terms of long-term information. Information gathered in this program has enabled us to demonstrate:

- improved water quality in many areas throughout the Hawkesbury-Nepean River (e.g. decreases in filterable and total phosphorus)
- declining water quality in some areas of the Hawkesbury-Nepean River (e.g. total and inorganic nitrogen downstream of West Camden Sewage Treatment Plant)
- increases in conductivity[1] throughout the Hawkesbury-Nepean River
- the effects of natural climate cycles (e.g. El Nino Southern Oscillation signals) and regulation on flow in the Hawkesbury-Nepean River
- long-term average flows at Penrith Weir have now consistently fallen below that of the unregulated Colo River for the first time since records began in the early 1900s
- declines in chlorophyll-a levels but little change in blue-green algal cell counts at many sites
- significant changes in blue-green algal species composition, with non-toxic species of *Aphanocapsa* largely replacing *Anabaena* and *Microcystis* as the dominant bloom species in the Hawkesbury-Nepean River
- little change over time in macroinvertebrate communities (assessed using AusRIVAS and SIGNAL indices) at many sites in the Hawkesbury-Nepean River.

Improvements in water quality from this monitoring program can be demonstrated. However, these are improvements from what was previously quite poor water quality in some areas and, for some analytes, water quality still has a long way to go before

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[1] Electrical conductivity of water samples is used as an indicator of how salt-free, ion-free, or impurity-free the sample is; the purer the water, the lower the conductivity.

water quality objectives (e.g. those in the ANZECC/ARMCANZ (2000) Guidelines for Fresh and Marine Water Quality) are met. Water quality in the Hawkesbury-Nepean is affected by sewage treatment plant discharges as well as by diffuse-source pollution from urban and agricultural runoff. These diffuse sources may become more important in the future as planned treatment plant upgrades are completed and some areas experience further urban growth. It is expected that the value of these long-term datasets for the Hawkesbury-Nepean will become even more important in the future as government seeks to understand the effects of Metropolitan Water Plan initiatives and climate change on the Hawkesbury-Nepean River.

River health is also not just about water quality and water quantity; the current focus of many monitoring initiatives (e.g. the NSW Monitoring Evaluation and Reporting (MER) strategy) is to measure biological outcomes such as ecological condition. However, although extensive long-term monitoring of flow and water quality has occurred in the past, similar long-term monitoring programs do not exist for many biological indicators[2] (e.g. fish, macrophytes and periphytic algae). This means that our ability to detect long-term trends in these biological indicators is currently limited. This capacity is likely to improve over time as more data become available, but assessment of trends in biological indicators such as fish and macrophytes will require targeted monitoring to be implemented.

This report provides an assessment of long-term trends in water quantity, water quality and a range of biological indicators (where sufficient monitoring data exist). It also provides a benchmark for future assessments, particularly as major initiatives under the Metropolitan Water Plan roll out. Of particular interest is the finding that algal community composition in the Hawkesbury-Nepean River has changed dramatically in the recent past, with cyanobacterial blooms previously dominated by *Anabaena* and *Microcystis* now largely being replaced by cyanobacterial blooms dominated by *Aphanocapsa*. The exact reasons for this community shift are unknown but raise important questions about the potential for future shifts in algal communities as a result of both climate and catchment management changes.

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[2] An exception to this is algal monitoring undertaken by Sydney Water and the Department of Water and Energy, which does have a significant historic record.

1. Introduction

The Hawkesbury-Nepean River is one of the most important river systems in NSW. It is the largest river/estuary system in the Sydney Region, and its complex ecosystems provide habitat for a multitude of native plant and animal species. Since European settlement it has been increasingly relied upon to meet the requirements of a burgeoning population, and it now provides 97% of the fresh drinking water for more than 4.8 million people living in and around Sydney (Greening Australia 2007). It also supports the agricultural industries that provide much of Sydney's fresh food, as well as supporting numerous other extractive, manufacturing and processing industries. In addition, the Hawkesbury-Nepean River is an important recreation and tourism destination.

As a result of cumulative development and population growth over time, the Hawkesbury-Nepean River system has been placed under increasing pressure and the environmental health of the river system has suffered. River regulation has resulted in large volumes of water being extracted for drinking water, irrigation and industrial uses. There are a number of sewage treatment plants (STPs) located in the catchment, and stormwater runoff from agricultural and urban areas can also carry pollutants into the river system. Algal and introduced macrophyte blooms have commonly occurred in the past and are likely to continue to occur in the future.

In 2006, the Metropolitan Water Plan (NSW Government 2006) committed the government to an Environmental Monitoring Program for the Hawkesbury-Nepean River:

> The Government is developing an integrated monitoring program for the Hawkesbury-Nepean River that will provide information on river health, the outcomes of environmental flows and recycling initiatives. This program will build on previous monitoring work and provide an information base for adaptive management as the Metropolitan Water Plan is carried out. Its development is expected to be completed by the end of 2006. (page 107)

The project reported here has developed a coordinated and integrated Hawkesbury-Nepean River Environmental Monitoring Program (HN-EMP), which will provide broad surveillance monitoring of the river system. The methodology is consistent with the indicators proposed for the State Monitoring, Evaluation and Reporting (MER) Strategy and recommendations in the Final Report of the Hawkesbury-Nepean River Management Forum (2004). Specific targeted studies will, however, still be required to give more detailed information on cause/effect pathways of specific initiatives, including environmental flows or recycling.

The Hawkesbury-Nepean River system has had a number of historical monitoring programs as well as the programs that currently exist, and the HN-EMP aims to consolidate this monitoring and maximise the value of historic data in interpreting the changes that have already occurred or are likely to occur in the future. Past monitoring data represent a substantial information resource that can now be fully explored and presented in terms of an overall river health assessment.

2. Program objectives and deliverables

Level of detail

- The HN-EMP aims to deliver broad-scale surveillance monitoring of the condition of the river system and will monitor the cumulative effects of management actions and changes in the catchment on the river system. This monitoring program therefore addresses the long-term trend assessment requirements.

- This broad-scale monitoring of the river system will not necessarily enable the resolution of localised or initiative-specific cause/effect questions. These targeted studies are usually undertaken over a much shorter time frame and are more intensive (requiring an increased frequency of sites and times monitored). Notably:
  - the need for detailed information on specific initiatives or localised areas will still need to be addressed through targeted studies
  - targeted studies identified to date that would be important to understanding the impacts of the Metro Water Plan on river health will include the e-flow studies being undertaken by the Sydney Catchment Authority (SCA), monitoring to be commissioned by Sydney Water Corporation (SWC) on the replacement flows project, and monitoring of the effectiveness of weir modification along the Nepean River
  - it is not anticipated the HN-EMP Program will exert any particular control over any targeted studies beyond providing a basis for the coordination of monitoring and data sharing. The HN-EMP can however, provide a longer-term temporal context for these targeted studies.
- Together, these two monitoring approaches (broad-scale and targeted) will provide both the long-term and short-term data needed to assess the system-wide effect of cumulative and initiative-specific management changes in the Hawkesbury-Nepean River system. They are complementary to one another, and both are required to monitor and understand the system and how it responds to future changes.
- This report focuses on the broad-scale surveillance monitoring program; initiative-specific monitoring is left to be conducted by the appropriate agencies at the appropriate times.
- A further objective of the initial phase of the project was to collate historic data, assess recent trends, and provide a benchmark for future monitoring and evaluation.

Time frame

The Program was not designed to replace existing SCA and SWC information collected under licensing obligations but it will make the best use of these data through collation, the application of systematic methods, and the analysis of collated data for a common purpose.

Limitations

The Program will not include monitoring of water-borne pathogens for recreational water use, riparian vegetation mapping, or ground water studies, unless the latter are likely to have significant river health implications.

Users

Primary users of Program data will be:

- the participating agencies: SCA, SWC, Department of Water and Energy (DWE) , Department of Environment and Climate Change (DECC), Department of Primary Industries (DPI)
- Metropolitan Water Directorate / Metro Water Chief Executive Officers
- Hawkesbury-Nepean Catchment Management Authority (CMA)

- local government
- other stakeholders.

The Program will also interact with, or support, other government initiatives, including the Metropolitan Water Sharing Plan, State of the Environment reporting, and MER Strategy outcomes to be achieved by 2015.

3. Monitoring program design

Pre-existing requirements and constraints

- The HN-EMP includes many components of existing SCA and SWC monitoring programs and resources. It also aims to draw on previous and future monitoring by other agencies, including DECC (and its predecessors), DWE (and its predecessors) and DPI Fisheries.
- A number of information gaps have been identified; these are primarily where indicators need to be aligned with predicted changes in the catchment, or in areas where change following management intervention is likely to occur but is not currently being monitored.

Spatial scale

- The program is designed to identify broad-scale changes in river health. The suggested approach of using broad-scale surveillance monitoring to which is added data from more intensively focused or targeted studies represents best practice in river system monitoring.
- This is an emerging theme in international literature and has been accepted by governments as the basis for setting up the Murray Darling Basin Sustainable Rivers Audit and State-wide monitoring under the NSW Natural Resource Monitoring, Evaluation and Reporting (MER) Strategy.

Temporal scale

- Some indicators such as hydrology and water quality are monitored frequently (e.g. hourly, daily or monthly), whereas many of the biological indicators are monitored less frequently (e.g. 6-monthly or annually) because their responses to changes in conditions generally take longer to become evident. In some cases, changes in biological indicators may not be able to show a significant trend for a number of years. Sampling biological indicators on a more frequent basis would not necessarily increase the ability to identify change, and in some cases (e.g. macroinvertebrates) excessive monitoring can itself create detrimental impacts.

Existing understanding

The existing scientific and research literature has already established the major ecological characteristics of concern, their spatial and temporal patterns and the effects of major stressors. It also establishes, through conceptual models (e.g. Figure 3.1), how a range of stressors are linked to ecological outcomes. In their most basic form, the models for the Hawkesbury-Nepean suggest that:

Figure 3.1: Conceptual model for the Hawkesbury-Nepean: schematic representation of likely impacts of Water Plan Initiatives

- excessive plant growth is an outcome of high levels of nutrient input, exacerbated by low river flow leading to longer retention times for nutrients, floating macrophytes and algae; and of reduced physical stress on introduced attached submerged macrophytes (e.g. Taylor-Wood 2003)
- algal growth and sediment runoff reduce light levels for native attached macrophytes below critical levels for photosynthesis (Roberts et al. 1999)
- barriers to migration, reduced flows, sedimentation, loss of native in-stream and riparian vegetation and excessive plant growth reduce habitats for native fish shelter and reproduction and can favour introduced fish species
- reduced flows, poor water quality, sedimentation, loss of native in-stream and riparian vegetation and excessive plant growth reduce the habitats available for food-chain fundamentals such as macro-invertebrates.

Allocation of river zones and relevance to management

For discussion purposes, the catchment has been grouped into six broad zones (see Figure 3.2), including South Creek, on the basis of river morphology, physical characteristics (e.g. salinity), biota and the locations of natural and artificial features such as weirs and tributary inflows. By using Table A1.1 (Appendix 1) the zones can be related back to the Reaches identified in the Hawkesbury-Nepean Management Forum (2004) Report.

- **Zone 1** represents the saline-dominated areas of the Lower Hawkesbury, from Wisemans Ferry to the Broken Bay entrance.
- **Zone 2** represents the largely tidal (but freshwater) section of the river from Wisemans Ferry to the junction with the Grose River. This includes areas around

Sackville that have been the site of extensive blue-green algal blooms in the past. Water is also extracted in this Zone for the North Richmond Water Filtration Plant.

- **Zone 3** represents the section from the Grose River junction to the confluence of the Warragamba River. This section contains Penrith Weir and the proposed discharge point for the Replacement Flows Project. It also contains sections under the influence of a number of other STP discharges (e.g. from Mt Riverview, Winmalee, Richmond and North Richmond STPs).
- **Zone 4** represents the section from the confluence of Warragamba River upstream to SCA's Upper Nepean Dams: Nepean, Avon, Cordeaux and Cataract. This section has been further divided into Zones 4a and 4b, largely on the basis of the locations of existing diversion weirs (Pheasants Nest and Broughtons Pass). Zone 4b is upstream of these weirs and is the area likely to receive the most significant benefits from environmental flows from the Upper Nepean Dams. Zone 4a, downstream of Pheasants Nest and Broughtons Pass weirs, is expected to receive lesser benefits from environmental flows. There are a number of large weirs in this section of the river (including the SCA's weirs: Menangle, Bergins, Thurns, Camden, Sharpes, Cobbity, Mount Hunter Rivulet, Brownlow and Wallacia), which are likely to be affected by the Weirs Modification program.
- **Zone 5** represents areas above the Upper Nepean Dams: Nepean, Avon, Cordeaux and Cataract.
- **Zone 6** represents the entire catchment of South and Eastern Creeks. This Zone is included because key initiatives of the Metropolitan Water Plan (including recycling and replacement flow projects) will be implemented in this area, significantly affecting flow and nutrient loads in this section. This zone is distinct from other predominantly rural sub-catchments, which, although important, do not currently contain any significant Metropolitan Water Plan initiatives and will not be subjected to rapid increases in urbanisation on the scale planned for South Creek catchment in the future.

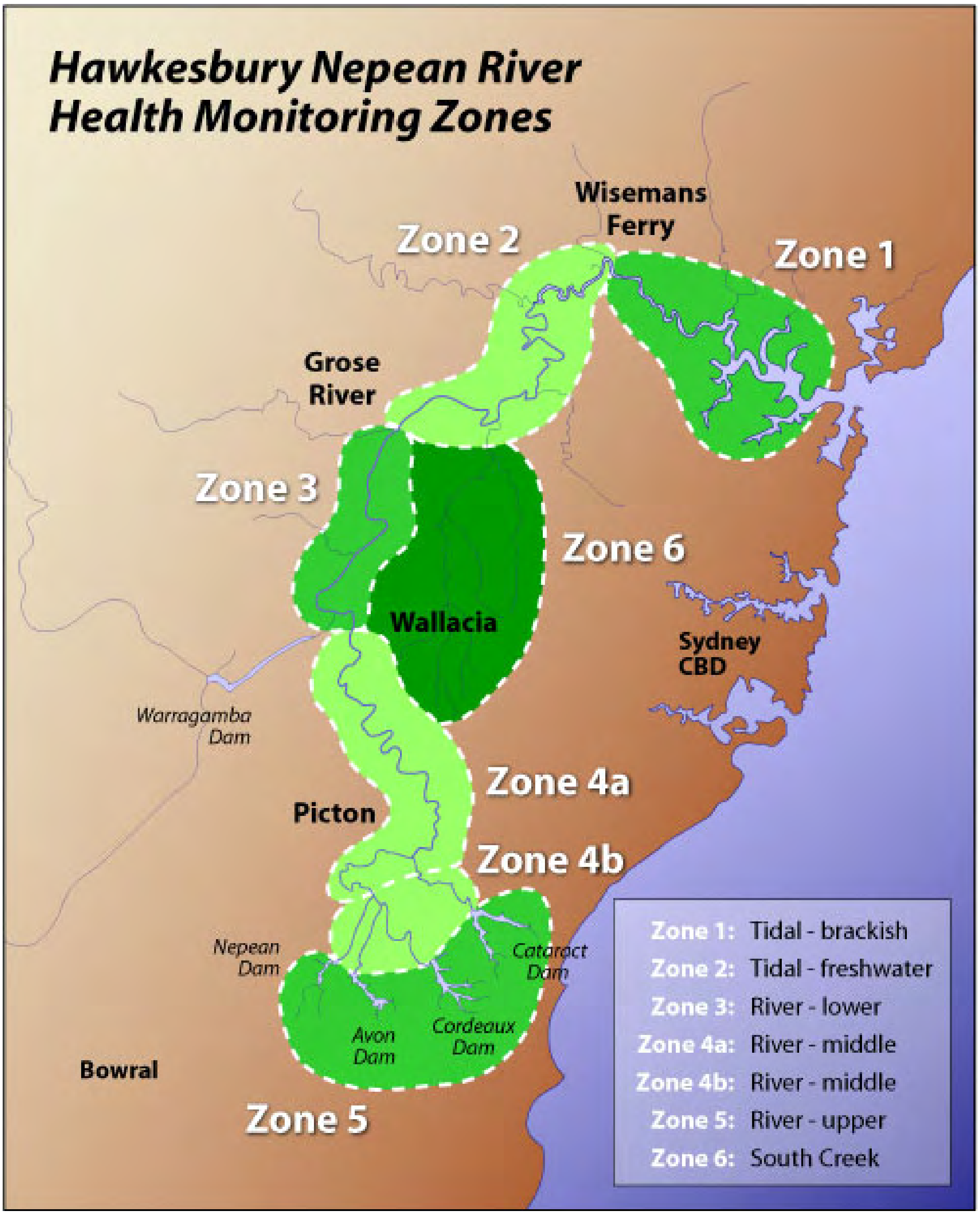

Figure 3.2: Hawkesbury-Nepean River monitoring zones

Long-term monitoring sites

A review was conducted of current and historic SCA, Sydney Water, DECC EPA, DWE and DPI Fisheries monitoring sites in the Hawkesbury-Nepean River. From this list, a selection of sites that had long-term ongoing monitoring was identified. Many of these sites are currently monitored as a result of various licences (e.g. Water Management Licences or DECC EPA Pollution Control Licences). Added to this were sites that were currently monitored under the SCA's Woronora Environmental Flows Project and sites that were not currently monitored but had a relatively long history of sampling and/or were located in strategic sections of the river system. These sites are identified in Table 3.1 and form the core of the Hawkesbury-Nepean Environmental Monitoring Program.

Hawkesbury - Nepean River Environmental Monitoring Program

Proposed Monitioring Sites, June 2008

		Key: status of monitoring:	Ongoing		Temporary funding, to June 2009		Planned, funding not confirmed		Monitoring Approach to be Developed
Zone	Site	Name	Water Quality	Hydro-graphics	Macro-invertebrate	Fish	Macro-phytes	Saltmarsh / mangroves	Seagrass
Zone 1	N04	Hawkesbury R at Peats Ferry Bridge							
Zone 1	N06	Hawkesbury R at Marlowe Ck			Estuarine				
Zone 1	170014	Mangrove Ck		212229	SRA				
Zone 1	N14	Nepean River at Wisemans Ferry		212408					
Zone 2	N18	Hawkesbury R at Leetsvale							
Zone 2	N21	Hawkesbury R at Lower Portland							
Zone 2	N26	Hawkesbury R at Sackville Ferry		212900					
Zone 2	N3001	Hawkesbury R at Cattai National Park							
Zone 2	N35	Hawkesbury R at Wilberforce (DS South Ck)							
Zone 2	N38	Hawkesbury R at Windsor Bridge (US South Creek)		212903					
Zone 2	N39	Nepean R DS Nth Richmond STP							
Zone 2	N40	Nepean R at Nth Richmond (DS Nth Richmond STP)							
Zone 2	N42	Hawkesbury R at North Richmond (US Nth Richmond STP)		212200					
Zone 2	GR4301	Grose River at Yarramundi		212291					
Zone 3	N44	Nepean R at Yarramundi Bridge		2122001					
Zone 3	N461	Winmalee Ck							
Zone 3	N48	Nepean R at Smiths St (US Winmalee Lagoon)		2122002					
Zone 3	N51	Nepean R at Jackson Lane (DS Penrith STP)							
Zone 3	N53	Nepean R at BMG Causeway (DS Penrith STP)							
Zone 3	N57	Nepean R at Penrith Weir (US Penrith STP)		212201					
Zone 3	N626	Erskine Ck (at Jack Evans track)		212218					
Zone 3	N6265	Erskine Ck US N626							
Zone 3	Weir Pool	Weir Pool DS Warragamba Junction							
Zone 3	N641	Warragamba River at Nortons Basin							
Zone 4a	N67	Nepean R at Wallacia Bridge		212202					
Zone 4a	N75	Nepean R at Sharpes Weir (DS Camden STP)							
Zone 4a	N78	Nepean R at Macquarie Grove Rd (US West Camden STP)							
Zone 4a	N80	Nepean R at Menangle Weir		212238					
Zone 4a	N92	Nepean R at Maldon Weir (US Picton STP)		212208					
Zone 4b	HUC1	Broughtons Pass Weir		212233					
Zone 4b	N93	Nepean ds dam ds Pheasants Nest		212203					
Zone 4b	N881	Nepean River DS Broughtons Pass Weir							
Zone 4b	N885	Cataract River DS Broughtons Pass Weir							
Zone 5	E602	Burke R		2122052					
Zone 5	E697	Nepean R at McGuires		212209					
Zone 5	E674	Avon River at Summit Tank		new					
Zone 5	E608	Goondarin Ck @ Vent Shaft		new					
Zone 5	E609	Cataract River D/S Angels Creek		new					
Zone5	DCA3	Loddon River		2122322					
Zone5	E6133	Goondarin Ck							
Zone 6	NS02	South Creek near Hawkesbury Junction							
Zone 6	NS081	Eastern Ck D/S Riverstone STP		212296					
Zone 6	NS23	South Ck D/S St Marys STP		212297					

Table 3.1: Hawkesbury-Nepean River: monitoring zones, monitoring sites and indicators

4. Data received from agencies

Water quantity and water quality

The majority of water quality and hydrology data for the Hawkesbury-Nepean River were provided to DECC by SCA and Sydney Water in January 2007. An update was requested from SCA in August 2007 to bring the water quality and hydrology data up to 30 June 2007 (or as close as possible to this date). Where there were multiple records for water quality on the same day, the median of readings have been calculated and included in all graphics and analyses. Some provisions for optimising data quality and consistency have been made, but this has not fixed all the problems that exist in the data; the results presented here assume that any further errors in individual recordings have occurred essentially at random and have little effect on the analyses.

SCA water quantity and water quality data were extracted from two main databases: Hydsys/Hydstra for water quantity; and the SCA's customized Water Quality database (Oracle Software). SCA flow (level) data for many sites are measured at 15-minute intervals, however, for this study a daily flow rate was extracted and used in subsequent analyses. Water quality is currently monitored (at most sites) on a 4-weekly basis, although the period between successive samples has varied over time, particularly in earlier monitoring periods.

Sydney Water's data were extracted from their Monitoring Service's Water Quality Data Warehouse. Water quality is monitored (at most sites) on a 4-weekly basis, although the period between successive samples has also varied over time, particularly in earlier monitoring periods. An exception to this is North Richmond (site N42) where water is extracted for water supply purposes and water quality monitoring is undertaken on a weekly basis. The differing frequencies of sampling are an important point and can influence the period required for the detection of trends.

Daily rainfall at Cataract Dam and southern oscillation index (SOI) data were obtained from the Bureau of Meteorology website (http://www.bom.gov.au/).

Macroinvertebrate data

SCA macroinvertebrate data are currently collected in two main projects:

- the Woronora Environmental Flows project, which repeats (with some additions) the sampling sites studied by Growns and Growns (2001)
- the Macroinvertebrate Monitoring Program (MMP), which samples a series of fixed and random sites throughout the Hawkesbury-Nepean and Shoalhaven catchments.

Sydney Water routinely monitors macroinvertebrates upstream and downstream of its major STP outlets.

Relevant data from these programs were collated, checked for consistency and combined into new datasets.

Algal and cyanobacterial data

Algal and cyanobacterial data were obtained from Sydney Water's Monitoring Data Warehouse and historical Algal Database. At many sites algal and cyanobacterial counts are conducted only if chlorophyll-a levels are above 10 µg/L. This means that much of the data collected are representative of relatively high algal conditions, including algal blooms. This presents problems when attempts are made to relate observed populations to the quality of water collected at different time scales or frequencies. An exception to this is North Richmond (site N42), where water is extracted for water supply purposes and water quality analysis and algal identification is undertaken on a weekly basis regardless of chlorophyll-a levels.

Periphytic diatom data

Periphytic diatom data were (up until recently) collected as part of SCA's Woronora Environmental Flows project, repeating (with some additional sites) the sampling sites and methods of Growns and Growns (2001). This appears to represent the only long-term study of periphytic diatoms in the Hawkesbury-Nepean River system, but more extensive searches of the scientific collections of museums and universities may be required to confirm this. Monitoring of diatoms at these sites using the methodology of Growns and Growns (2001) has now ceased (A. Kotlash (SCA) pers. comm. 2008). Some information on diatoms in the water column is, however, still being collected and is available in the algal monitoring program (see previous Section).

Fish data

Fish data were obtained from the NSW DPI Fisheries database and supplemented by targeted sampling at 15 sites conducted as part of the initial investigations of the current program. This latter sampling took place from October to December 2007; these results have been combined with historic data from the NSW DPI Fisheries database.

Macrophyte data

No routine long-term monitoring of native and introduced macrophytes currently occurs in the Hawkesbury-Nepean River system (although some small-scale programs are undertaken by the Hawkesbury-Nepean CMA and Hawkesbury County Council (Thiebaud and Williams 2008)). In 2004, NSW DPI mapped the distribution of submerged macrophytes in the Hawkesbury-Nepean River downstream of the confluence with the Warragamba River (Williams and Thiebaud 2007). DECC commissioned DPI Fisheries to repeat this sampling as a component of the current monitoring program. These data provide an indication of the potential expansion or contraction of populations of native and introduced macrophytes in the Hawkesbury-Nepean River.

Sediment data

There is no routine long-term monitoring of sediments in the Hawkesbury-Nepean River system. However, data are available in a dispersed collection of papers and reports (e.g. Jones 1982; PWD 1987; Thoms and Thiel 1995; NSW EPA 1996; Birch et al. 1998; Coastal and Marine Geosciences 1998; Thoms et al. 2000; Simonovski et al. 2003). Further information may be available in the scientific publications of museums and universities, but there was insufficient time to collate all this information for the current project. Sediments would be expected to change only over much longer timeframes than for the other indicators considered in the current project. However, there are suggestions of significant sediment movement at some sites in the Hawkesbury, with anecdotal reports of previously deep holes now having been infilled with sediments. Sediments can also act as sources and sinks of various chemicals (e.g. phosphorus and nitrogen) that may influence water quality in certain areas (Turner and Erskine 2005). Sediments also provide physical habitat, thereby affecting a range of animal and plant species (e.g. estuarine/marine and freshwater macroinvertebrates).

5. Trends in water quality and quantity

Water quality in rivers is largely a function of land use and catchment geology as well as in-stream processes. A wide range of human-related inputs to river systems can affect in-stream processes and can be detected by using water quality analyses. For example, high nutrient levels can stimulate algal blooms and toxic chemicals can severely affect aquatic plant and animal communities.

One of the limitations of water quality sampling and analysis in the Hawkesbury-Nepean is that it is generally undertaken monthly, so that short-term changes may not be easily detected without further additional investigation. It also means that it may take some time (years) before trends in water quality become evident in the routine monitoring program. Water quality sampling also focuses on only a subset of indicators, as it is both impractical and prohibitively expensive to test for all known chemical compounds that could be detrimental to river health. Appropriate water quality indicators are extensively discussed in the ANZECC/ARMCANZ (2000) Guidelines (particularly Volume 2, Section 8.2) and the indicators used in the Hawkesbury- Nepean Monitoring Program are considered to be an appropriate subset of water quality indicators to monitor. More specialised programs are required where specific contaminants are the primary focus of concern (e.g. pesticides/herbicides or endocrine disruptors).

Longitudinal trends in water quality

Sites that have been extensively sampled in the past for water quality are identified in Figure 5.1. Figure 5.2 illustrates the changes in various analytes as you move from the bases of the dams downstream to the mouth of the Hawkesbury River at Broken Bay. These figures include historic data from a more extensive network of sites than is being monitored or identified for monitoring in the current Program. They also contain a number of tributary sites that are likely to be unrepresentative of water quality in the main channel of the Hawkesbury-Nepean River. Despite this, they are useful in identifying specific tributaries (e.g. South Creek, Rickaby's Creek, Grose River) where water quality is significantly different from that in the main stem of the river and can contribute (both negatively and positively) to overall water quality and ecosystem health in the Hawkesbury-Nepean River system. The figures are based on long-term medians, and the data file from which these graphs have been produced is included in Table A1.2 (Appendix 1). Recent changes (e.g. nutrient reductions at STPs) are likely to reduce some of the highest spikes, and this can be seen in the gradual decreases in the time series of nutrient concentrations at many of these sites (See *Water quality trends using statistical models* below).

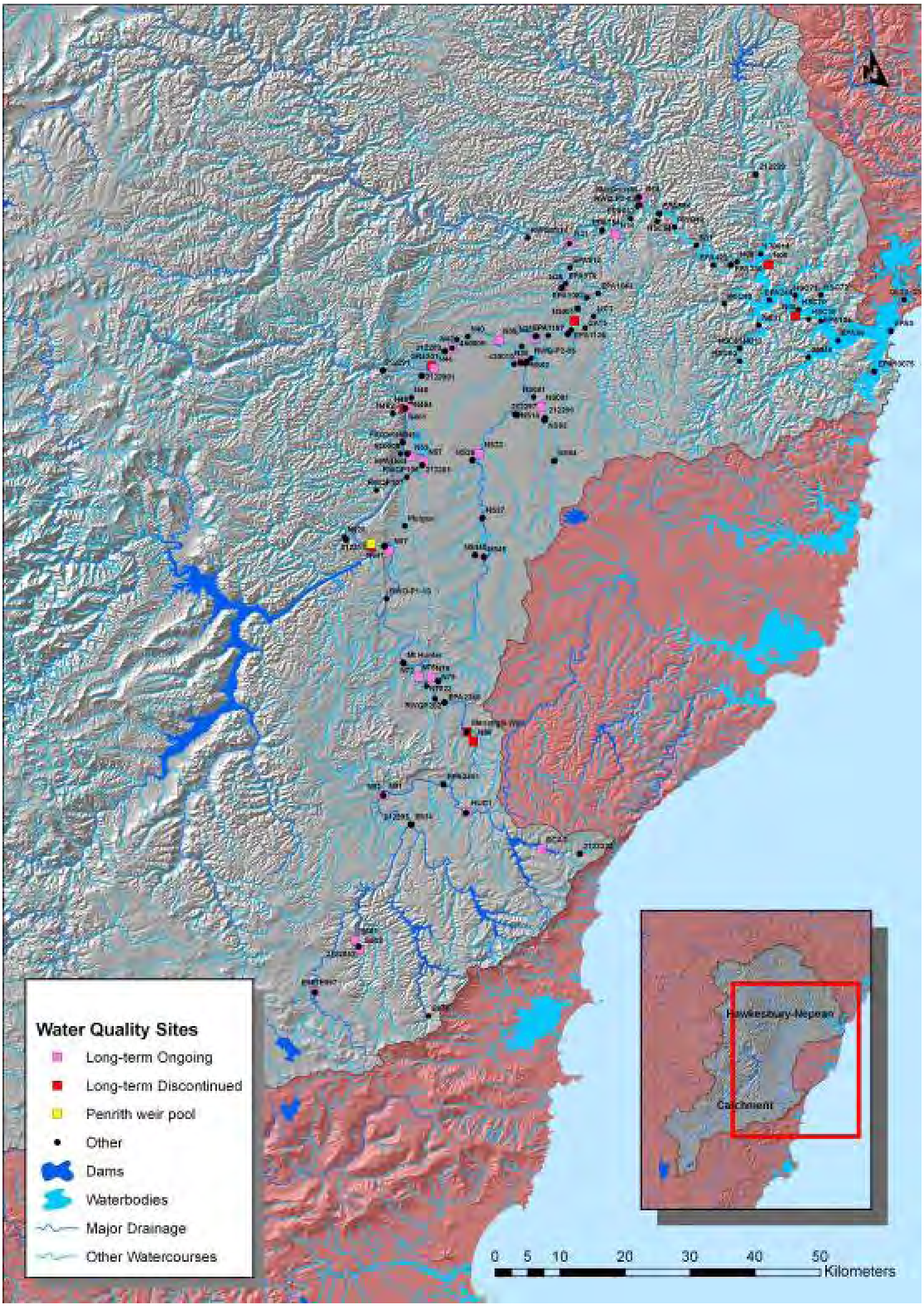

Figure 5.1: Long-term sampling sites in the Hawkesbury River downstream of the major dams[3]

[3] This is not meant to be a comprehensive list of all sites that have been sampled at some stage in the past, but an indication of sites in the Hawkesbury-Nepean River that have relatively long time series of water quality measurements.

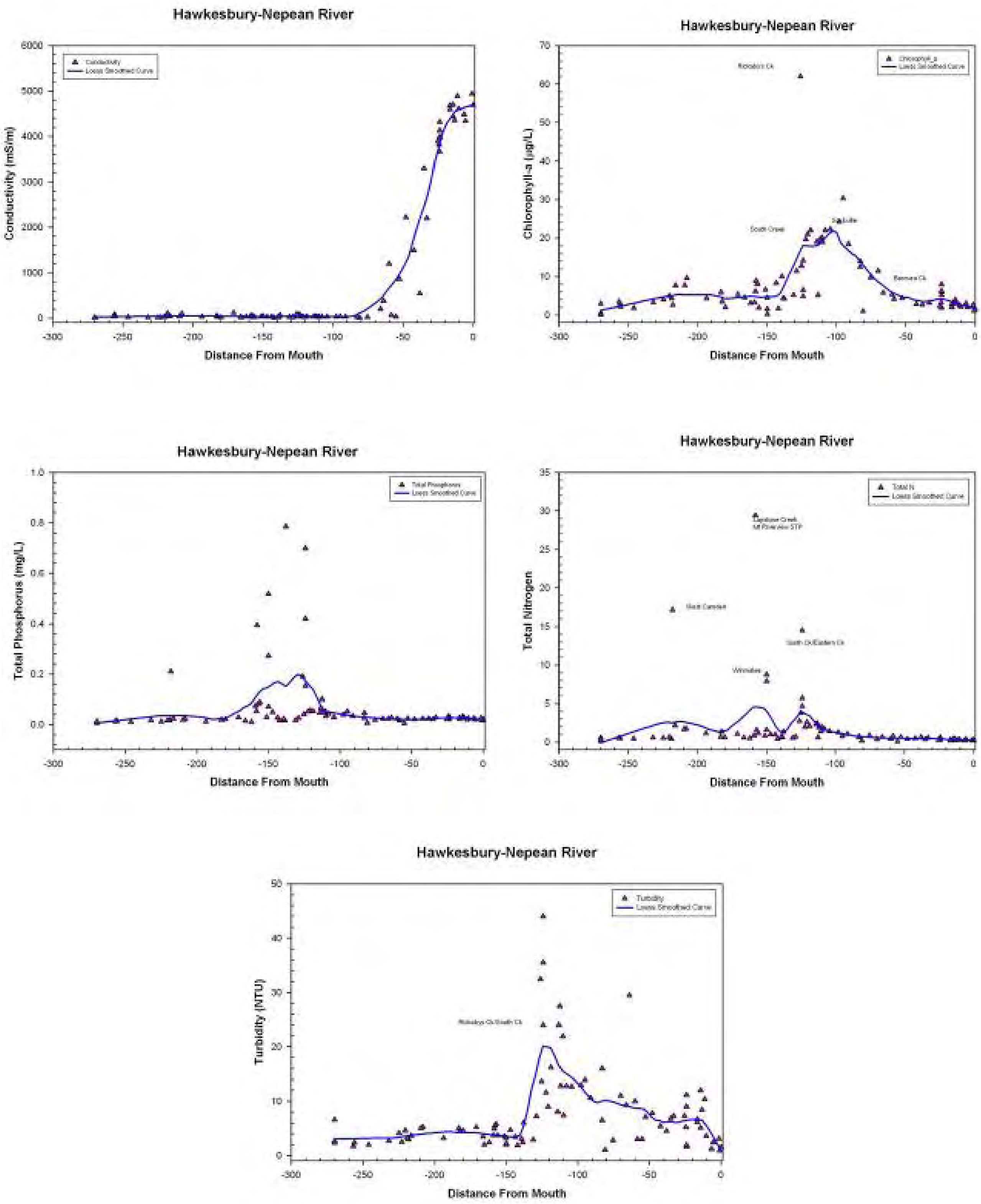

Figure 5.2: Longitudinal trends in water quality indicators in the Hawkesbury-Nepean River. Smoothed trend lines are Loess smoothed curves

General observations from these graphs suggest that moving downstream:

- long-term median conductivity levels remain low until about Wiseman's Ferry, where saline influences gradually become more dominant. Occasional small spikes in conductivity levels do occur in some areas (e.g. Matahill and Mulgoa Creeks)
- long-term median chlorophyll-a levels increase from about Camden Weir and are highest in the stretch of the Hawkesbury between the South Creek confluence and Sackville
- long-term median total phosphorus levels are strongly linked to areas under the influence of STP discharges, particularly between Lapstone Creek and Cattai Creek
- long-term median total nitrogen levels are also strongly linked to areas under the influence of STP discharges, increasing initially downstream of West Camden STP, with peaks at Winmalee Creek, Lapstone Creek and South and Eastern creeks.
- long-term median turbidity levels generally remain relatively low until the Rickaby's and South Creek confluences, with a gradual reduction back to low levels close to the mouth of the Hawkesbury River.

Temporal trends in water quantity at individual sites

The locations of river gauge and water level monitoring sites can be seen in Figure 5.3. Trends in hydrology and water quality in the Hawkesbury-Nepean River need to be interpreted in terms of both longer term cycles (e.g. the El Nino Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO)) and human-induced changes, including potential climate change impacts in the future. Although the international scientific community has reached a consensus that global warming is unequivocal (IPPC 2007) the exact implications this has for rainfall and hydrology are far more uncertain, particularly at a regional scale in New South Wales. Smoothed trends in rainfall and flow at a number of sites in the Hawkesbury-Nepean are shown in Figure 5.4. From this it is clear that there have been cyclic periods of higher and lower rainfall and flow. These trends are likely to continue even under a global warming scenario. Some of these trends can be related directly to large-scale climatic patterns such as ENSO and IPO (for example, see the SOI trend in Figure 5.4). Since many water quality variables are significantly affected by flow, assessments of changes and/or trends in water quality necessarily need to consider variation in flow.

Although smoothed trends in flow for various gauging stations can be seen in Figure 5.4, it is also informative to look at individual flows from each of the gauging stations. The long-term record for Penrith Weir stretches back to 1891 and is illustrated in Figure 5.5. Further appreciation of the changes that have occurred in flow over the last 100 years can be gained from the cumulative frequency with which flows of various magnitudes are exceeded (Figure 5.6). The much lower flows at Penrith in recent times should be obvious from these graphs. Similar graphs for other gauging stations are provided in Appendix 2.

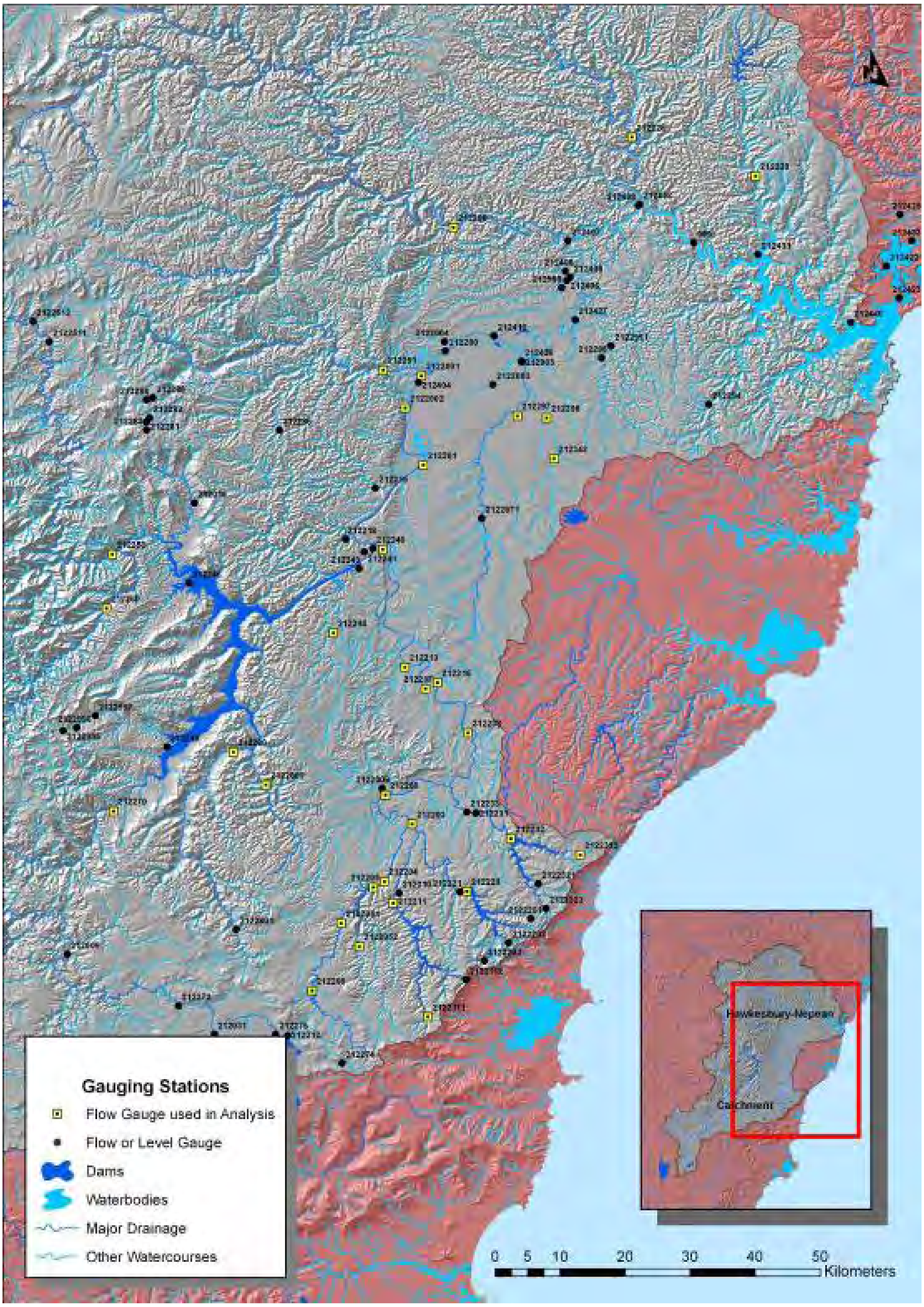

Figure 5.3: Long-term gauging and water level sites in the Hawkesbury River

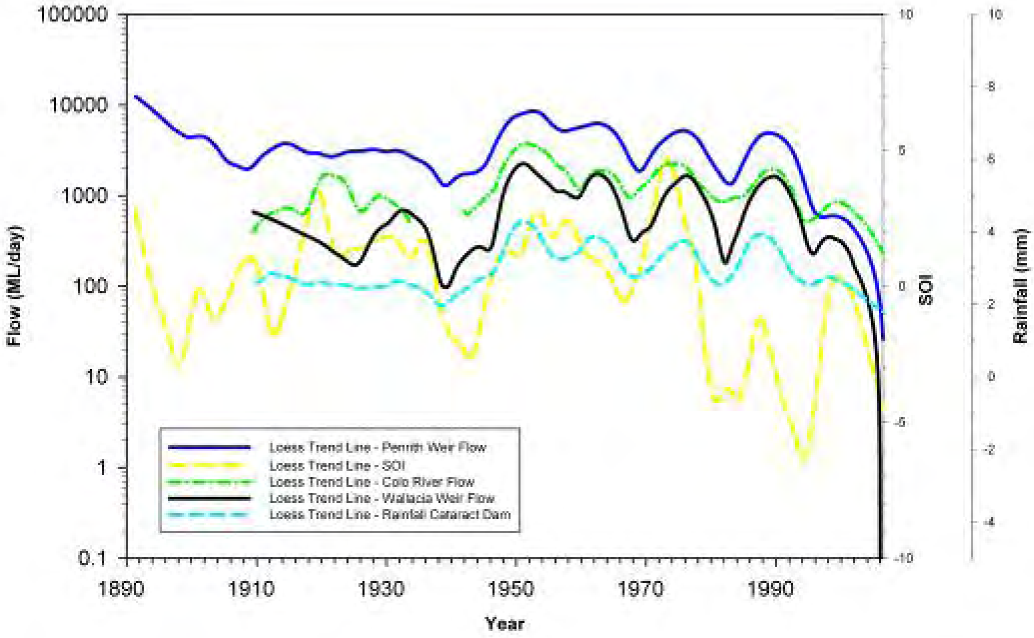

Figure 5.4: Smoothed trend lines for flow at Penrith Weir, Wallacia Weir and Colo River; rainfall at Cataract Dam; and the Southern Oscillation index (SOI)

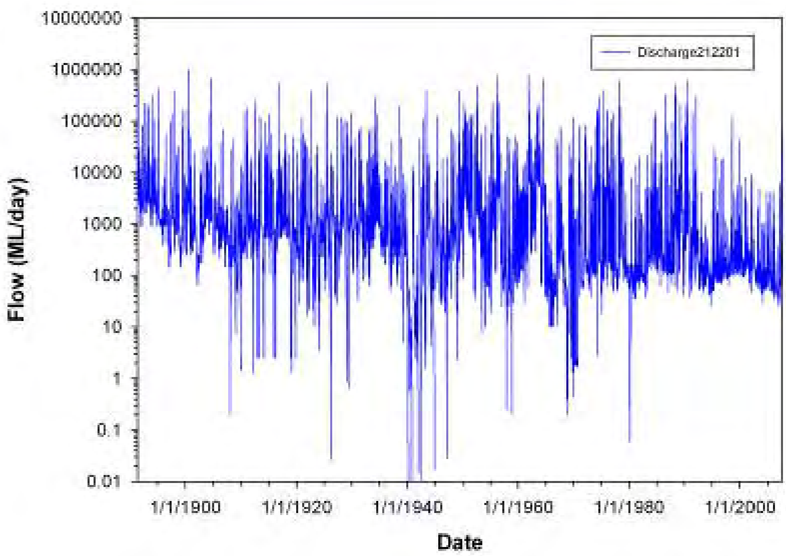

Figure 5.5: Time series of flows recorded at Penrith Weir (Stn212201)

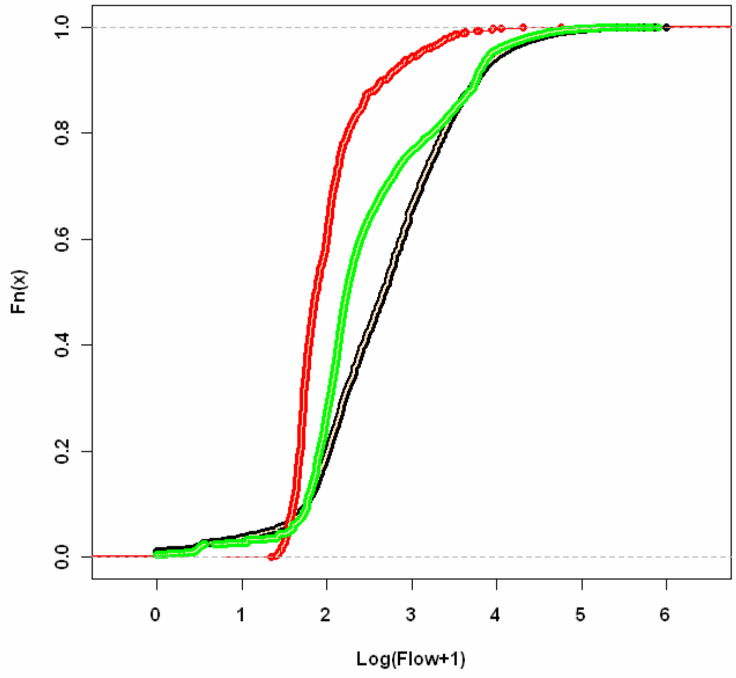

Figure 5.6: Empirical distribution function showing percentile flows for Penrith Weir. Black = Penrith Weir for entire period (1891-2007); Red = Penrith Weir after 1/6/05, when environmental flows were halved; Green = Penrith Weir after 1/1/60, i.e. after Warragamba Dam was built

General conclusions

- There has been a significant reduction in flows over Penrith Weir as a result of the ongoing drought and subsequent government policy that has seen interim e-flows halved.[4]
- River flow levels are now much less than the long-term (>100-year) average.
- River regulation is not the sole factor involved in this decline, since similar declines are also noticeable in the flow record for the unregulated Colo River. However, regulation is still important, since the smoothed trend line for flow at Penrith Weir (blue line in Figure 5.4) has now consistently fallen below that of the Colo River (green line in Figure 5.4) for the first time since records began.
- Since many water quality variables are significantly affected by flow, assessments of changes and/or trends in water quality necessarily need to consider variation in flow.
- Because river extraction also affects flow, there is a need to understand quantitatively where, when and how much water is extracted from the Hawkesbury-Nepean River.

Temporal trends in water quality at individual sites

In many cases the length of time for which water quality records have existed for the Hawkesbury-Nepean River is much shorter than that for flow. Water quality records

[4] Full environmental flows (e-flows) from Warragamba Dam have now been reinstated.

are also highly variable in terms of the temporal and spatial frequency of sampling. Most data received from the SCA and Sydney Water date back to the early 1980s, although data for some individual analytes may stretch further back in time. Additional water quality data are available for a range of shorter term studies and/or programs, but these are dispersed and of lesser value when attempting to interpret longer term trends. They are nonetheless valuable in their own right for the time periods and sites covered, but no attempt has been made to try to bring all these data into a central location for this project. Data analysed for this project have therefore been restricted to the long-term sites monitored by Sydney Water and the SCA and summarised in Table 3.1. These data are illustrated graphically in Appendix 3.

In terms of water quality, many areas in the Hawkesbury-Nepean can be described as being stressed, and some areas can probably best be described as being eutrophic. Large amounts of water are diverted for water supply and irrigation, and nutrient levels are often high, with outbreaks of algal blooms being common. Introduced macrophytes also occur extensively throughout the river system. When discussions of trends are undertaken here, it should be realised that although improvements in water quality in recent times can be demonstrated, they are improvements from what was a relatively poor condition; water quality in many areas of the Hawkesbury-Nepean still has a long way to go before meeting water quality objectives (e.g. ANZECC/ARMCANZ Guidelines).

Comparison of water quality with ANZECC/ARMCANZ (2000) guidelines

An initial assessment of changes in water quality in the Hawkesbury-Nepean River was achieved by dividing the data into three periods: the period from 2003 to 2007; the period from 1999 to 2003; and the historic period before 1999. The quartiles (25th percentile, median and 75th percentile), maximum and minimum of the data at each site (Table A4.1.1 in Appendix 4) were then compared with the ANZECC/ARMCANZ (2000) Guidelines. The results of these comparisons are included in Table 5.1: the colour coding indicates the conformance of measured values with the ANZECC guideline trigger values (Tables 3.3.2 and 3.3.3 in ANZECC/ARMCANZ 2000). Here, blue indicates 100% conformance with ANZECC/ARMCANZ guideline levels, whereas bright pink indicates 100% non-conformance (i.e. 100% of the data recorded at that site are outside ANZECC/ARMCANZ guideline levels).

An assessment of these results suggests that:

- improvements (decreases) in the number of samples exceeding ANZECC guidelines are noticeable at many sites in the river system (e.g. red in the historic period changing to orange, yellow, green or blue in later periods)
- nitrogen levels are often well above ANZECC guideline levels in many parts of the river system
- the effects of individual sewage treatment plants can potentially be inferred from these data (e.g. Penrith STP and changes in phosphorus levels at site N53) although other sources such as urban and agricultural runoff also contribute to water quality in these areas
- some sites appear to be experiencing a decline in water quality on the basis of raw data summary statistics (e.g. inorganic nitrogen [NOx-N] and total nitrogen [TN] at sites N75 and N53)
- nutrient levels are still an important issue in South and Eastern Creeks (sites NS23 and NS081).

Table 5.1: Comparison of water quality with ANZECC/ARMCANZ (2000) guideline levels*

	Chla	Chla	Chla	Conduct	Conduct	Conduct	DO_Sat	DO_Sat	DO_Sat	TP	TP	TP	Filt-P	Filt-P	Filt-P
	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007
N14	n = 292	n = 80	n = 65	Guidelines inapplicable			n = 293	n = 64	n = 72	n = 296	n = 64	n = 71	n = 247	n = 64	n = 71
N18	n = 136	n = 7	n = 46	n = 89#	n = 6	n = 53	n = 124	n = 6	n = 53	n = 134	n = 7	n = 53	n = 117	n = 7	n = 53
N21	n = 181	n = 79	n = 57	n = 102	n = 63#	n = 55	n = 175	n = 63	n = 57	n = 177	n = 79	n = 56	n 136	n = 79	n = 56
N26	n = 434	n = 67	n = 46	n = 268#	n = 50	n = 53	n = 422	n = 50	n = 53	n = 430	n = 53	n = 53	n = 348	n = 53	n = 53
N3001	n = 127	n = 59		n = 103#	n = 43 #		n = 112	n = 43		n = 126	n = 59		n = 125	n = 59	
N35	n = 237	n = 81	n = 65	n = 200#	n = 63#	n = 71	n = 224	n = 63	n = 72	n = 240	n = 67	n = 71	n = 208	n = 67	n = 71
N38	n = 341	n = 7	n = 44	n = 206#	n = 6#	n = 52#	n = 336	n = 6	n = 52	n = 339	n = 7	n = 51	n = 263	n = 7	n = 51
N39	n = 666	n = 67	n = 45	n = 60#	n = 50#	n = 52	n = 60	n = 50	n = 52	n = 66	n = 51	n = 52	n = 66	n = 51	n = 52
N42	n = 846	n = 209	n = 243	n = 548#	n = 174#	n = 250#	n = 819	n = 174	n = 249	n = 810	n = 191	n = 249	n = 760	n = 139	n = 72
GR4301	n = 229	n = 130		n = 144#	n =95#		n = 130	n = 95		n = 227	n = 130		n = 220	n = 130	
N44	n = 574	n = 150	n = 58	n = 264#	n = 113#	n = 57#	n = 566	n = 113	n = 58	n = 576	n = 150	n = 57	n = 494	n = 150	n = 57
N461	n = 110	n = 13		n = 57			n = 69			n = 115	n = 13		n = 104	n = 13	
N48	n = 582	n = 136	n = 47	n = 454#	n = 100	n = 54	n = 576	n = 100	n = 54	n = 628	n = 123	n = 54	n = 536	n = 123	n = 54
N53	n = 483	n = 137	n = 47	n = 424#	n = 102#	n = 54	n = 469	n = 101	n = 54	n = 529	n = 124	n = 54	n = 455	n = 122	n = 54
N57	n = 666	n = 152	n = 67	n = 416#	n = 116#	n = 74	n = 687	n = 116	n = 74	n = 727	n = 139	n = 73	n = 619	n = 138	n = 73
N641	n = 237	n = 130	n = 1	n = 196#	n = 95#	n = 1	n = 189	n = 95	n = 1	n = 238	n = 130	n = 1	n = 214	n = 130	n = 1
N67	n = 830	n = 149	n = 58	n = 260#	n = 114#	n = 58	n = 783	n = 114	n = 58	n = 832	n = 149	n = 57	n = 653	n = 149	n = 57
N75	n = 478	n = 152	n = 60	n = 413#	n = 116#	n = 67	n = 463	n = 116	n = 67	n = 488	n = 152	n = 70	n = 431	n = 136	n = 66
N78	n = 483	n = 137	n = 46	n = 415#	n = 101#	n = 53	n = 472	n = 101	n = 53	n = 484	n = 120	n = 53	n = 439	n = 120	n = 53
N92	n = 492	n = 208	n = 100	n = 406#	n = 172#	n = 108#	n = 442	n = 173	n = 107	n = 507	n = 194	n = 106	n = 417	n = 194	n = 106
	SOUTH CREEK SITES														
NS23	n = 52	n = 51	n = 48	n = 6	n = 38	n = 56		n = 38	n = 56	n = 40	n = 51	n = 56	n = 40	n = 51	n = 56
NS081	n = 42	n = 52	n = 48		n = 38	n = 56		n = 38	n = 56	n = 30	n = 52	n = 56	n = 30	n = 52	n = 56

	TN	TN	TN	NH3-N	NH3-N	NH3-N	NOx-N	NOx-N	NOx-N	pH (low)	pH (low)	pH (low)	pH (High)	pH (High)	pH (High)	Turb	Turb	Turb
	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007	Historic	1999 - 2002	2003 - 2007
N14	n = 293	n = 64	n = 71	n = 291	n = 64	n = 71	n = 294	n = 54	n = 71	n = 115	n = 52	n = 72	n = 115	n = 52	n = 72		n = 6#	n = 12#
N18	n = 133	n = 7	n = 53	n = 133	n = 7	n = 53	n = 133	n = 7	n = 53	n = 89	n = 6	n = 53	n = 89	n = 6	n = 53		n = 6#	n = 12#
N21	n = 176	n = 79	n = 56	n = 175	n = 79	n = 56	n = 176	n = 79	n = 56		n = 51	n = 57		n = 51	n = 57		n = 51#	n = 57#
N26	n = 413	n = 53	n = 53	n = 401	n = 53	n = 53	n = 413	n = 53	n = 53	n = 156	n = 38	n = 53	n = 156	n = 38	n = 53		n = 38#	n = 52#
N3001	n = 127	n = 59		n = 127	n = 59		n = 127	n = 59			n = 31			n = 31				n = 30#
N35	n = 237	n = 67	n = 71	n = 236	n = 67	n = 71	n = 236	n = 67	n = 71	n = 101	n = 51	n = 72	n = 101	n = 51	n = 72		n = 50#	n = 72#
N38	n = 332	n = 7	n = 51	n = 328	n = 7	n = 51	n = 332	n = 7	n = 51	n = 156	n = 6	n = 52	n = 156	n = 6	n = 52		n = 6#	n = 51#
N39	n = 65	n = 51	n = 52	n = 66	n = 51	n = 52	n = 66	n = 51	n = 52	n = 1	n = 40	n = 52	n = 1	n = 40	n = 52		n = 38#	n = 52#
N42	n = 785	n = 191	n = 249	n = 775	n = 139	n = 72	n = 787	n = 139	n = 72	n = 323	n = 150	n = 250	n = 323	n = 150	n = 250		n = 148#	n = 249#
GR4301	n = 229	n = 130		n = 227	n = 130		n = 229	n = 130		n = 3	n = 71		n = 3	n = 71			n = 69#	
N44	n = 573	n = 150	n = 57	n = 570	n = 150	n = 57	n = 575	n = 150	n = 57	n = 3	n = 89	n = 58	n = 3	n = 89	n = 58		n = 87#	n = 58#
N461	n = 114	n = 13		n = 114	n = 13		n = 114	n = 13										
N48	n = 623	n = 123	n = 54	n = 622	n = 123	n = 54	n = 624	n = 123	n = 54	n = 223	n = 76	n = 54	n = 223	n = 76	n = 54		n = 74#	n = 54#
N53	n = 534	n = 124	n = 54	n = 534	n = 122	n = 54	n = 535	n = 122	n = 54	n = 195	n = 78	n = 54	n = 195	n = 78	n = 54		n = 75#	n = 54#
N57	n = 701	n = 139	n = 73	n = 686	n = 138	n = 73	n = 706	n = 138	n = 73	n = 235	n = 92	n = 74	n = 235	n = 92	n = 74		n = 90#	n = 74#
N641	n = 238	n = 130	n = 1	n = 238	n = 130	n = 1	n = 238	n = 130	n = 1	n = 2	n = 71	n = 1	n = 2	n = 71	n = 1		n = 69#	n = 1#
N67	n = 833	n = 149	n = 57	n = 833	n = 149	n = 57	n = 833	n = 149	n = 57	n = 2	n = 90	n = 57	n = 2	n = 90	n = 57		n = 88 #	n = 58#
N75	n = 472	n = 136	n = 66	n = 468	n = 136	n = 66	n = 472	n = 136	n = 66	n = 184	n = 92	n = 66	n = 184	n = 92	n = 66		n = 90#	n = 67#
N78	n = 478	n = 120	n = 53	n = 473	n = 120	n = 53	n = 478	n = 120	n = 53	n = 182	n = 77	n = 53	n = 182	n = 77	n = 53		n = 75#	n = 53#
N92	n = 508	n = 194	n = 106	n = 506	n = 194	n = 106	n = 509	n = 194	n = 106	n = 173	n = 149	n = 107	n = 173	n = 149	n = 107		n = 147#	n = 107#
NS23	n = 40	n = 51	n = 56	n = 40	n = 51	n = 51	n = 40	n = 51	n = 56	n = 6	n = 38	n = 56	n = 6	n = 38	n = 56		n = 25#	n = 56#
NS081	n = 30	n = 52	n = 56	n = 30	n = 52	n = 56	n = 30	n = 52	n = 56		n = 38	n = 56		n = 38	n = 56		n = 25	n = 56

	None > ANZECC Guidelines
	Maximum > ANZECC Guidelines
	75th Percentile > ANZECC Guidelines
	50th Percentile > ANZECC Guidelines
	25th Percentile > ANZECC Guidelines
	Minimum > ANZECC Guidelines
	No available data
#	Values < Lower part of ANZECC Range

*Wl value (e.g. for dissolved oxygen saturation) the colour coding has been reversed : i.e. blue indicates that no values are less than the ANZECC lower limit, green indicates that the minimum is less than ANZECC, yellow indicates that the 25th percentile is less than ANZECC and brown indicates that the 50th percentile is less than the ANZECC lower limit. Variables are: chlorophyll-a (Chla); conductivity (Conduct); dissolved oxygen saturation (DO Sat); total phosphorus (TP); filterable phosphorus (Filt-P); total nitrogen (TN); ammonia-nitrogen (NH3-N); inorganic nitrogen (NOx-N); turbidity (Turb). Trigger levels used: chlorophyll a = 5 µg/L; conductivity 125–2200 µS/cm; dissolved oxygen (% saturation) = 85%–100%; total phosphorus = 50 µg/L; filterable phosphorus = 20 µg/L; total nitrogen = 500 µg/L; total ammonia N = 20 µg/L; oxides of nitrogen = 40 µg/L; pH = 6.5-8; turbidity = 6-50 NTU. Note: ANZECC trigger values for NSW east-flowing coastal rivers are slightly lower for some analytes than the values used here.

Water quality trends using statistical models

As stated earlier, assessment of trends in water quality need to take into account changes in rainfall, flow and other important environmental variables. A suitable statistical model to use is one that includes the major covariates considered to have an impact on water quality (e.g. flow, season); the trend over time in water quality analytes is then assessed after allowing for variation due to these important covariates. 'Best-fitting' models can then be specified by investigating the significance of each contributing term. Using this rationale, statistical models — generalized linear models (GLM) and generalized additive models (GAM) — were developed to model water quality in the Hawkesbury-Nepean River using the data provided by SCA and Sydney Water.

The predictor variables used in these models were generally flow at the gauging station closest to the water quality sampling site, flow on the day before sampling, flow at important tributary sites relevant to these individual sites (e.g. the Grose River when considering water quality at North Richmond), seasonal terms and time[5] (consecutive number of days since 1/1/1984). In these analyses, the stochastic effects of rainfall were assumed to be captured through their effects on flow and were not modelled directly.

For sites farther downstream in the Hawkesbury and under the influence of tidal regimes a different approach was required. Flow at these sites cannot simply be modelled on the basis of flows at Penrith Weir or Yarramundi (the most downstream flow-gauging station) because of issues associated with transit time (which could vary from days during very low flows to hours in large events) and because of the effect of tides backing the freshwater up and thereby altering the residence and transit times in different sections of the river. In these cases, flow at Penrith weir was categorized into quartiles (minimum to 25th percentile; 25th to 50th percentile; 50th to 75th percentile; and 75th percentile to maximum). A categorical variable representing these quartiles was then used in the GAM models instead of continuous flow records.

GLMs were fitted to the water quality and quantity data by using the GLM procedure in SAS Enterprise Guide 4.1 (SAS Institute Inc 2006). GAMs were fitted to the data by using the *mgcv* package (Wood 2006) in R Version-2.5.1 (The R Foundation for Statistical Computing 2007). GAMs provide more flexibility; do not assume linearity of dependent variables (unless you define them to be linear); provide a less subjective choice of appropriate form of relationship between predictor and independent variables; and can be implemented in several ways in the R statistical package. One disadvantage is that more parameters often need to be estimated (potentially requiring more data) and the models are slightly more complicated. GAMs also have different assumptions from those used in GLMs. In the current report, the results of the GAM analyses have been presented. All models could potentially be improved and developed by further exploration of outlying points and the use of additional variables and/or by considering the effects of spatial or temporal autocorrelation (if the latter exists at the temporal frequencies sampled).

Further details on the particular model used at a particular site are given in Appendix 4. The results from the GAM assessment of trends are summarised in Table A4.1.2 (Appendix 4). The colour coding in Table A4.1.2 is used as an indicator of model explanatory power, with blue indicating a model with a very good fit to the data (explaining more than 80% of the variance in the data) to pink indicating a model with

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[5] Time was taken to be an increasing series from 1 on a start date of 1/1/1984 up to a maximum on the latest record for that site (e.g. 8614 for 1/8/2007).

a relatively poor fit to the data (explaining less than 20% of the variance in the data). This summary therefore indicates both the direction of the (non-linear) trend in time and the explanatory power of the model for a specific water quality variable at a specific site. A graphical example of the measured data and the results of the modelled time trends are provided in Figures 5.7, 5.8 and 5.9.

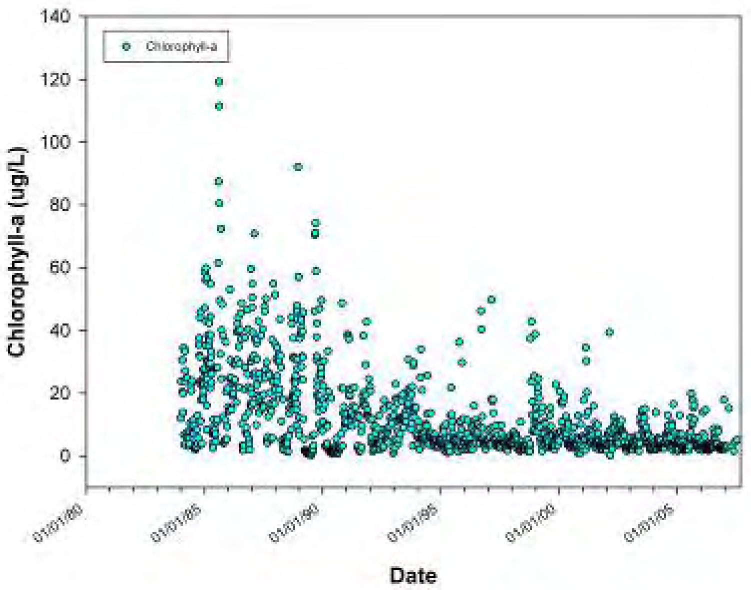

Figure 5.7: Time series plot of chlorophyll-a levels at North Richmond

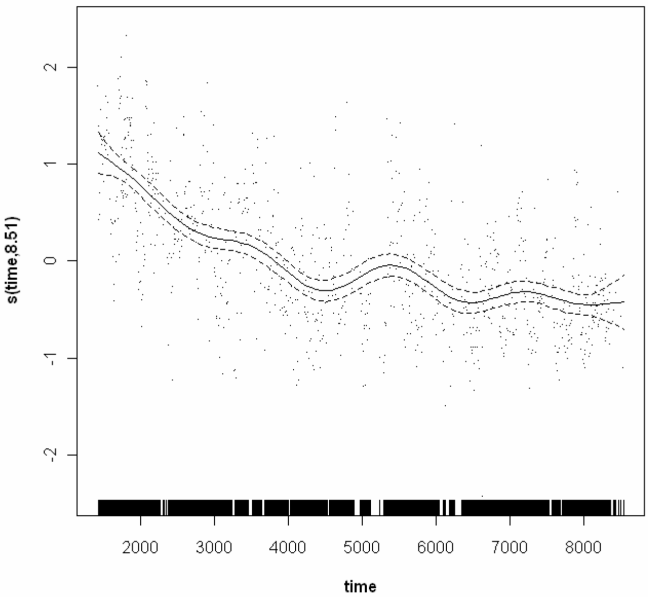

Figure 5.8: Non-linear time trend in chlorophyll-a levels at North Richmond, modelled using GAMs. Values on the y-axis represent partial residuals; Time = 1 on the x-axis corresponds to 1/1/1984; Time = 8614 is 1/8/07

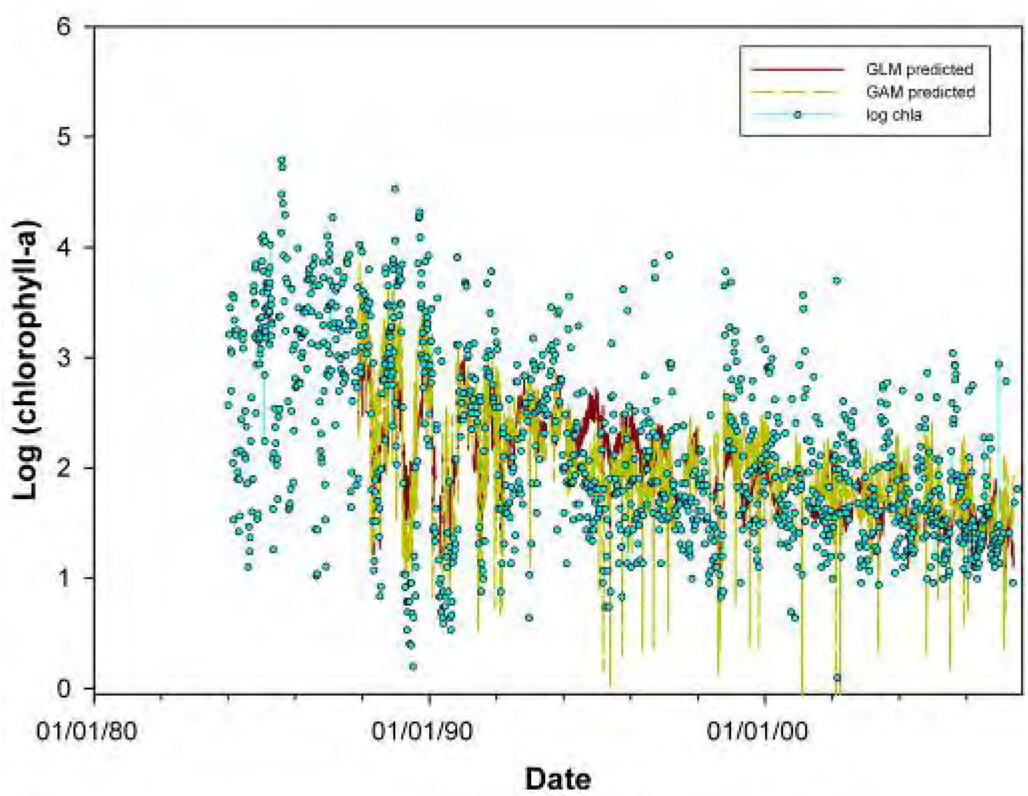

Figure 5.9: Chlorophyll-a levels over time at North Richmond, showing GLM and GAM predicted values. Records of flow for the Grose River commenced on 19/11/87, so earlier records for chlorophyll-a could not be modelled when this co-variable was included in the model.

General conclusions

- GLM and GAM modelling were generally in agreement with the results of comparisons with ANZECC/ARMCANZ guideline levels (see *Comparison of Water Quality with ANZECC/ARMCANZ (2000) Guidelines* above).
- Phosphorus levels (both total and filterable) have generally been declining throughout most of the river system (with perhaps the exception of the uppermost site considered: Maldon Weir — site N92). Phosphorus levels downstream of Penrith STP (e.g. at N53) remain elevated compared with those in many other areas in the system.
- Nitrogen levels have declined at many sites throughout the river system. Exceptions to this are Sharpes Weir (downstream of West Camden STP) and Wallacia Bridge (sites N75 and N67), where nitrogen levels (particularly inorganic nitrogen levels) appear to be increasing (e.g. see Figure 5.10). Despite many decreasing trends in nitrogen levels, nitrogen levels often remain above ANZECC/ARMCANZ guideline levels throughout the river system.

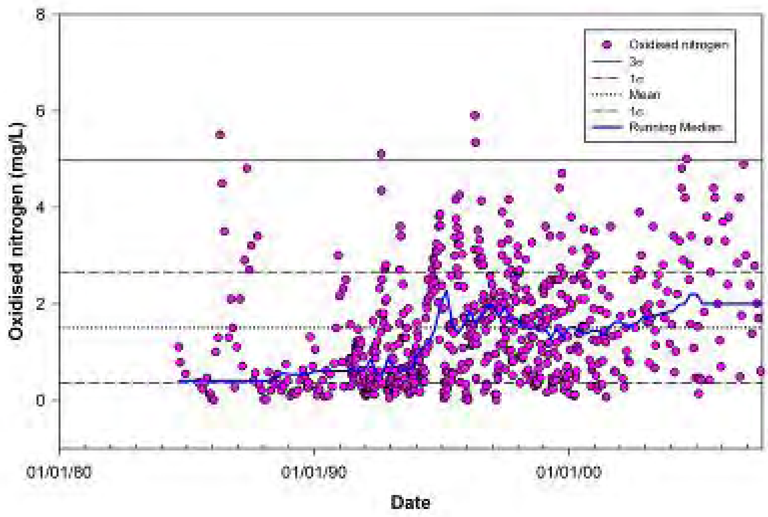

Figure 5.10: Oxidised nitrogen levels at Sharpes Weir

- Dissolved oxygen and temperature levels have largely remained steady, although slight increases in temperature are suggested at sites upstream of Wallacia Weir.
- Conductivity levels appear to be increasing at the majority of monitoring sites[6]. Although the absolute magnitude of this increase is not large and conductivity levels are still well within ANZECC/ARMCANZ guidelines, the ANZECC/ARMCANZ guidelines for conductivity in lowland rivers are quite broad (125 to 2200 µS cm^{-1}).
- Chlorophyll-a levels have mostly declined or remained stable at most sites.
- Cyanobacterial cell counts have largely remained stable, although some slight increases are suggested (at sites N21, N38, N39, N57, N67 and N92). Most recent blooms downstream[7] of the dams have not been dominated by *Microcystis* or *Anabaena*, although *Anabaena* was the dominant species in the January 2007 bloom at Maldon Weir.
- Trends in other water quality indicators were variable among sites.

6. Trends in biological indicators

Aquatic ecology in the Hawkesbury-Nepean River system is affected by flow and water quality, changes due to catchment disturbance and runoff, the discharge of treated effluent, and flow regulation and modification. Long-term information on biological indicators is much more limited than that on water quantity and quality. The most well-developed and widespread of the available biological indicators are macroinvertebrates collected by the methods of either Chessman (1995) or Turak et

6 This is in agreement with the findings of Wood, J. (2006) *Western Sydney Salinity: Water Quality Assessment*. Report prepared for the Hawkesbury Nepean CMA, NSW Department of Natural Resources.

7 At the time of writing, *Microcystis* was the dominant alga present on the surface of Warragamba Dam.

al. (1999, 2004). Sydney Water routinely monitors macroinvertebrates upstream and downstream of its major STP outlets. SCA uses macroinvertebrates as an indicator to inform its environmental flows and catchment health projects. Macroinvertebrate monitoring is also a major component of the State Monitoring, Evaluation and Reporting (MER) Strategy. Other important biological indicators included in at least some monitoring programs in the Hawkesbury-Nepean River system are algal communities (chlorophyll-a, cyanobacterial cell counts, biovolume and species composition), periphytic diatoms and fish.

Trends in macroinvertebrates

Macroinvertebrates have been studied at a variety of sites throughout the Hawkesbury-Nepean catchment (see Figure 6.1). However, we are only now approaching periods of approximately 10 years or more in which macroinvertebrates have been monitored consistently at the same site, by the same organisation and using the same sampling methodology. Very few sites in NSW actually have such an extensive history of sampling for macroinvertebrates at the same site using the same methodology. Significant advances in taxonomy have also occurred over this time period, meaning that adjustments are usually required if the results of recent monitoring are to be compared with results further back in time (and between different organisations using different taxonomic resolutions). Sites that have been monitored for relatively longer periods of time are summarised in Table A5.1.1 (Appendix 5). A further advantage of the many samples from sites in Table A5.1.1 is that taxonomic resolution has been at the genus level (as opposed to family level) of identification.

A much more complicated problem is determining whether we can actually detect trends over time or whether we can detect only step changes when dealing with multivariate communities collected by using rapid biological assessment (RBA) protocols. Most macroinvertebrate sampling is non-quantitative and based on family-level identifications; although various indices exist for assessment of condition (O/E 50, Signal — Chessman 1995, Turak et al. 1999, 2004, Besley and Chessman 2008), long-term trend assessment using these indices requires further research and development. The variability in individual macroinvertebrate family detections based on a single RBA samples can also be very high (Gillies et al. 2009); this is clearly demonstrated in Figure 6.2 for the Nepean River at the Avon Dam Road site (N95). The picture that Figure 6.2 is meant to convey is that although some families are collected consistently through time (unbroken yellow or orange lines covering the period of sampling), there are many families that are collected only intermittently — sometimes on only one or two occasions. The potential effect this has on comparisons and assessment of trends through time needs further consideration.

During the analysis of the macroinvertebrate data, ‘natural’ breaks in species community compositions were found longitudinally down the river (e.g. upstream and downstream of Yarramundi). Trend assessments therefore need to consider not only habitat and season of sampling, but also where in the river sampling takes place. For the purposes of this report, the macroinvertebrate data were separated on the basis of habitat (riffle and edge), season (spring and autumn), the organisation undertaking the monitoring, and the section of the river sampled. This led to the following categorization of sites:

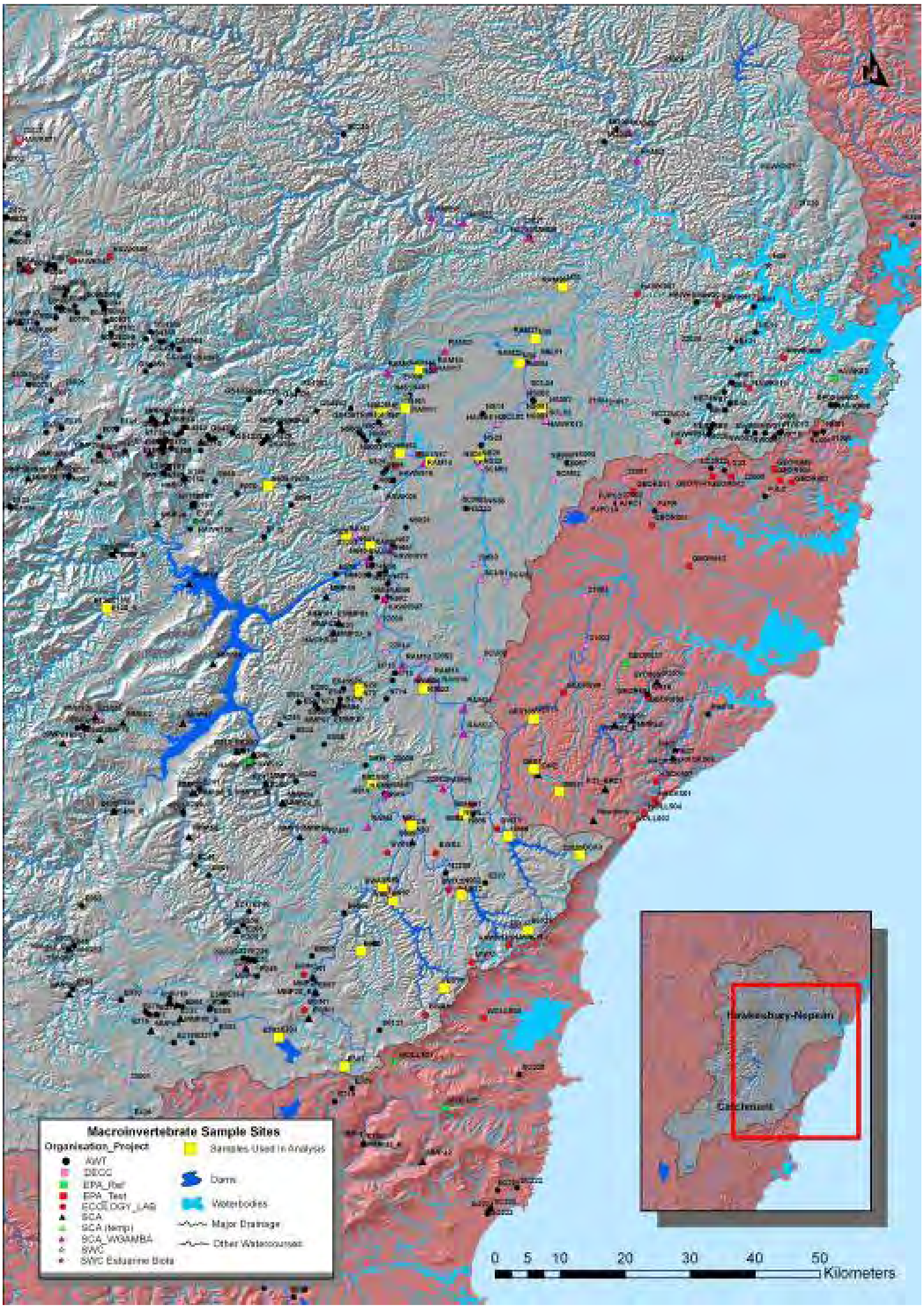

Figure 6.1: Sampling sites for macroinvertebrates in the Hawkesbury-Nepean River Catchment[8]

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8 This Figure is not meant to be a comprehensive list of all sites that have ever been sampled for macroinvertebrates in the Hawkesbury-Nepean catchment; it represents the locations where samples have been collected for major programs undertaken by DECC/EPA, Sydney Water/AWT and the Sydney Catchment Authority. Specific sites with a longer-term history of sampling and used extensively in analyses for this report are identified as yellow boxes.

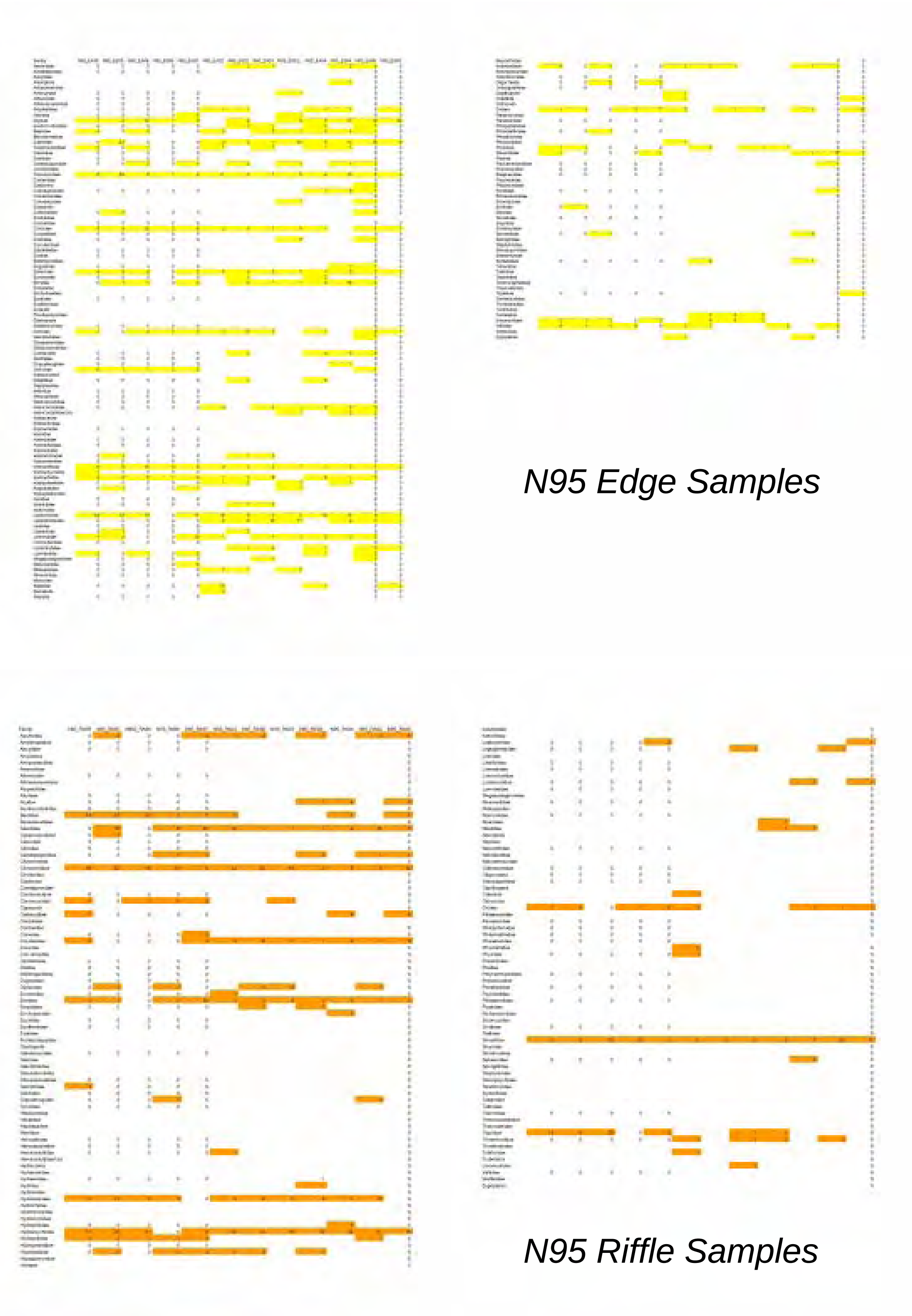

Figure 6.2: Consistency of detection of macroinvertebrate taxa downstream of Nepean Dam (Site N95 edge habitat top; Site N95 riffle habitat bottom)[9]

[9] The individual families can be identified by increasing the magnification of the page (zoom) when the Main Report pdf file is opened.

- sites on the main-stem of the Hawkesbury River (Maldon Weir [Site N92] to Wisemans Ferry [Site N14] and sampled consistently by Sydney Water
- sites upstream, downstream and at reference locations as described by Growns and Growns (2001) and sampled in more recent times by Ecowise Environmental as part of the SCA's Woronora Environmental Flows Project.

The macroinvertebrate composition data were analysed with the Primer V6 Package (Clarke and Gorley 2006), with samples separated into sites, habitat, season and sampling organisation for later comparisons using multidimensional scaling, ANOSIM and SIMPER (Clarke and Warwick 2001). In each case the data have been transformed to presence/absence, and the Bray-Curtis similarity measure has been used to construct the similarity matrices (see Clarke and Warwick 2001). The results of these analyses are given in detail in the individual sections below.

Sites on the main-stem of the Hawkesbury River (Maldon Weir N92 to Wisemans Ferry N14)

Changes in water quality and macroinvertebrate abundance and diversity are measured by Sydney Water upstream and downstream of its inland sewage treatment plants. Monitoring is carried out at receiving water sites upstream and downstream of treatment plants in the Blue Mountains, the Nepean River, South Creek, Cattai Creek, Berowra Creek and the lower Hawkesbury River (SWC 2007). Macroinvertebrates are sampled twice a year in autumn and spring, generally by the methodology described by Chessman (1995) and Besley and Chessman (2008). Variable weather conditions can influence the upstream and downstream health of streams. Heavy rain can affect creeks by washing away macroinvertebrates and in drier conditions can cause creeks to dry out, compromising stream health. A subset of Sydney Water's monitoring sites (see Table A5.1.1; Appendix 5) was considered in this section. In most cases these were sites located either in, or at, tributary sites closest to the main-stem of the Hawkesbury-Nepean River.

Analysis of these data indicated that:

- the data were taxonomically consistent with just one organization (Sydney Water Corporation and its predecessors) having collected the data over a period of approximately 12 years
- there were significant differences among habitats (riffle and edges; ANOSIM P = 0.001) in the main-stem of the Hawkesbury-Nepean River (Figure 6.3)
- there were significant differences among sites that were upstream and downstream of Yarramundi in terms of macroinvertebrate community (ANOSIM P = 0.001; Figure 6.4)
- the taxa that contributed the most to these upstream/downstream differences included *Cymodetta, Physa, Triplectides, Cricotopus/Paratrichocladius, Corbicula, Rheotanytarsus, Cheumatopsyche, Cura, Simulium, Paratya* and *Edmundsiops* (see Figure 6.5)
- there were also significant differences in water quality upstream and downstream of N44 (ANOSIM P = 0.001; based on Euclidean distance for normalised water quality data). Chlorophyll-a, suspended solids and reactive silica contributed the most to these upstream–downstream differences.
- the patterns for macroinvertebrates and water quality were, however, quite different because of the differences in temporal frequency of sampling employed by the different programs; further analysis of the concordance between water

quality and macroinvertebrate community composition needs to be undertaken[10] (Figure 6.6)

- individual differences among sites were readily discernible in macroinvertebrate communities (ANOSIM global test among sites; $P = 0.001$)
- pair-wise differences among sites were mostly significant (ANOSIM $P < 0.05$) with the exception of N26 and N35; N38, N40 and N42; N75 and N80; and N78 and N80.
- yearly differences in macroinvertebrate communities were not as readily discernible, although still statistically significant (ANOSIM global test among years, $P = 0.006$)
- pair-wise differences were mostly non-significant among years (ANOSIM $P >$ 0.05), with the exception of 1994 versus 2003–2006 ($P = 0.001$ to $P = 0.006$), 1995 versus 2000–2005 ($P = 0.013$ to $P = 0.024$); 1997 versus 2003 and 2005 ($P = 0.036$ and $P = 0.040$, respectively); and 1998 versus 2005 ($P = 0.024$).

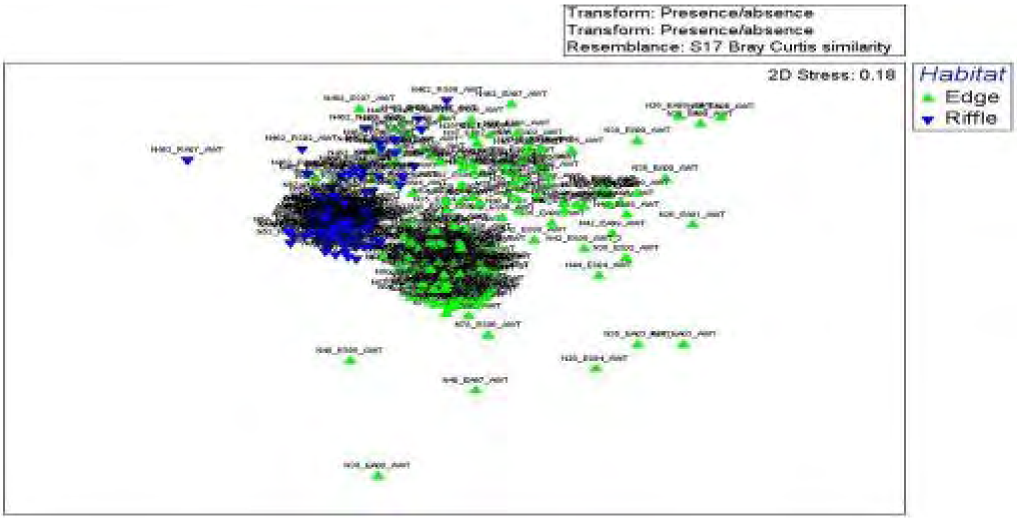

Figure 6.3: Multidimensional scaling ordination of macroinvertebrate samples in the main-stem of the Hawkesbury-Nepean River, illustrating the difference between edge and riffle habitats

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10 For example, water quality could be averaged over a period of days or months preceding macroinvertebrate sampling and summarised by using simple univariate statistics (e.g. medians). However, a significant difficulty arises in defining exactly what the appropriate period of averaging should be — or indeed the temporal frequency over which macroinvertebrates may (or may not) be responding to changes in water quality (e.g. the previous day, week, month, 6 months, year or other time since the last major event). Further research in this area is warranted.

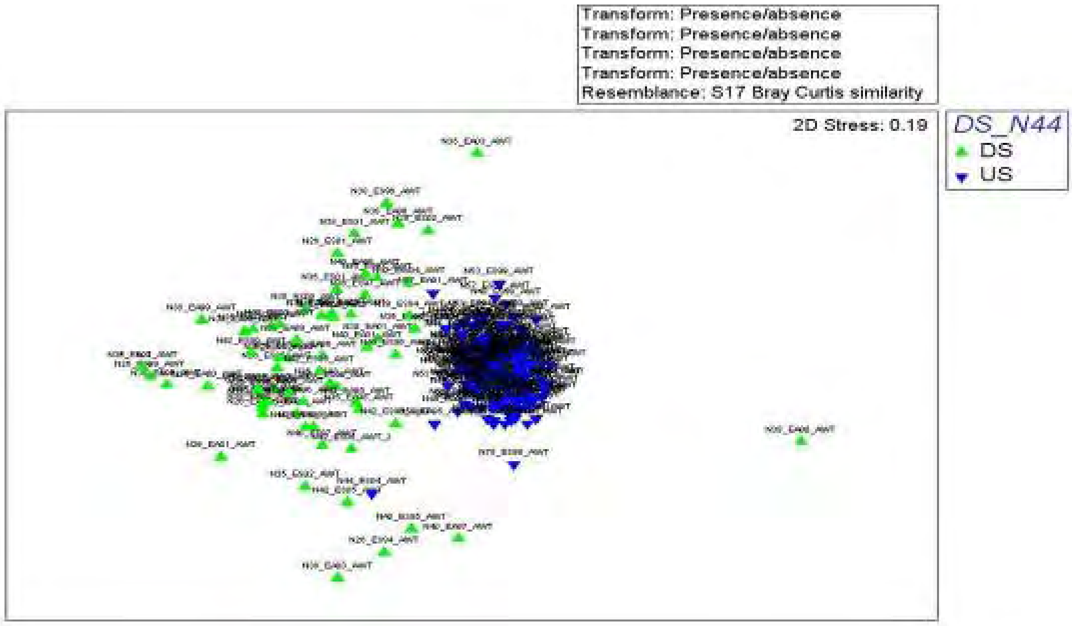


Figure 6.4: Multidimensional scaling ordination of macroinvertebrate samples, illustrating the difference between edge samples upstream (US) and downstream (DS) of Yarramundi (Site N44)

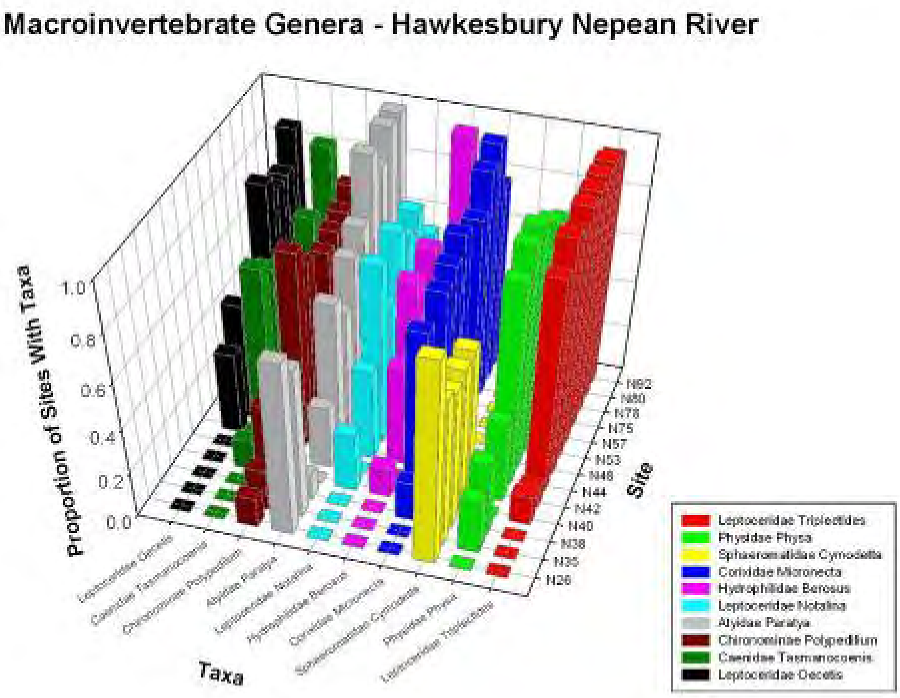


Figure 6.5: Proportional abundances of the top 10 macroinvertebrate taxa contributing to differences among edge sites upstream and downstream of Yarramundi (Site N44)

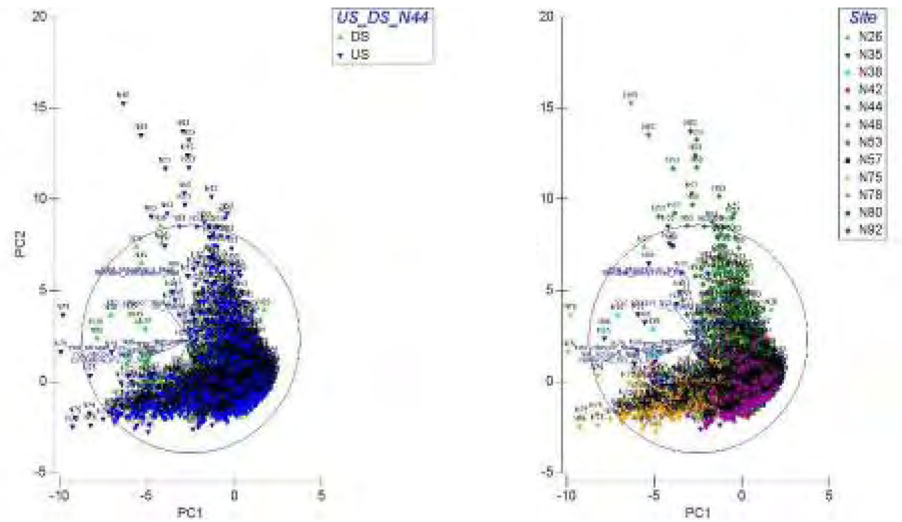


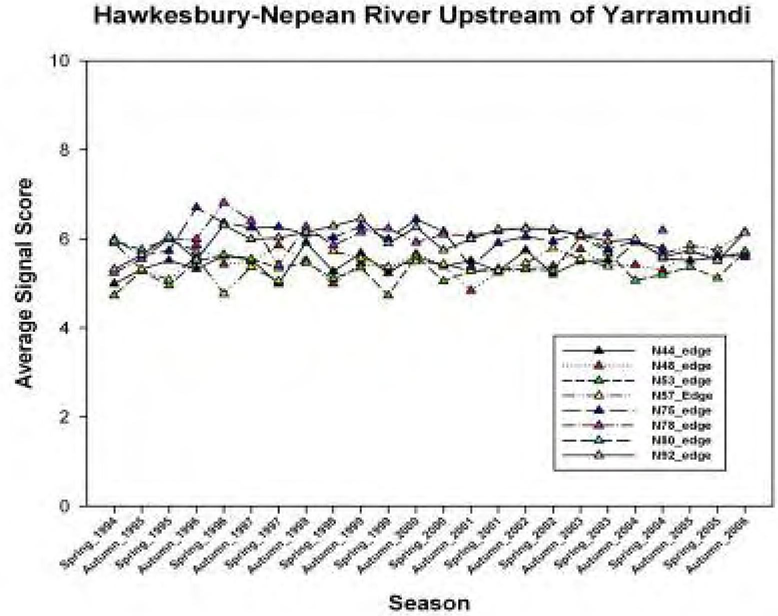
Figure 6.6: Principal components analysis of water quality, illustrating differences between sites upstream (US) and downstream (DS) of Yarramundi and among individual sites

Temporal trends in SIGNAL-based assessments. Average SIGNAL-SG (Chessman et al. 2007) scores were calculated for macroinvertebrates found at sites on the main-stem of the Hawkesbury River, and these data are presented graphically in Figures 6.7, 6.8 and 6.9. At sites upstream of Yarramundi (Figure 6.7) the average SIGNAL-SG scores in edge habitats indicated a very consistent pattern over time that does not suggest major changes have occurred in macroinvertebrate communities (in terms of average SIGNAL-SG scores). Greater variation was found at edge sites below Yarramundi (Figure 6.7), but there was an absence of more recent macroinvertebrate data in these areas. Further sampling at these sites may help determine whether these sites have also remained relatively stable over this time period (in terms of average SIGNAL-SG scores).

The large variation between sampling events for the edge habitat may, at least in part, be due to the types of microhabitats sampled. Sydney Water also sampled submerged macrophyte habitat in the fluvio-tidal reaches of the Hawkesbury, finding it a more stable habitat with a relatively extensive taxa list when compared with the edge habitat (C. Besley (SWC) pers. comm. 2008). From 2003 onwards, the macrophyte habitat was therefore replicated in this reach. Average SIGNAL-SG scores in macrophyte edge habitats also indicated a very consistent pattern over time (Figure 6.8), which again does not suggest that major changes have occurred over time in macroinvertebrate communities in this stretch of the Hawkesbury-Nepean River (in terms of average SIGNAL-SG scores).

Data from riffle habitats in the lower sections of the Hawkesbury-Nepean River were less common, but, where they occurred, again there was little evidence of major changes in average SIGNAL-SG scores over time (Figure 6.8). An unusual peak in average SIGNAL-SG scores occurred at N53 (downstream of Penrith STP) in autumn 2004; the reasons for this need further exploration (including potentially looking at relationships with water quality at that time).

Although there appears to be a lack of temporal trends in the average SIGNAL-SG scores at individual sites, there do appear to be longitudinal differences in average SIGNAL-SG scores as you move down the river (i.e. from Maldon Weir (N92) to Sackville (N26); Figure 6.9). The change downstream of Yarramundi is quite pronounced (particularly in the edge habitat), with fewer macroinvertebrate taxa, generally lower average SIGNAL-SG scores, and greater variability in those scores over time[11]. The South Creek sites (NS081, NS23) in particular stand out in terms of their low SIGNAL-SG scores.



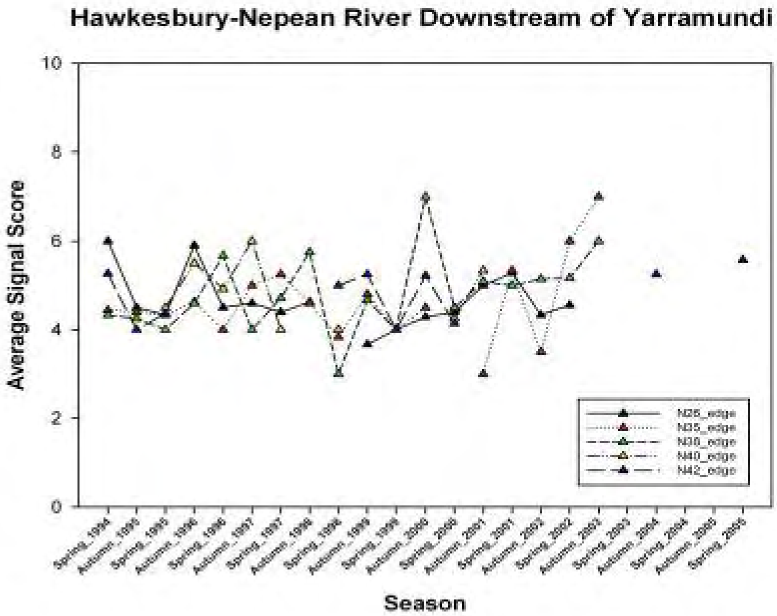


Figure 6.7: Average SIGNAL-SG scores for edge habitats upstream (top) and downstream (bottom) of Yarramundi; Hawkesbury-Nepean River

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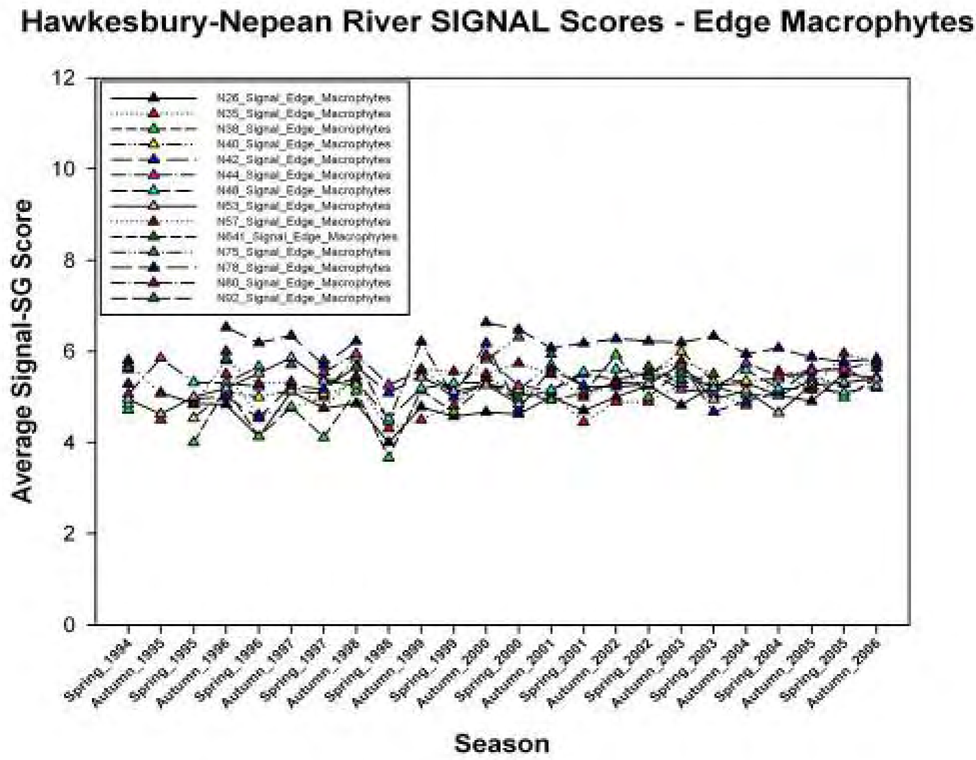
11 Although note the lack of data in more recent times for some of the downstream edge habitat sites.



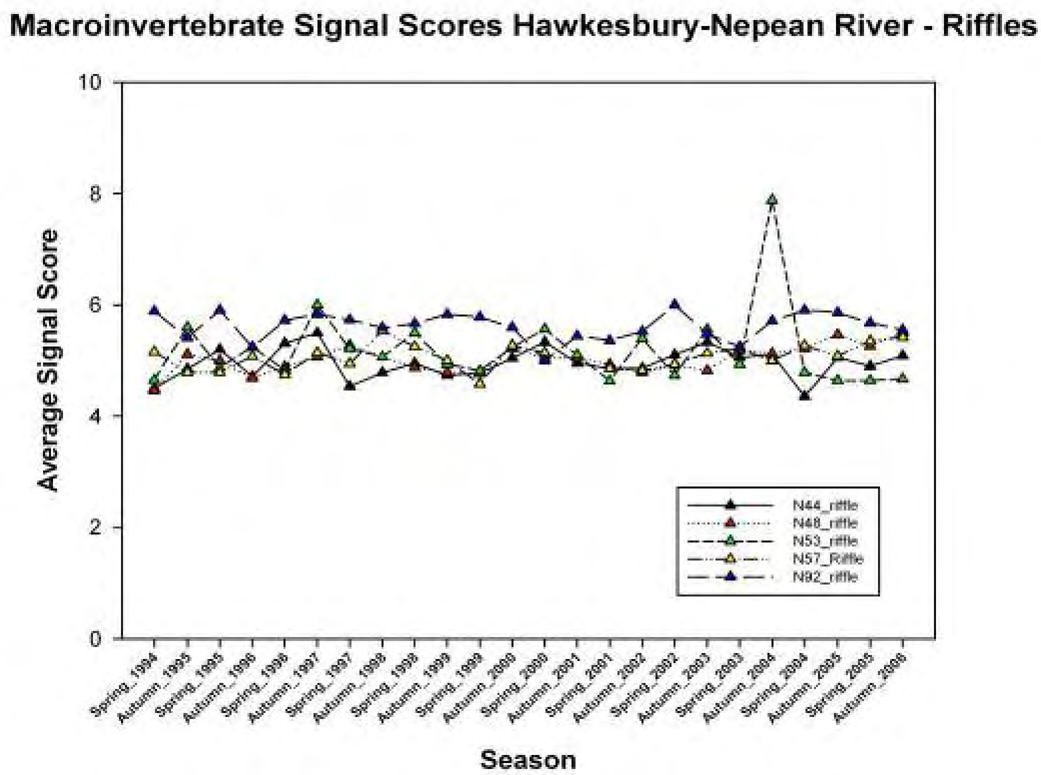


Figure 6.8: Average SIGNAL-SG scores for edge macrophyte habitats (top) and riffle habitats (bottom); Hawkesbury-Nepean River

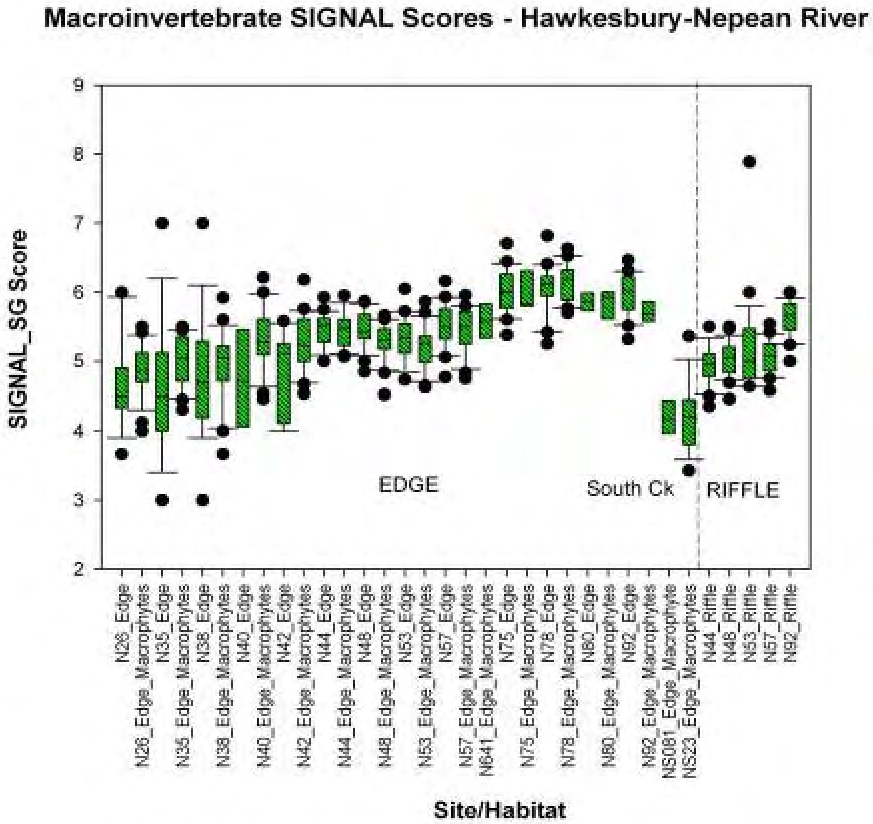


Figure 6.9: Longitudinal variability in average SIGNAL-SG scores for edge, riffle and macrophyte habitats from Sackville (N26) to Maldon Weir (N92); Hawkesbury-Nepean River

General discussion. The tidal limit of the Hawkesbury River occurs at Yarramundi, approximately 140 km upstream from the river mouth. The differences in community structure between sites upstream and downstream of N44 therefore most probably reflect the importance of tidal influences in these areas. Other potential contributing factors include the effects of the Grose River inflow and/or differences in microhabitat (created by tidal influences, river geomorphology and other factors).

Differences among sites were generally greater than those among years, although the macroinvertebrate communities in 1994 and 1995 were found to be significantly different from communities sampled in more recent years. There appears to be a lack of temporal trend in the average SIGNAL-SG scores at individual sites on the main-stem of the Hawkesbury-Nepean. There do, however, appear to be longitudinal differences in average SIGNAL-SG scores as you move down the river (i.e. from Maldon Weir (N92) to Sackville (N26)).

Sites upstream and downstream of dams, and at reference sites in the Hawkesbury-Nepean River

An assessment of the effects of dams and weirs on diatom and macroinvertebrate assemblages of the Hawkesbury-Nepean River system was undertaken by AWT(1998) and Growns and Growns (2001). As part of the SCA's Woronora Environmental Flows Project, sampling of macroinvertebrates (and diatoms) was repeated in 2002 at the same sites (with some additional sites in the Woronora catchment) and using (as far as possible) the same design as Growns and Growns (2001). This project has continued to sample macroinvertebrates over the intervening time period, meaning that some sites have now been sampled over a period of approximately 12 years (with a gap of about 5 years between 1997 and 2002). Sampling in the later period has been undertaken consistently by Ecowise Environmental under contract to the SCA (Ecowise Environmental 2007). A list of the monitoring sites considered in this section is included in Table A5.1.1 (Appendix 5).

A complicating factor in the analysis of these data is the different organisations and slightly different methodologies used to collect the data in different time periods. Macroinvertebrate samples collected by Sydney Water/AWT were generally sampled twice a year in autumn and spring using the methodology described by Chessman (1995), AWT (1998) and Growns and Growns (2001). Samples collected by Ecowise Environmental as part of the SCA's Woronora Environmental Flows Project were also usually sampled twice a year in autumn and spring but were collected using AusRIVAS protocols. The latter methodology is further described by Turak et al. (1999, 2004) and Ecowise Environmental (2007).

In order to compare the results from these programs, (at least) two assumptions need to be made, i.e. that:

- the taxonomy is consistent between the two organisations and over the two main periods of sampling
- the families or genera collected in samples are not greatly affected by slight differences in the sampling methodology used by the two organisations.

The first assumption was addressed by matching the taxonomic levels used by Growns and Growns (2001) with that of Sydney Water/AWT and Ecowise Environmental. This involved pooling of some genera into higher taxonomic categories (e.g. subfamilies of the Chironomidae) to achieve consistency with earlier taxonomic resolutions. The taxonomy used is described further in Table A5.1.2 (Appendix 5). It still relies, however, on consistent identifications by individual taxonomists/scientists (i.e. a lack of individual operator effects). The second assumption has been investigated previously by Growns et al. (1997, 2006) who found similar results were obtained when four live-sorting methods were used in rapid biological assessments.

What these differences in sampling methodologies mean, however, is that any putative temporal changes over time are confounded by changes in sampling organization, sampling protocol and operator differences (assuming they are still sampling the same site)[12]. This issue is returned to later in the discussion.

The impacts of river regulation have already been assessed by Growns and Growns (2001) and Ecowise Environmental (2007). The objective of this section is therefore

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[12] Although every attempt was made to relocate the sites sampled by Dr Growns and described by AWT (1998) and Growns and Growns (2001), there remains the possibility that the stream reach sampled may be slightly different (but most likely within 100's of metres) from the site originally sampled.

not to reanalyse all the data to make an assessment of the impacts of the dams on macroinvertebrate communities, but rather to look more closely at putative trends over time in macroinvertebrate communities at these long-term monitoring sites. The context of differences among sites upstream, downstream and at reference locations is, however, still required in order to interpret temporal trends and is provided below.

Analysis of these data indicated that:

- although there are potential inconsistencies due to sampling by different organizations, consistent comparisons among sites can still be undertaken within a time period (i.e. within the periods 1995–1997 and 2002–2006).
- there were significant differences among macroinvertebrate communities among riffle and edge habitats (ANOSIM $P = 0.001$) in upstream, downstream and reference locations (Figure 6.10)
- there were consistent differences between sites upstream and downstream of dams and between downstream sites and reference sites in both edge and riffle habitats (ANOSIM $P = 0.001$ for both edge and riffle habitats; Figures 6.11 and 6.12). Pair-wise differences among upstream, downstream, and reference sites were also significant ($P < 0.05$).
- important taxa contributing to the differences among upstream, downstream, and reference sites included *Berosus*, *Koorrnonga*, and species in the Chironomidae subfamily Orthocladiinae (SIMPER analysis).
- there were significant differences between organisations in both edge and riffle habitats (ANOSIM $P = 0.001$; Figures 6.11 and 6.12). There were also significant differences between organisations at individual sites. There were many taxa that contributed to these differences, and in most cases it was differences in relative abundance (occurrence in samples) as opposed to one organization recording a taxa and the other organization not. This is affected to some degree by the selection of sites being compared in each period and, as noted above, may be confounded by true temporal changes in proportional abundance.
- there were consistent differences[13] among years between upstream, downstream and reference sites in both edge and riffle habitats (ANOSIM $P = 0.001$ for both edge and riffle habitats; Figures 6.11 and 6.12).
- pair-wise differences among years were often significant (ANOSIM $P < 0.05$; Figures 6.11 and 6.12). However, macroinvertebrate communities collected in riffle habitats in 1994 were not found to be significantly different ($P > 0.05$) from those found in 1995–1997 or 2002–2006[14]. The same result was found for edge habitats. The implications of differences among years are discussed further in the following section.
- there were significant differences among sites in both edge and riffle habitats (ANOSIM global test $P = 0.001$; Figures 6.11 and 6.12).

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[13] Note the potential confounding effect of different organizations and methods in these comparisons though.

[14] Riffle samples at many sites were under-represented in the 2002–2006 samples. As a result, some pair-wise comparisons among years involving the 1994 riffle samples were unable to reach the 0.05 probability level owing to low numbers of possible permutations.

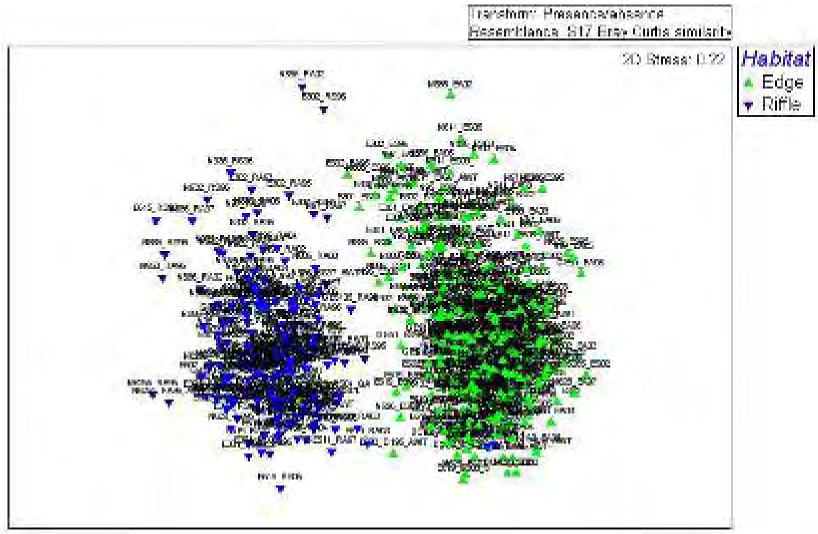

Figure 6.10: Multidimensional scaling ordination of macroinvertebrate samples, illustrating the difference between edge and riffle habitats for sites upstream and downstream of dams and at reference sites

- pair-wise differences among sites were also often significant (ANOSIM *P* < 0.05; Figures 6.11 and 6.12). In edge habitats, the Erskine Creek sites (N626 and N6265) were not found to be significantly different from each other. Similar results occurred for riffle habitats, although in these habitats other sites were also found to be similar (e.g. sites N886, N932 and N97)[15].
- there are few water quality data available for some sites upstream or downstream of dams or at reference sites; depending largely on whether or not the macroinvertebrate sampling site coincided with a routine water quality monitoring site. This means that there was limited scope for investigating the relationship between macroinvertebrate communities and water quality at these sites.
- in the above comparisons, differences over time are potentially confounded with sampling organisation, flow changes and periods of drought.

[15] Because of a lack of riffle samples at N93, pair-wise comparisons among sites involving N93 were often unable to reach the 0.05 probability level owing to low numbers of possible permutations.

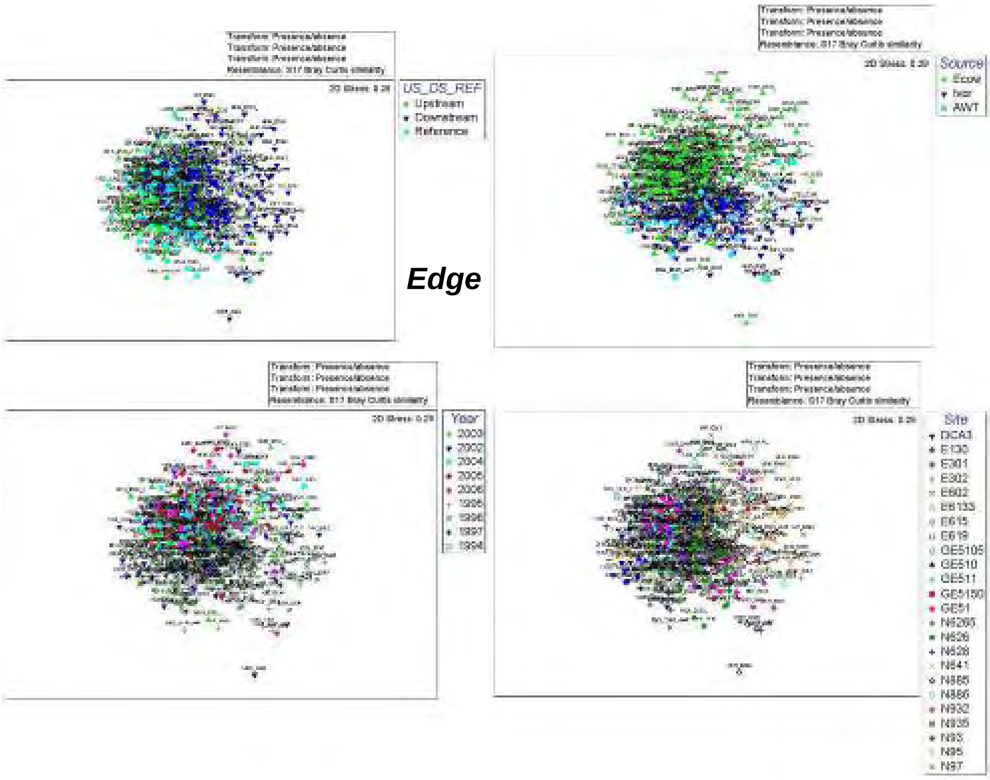

Figure 6.11: Multidimensional scaling ordination of macroinvertebrate samples, illustrating the difference between upstream/downstream/reference sites, organisations, years and sites in edge habitats.

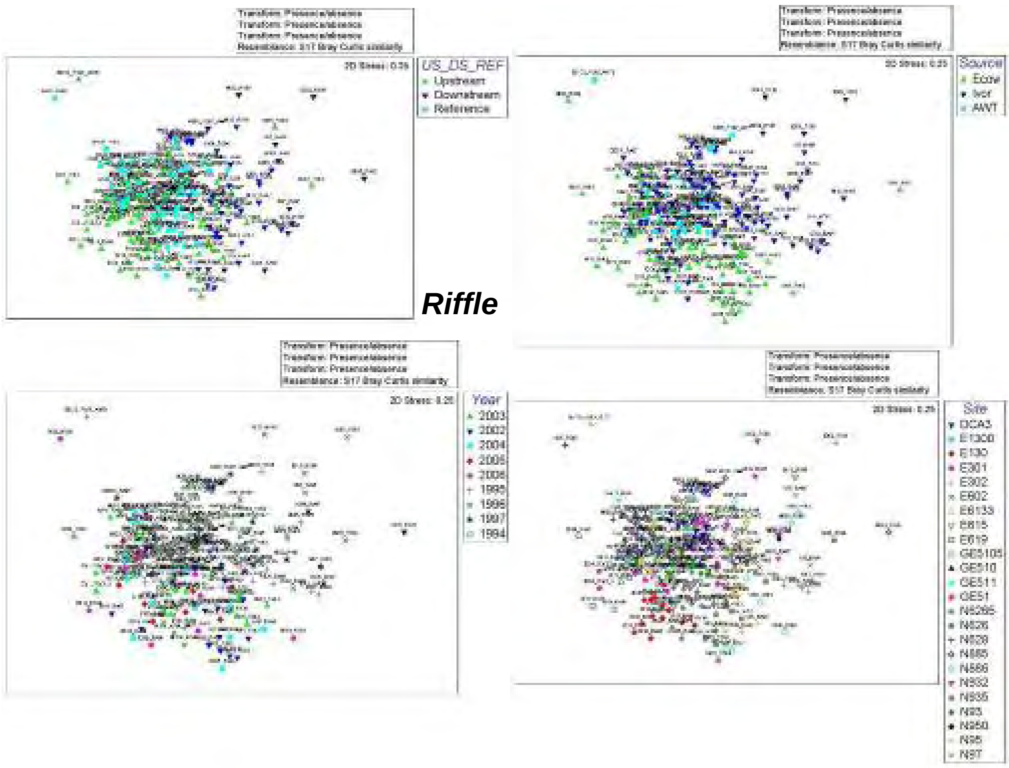

Figure 6.12: Multidimensional scaling ordination of macroinvertebrate samples, illustrating the difference between upstream/downstream/reference sites, organisations, years and sites in riffle habitats

Temporal trends in AusRIVAS-based assessments. AusRIVAS O/E50 scores were calculated for samples from the sites listed in Table A5.1.1 (Appendix 5). An example of a comparison of O/E50 scores is provided below (Figure 6.13). Important caveats to note in this representation of the data is that different seasonal models exist for AusRIVAS samples collected in autumn and spring; this can lead to different O/E50 band levels for the different seasons (although, as can be seen in Figure 6.13, these differences are not large). A further complication is that the earlier sampling reported by Growns and Growns (2001) was undertaken using protocols that were similar, but slightly different from, those of Ecowise Environmental. Moreover, Growns and Growns (2001) did not measure some of the environmental variables required for use in the AusRIVAS models.

When comparing O/E50 scores at a site over time, an assumption needed to be made that the sampling protocols were essentially equivalent in providing an unbiased assessment of the families present at a site at any given time. A further assumption was that the environmental variables described by Ecowise Environmental in more recent samples are also applicable to the samples collected in the 1990s by Growns and Growns (2001) and therefore could be applied to produce O/E50 scores for Growns and Growns's (2001) macroinvertebrate data. The errors/uncertainties introduced by taking this approach are largely unknown, and these analyses should be considered as preliminary in nature.[16] They do, however, provide a means of comparing rapid assessment indices over time at these sites.

Provided that this approach is reasonably free of systematic errors, the results suggest that, at many sites, major changes in O/E50 scores have not occurred over time (although the variability around the average O/E50 score for a site can at times be relatively high). For example, at the Nepean River downstream of Pheasants Nest Weir (Site N93), whereas individual AusRIVAS O/E50 scores for edge habitat have varied between 0.6 and 1.06 (average = 0.836; SD = 0.124) over all years and seasons, they have generally remained within the high-Band B to Mid-Band A levels (Figure 6.13). Similar results were found for the Nepean River at Avon Dam Road (Site N95; Figure 6.13), although at this site there is a suggestion that conditions may have improved slightly on the basis of O/E50 scores. Such hypotheses require further interpretation in the light of longer term variations in flow at this site and finer scale matching of flow results to actual sampling dates. Temporal trends for other sites using this approach can be found in Appendix 5.

General discussion. Regulation has been shown previously to have a significant impact on macroinvertebrate communities (Growns and Growns 2001; Marchant and Hehir 2002; Ecowise Environmental 2007). What has not previously received close scrutiny, however, is putative trends over time in macroinvertebrate communities at the SCA monitoring sites. Differences among sites were generally greater than those among years, and whereas pair-wise differences among years were often significant, macroinvertebrate communities collected in riffle habitats in 1994 were not found to be significantly different from those found in 1995–1997 or 2002–2006. The same result was found for edge habitats.

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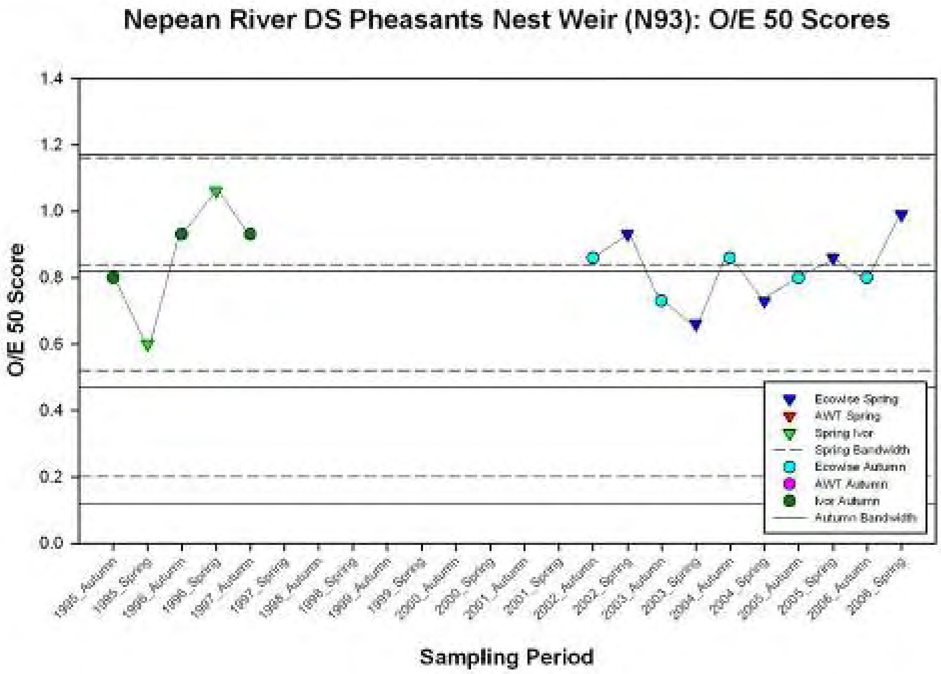
[16] For example, alkalinity can be variable at some of these sites; there appears to be relatively little information on the sensitivity of AusRIVAS outputs to site-specific variability and the effect this may have on subsequent O/E50 scores (but see Barmuta et al. (2003) for an investigation of sensitivities of the AusRIVAS models for various percentage tolerance levels). The AusRIVAS models themselves have also not been updated since their initial development, and further research and development in this area are required.

Analysis of the data also suggested that although variability around the average O/E50 score for a site can at times be relatively high, at many sites there appears to have been little overall change in macroinvertebrate communities over time (on the basis of O/E50 scores). The sensitivity of trend assessments using RBA indices and their ability to detect change over time requires further assessment.



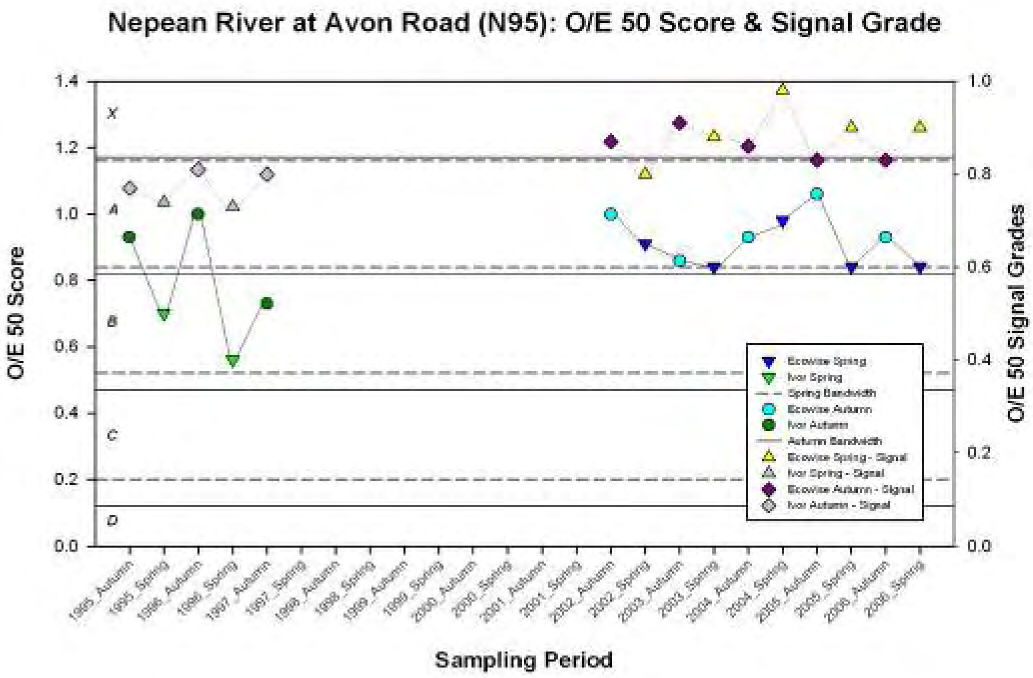


Figure 6.13: Temporal variation in AusRIVAS O/E 50 scores for the Nepean River downstream of Pheasants Nest Weir (N93) and downstream of Nepean Dam (N95)

Trends in periphytic diatom communities

Diatoms are single-celled plants that occur in aquatic environments throughout the world. They are abundant and diverse in streams of south-eastern Australia, including streams in the Hawkesbury-Nepean catchment. Diatoms are important primary producers within pelagic, benthic, and epiphytic communities, and their siliceous frustules (the hard and porous diatom cell wall) sink rapidly to the sediment (Haese et al. 2007). At times the benthic diatom community can dominate the biomass of chlorophyll and exceed the chlorophyll biomass in the water column above it (Lukatellich and McComb 1986). Diatoms have been shown to be responsive to ionic chemistry and nutrients as well as elevated metal concentrations (Townsend 2001, Gell et al. 2002, Schultz et al. 2002). In some states, diatoms are being considered as a more direct biological integrator of water quality than macroinvertebrates[17].

Long-term periphytic diatom monitoring data are uncommon in the Hawkesbury-Nepean River catchment. However, an assessment of the effects of dams and weirs on periphytic diatom assemblages of the Hawkesbury-Nepean River system was undertaken in conjunction with studies of macroinvertebrates described previously (AWT 1998; Growns 1999; Growns and Growns 2001). As part of the SCA's Woronora Environmental Flows Project, Ecowise Environmental continued to sample periphytic diatoms over the period from 2002 to 2006 using (as far as possible) the same methodology and sites as described by Growns (1999) and Growns and Growns (2001). A list of the periphytic diatom monitoring sites is given in Table A6.1 (Appendix 6) and illustrated in Figure 6.14.

A complicating factor in the analysis and comparison of these data is the different organisations used to collect the data in the different time periods. A major component in this complication has been the inconsistency of diatom taxonomy, both recently and in previous time periods. A consistent approach therefore needed to be taken to allocating species identified in these studies (including species names considered to be synonyms) to an established species/genus.

In the current study, consistency checks were undertaken by reference to ITIS, the Integrated Taxonomic Information System, which provides authoritative taxonomic information on plants, animals, fungi, and microbes (http://www.itis.gov/index.html). Although the base for this taxonomic information system is North America, it includes many species from around the world. For each scientific name, ITIS includes the authority (author and date), taxonomic rank, associated synonyms and vernacular names, where available, a unique taxonomic serial number, data source information (e.g. publications, experts) and data quality indicators.

Species names from the relevant datasets (AWT/Growns and Ecowise) were input into ITIS and the authoritatively correct species/genus identified. In some cases genera and/or species were not included on the ITIS database, and in these situations a search of the web was undertaken (where possible) to identify the correct species/genus name. Some of these species appeared to be absent from the ITIS database because of their geographic location (e.g. some appeared to be restricted to the Australasian region), whereas others appeared to be recent taxonomic descriptions (which presumably hadn't yet made it on to the ITIS database). Some

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17 Townsend, S, 2001, *Australia-Wide Assessment of River Health: Northern Territory Status Report and Commentary (2001)*, Monitoring River Health Initiative Technical Report no. 8b, Department of Infrastructure, Planning and Environment, Palmerston NT.

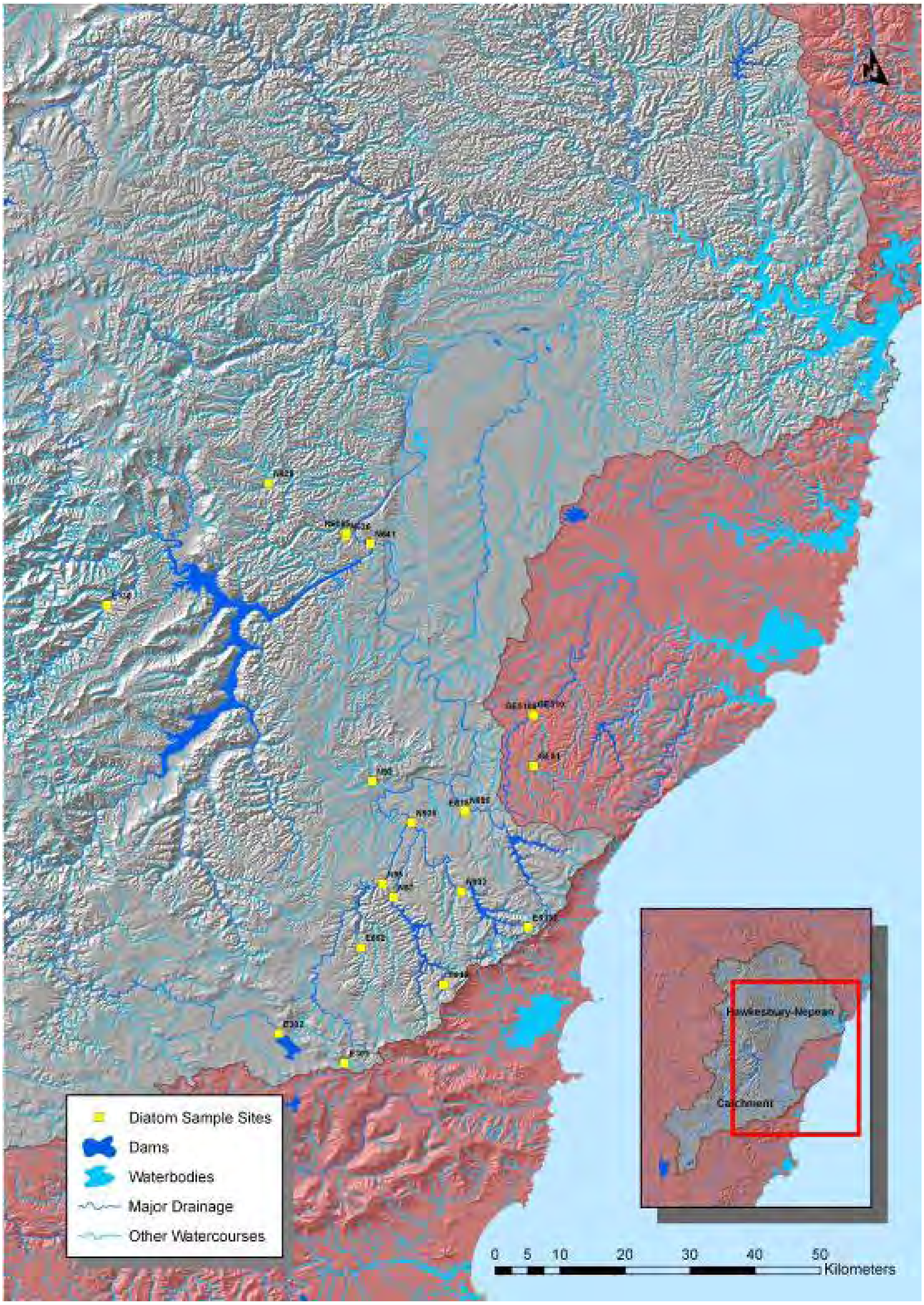

Figure 6.14: Periphytic diatom sampling sites in the Hawkesbury-Nepean River catchment

species did not appear in searches of either ITIS or the web. In these latter cases, the genus/species used in the individual datasets was retained. Further resolution of these taxonomic issues is required. A description of the species/genus taxonomy used in this study is included in Table A6.2 (Appendix 6).

Most of AWT's (1998) diatom analyses were undertaken at the genus level of identification, whereas those of Ecowise Environmental were taken down to species level. Growns (1999, and pers. comm.) did have species-level identifications for one season (autumn 1997), and Dr Growns kindly allowed these data to be analysed for this project. The diatom composition data was analysed with the Primer V6 Package (Clarke and Gorley 2006), with samples separated into sites, years and sampling organisation for later comparisons by using multidimensional scaling, ANOSIM and SIMPER. In each case the Bray-Curtis similarity measure was used on the raw (untransformed) data[18] to construct the similarity matrix (see Clarke and Warwick 2001). The sites and seasons sampled appear in Table A6.1 (Appendix 6).

One major conclusion from these analyses was that there were inconsistencies in both the taxonomy and the sampling methodology[19] of diatoms in past studies, and this has the potential to affect comparisons over time.

Conclusions from the analysis of individual replicates were as follows:

- There were significant differences among organizations when the species-level data were compared[20] (ANOSIM, P = 0.001; Figure 6.15).
- Some of the species that contributed the most to these differences (SIMPER analysis) were found in the records for only one organization (e.g. *Achnanthidium microcephalum*, *Cyclotella stelligera*, *Navicula cryptochephala*, and *Navicula subtilissima* were identified only in AWT/Growns's records and *Achnanthidium minutissimum*, *Frustulia rhomboides* var. *saxonica*, *Diatomella balfouriana*, *Cyclotella pseudostelligera* and *Brachysira irawanoides* were identified only in Ecowise's records). These differences suggest either a shift in the species composition of diatoms at these sites in the different periods, or a difference in taxonomic identification between organizations, or both.
- To avoid potential complications introduced by (putative) differences in species-level identifications, species were also pooled to the genus level and analysed. This enabled a greater range of sites and times to be compared. Again, there were significant differences among organizations when the genus-level data were compared (ANOSIM, P = 0.001; Figure 6.15).
- The major genera contributing to the difference were *Achnanthidium*, *Encyonema, Navicula, Frustulia* and *Tabellaria*, accounting for just over 50% of the differences between the organizations (or, equivalently, the differences between the time periods 1995–1997 and 2002–2006).

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18 The data represent percentages (relative abundances) of diatom species found in each of five replicates collected at each site in each season. In these samples, a minimum of 100 valves (50 frustules) to 300 valves (150 frustules) was made (Ecowise Environmental 2007). Data from the Woronora River catchment sites (WON01, WON02, WON03, WON04, E677, E678, E6131) were not included in these analyses.

19 For example, diatom 'scrapings' have been taken on different substrates — rocks and logs — and it is unknown whether this has an effect on the types of diatom species collected.

20 Note that species-level data were available only for autumn 1997 in AWT/Growns's study.

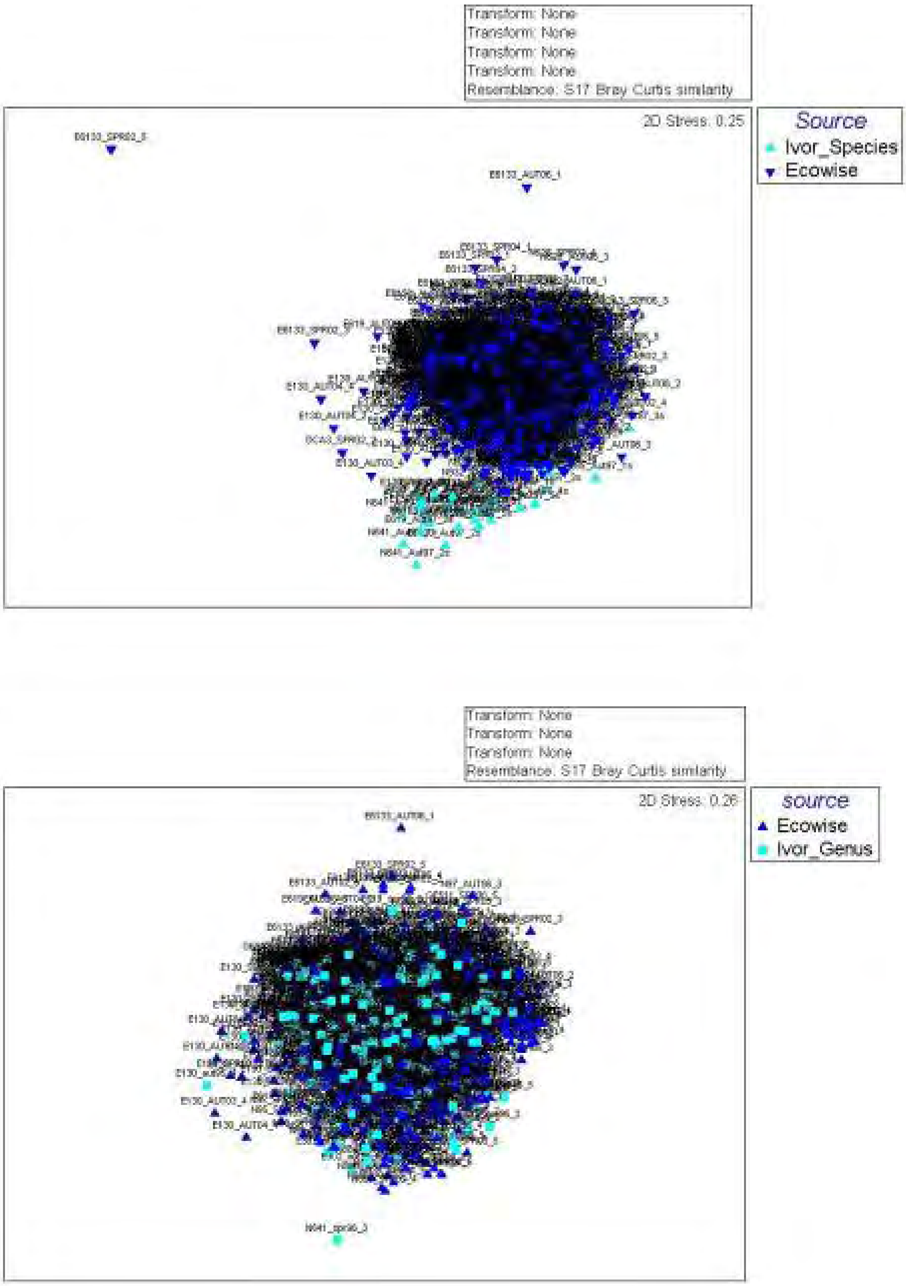

Figure 6.15: Multidimensional scaling ordination of diatom samples, illustrating the difference between samples from different organisations (Ecowise Environmental 2007 and Growns and Growns 2001 (Ivor)) at the species (top) and genus (bottom) levels of identification—individual replicates

- There were significant differences among years when the genus-level data were compared (ANOSIM, *P* = 0.001).
- Pair-wise differences among years were in most cases significant (ANOSIM, *P* < 0.05), with the exception of 1997 versus 2002–2006 (ANOSIM, *P* = 0.148 to *P* = 0.997) and 2003 versus 2005 (*P* = 0.326).
- Seasonal differences were significant across all times/sites and within each time period (1995–2006, 1995–1997 and 2002–2006; ANOSIM, *P* = 0.001). However,

the average percentage abundances (across all replicates and sites) were often quite similar.

- Although occasional increases in proportional abundance for some genera were observed, the percentage abundance (across all replicates and sites) of many genera remained reasonably constant over time (Figure 6.16). This is not suggestive of major changes over time in the proportional abundance of these genera at the sites studied.

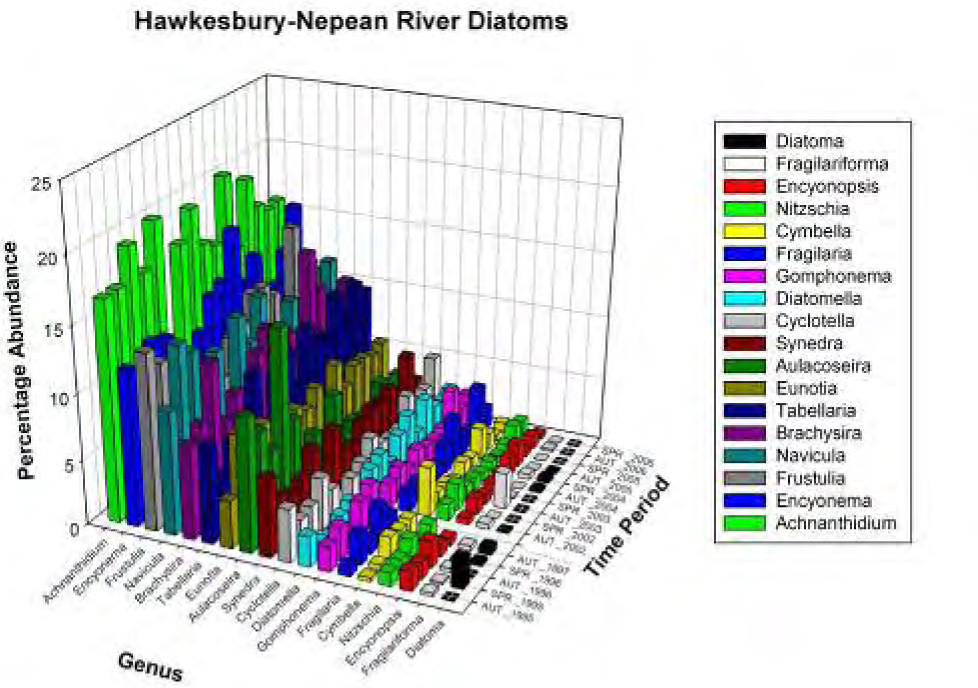

Figure 6.16: Relative abundance (across all replicates and sites) of diatom genera over time; Hawkesbury-Nepean River

- There were significant differences among sites (ANOSIM, *P* = 0.001).
- Pair-wise differences were also mostly significant (*P* < 0.05) with the exception of the Erskine Creek sites (N626, N6265; *P* = 0.071) and sites E619 and GE5105 (*P* = 0.194)[21].
- There were significant differences among upstream, downstream and reference locations (ANOSIM, *P* = 0.001). Pair-wise differences among upstream, downstream and reference locations were also significant (ANOSIM, *P* = 0.001).
- Consistent patterns to emerge from analysing pair-wise differences among upstream, downstream and reference locations in the different time periods were: higher percentage abundances of *Aulacoseira* and *Cyclotella* and lower percentage abundances of *Eunotia*, *Navicula* and *Diatomella* at the downstream

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21 Reference sites in O'Hares Creek were also found to be similar (GE5105, GE511, GE510, GE511; *P* = 0.137 to *P* = 0.535).

sites; and higher percentage abundances of *Brachysira*, *Eunotia* and *Tabellaria* and lower percentage abundances of *Synedra* and *Aulacoseira* at reference locations.

Conclusions from the analysis of pooled replicates were as follows:

- The results for the analysis of pooled[22] data were very similar to those of the analysis of individual replicates.
- There were significant differences among organizations for both the species and genus level data (ANOSIM, P = 0.001; Figure 6.17).
- There were significant differences among years when the genus-level data were compared (ANOSIM, P = 0.001).
- Fewer pair-wise differences were significant, with 1997 again judged to be similar to 2002–2006 (P = 0.208 to P = 0.866), most years within 2002–2006 not being significantly different from one another (P = 0.056 to P = 0.902), and 1996 not being significantly different from 1997 (P = 0.087).
- Seasonal differences were significant across all times/sites and within each time period (1995–2006, 1995–1997 and 2002–2006; ANOSIM, P = 0.001). However, the average percentage abundances (across all replicates and sites) were often quite similar.
- There were significant differences among sites (ANOSIM, P = 0.001).
- Pair-wise differences were also mostly significant (P < 0.05), with the exception of the Erskine Creek sites (N626, N6265; P = 0.763), and the Pheasants Nest Weir sites (N935, N93; P = 0.359). Some of the upstream dam sites were also found to be similar (E301, E6133 and E619; P = 0.114 to P = 0.238).
- There were significant differences among upstream, downstream and reference locations (ANOSIM, P = 0.001). Pair-wise differences among upstream, downstream and reference locations were also significant (ANOSIM, P = 0.001).

Overall conclusions were as follows:

- The degree of pooling of replicates and whether species or genus level identifications are used can affect interpretation of the data.
- Nevertheless, consistent conclusions were found in terms of overall site differences, year differences, seasonal differences, organizational differences and differences among upstream, downstream and reference locations.
- Organizational differences were confounded by the period of sampling (AWT/Growns in 1994–1997 and Ecowise in 2002–2006).
- Consistent patterns emerged for some genera in upstream, downstream and reference locations.

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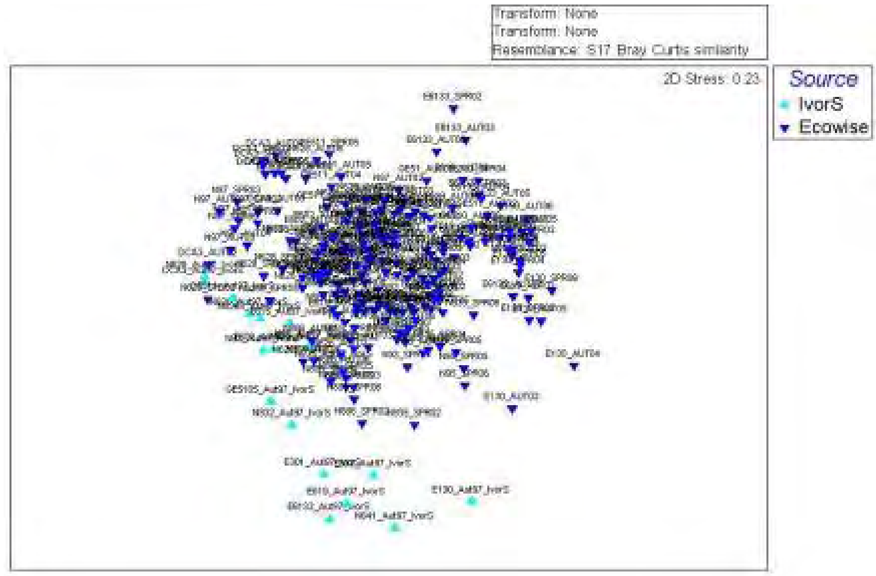
[22] Replicates were pooled by taking the average of the percentages (relative abundances) of diatom species in the five replicates collected at each site in each season. At some sites where there were fewer than five replicates, the average of all available replicates was taken.



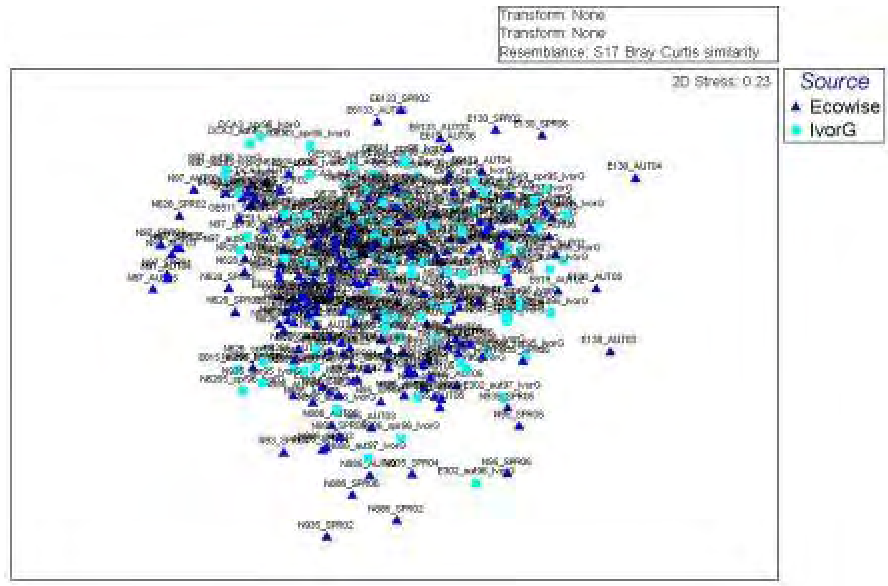


Figure 6.17: Multidimensional scaling ordination of diatom samples, illustrating the difference between samples from different organisations (Ecowise Environmental 2007 and Growns and Growns 2001 (Ivor)) at the species (top) and genus (bottom) levels of identification — pooled replicates

- Diatom populations are variable and may need to be interpreted at the species level of identification and at an individual site and season scale.
- Routine monitoring of periphytic diatoms in the Hawkesbury-Nepean using the methodology of Growns (1999) has now ceased (A. Kotlash (SCA) pers. comm. 2008).

Trends in fish communities

Fish have been sampled at a variety of sites throughout the Hawkesbury-Nepean River catchment (see Figure 6.18). However, over the last 15 years in particular, fish sampling has been very inconsistent. There are only two long-term DPI Fisheries River Survey sites (Mangrove Mountain (Site 67) and Wallacia (Site 70)) in the Hawkesbury-Nepean River downstream of the dams, and although extensive sampling was conducted in the Hawkesbury-Nepean in the early 1990s, sampling since that time has been very sporadic (see Table A7.1; Appendix 7). This makes assessment of long-term trends in fish presence and/or abundance very difficult.

DECC commissioned DPI Fisheries to undertake further sampling to determine the current status of fish communities in the Hawkesbury-Nepean system. A total of 15 sites were surveyed by NSW DPI between 29/10/2007 and 20/12/2007 as part of the current program. Site selection was based on sites with a relatively higher frequency of historic sampling and/or sites considered to be the most relevant to proposed changes under the Metropolitan Water Plan. The results of this sampling are described by Knight and Creese (2008; included in Appendix 7), and the specific sites sampled are identified in Figure 6.18.

A total of 3055 fish were recorded in this component of the study, comprising 1496 fish caught by electrofishing, 322 fish caught in traps and 1237 observed fish[23]. The total catch (fish caught + observed) was dominated by three species: Australian smelt (23% of catch), Australian bass (15%) and empire gudgeon (12%). The former two species were also among the most widely distributed species sampled, being respectively recorded at 10 (67% of sites) and 11 (73%) of the 15 sites sampled. These species are relatively common in the rivers of south-eastern Australia, are often locally abundant, and are documented to frequently dominate fish communities (Knight and Creese 2008).

The 2007 sampling data were combined with historical data obtained from the NSW DPI Fisheries Database. The fish community composition data were analysed with the Primer V6 Package (Clarke and Gorley 2006), with samples separated into sites, month/year and decade of sampling for later comparisons by multidimensional scaling, ANOSIM and SIMPER. The data were first pooled for all fishing methods (electrofishing, trap, observed, etc.) and then transformed to presence/absence data for each site/month/year combination. The Bray-Curtis similarity measure was then used to construct the similarity matrix (see Clarke and Warwick 2001). The proportional abundance of species is presented for one of these sites (Wallacia) in Figure 6.19. Data for other sites and length frequencies for individual species can be found in Appendix 7. Further analyses on the abundance of species caught could be considered, but this will need to take account of fishing method and will still be affected by variability in sampling sites and times.

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[23] Captured fish were identified, measured and released at their points of capture.

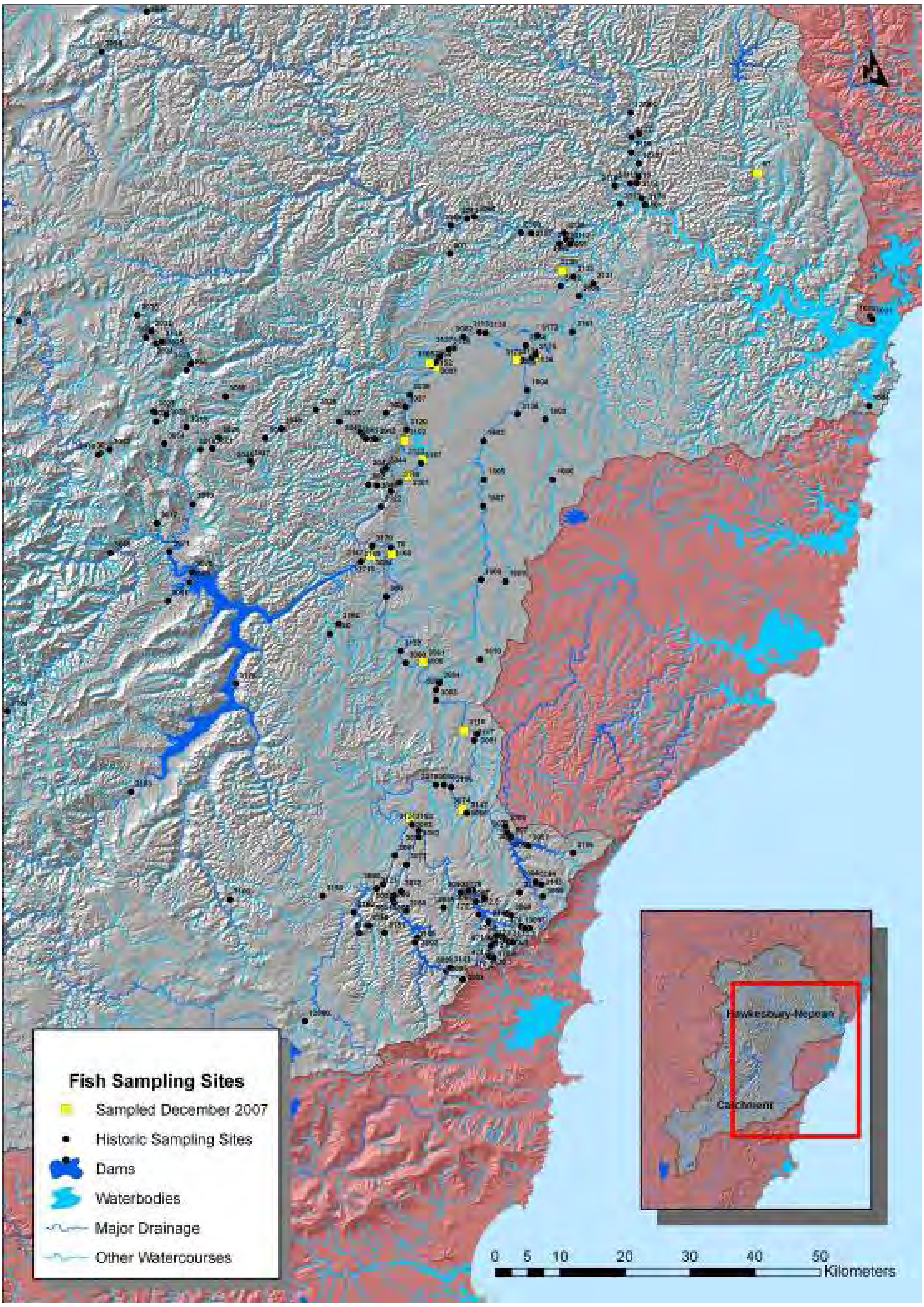

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Figure 6.18: Sampling sites for fish in the Hawkesbury-Nepean River catchment

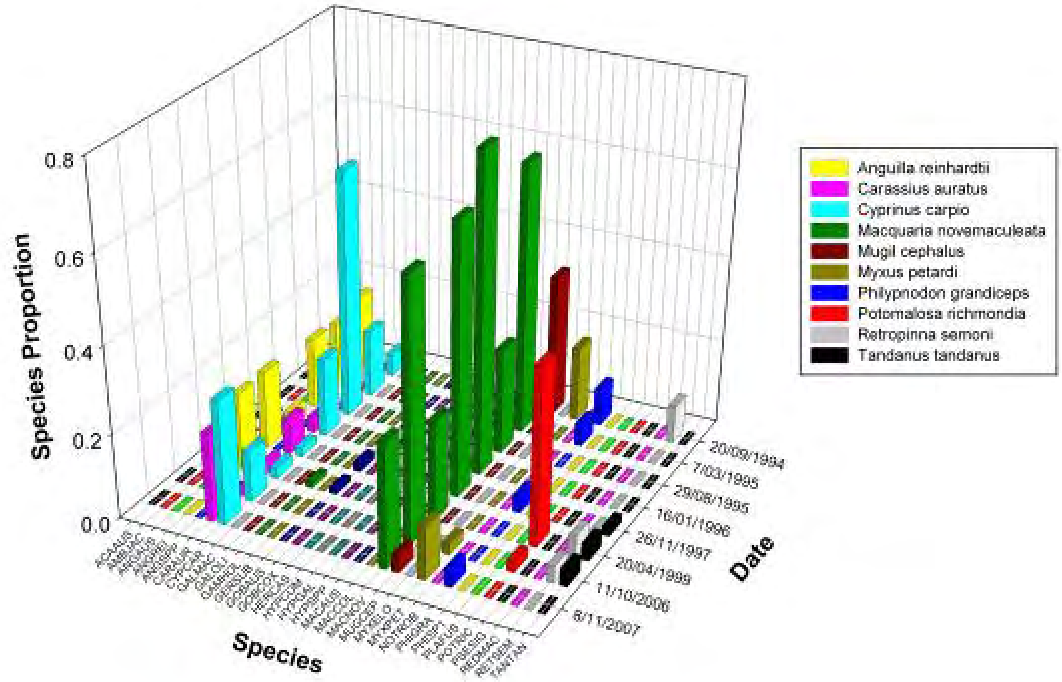

Figure 6.19: Proportional abundance of fish species[24] caught at Wallacia over time

General conclusions

- Sampling of fish in the Hawkesbury-Nepean River has been inconsistent over the past 15 years.
- Most species still appear to be present in the river system (i.e. there appear to have been no losses at individual sites considered over the last 20 years[25]).
- Because of the low occurrence of rare species (e.g. Macquarie Perch, Australian Grayling) in the dataset, however, it is difficult to be definitive about changes in their occurrence.
- if the sites with the longest history of sampling (Wallacia, Windsor, Sackville, Mangrove Mountain, Penrith Weir Pool, Jackson's Lane and Devlin's Lane) are considered, then significant differences among sites can be identified (ANOSIM *P* = 0.001; Figure 6.20). Mainly estuarine/marine species (e.g. *Acanthopagrus australis, Ambassis jacksoniensis, Platycephalus fuscus, Redigobius macrostoma*) were caught only at Sackville or Windsor; whereas species of

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24 Only the most common species have been included in the legend. Further explanation of the species codes used can be found in Table A7.2.1, Appendix 7.

25 However, note the effects of regulation and the lack of some species upstream of major barriers (Baumgartner, L. and Reynoldson, N. 2007. Fish communities of the Nepean River in the vicinity of Pheasants Nest Weir. NSW Department of Primary Industries – *Fisheries Research Report Series* 15. NSW Department of Primary Industries. ISSN 1449-9959).

Hypseleotris were caught only much farther upstream in Penrith Weir Pool and at Wallacia.

- Pair-wise differences among sites were also significant in most cases, with the exception of Devlin's Lane and Penrith Weir Pool (ANOSIM, P = 0.542), Sackville and Windsor (ANOSIM, P = 0.154) and Penrith Weir Pool and Windsor (ANOSIM, P = 0.079).
- The multidimensional scaling ordination (Figure 6.21) is suggestive of longitudinal variations in fish communities from downstream (Sackville) to upstream (Wallacia and Mangrove Mountain) sites. This is perhaps not all that surprising considering the differences in salinity and other physical attributes at these sites.
- Analysis of data sites with the longest history of sampling indicated no significant difference among decades (1990s vs 2000s; ANOSIM, P = 0.183), although the much lower frequency of sampling during the 2000s may have some bearing on this conclusion (Figure 6.22).
- Proportional differences in the occurrence of some species (e.g. an increase in proportional representation of goldfish) were suggested from the 1990s to 2000s at these long-sampled sites, but this may simply be a result of the sampling frame (i.e. the specific sites and times sampled during the 2000s decade).
- An attempt was made to look at length frequencies, but this served only to further illustrate the sporadic nature of the sampling and the relatively low numbers of individual fish species collected and measured at each site and time (Figure 6.23). Length frequencies for other species and sites are included in Appendix 7.

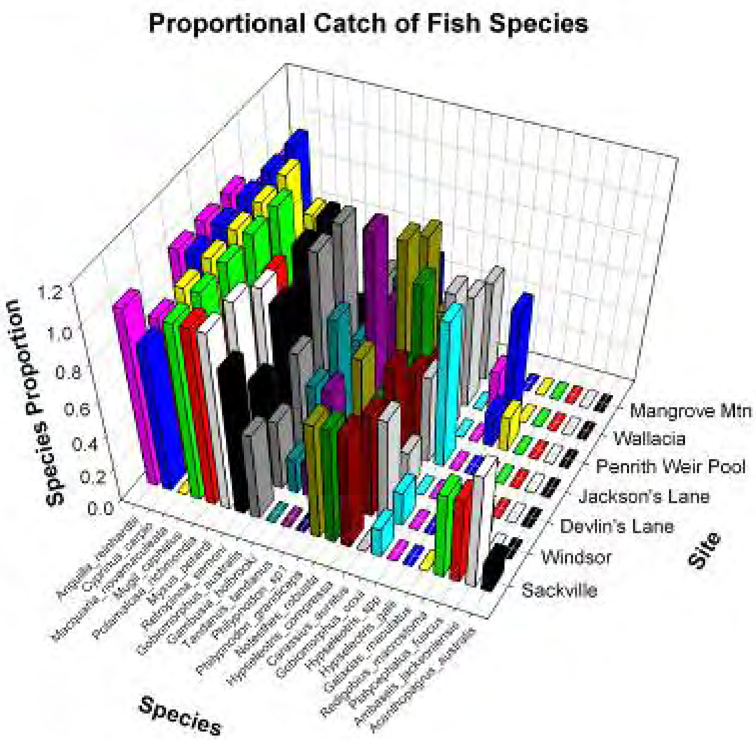

Figure 6.20: Proportional abundance of fish species at sites in the Hawkesbury-Nepean River

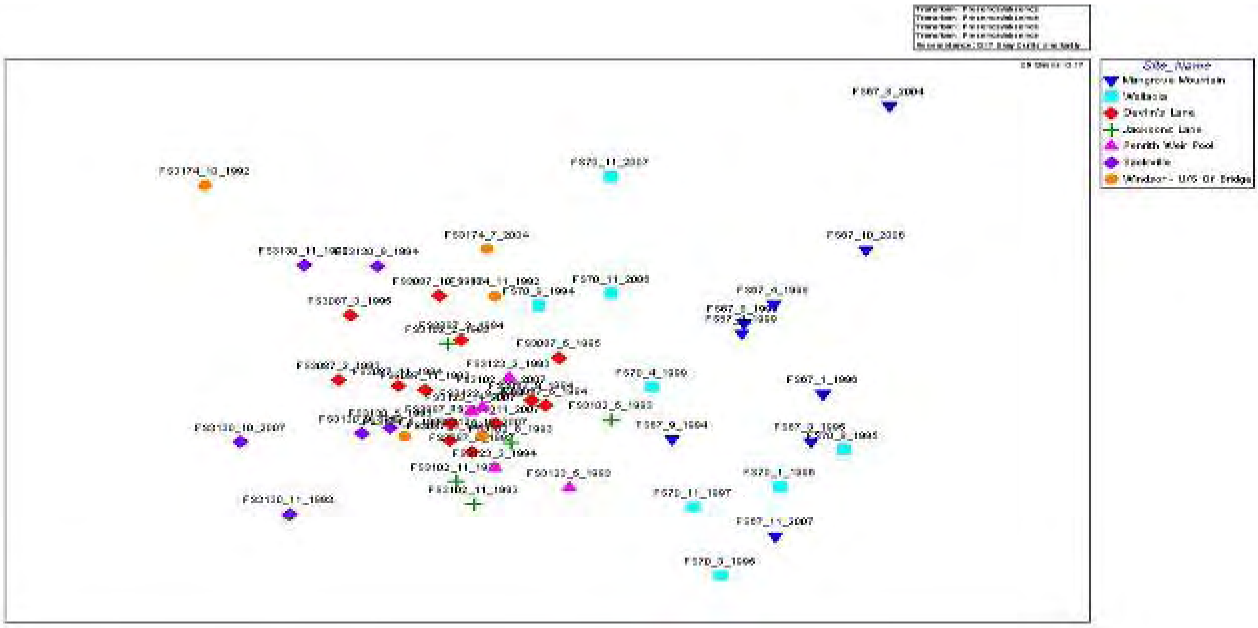

Figure 6.21: Multidimensional scaling ordination of fish communities at Wallacia (light blue), Windsor (orange), Sackville (purple), Mangrove Mountain (dark blue), Penrith Weir Pool (pink), Jackson's Lane (green) and Devlin's Lane (red); Hawkesbury-Nepean River

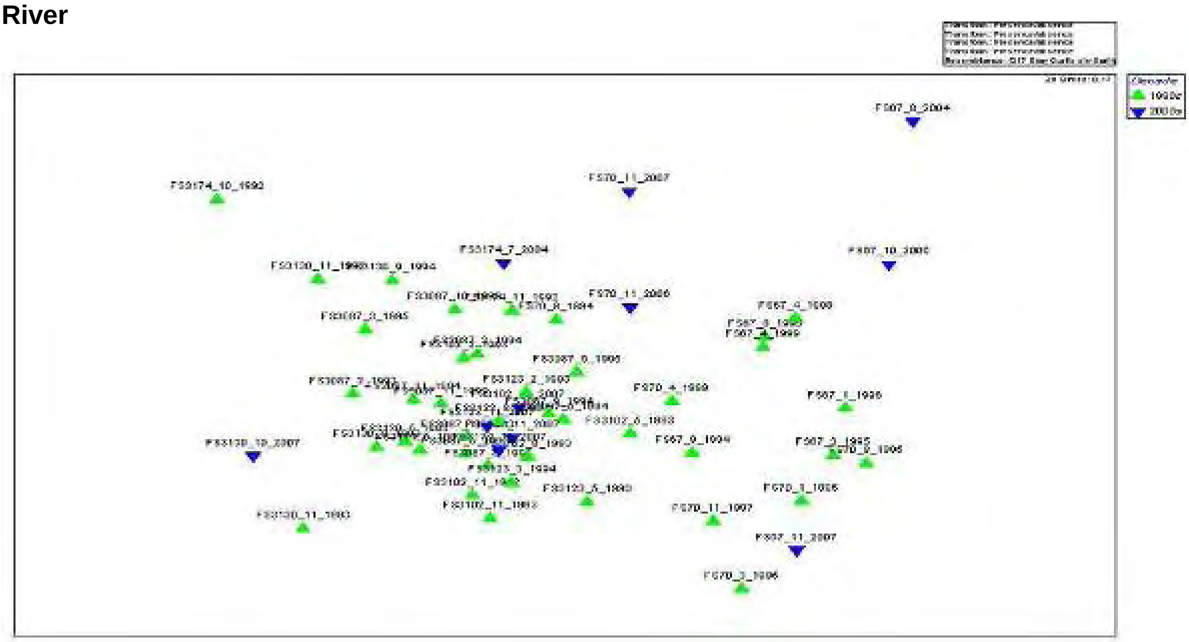

Figure 6.22: Multidimensional scaling ordination of fish communities, comparing differences among decades [green = 1990s; blue = 2000s]; Hawkesbury-Nepean River

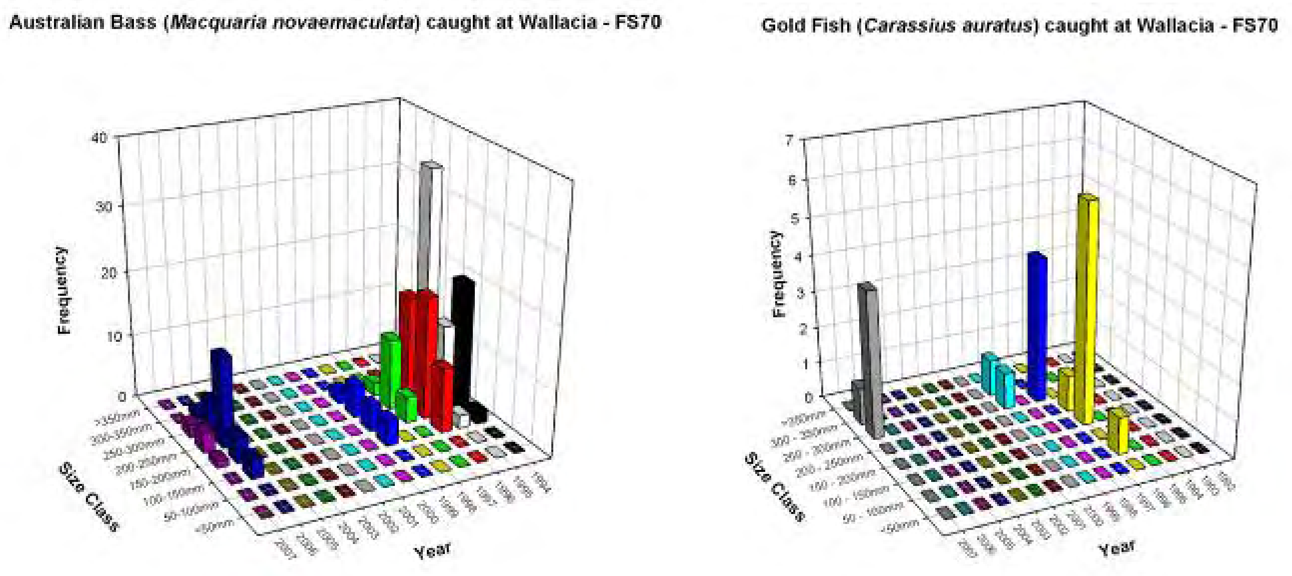

Figure 6.23: Length frequencies of bass (left) and carp (right) caught at Wallacia over time; Hawkesbury-Nepean River

Trends in algae and cyanobacteria

Algae are present in creeks, rivers and wetlands at all times. However, when the environmental conditions for the algae become optimal, the algae grow rapidly and blooms can form. Although many species of freshwater algae proliferate quite intensively in eutrophic waters, they do not accumulate to form dense surface scums of extremely high cell density, as do some cyanobacteria. The toxins that freshwater algae may contain are therefore not accumulated to concentrations likely to become hazardous to human health or livestock (Chorus and Bartram 1999).

Cyanobacteria are, however, recognised as a serious water quality problem with regard to both drinking water supply and recreational water use in Australia. The conditions that favour the growth of cyanobacteria and lead to blooms are nutrient enrichment, warm temperatures, and calm, stable water conditions such as those occurring in slowly flowing rivers and thermally stratified lakes. These conditions are often caused by human actions and activities, but they can also be associated with natural climatic cycles that prevail over wide geographical areas. In temperate climates, cyanobacterial dominance is most pronounced during the summer months, which coincide with the period when the demand for recreational water use is highest.

Highly variable river flows have always been a regular cyclical feature of the hydrology in a continent with regular droughts, but the regulation of large rivers has led to an overall reduction in flow and flow-duration characteristics (Walker and Thoms 1993; Maheshwari et al. 1995). Prolonged low flows have previously been associated with blue-green algal blooms in the Hawkesbury River between Windsor and Wisemans Ferry. It is believed that prolonged low flows, coupled with point- and diffuse-source nutrient discharges, water temperatures and the associated light regimes, together interact in this section of the river to provide conditions conducive to the development of blue-green algal blooms (Hawkesbury-Nepean River Management Forum 2002).

Chlorophyll-a and cyanobacterial cell counts

The distributions of chlorophyll-a and cyanobacterial cell counts over time are shown in Figure 6.24. The results for trend analyses of chlorophyll-a and cyanobacterial cell counts have been discussed previously (in section 5 under *Water quality trends using statistical models*) and are summarised in Appendix 4.

Genus/species composition results

The species data arrived relatively late in the project and, as a result, could be only briefly assessed. The dataset that was assessed contained algal species data for North Richmond (N42) and Sackville (N26) from the early 1970s up until August 2006. It would be advantageous to add more recent data to future analyses and to include more in-depth comparisons of algal community changes with changes in water quality, flow and other environmental variables.

The algal composition data were analysed by using the Primer V6 Package (Clarke and Gorley 2006), with samples separated into decade and season for later comparisons by multidimensional scaling, ANOSIM and SIMPER. The algal composition data were also combined with the daily flow data for Penrith Weir to provide an indication of the flow conditions during which past and more recent blooms have occurred. Further analysis is still required to investigate potential relationships between changes in algal communities and changes in water quality and flow.

As identified earlier, at many sites (including N26) algal and cyanobacterial counts are conducted only if chlorophyll-a levels are above 10 µg/L. This means that many of the data analysed are representative of relatively high algal conditions, including algal blooms. This presents problems when attempting to relate observed populations to water quality data collected at different time scales/frequencies (including the effect of time lags). An exception to this is North Richmond (site N42) where water is extracted for water supply purposes and algal identification is undertaken on a weekly basis regardless of chlorophyll-a levels. These facts need to be kept in mind when interpreting the results of the statistical analyses below.

Hawkesbury River – Sackville Reach (N26). If the algal data at site N26 are divided into the various decades, then clear differences are distinguishable (Figure 6.25), particularly for algal samples taken more recently (2000s decade). This analysis was based on genus-level differences rather than species-level differences, since taxonomic resolution has varied over time. Bray-Curtis similarity matrices were calculated using the raw (untransformed) data[26]. These analyses indicate significant differences among decades in terms of the genus-level composition of algae in the Hawkesbury-Nepean River (ANOSIM; P = 0.001). Pair-wise comparison of decades

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[26] When Bray-Curtis similarities are used on untransformed cell-count data, the more common genera have a greater influence on the resulting multidimensional scaling ordination and other analyses. In the future it would be useful to revisit this issue and consider other transformations that might increase the influence of the medium abundance and/or less common taxa (see Clark and Warwick 2001).

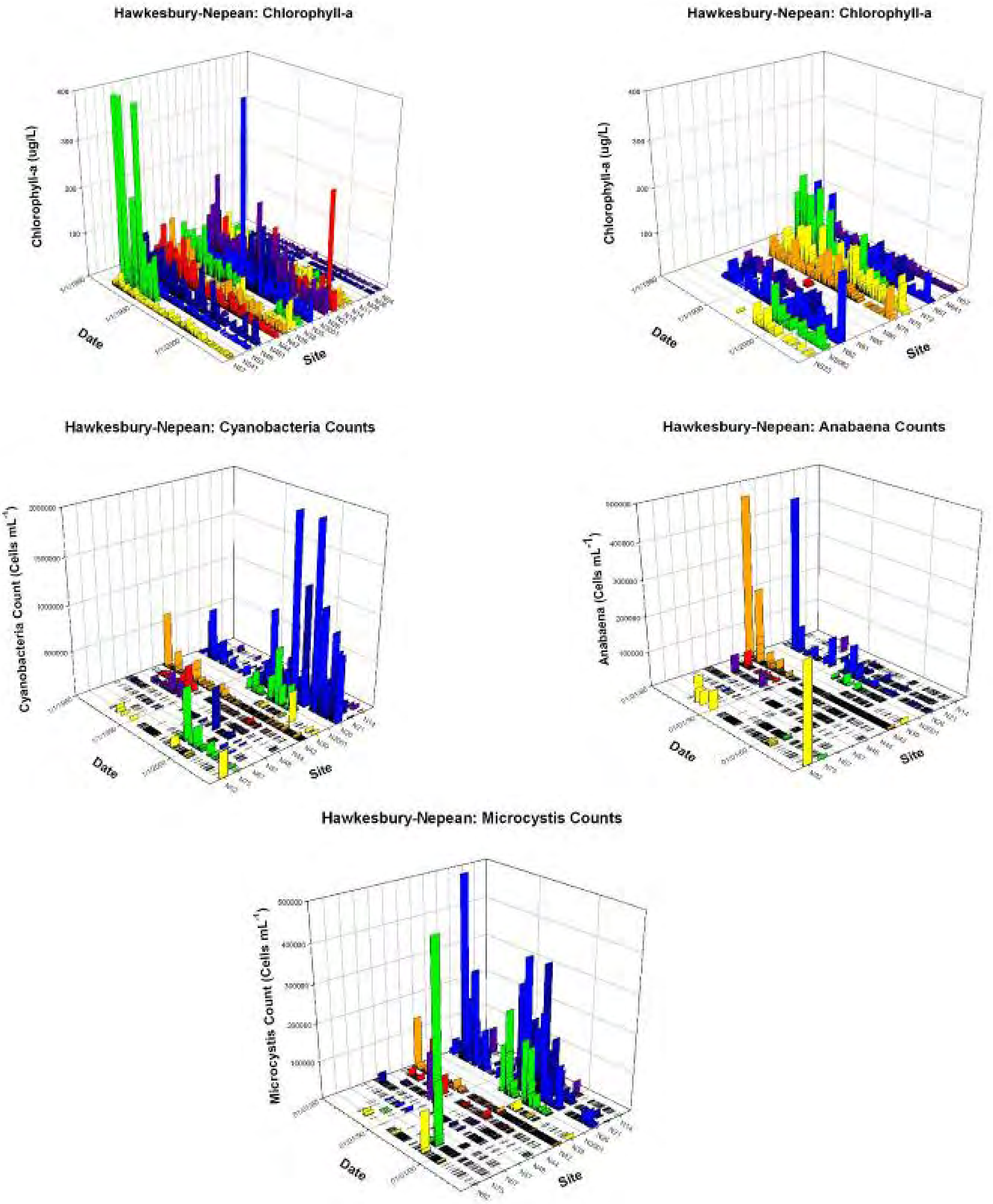


Figure 6.24: Chlorophyll-a, total cyanobacteria, *Anabaena* and *Microcystis* levels over time; Hawkesbury-Nepean River

also indicated significant differences among each of the decades when compared with one another (ANOSIM; $P = 0.001$). The results for the 1970s however, may require some degree of caution in interpretation, since only eight samples were available at N26 during the 1970s. SIMPER (Clarke and Gorley 2006) was used to identify which genera contributed the most to the significant differences among decades. This information is summarised in Table A8.1 (Appendix 8).

For the 2000s decade samples the most distinguishing factor is an increase in occurrence and density of *Aphanocapsa* (Figure 6.26). *Aphanocapsa* was not recorded at N26 before August 1999, but it is now the dominant genus in the algal community, being responsible for many recent blooms (up to 1 138 807 cells/mL on 19/12/03). Other genera contributing to the observed differences among decades include *Microcystis* (much higher average abundances in the 1980s and 1990s than in the 2000s); *Aphanothece* (much higher average abundances in the 1990s than in the 2000s or 1980s); *Cyanodictyon* (not recorded at N26 in the 1970s, 1980s or 1990s, but averaging 55 716 cells/mL in the 2000s); *Anabaena* (much higher average abundances in the 1980s and 1990s than in the 2000s); and *Skeletonema* (much higher average abundances in the 1980s than in the 1990s or 2000s). Other genera at times showed peaks in occurrence at various times but did not contribute as much to the dissimilarity among decades as these five genera.

What does seem apparent is that the blue-green algal component of aquatic flora of the Hawkesbury River at Sackville is now quite different from what was there throughout the 1980s and 1990s, with *Aphanocapsa* and *Cyanodictyon* replacing *Anabaena* and *Microcystis* as the dominant blue-green-algal genera.

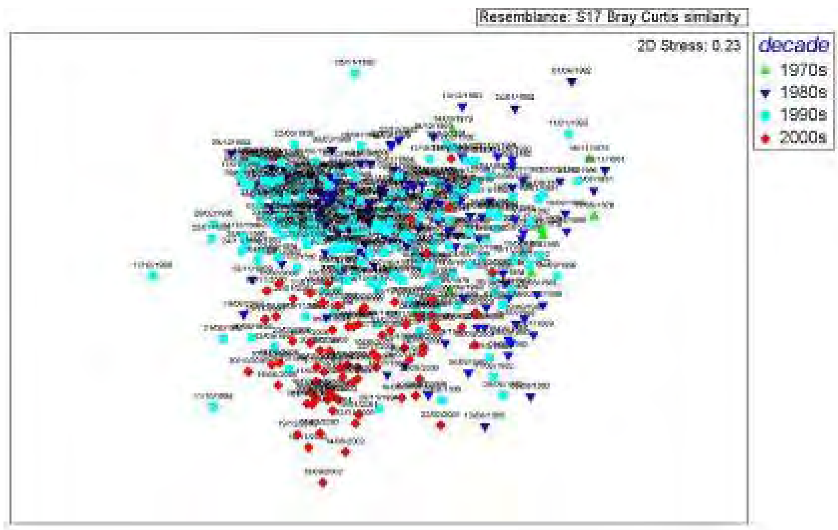


Figure 6.25: Multidimensional scaling ordination identifying decadal differences in algal communities at Sackville (N26)

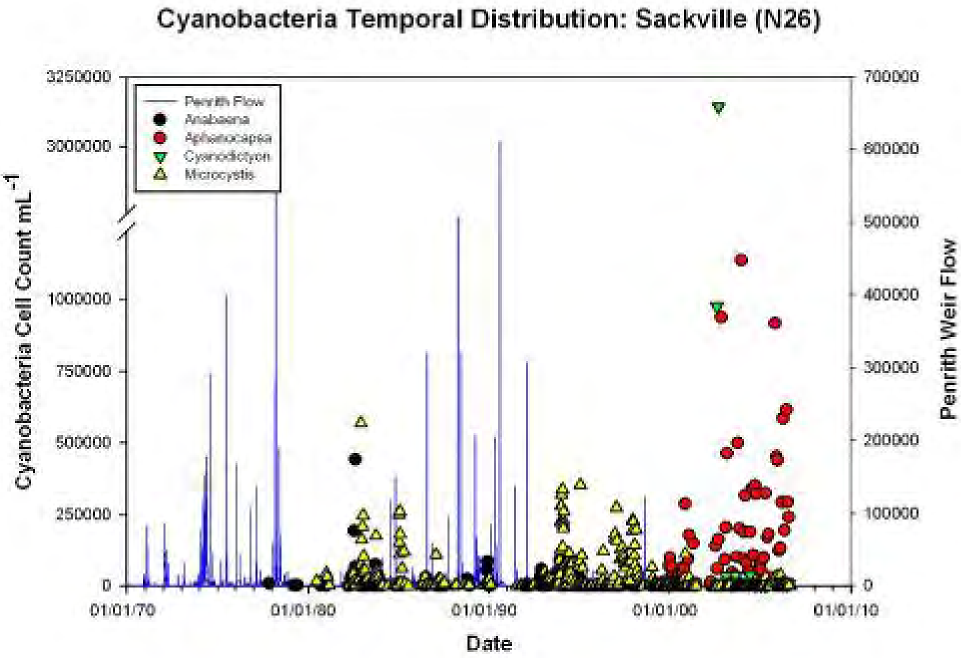
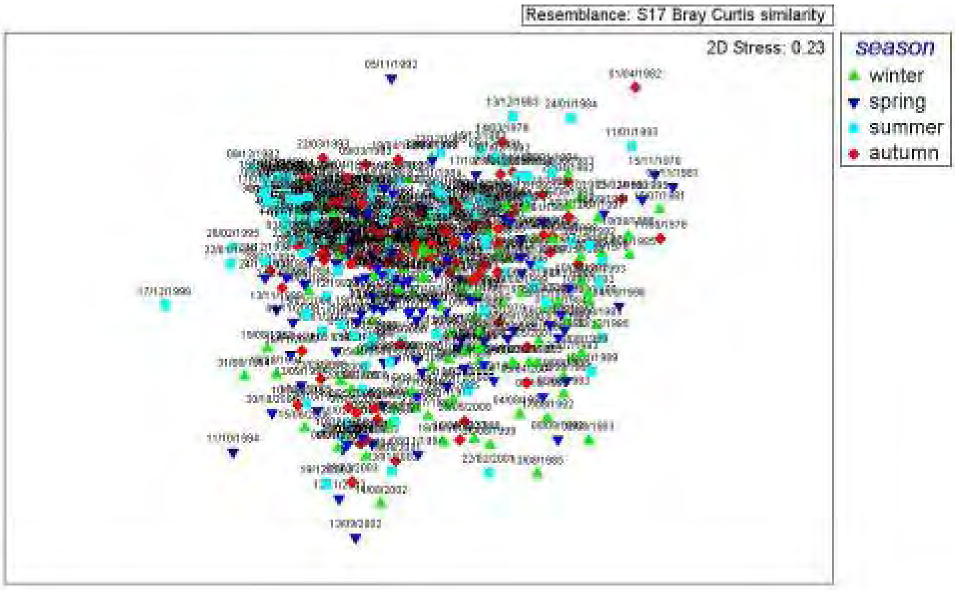


Figure 6.26: Temporal differences in cyanobacterial counts at Sackville (N26)

If the algal data at N26 are divided into different seasons (summer, autumn, winter and spring) then the differences are less clear cut (Figure 6.27) but still significantly different from one another (ANOSIM, P = 0.001). Pair-wise comparison of seasons also indicated significant differences among each of the seasons when compared with one another (ANOSIM, P = 0.001 to P = 0.021). These putative seasonal differences are dominated by *Microcystis* (more abundant in summer), *Aphanocapsa* (more abundant in summer, autumn and winter than spring), *Aphanothece* (more abundant in summer and, to a lesser extent, winter), *Anabaena* (more abundant in summer) and *Skeletonema* (more abundant in winter).

If just the more recent data for the 2000s decade are considered, however, no significant difference among seasons can be determined (ANOSIM, P = 0.083; Figure 6.27). This may be affected to some degree by the lower number of samples and the fact that, at N26, algal and cyanobacterial counts are conducted only if chlorophyll-a levels are above 10 µg/L.

Hawkesbury River – North Richmond (N42). If the algal data at N42 are divided into the various decades, then clear differences are again distinguishable (Figure 6.28), particularly for algal samples taken more recently (2000s decade). This analysis was based on genus-level differences rather than species-level differences, since taxonomic resolution has varied over time. Bray-Curtis similarity matrices were calculated using the raw (untransformed) data. These analyses indicated significant differences among decades in terms of the genus-level composition of algae in the Hawkesbury-Nepean River (ANOSIM, P = 0.001). Pair-wise comparison of decades also indicated significant differences among each of the decades when compared with one another (ANOSIM, P = 0.001). The results for the 1970s should be more reliable at this site, since 120 samples were available at N42 throughout the 1970s. SIMPER (Clarke and Gorley 2006) was used to identify which genera contributed the most to the significant differences among decades. This information is summarised in Table A8.2 (Appendix 8).



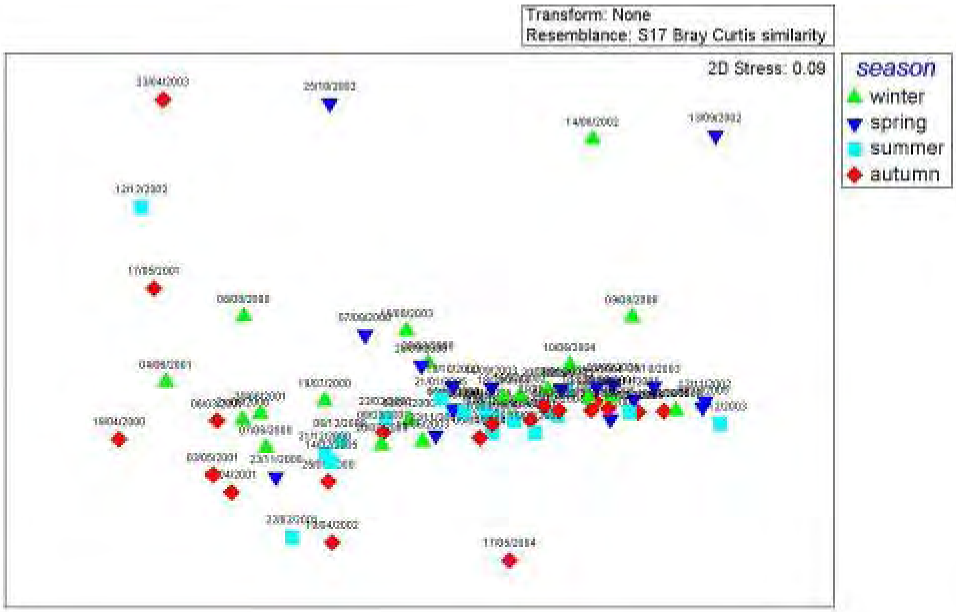


Figure 6.27: Multidimensional scaling ordination indicating seasonal patterns of algal communities at Sackville, Site N26; all data (top); 2000s data only (bottom)

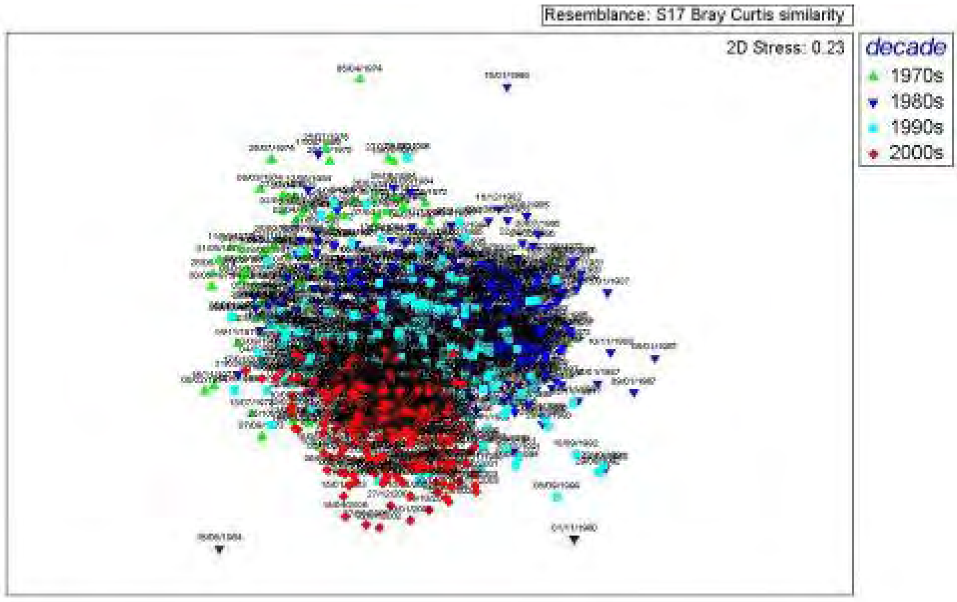


Figure 6.28: Multidimensional scaling ordination identifying decadal differences in algal communities at North Richmond (N42)

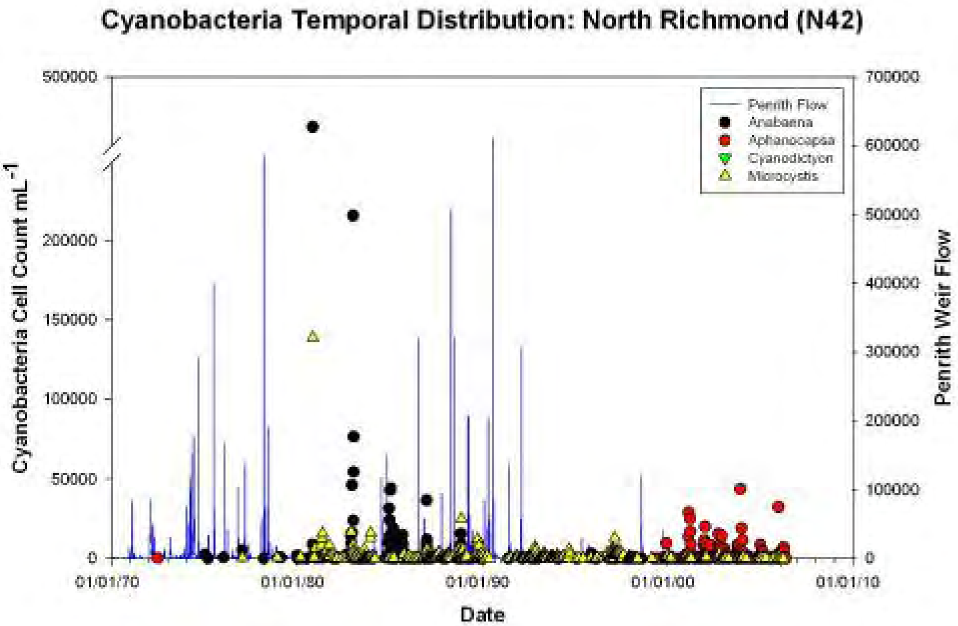


Figure 6.29: Temporal differences in cyanobacterial counts at North Richmond (N42)

Again the most distinguishing factor was an increase in occurrence and density of *Aphanocapsa* at N42 in recent times (Figure 6.29). Before August 1999, *Aphanocapsa* was recorded (in the dataset) only once (on 16/6/72) at N42 (Figure 6.29), but it is now the dominant genus in the algal community, being responsible for many recent blooms (up to 43 732 cells/mL on 11/12/03). Other genera contributing to the observed differences among decades include *Chroomonas* (higher average abundances in the 1980s and 1990s than in the 2000s and 1970s); *Scenedesmus* (similar average abundances in the 1980s, 1990s and 2000s, but far lower average abundance in the 1970s); *Cyclotella* (much lower average abundance in the 2000s than in the 1970s, 1980s or 1990s); *Microcystis* (much higher average abundances in the 1980s and 1990s than in the 2000s or 1970s); *Dictyosphaerium* (much higher average abundance in the 2000s than in the 1970s, 1980s or 1990s); an unidentified unicellular green alga recorded in high average abundance in the 2000s but not recorded as a category in the 1970s, 1980s or 1990s; *Skeletonema* (much higher average abundances in the 1980s than in the 1990s and very low average abundance in the 2000s); *Merismopedia* (much higher average abundances in the 1980s than in the 1990s and very low average abundance in the 2000s); *Phormidium* (much higher average abundances in the 1990s and very low average abundance in the 2000s); *Melosira*[27] (higher average abundances in the 1980s and 1990s and very low average abundance in the 2000s); and *Anabaena* (much higher average abundances in the 1980s than in other decades). Other genera at times showed peaks in occurrence at various times (Figure 6.30) but did not contribute as much to the dissimilarity among decades as the genera mentioned above.

If the algal data at N42 are divided into different seasons (summer, autumn, winter and spring), then significant differences are also found (Figure 6.31; ANOSIM, P = 0.001). Pair-wise comparison of seasons also indicated significant differences among each of the seasons when compared with one another (ANOSIM, P = 0.001). These putative seasonal differences are dominated by *Chroomonas* (more abundant in summer, autumn and winter than in spring); *Skeletonema* (more abundant in winter and spring); *Cyclotella* (low abundance in autumn); *Merismopedia* (more abundant in summer); *Microcystis* (more abundant in spring and summer), *Aphanocapsa* (more abundant in summer), *Anabaena* (more abundant in summer and to a lesser extent spring); *Scenedesmus* (more abundant in spring), and *Dictyosphaerium*, *Achnanthes* and *Phormidium* (more abundant in spring).

If just the more recent data for the 2000 to 2006 period are considered, significant differences among seasons are still important (ANOSIM, P = 0.001; Figure 6.31). Seasonal differences in recent times are dominated by *Aphanocapsa* (more abundant in summer); an unidentified green alga (more abundant in spring and to a lesser extent summer); *Dictyosphaerium* (more abundant in spring); *Chroomonas* (more abundant in winter); *Scenedesmus* (more abundant in spring); and *Synura*, *Cyclotella* and an unidentified monoflagellate (more abundant in winter). *Microcystis* and *Anabaena* were in relatively low abundance in this period but still more abundant in summer.

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27 The genera *Melosira* and *Aulacoseira* are both accepted genus names according to ITIS, but Sherman et al. (1998) have suggested species previously referred to the genus *Melosira* should now be referred to *Aulacoseira*. Further consideration of this apparent taxonomic inconsistency is required when interpreting the *Melosira* (and *Aulacoseira*) results.

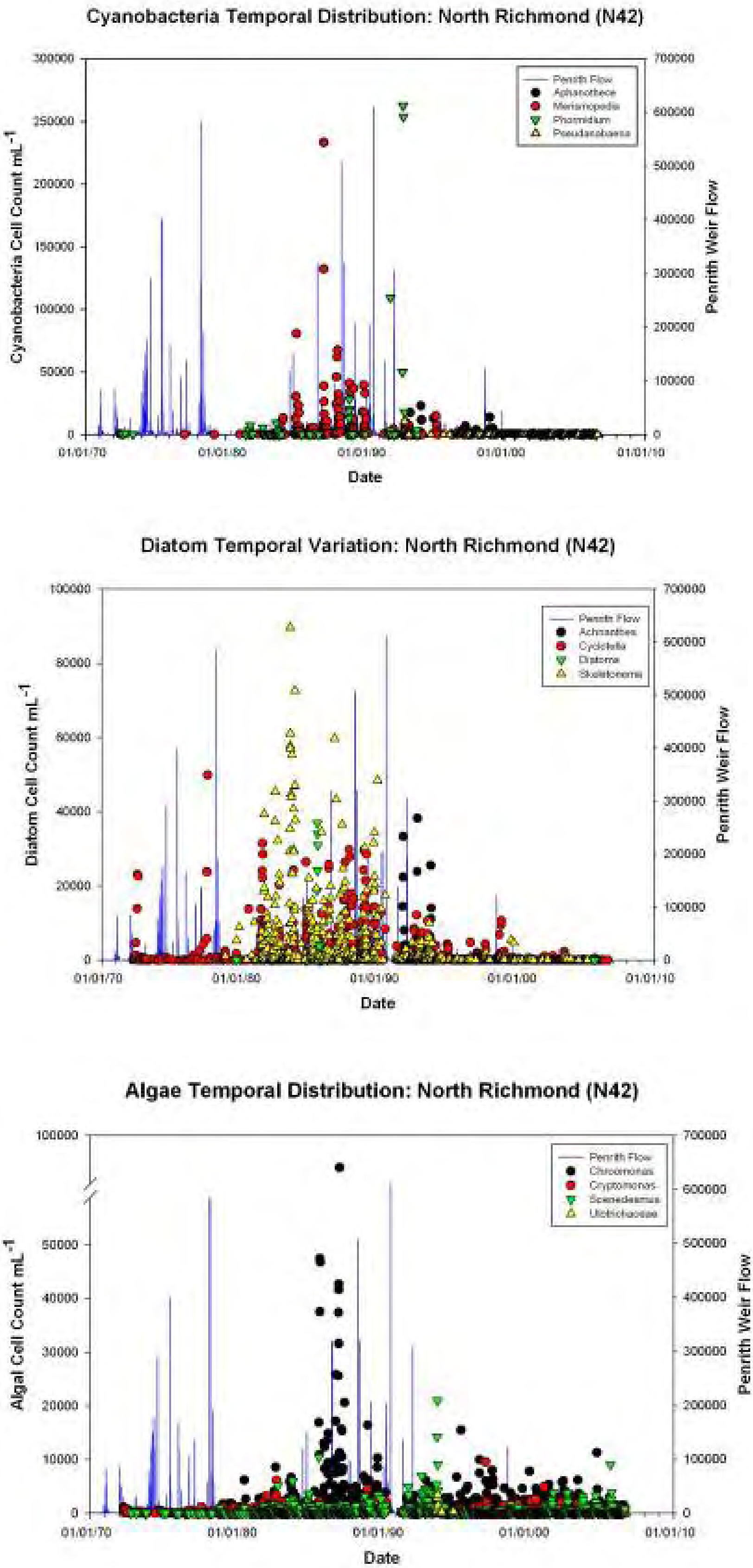
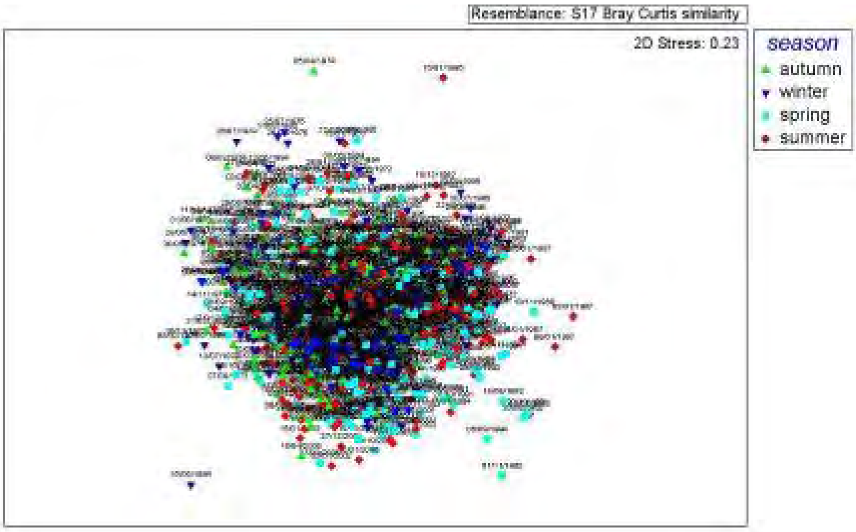


Figure 6.30: Temporal differences in other algal genera at North Richmond (N42)



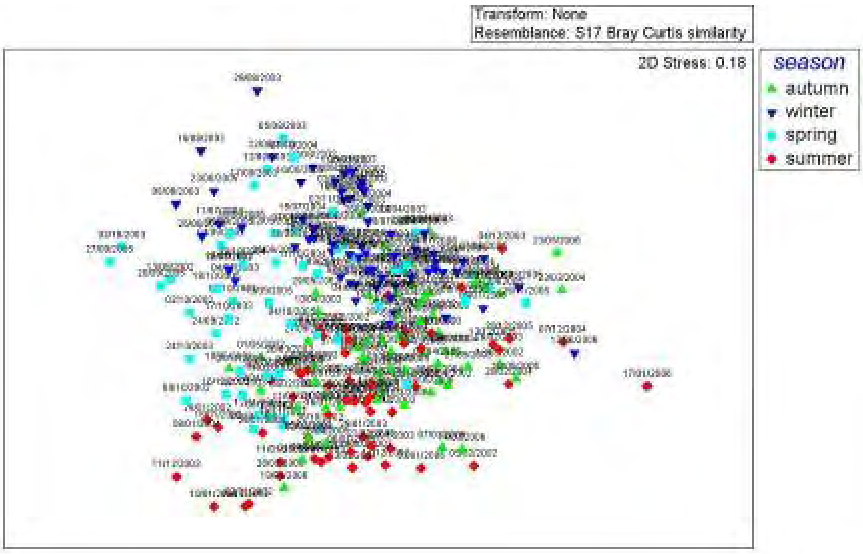


Figure 6.31: Multidimensional scaling ordination indicating seasonal patterns of algal communities at North Richmond, Site N42: all data (top); 2000s data only (bottom)

Comparisons between Sackville (N26) and North Richmond (N42). Although there are many similarities in the algal communities at N42 and N26, there are also some important differences. Throughout the 1980s, when *Anabaena* was blooming at N42, it was also blooming at N26 (Figure 6.32). However, in the 1990s, *Anabaena* bloom formations at N26 were not accompanied by blooms of similar magnitude at N42. In contrast, when *Microcystis* was blooming at N26 it was occasionally blooming at N42 but with much lower cell counts (Figure 6.32). More recently, *Aphanocapsa* blooms have occurred at both N42 and N26, but cell counts have been much higher at N26 (Figure 6.32). In the past, significant blooms of some cyanobacterial genera (e.g. *Merismopedia*, *Phormidium*) have been more prevalent at N42, whereas blooms of other genera (e.g. *Aphanothece*) have been more prevalent at N26.

Diatom blooms have been more prevalent at N42, particularly *Skeletonema* and *Cyclotella* in the 1980s and early 1990s and *Achnanthes* in the early 1990s. Blooms of some algal genera (e.g. *Chroomonas*, *Cryptomonas* and *Scenedesmus*) have been more prevalent at N42, whereas uncategorized genera in the family Ulotrichaceae had much higher cell counts at N26 in spring 1993, winter 1994 and spring 1994 than at N42, which only had blooms with much lower cell counts in the spring-summer period of 1993–94 (Appendix 8). Some of these differences may have been affected to some degree by the fact that at N26 algal and cyanobacterial counts are conducted only if chlorophyll-a levels are above 10 µg/L. However, if a bloom was present (and chlorophyll-a levels were above 10 µg/L) the dominant genus/species would still have been identified.

Discussion: algae and cyanobacteria

Historically, *Anabaena* and *Microcystis* have been the major causes of concern in algal blooms in the Hawkesbury-Nepean River system because of their capacity to form toxins. These genera/species now occur infrequently and at much lower cell counts than in the 1980s and 1990s. Other cyanobacterial species, particularly *Aphanocapsa*, appear to have replaced the *Anabaena* and *Microcystis* blooms of the past. *Aphanocapsa* spp. are very small blue-green algae that are not known to produce neurotoxins or hepatotoxins. However, the outer walls of all blue-green algae contain lipopolysaccharides that are mainly contact irritants and may cause dermatitis and conjunctivitis in people coming into contact with the algae through swimming or showering. If blue-green algae are swallowed they can cause stomach cramps, nausea, fever and headaches, and irritation to airways and breathing difficulties. To date, there have been no reports of these effects linked to exposure to *Aphanocapsa* spp. (Water Directorate 2002).

Aphanocapsa spp. therefore pose a much lower hazard for contact irritants, being a smaller non-toxic species of blue-green algae and occupying much less volume than an equivalent cell count of larger species (Water Directorate 2002). To put *Aphanocapsa* spp. cell counts into perspective, initial studies on biovolume and approximate cell numbers indicate that for the same biovolume of *Microcystis aeruginosa* and *Aphanocapsa* spp., a cell count of 20 000 cells/mL for *Microcystis aeruginosa* is equivalent to between 220 000 cells/mL and 412 000 cells/mL for *Aphanocapsa* spp. (Water Directorate 2002). Other cyanobacterial species (e.g. *Aphanothece*, *Cyanodictyon* and *Cylindrospermopsis*) have not been recorded extensively in the past, but they have been major components of some recent blooms. The genus *Cylindrospermopsis*, in particular, is known to contain species that have the ability to produce toxins (Neilan et al. 2003) and may require further scrutiny in the future.

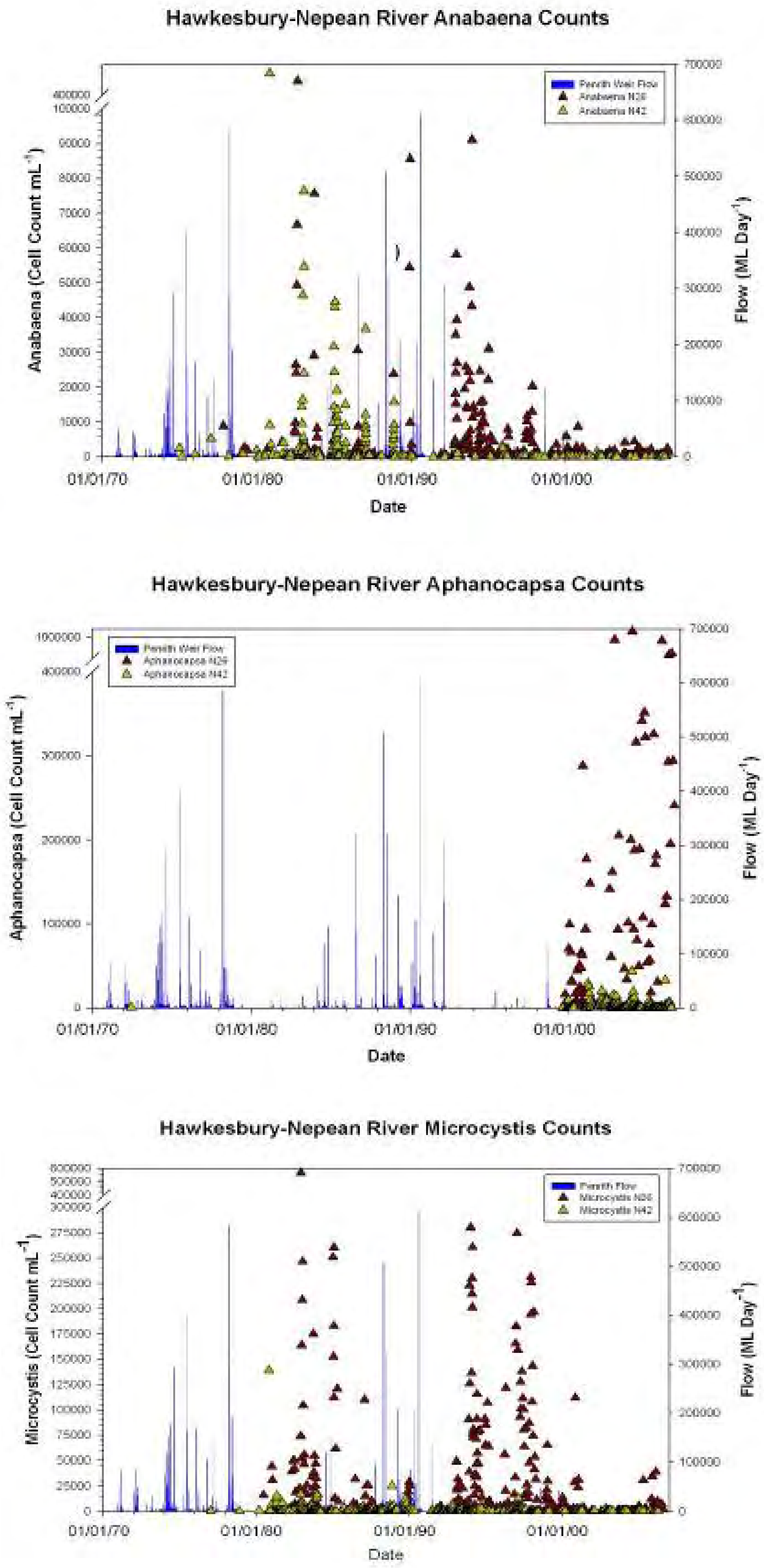


Figure 6.32: Comparison of major cyanobacterial cell counts at sites N26 and N42

Macrophytes

Large aquatic plants play an important role in the freshwater aquatic ecosystems of southeast Australia, absorbing nutrients, providing shelter for some species of fish, and creating foraging locations for others (Thiebaud and Williams 2008). Water ribbon (*Vallisneria gigantea*), a native to eastern Australia, is considered an indicator of good water quality and is known to be a nursery habitat for juvenile bass and a foraging habitat for adult bass (Harris 1988).

Many complaints are heard in the warmer months from users of swimming, fishing and boating facilities in the Hawkesbury-Nepean River about plants that restrict the recreational use of the waterway (Thiebaud and Williams 2008). Almost invariably, the plants in question are exotic species (e.g. see Figures 6.33 and 6.34), the decomposition of which reduces water quality and aesthetic values (Thiebaud and Williams 2008). Some of these exotic species are capable of reproducing via fragmentation (Sainty and Jacobs 1981); their dispersion possibilities are therefore increased through anthropogenic means (e.g., fragments on boat motors or fishing gear).

Macrophyte monitoring

Williams and Thiebaud (2007) analysed changes to aquatic habitats and adjacent land use in downstream areas of the Hawkesbury-Nepean River. In that study, the presence of submerged macrophytes was mapped in early 2004 from Wisemans Ferry to Warragamba Dam. Other studies of exotic floating macrophytes are currently under way (R. Coventry, pers. comm., cited by Thiebaud and Williams 2008). However, no recent studies of the large-scale distribution of all of the three main categories of aquatic macrophytes (submerged, floating, emergent) within the river had been reported (Thiebaud and Williams 2008).

Figure 6.33: *Salvinia* bloom at the junction of the Warragamba and Nepean Rivers, December 2006

DECC commissioned DPI Fisheries to undertake additional fieldwork to determine the current distribution of submerged, emergent and floating macrophytes in the Hawkesbury River. The fieldwork for this study was conducted in autumn and winter 2007, and the distribution of freshwater macrophytes was mapped from Warragamba

Dam to Wisemans Ferry. The results of this study are reported by Thiebaud and Williams (2008) and included in Appendix 9.

Native as well as exotic species were encountered in each of three categories: submerged, emergent, and floating vegetation. Macrophytes in the submerged category included the native plants *Ceratophyllum demersum, Hydrilla verticillata*, *Najas tenuifolia*, and *Vallisneria gigantea.* Two exotic species in this category, *Egeria densa* and *Elodea canadensis*, were also encountered, the former being widespread in occurrence and of particular concern as it has spoiled the recreational amenity of the waterway.

Emergent macrophytes included *Bolboschoenus fluviatilis*, *Juncus usitatus*, *Phragmites australis*, *Schoenoplectus validus*, *Triglochin procerum*, and *Typha orientalis*. *Gymnocoronis spilanthoides* and *Sagittaria graminea* ssp*. platyphylla*, two introduced species, had a limited distribution, being found only within the central portion of the study area.

Native floating macrophytes included *Azolla* spp., *Lemna* spp., and *Ludwigia peploides* ssp. *montevidensis*, whereas the introduced *Alternanthera philoxeroides*, *Eichhornia crassipes* and *Salvinia molesta* were confined to the upper and central portions of the study area. The latter three species have been of particular concern in the past.

Figure 6.34: *Egeria densa* stranded after minor flooding in June 2007 (Photos courtesy of DPI Fisheries—Thiebaud and Williams 2008)

Major conclusions from Thiebaud and Williams's (2008) study were:

- Much of the shoreline of the Hawkesbury-Nepean River from Warragamba Dam to Wisemans Ferry was vegetated with emergent or submerged macrophytes.
- The distribution of the floating macrophytes was restricted to the more central section of the study area.
- The introduced submerged species *Egeria densa* was present throughout much of the study area.
- The introduced submerged species *Cabomba caroliniana* was not found in the study area.

- Two species of weeds, *Gymnocoronis spilanthoides* and *Sagittaria graminea* ssp. *platyphylla*, each with an emergent lifestyle, were present in limited amounts in the central portion of the study area.
- The native submerged species *Vallisneria gigantea* was present throughout the study area.
- Reaches 21, 22 and 23 (Wilberforce to Fairlight Gorge) have the greatest number of exotic species of all three major groups, and they also have the greatest number of native species. This part of the river is where most action for control of exotic floating and submerged species has taken place in the past and should continue into the future.
- The abundance of *Egeria*, and possibly some other species, was markedly influenced by the minor flooding that occurred in the winter of 2007.

DPI Fisheries sampling in 2004 and 2007 has revealed that *Egeria* appears to have expanded its range in recent times, particularly in the reach around Richmond and Windsor (Figure 6.35).

7. Conclusions

Monitoring context

Cumulative development and population growth in the Sydney region and catchments have placed the Hawkesbury-Nepean River system under increasing pressure. The 2006 Metropolitan Water Plan sets out how the NSW Government will provide a secure supply of water that can meet the long-term needs of Sydney. The 2006 Metropolitan Water Plan aims to ensure that there is:

- sufficient water available over time to meet the needs of a growing city and to protect river health
- the ability to withstand current and future droughts, and impacts from climate change.

The Hawkesbury-Nepean Environmental Monitoring Program will help in the long-term monitoring and evaluation of the Metropolitan Water Plan. It will provide information on broad-scale trends in river water quality (including nutrients, turbidity and conductivity) and stream flows, as well as the biological patterns of the river's ecosystem (including invertebrates, fish and water plants). Evidence of trends will guide future decisions and help assess the effectiveness of environmental flow releases and other changes (NSW Government 2007). This report aims to identify the current direction of water quality, quantity and ecosystem trends, and to provide a benchmark for future monitoring as various initiatives under the Metropolitan Water Plan roll out.

Figure 6.35: Example of fine-scale historical comparison of the apparent change in distribution of *Egeria densa* near Richmond between surveys conducted in 2004 (top) and 2007 (bottom) (Thiebaud and Williams 2008)

Water quantity and quality monitoring

The Hawkesbury-Nepean River is relatively well serviced by river flow/level gauges and pluviometers, with data for some sites stretching back over 100 years. Recent trends in hydrology and water quality in the Hawkesbury-Nepean River need to be interpreted in terms of longer-term cycles (e.g. El Nino Southern Oscillation and Interdecadal Pacific Oscillation); in terms of major government initiatives under the Metropolitan Water Plan; and in terms of potential climate change effects in the future. Analysis of the data indicated that there has been a significant reduction in flows over Penrith Weir (and other areas), and river flow at Penrith weir remains much less than the long-term (>100-year) average. River regulation is not the sole factor involved in this decline, since similar declines are also noticeable in the flow record for the unregulated Colo River. However, regulation is still important, since the smoothed trend line for flow at Penrith Weir has now consistently fallen below that of the unregulated Colo River for the first time since records began.

Most water quality monitoring in the Hawkesbury-Nepean River is much more recent in origin (from the early 1980s onwards), and there have been a wide variety of programs, sites and times monitored. The routine Water Quality Monitoring Network outlined in the HN-EMP contains some of the best long-term data series in NSW (and Australia). This is to the credit of the organisations and individuals involved in its initial design and implementation. The data collected up until the present time represent not only a significant historical and ongoing investment, but a very valuable resource in terms of long-term information on water quality and quantity in the Hawkesbury-Nepean River. It is expected that the value of these long-term data will become even more important in the future as government seeks to understand the potential consequences of Metropolitan Water Plan changes and climate change.

Although some improvements in water quality can be demonstrated from this monitoring program, these are improvements from what was previously quite poor water quality in some areas and, for some analytes, water quality still has a long way to go before water quality objectives (e.g. ANZECC/ARMCANZ Guidelines) are met. The effects of individual sewage treatment plants can still be inferred from these data, although other sources such as urban and agricultural runoff also contribute to poor water quality in these areas.

Phosphorus levels (both total and filterable) have generally been declining throughout most of the river system, although phosphorus levels downstream of Penrith STP often remain elevated compared with those in many other areas in the system.

Nitrogen levels have also declined at many sites throughout the river system, with the exception of Sharpes Weir (downstream of Camden STP) and Wallacia Bridge, where nitrogen levels — particularly inorganic nitrogen levels — appear to be increasing. Despite many decreasing trends in nitrogen levels at other sites in the Hawkesbury-Nepean River, nitrogen levels often remain well above ANZECC/ARMCANZ guideline levels throughout the river system.

Conductivity levels appear to be increasing at many sites. Dissolved oxygen and temperature levels have largely remained steady, although slight increases in temperature are suggested at sites upstream of Wallacia Weir.

Chlorophyll-a levels have mostly declined or remained stable at most sites. Cyanobacterial cell counts have largely remained stable, although some slight increases are suggested. Most recent blooms downstream of the dams have not been dominated by *Microcystis* or *Anabaena*, although *Anabaena* was the dominant species in the January 2007 bloom at Maldon Weir. Trends in other water quality indicators have been variable among sites.

Biological indicator monitoring

Monitoring of biological indicators such as macroinvertebrates, periphytic diatoms and fish has been far less extensive than water quality and quantity monitoring. Although a substantial number of sites have now been sampled for macroinvertebrates in the Hawkesbury-Nepean catchment, there are far fewer sites that have been consistently sampled over time (and therefore can be assessed for long-term trends). At some of the sites that do have longevity of sampling, further inconsistencies have been introduced because different sampling organisations have used different sampling and analysis protocols. At such sites, any putative change from one time period to another may be confounded by these changes in organisation and sampling protocol. Differences in the level of taxonomic resolution can also affect such comparisons over time. These are important considerations for any long-term monitoring program seeking to detect trends in aquatic health.

The two main macroinvertebrate programs considered in this report include sites with some of the longest histories of macroinvertebrate monitoring in the Hawkesbury-Nepean River catchment (and possibly in NSW). These data will become even more important in the future to address questions about trends in aquatic health and to test the ability of RBA indices (e.g. O/E50, SIGNAL) to identify changes in aquatic health over time.

In the past, there has been a significant investment in periphytic diatom monitoring at a number of sites in the Hawkesbury-Nepean catchment. This has yielded some insights into periphytic diatom populations and their response to regulation. However, assessment of long-term trends has been affected by changes in organisational responsibility for the sampling and by inconsistencies in sampling methodology and taxonomy.

The data available to assess long-term trends in fish communities in the Hawkesbury-Nepean River are still limited. The persistence of introduced species (e.g. carp and goldfish) in the river system and the potential introduction of further exotic species (e.g. redfin perch) are of concern.

Although the excessive growth of native and exotic macrophytes is of management concern, it is believed that it is better to have excessive growth of macrophytes in the river — even if they are exotic species — than to have no macrophytes at all (Hawkesbury-Nepean River Management Forum 2002). Experience has shown that where macrophytes have been lost from aquatic systems, the lack of competition for nutrients and light, together with the loss of habitat for zooplankton and fish, has resulted in these systems becoming algae-dominated (Hawkesbury-Nepean River Management Forum 2002). Given the extent of the problem and the anthropogenic uses of the river, there is no simple solution to the control of these species (Taylor-Wood 2003). Before the studies of Thiebaud and Williams (2008)[28], no recent studies of the large-scale distribution of all of the three main categories of aquatic macrophytes (submerged, floating, emergent) within the river had been reported. There is also little ongoing monitoring of the distribution and biomass of important macrophyte species (e.g. *Vallisneria*, *Egeria*). As a result, long-term trend information on native and introduced macrophytes in the Hawkesbury-Nepean River system is largely lacking. There are, however, indications that *Egeria* has increased its distribution in some areas of the Hawkesbury-Nepean, particularly around Windsor and Richmond (Thiebaud and Williams 2008).

In contrast to the use of the biological indicators already considered, algal monitoring (a component of the wider water quality monitoring program) is much more established, with records dating back to the early 1970s. Historically, *Anabaena* and *Microcystis* have been the major causes of concern in algal blooms in the Hawkesbury-Nepean River system because of their capacity to form toxins. These genera/species now occur infrequently and generally at much lower cell counts than in the 1980s and 1990s. Other cyanobacterial species, particularly *Aphanocapsa*, appear to have replaced the *Anabaena* and *Microcystis* blooms of the past. *Aphanocapsa* spp. are very small blue-green algae that fortunately are not known to produce neurotoxins or hepatotoxins (Water Directorate 2002). If we are to understand exactly why algal community composition in the Hawkesbury-Nepean

[28] Initiated as a component of the current study

River has changed in the recent past, and the potential for future community shifts, further assessments will be needed.

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9. Acknowledgements

This report was compiled in August 2008 by Martin Krogh, Aaron Wright and Jan Miller of the Waters and Coastal Science Section, Scientific Services Division, Department of Environment and Climate Change.

A large number of people from many agencies have helped in some way in the delivery of this project, either through provision of data, clarification of sampling/methodology issues and/or contributions to reviewing and discussing various components of the monitoring program and report. Their contributions are gratefully acknowledged.

Department of Environment and Climate Change: Barbara Richardson, Tim Pritchard, Peter Scanes, Bruce Chessman, Evette Camroux, Orlando Luminere, Dan Mawer, Geoff Coade, Geoff Gordon, Gunther Theischinger, Eren Turak

Sydney Catchment Authority: Tony Paull, Ian Tanner, Stephen Blockwell, Mahes S. Maheswaran, Nimi Manoharan, Amanda Kotlash, Tim Berryman, Andrew Bryan, Bala Vigneswaran

Sydney Water: Judi Hansen, Greg Allen, Renee Kidson, Shafiqul Hassan, Colin Besley, Merran Griffith, Lynn Tamsitt, Monika Cariss

DPI Fisheries: Bob Creese, Rob Williams, Isabelle Thiebaud, Simon Hartley, Jamie Knight

Department of Water and Energy: Ivor Growns, Salim Vhora, Simon Williams, Helen Keenan, Maree Abood, Bruce Cooper

Metropolitan Water Directorate (formerly in the Cabinet Office): Sarah Rish, Marion Bennett

Hawkesbury-Nepean CMA: Bill Dixon, Kerry Brew

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