An Assessment of the Health of the Georges River

T. Mark Florence, Glen D. Moody and Graham J. Whitelaw

The Georges River Combined Councils Riverkeeper Program,

P.O. Box 57, Oatley, NSW 2223

July, 1999

How will I find out what activities are coming up?

Each group has a Group Co-ordinator who keeps in touch with the group and with the Riverkeeper Co-ordinator. When you join the Riverkeeper program, you will receive a regular newsletter. If you need more information, phone the Riverkeeper Co-ordinator

How can I find out more about the Riverkeeper Program?

When you join, you will receive a Volunteer Handbook which sets out your role as a volunteer, the vision, mission, ethic, goals, strategies and lots of other useful information about how we will put our vision into action. The Riverkeeper Co-ordinator will be happy to answer any other questions you have or refer you to someone who can help.

What does it cost to join?
Just a small amount of your time. The program is currently sponsored by the Georges River Combined Councils' Committee Inc and has received funding from the Bankstown City Council, Hurstville City Council, Kogarah Municipal Council, Rockdale City Council and Sutherland Shire Council.

To Join Riverkeeper Simply Contact:
Riverkeeper Co-ordinator
Phone: 02-95864288 (Mon/Tues/Thurs)
Fax: 02-95864299
PO Box 57, Oatley 2223

Councils in the Catchment
Bankstown Council* - (02) 97079495
After Hrs: 99631210
Campbelltown Council - (02) 46201510
Fairfield Council - 02-97250222
Hurstville Council* - (02) 93306164
After Hrs: 99631355
Kogarah Council* - (02)93309400
After Hrs: 99632972
Liverpool Council - (02) 98219222
Rockdale Council* - 95621666 (24 hrs)
Sutherland Council* - 97100333
After Hrs: 99631233
Wollondilly Council - 02-46771326
* Riverkeeper Sponsoring Councils

Useful Phone Numbers:
EPA 24 hr Hotline: 131555
NSW Fire Brigade (cleanups) - Dial 000
Sydney Water (Sewerage Overflows):
24 hrs - 132090
Fishwatch (Illegal Fishing)
24 hrs - 1800043536
Waterways Authority (Boat Pollution) :
0418976165
National Parks (Wildlife Cleanup)
24 hrs - 0419428052

YES.....

You Can Help Restore the Georges River

Become a Volunteer for the Riverkeeper Program

There are 1.3 million people - including YOU - who are part of the Georges River Catchment.......from Wollondilly Shire to Botany Bay. YOU CAN make a difference

How can I help?

- Get involved in one (or more) of the volunteer groups
- Attend clean ups and combined Riverkeeper events
- Watch for sources of pollution in your own area and notify the Riverkeeper Co-ordinator, local council, Environment Protection Authority or other authority
- Become an "Ambassador" for the River by raising public awareness of the Riverkeeper Program and its aims.
- Become a sponsor for the program
- Attend regular group meetings on Thursday evenings if available.

What Volunteer Group(s) can I join?

You can help with any of the following, depending on your interest and available time -

- Boat Survey
- Water Testing
- Land Survey
- Education
- Research
- Administration

"Our River, Our Life"
(Produced by Georges River Riverkeeper Volunteers)

What does each group do?

Boat Survey Group

- Maintains a visible presence on the River watching for sources of pollution or degradation through regular river-based activities
- Responds to emergency call-outs
- Provides transport for other volunteers when required to access difficult sites for survey or testing
- Participates in river clean-up operations, public displays etc.

Water Testing Group

- Accesses existing records of water quality tests from other sources such as Streamwatch and local councils
- Researches appropriate sampling regimes
- Determines locations and priorities for water sampling
- Collects and labels regular water samples
- Conducts basic tests on site
- Arranges installation of monitoring equipment on suspect drains

Land Survey Group

- Organises walks along riverbank with map and drain report sheets and records each drain end pipe on map and a description about the drain on a Drain Report sheet
- Reviews and monitors identified trouble spots
- Updates mapping on Geographical Information System (GIS)

Education Group

- Develops resources to promote understanding of issues relating to management of the river
- Participates in community events selected for Riverkeeper involvement
- Produce brochures, stickers etc and explains the Riverkeeper initiative to schools and community groups
- Helps develop project models
- Develops educational/promotional display kits
- Identifies and co-operates with community groups in sub-catchment areas to establish linked programs

Research Group

- Maintains a watching brief for the publication of reports, proposals, studies and statements which relate to the Georges River
- Procures, analyses and responds to the content of reports, Environmental Impact Statements (EIS), Plans of Management (PoM), Regional Environmental Plans (REP) and Local Environment Plans (LEP) and other relevant studies

Administration Group

- Modifies and updates volunteer database and manual records
- Keep a check on the Riverkeeper worldwide web home page
- Modify/update map inventory (with help from land survey group) library (with education group) and filing (with assistance from co-ordinator)
- Collects newspaper clippings or Riverkeeper reports and articles concerning the Riverkeeper program
- Help produce the volunteer newsletter on a bi-monthly basis

Website:
(http://www.sinsw.gov.au/plb/libs/hurstville/riverkeeper/index.html)

Executive Summary

Water quality in the Georges River has deteriorated from the 1950s, and was poorest in the late 1970s to the mid-1980s. However, since the upgrading and diversion of the Glenfield and Liverpool sewage treatment plants in the mid-1980s, there has been a marked improvement, with the result that, in 1998, regulatory body guideline values for water and sediment were met for most of the year and in most parts of the river. The exception is faecal coliforms, which can still exceed guideline values after heavy rain, especially in the Upper Georges River. Also, some of the tributary creeks, especially Prospect Creek and the upper reaches of Salt Pan Creek have relatively poor water and sediment quality. Heavy metals in Georges River oysters now meet health guidelines, and the risk of eating fish caught in the Georges River itself is minimal, and is insignificant compared with the general health benefits of fish consumption. It would be prudent, however, to avoid eating fish from the polluted creeks, especially Prospect Creek and the upper reaches of Salt Pan Creek. The commercial yield of finfish from Botany Bay/Georges River (kg of fish per fisher-day of effort) has not changed significantly in the past 15 years, and the annual fish catch from these areas is still similar to much earlier years. However, no separate data are available for fish catches in Georges River alone. The areas of seagrass, mangroves and salt marsh in the river have declined markedly in the past 50 years. The greatest single threat at present to the river is increasing urban runoff from the rapid urbanisation of the Georges River catchment. Stormwater drains are adding large amounts of freshwater, suspended solids, and nutrients to the river. Suggestions are made for further research on the river and some avenues for rehabilitation are discussed. In 1999 we can be cautiously optimistic about the future of the Georges River, despite the enormous pressures on it from increasing population and use. The degradation in water and sediment quality that occurred over three decades has now been largely contained, and we can expect it to improve further in the future as long as we are vigilant, have the will to protect the river, and are prepared to commit the necessary funds.

Table of Contents

	Page

An Assessment of the Health of the Georges River

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1. Introduction

At the end of the millenium, there is considerable anxiety throughout the world about our ability, in the face of increasing population and industrialisation, to maintain the health and integrity of our natural environment. This is especially so in large, rapidly growing urban areas such as Sydney. Sydney now contains 22% of Australia's total population and is the city where a high percentage of Australia's new migrants prefer to settle. Because of the demand for waterfront living, the city's waterways are subject to intense housing development and pressure. The Georges River Catchment encompasses some of the most rapidly growing Local Government Areas (LGAs) in Australia, and contains over one-third of Sydney's population. The following twelve LGAs (in decreasing order of population) are completely or partly within the Georges River Catchment: Sutherland, Fairfield, Wollongong, Bankstown, Campbelltown, Canterbury, Liverpool, Rockdale, Holroyd, Hurstville, Kogarah, and Wollondilly. The Georges River Riverkeeper Program is at present funded by Bankstown, Hurstville, Kogarah, Rockdale and Sutherland Councils. The total population growth of seven of the LGAs in the Georges River Catchment is shown in **Figure 1** (Australian Bureau of Statistics, 1996).

The Georges River rises 3 km south-east of Appin. It flows northwards to Liverpool then turns south-east at Chipping Norton and finally eastwards to Botany Bay. The main river channel is about 100 km long with a mean depth of 4 m, and drains an area of 960 km^2. It is divided into three main regions: *The Headwaters* (the freshwater section from Appin to Liverpool Weir), *The Upper River* (Liverpool Weir to Salt Pan Creek), and *The Lower River* (Salt Pan Creek to Botany Bay) (**Figure 2**). In addition to being used intensively for recreation (boating, swimming, angling), the Georges River and its catchment have to cope with a wide range of potentially-polluting commercial activities, including land development, fish netting and trapping, waste disposal, sand mining (now ceased), soil extraction, poultry and pig farming, market gardening and other agricultural uses, and some industrial processing, mainly along Prospect Creek at Smithfield and in Bankstown on tributaries of the Georges River (Department of Urban Affairs and Planning, 1998).

If the community using the Georges River were to write a "wish list" for the state of their river, it would probably include the following three main points:

- That the river appears clean and healthy and that it supports a large number and wide variety of fauna and flora,
- That they can swim and go boating in the river without suffering any ill-effects from contact with the water or sediment,
- That they can catch fish and other seafood from the river and eat them without any health detriments.

In addressing the questions of the health and future of the Georges River, it is important to accept, however, that the river can never be restored to a *pristine* condition, particularly when it has to cope with such a large and increasing human population (**Figure 1**). What is meant by "pristine", anyway? The way that the river was before white people came to Australia, or even, perhaps, before the Aborigines settled here? The Aboriginal practice of forest burning would have substantially increased phosphorus levels in the water (State Pollution Control Commission, 1979), and led to some erosion of the river banks resulting in an increase in water turbidity. Their extensive use of fish traps would have brought about some changes in the ecology of the river. These changes, however, would have been trivial compared to the massive disruption of the river's ecology caused by white settlement in the catchment. So if we are to attempt to assess the extent of the *degradation* of the Georges River in 1999, we need to have some reference, or starting point. Degraded compared to what or when? A scientific study can use only reliable, accurate data for an environmental assessment, and cannot take into account anecdotal or heresay accounts. The earliest reference point, then, would be when reliable data first became available. Very few scientific data of any kind on the Georges River were collected before World War II, and the first reliable water quality data did not begin to appear until the 1950s. For some important water quality parameters, the technology needed to make the measurements was not available until much later. Heavy metals (eg, copper, lead, zinc and mercury) in seawater at the natural levels could not be reliably determined until the late 1970s and, even now, there are a limited number of laboratories in Australia that can make these measurements on a routine basis (Florence and Morrison, 1992; Morrison, 1999).

It is important to understand that estuaries are dynamic systems, and are continuously undergoing change (Morrison, 1999). Many of these changes arise from natural processes, including wave action, wind, stormwater, and tidal cycles, while other changes are anthropogenic (ie, from human activities).

This report assesses the present state of health of the Georges River, and compares recent water quality and biological data with historical data which are considered reasonably reliable and accurate. Because this report is of a limited nature, we have not attempted to review the literature exhaustively, but we believe that we have consulted most of the important documents. We have excluded Botany Bay from the study because the health of Botany Bay has been the subject of several recent reports (eg, Larkum and West, 1990; Smith, 1998). After assessing the present health of the river, we identify some of the most important parameters that are the cause of degradation, pinpoint some important gaps in the available data, and discuss possible avenues for rehabilitation of the Georges River.

2. Possible Sources of Pollution and Causes of Degradation of the Georges River

The total area of the catchment draining to the Georges River is 960 km^2 (Sydney Water, 1998). The upper catchment (Ingleburn Weir to Liverpool Weir) in 1998 was 9% residential, 26% agricultural, 4% industrial, 29% military, 28% reserves and 4% other uses (PPK, 1998). The central catchment (Liverpool Weir to Salt Pan Creek) contained 53% residential, industrial, and open space, 15% rural and 32% natural areas (Sydney Water, 1998). The lower catchment (Salt Pan Creek to Botany Bay) is divided into 57% residential, 11% industrial and 32% open space (Sinclair Knight Merz, 1999). The likelihood of extensive future development of the upper regions of the catchment is high (Water Board, 1991). The turnover of water in the Upper Georges River is slow, with a turnover time of 20 to 30 days occurring at least 30% of the time and, even at Lugarno, average flushing time is 10 days (Birch *et al.*, 1996). Chipping Norton Lake, under some weather conditions, can take 50 days to be flushed by tidal flow (Department of Urban Affairs and Planning, 1998). These low flushing rates increase the effects of pollutants on the river's flora and fauna.

Pollution sources can be divided into *point sources* and *diffuse sources*. Some examples of point source pollution are sewage treatment plants, waste disposal sites and stormwater drains, while diffuse sources include river bank erosion, atmospheric dust, and domestic gardens. These pollution sources basically cause deterioration in the quality of the riverwater. Degradation of the river system can also result from changes in the course and depth of the river as a result of dredging, mining operations, siltation from land development, and filling of river bays for new real estate. Loss of seagrass beds, mangrove areas and salt marshes can also have a dramatic effect on the number and diversity of animals such as fish that live in the river.

The main tributaries of the Georges River are the Woronora River, and Prospect, Salt Pan, Little Salt Pan, Bunbury Curran, Cabramatta, Williams, Mill, Deadmans and O'Hare's Creeks. The water quality of the Woronora River is superior to that of the Georges River (Healthy Rivers Commission,1999), but most of the creek tributaries of the Georges River suffer higher pollution than the river itself.

Some of the potential sources of pollution and degradation are:

- Sewage treatment plants, sewerage system overflows and septic tank leakage (suspended solids, nutrients, bacteria, heavy metals)
- Stormwater drains (suspended solids, nutrients, bacteria, heavy metals)
- Industrial discharges (oil, solvents, PCBs, heavy metals, organic matter)
- Agricultural and domestic runoff (nutrients, pesticides, herbicides)
- Waste disposal sites (suspended solids, heavy metals, PCBs, bacteria)
- Marinas and boating (antifouling paints, heavy metals, fuel)
- River bank and soil erosion (suspended solids, heavy metals, nutrients)
- Dredging (suspended solids, nutrients, changes in the course of the river)
- Sand and gravel mining (acid production, nutrients, suspended solids, changes in river course)
- Land development (suspended solids, nutrients, changes in river bank and river depth)
- Loss of habitat (seagrass beds, mangrove stands, salt marshes)

Some of these are discussed in more detail below.

Sewage treatment plants, sewerage system overflows and septic tank leakages

Within the Georges River Catchment there are two sewage treatment plants (STPs), at Liverpool and Glenfield, and one storm STP at Fairfield, operated by Sydney Water. During most weather conditions, the effluent from the Glenfield and Liverpool STPs is pumped into the main sewer line to Malabar, where it is discharged to the ocean via the deep ocean outfall. However, after heavy or prolonged rain, treated and disinfected effluent from these two treatment plants is discharged into the Georges River near Chipping Norton. Also, the Fairfield STP operates in wet weather. If its capacity is exceeded, the treated and disinfected effluent is released into Orphan School Creek, and flows into Georges River via Prospect Creek. The average wet weather overflows into the Georges River are 570 ML/y, 4,200 ML/y, and 360 ML/y into the Upper, Central, and Lower Georges River catchments, respectively. These overflows constitute a minor fraction of the wet weather river flow of about 344,000 ML/y (AWT Ensight, 1997; Sydney Water, 1997; Sydney Water, 1998).

During prolonged, heavy rain, rainwater gets into the sewerage system through leaky sewer pipes and from a range of illegal connections. Sydney Water's sewerage system is designed to handle 3-4 times the peak dry weather flow but, if this input is exceeded, sewerage system overflows can occur (Sydney Water, 1998). Most overflows (about 90%) occur in a directed, controlled manner. Within the entire Cronulla and southern suburbs sewerage systems (part of which are outside the Georges River catchment), Sydney Water has identified a total of 1,195 designed overflow structures including 31 major (ie, high volume or frequency) potential overflow points (Colin Heath, Sydney Water, private communication). Most of the overflows affect the Upper Georges River, with the highest overflow occurring from Chipping Norton. This point overflows an average of 20 times a year, with an average annual overflow volume of 1,470 ML/y (Sydney Water, 1998a).

The contribution to pollution of the Georges River by sewerage system overflows is much less than that of stormwater (**Section 3.1**), but the overflows do provide significant amounts of phosphorus and faecal coliforms, especially to Salt Pan Creek (Department of Urban Affairs and Planning, 1998). The effects of both sewage discharge and sewer overflows is diminished by the high dilution of the sewer water by rainwater (up to 10 times) (Sydney Water, 1998a). Also, under conditions of heavy or prolonged rain, the river is flushed rapidly and thoroughly by flood water. However, settleable solids in the sewage may act as a source of sediment oxygen demand for a considerable time after a rain event.

Sydney Water plans to tackle the problem of sewerage system overflows in Sydney with a major progam that is scheduled for completion in 2020, with most of the Georges River overflows being corrected by 2010. The total cost for this remedial work to Sydney's sewage system is budgeted at $2 billion (Sydney Water, 1999).

In 1991, there were 280 unsewered properties along the Georges River (EPA, 1994). These are of concern, since many septic systems are leaky. However, leakage from septic tank systems is not considered a major source of pollution on a catchment-wide basis, but local problems may occur in some rural areas (eg, near Appin) in the sensitive upper parts of the catchment (Department of Urban Affairs and Planning, 1998).

Stormwater drains (urban runoff)

Urban runoff increases with urbanisation. As more roads, parking lots, houses and driveways are built, the increase in impervious paved surfaces and in the stormwater drains that drain these surfaces leads to greatly increased volumes of stormwater entering the river. As an example, Sutherland Shire Council in 1999 has identified about 13,000 operating stormwater drains in the Shire (G. Morton, SSC, private communication). Unpaved surfaces (grass, bushland) absorb much of the initial rainfall; in 1997/8, Sydney Water measured catchment yields (volume of stormwater runoff per hectare) of 3.7 ML/ha for the urban Orphan School Creek sub-catchment, but only 0.6 ML/ha for the more rural Liverpool Weir sub-catchment (Sydney Water, 1998b).

The volume of stormwater entering stormwater drains is always much greater than the volume of sewerage system overflow water. For example, in 1997/8, the ratio of sewage overflow to stormwater was 0.1% in the Liverpool Weir sub-catchment and 0.7% in the Orphan School Creek sub-catchment (Sydney Water, 1998; 1998b). Urban stormwater is usually highly polluted. It carries a high load of sediment, heavy metals and bacteria (**Section 1**) and, for this reason, plus its high volume, is usually a more important source of pollutants than sewerage system overflows. However, sewage overflow may contribute slightly more faecal coliforms to the river than stormwater, and the input of phosphorus may be similar from both sources (EPA, 1994). Urban runoff is also a source of seeds and cuttings of exotic plants, which may later establish themselves on river banks. Soil from land development enters the stormwater drains and may be a major contributor to river suspended solids in areas where housing development is proceeding (Sinclair Knight Merz, 1999).

In addition to rainfall, stormwater drains carry water that has been imported from extra-basin water reservoirs into the catchment for domestic purposes. A substantial portion of this imported water is used outside the home (eg, for watering gardens, washing cars). Warner and McLean (1977) estimated that this imported water is equivalent to as high as an extra 43% in annual rainfall. In 1999, this artificial increase in rainfall in the catchment may be even higher.

The steadily increasing input of freshwater and pollutants to the Georges River from stormwater drains as a result of urbanisation may be one of the most significant changes in the river's environment in the past 50 years (**Section 3.1**).

Industrial discharges

The *Protection of the Environment Operations Act, 1997* states that all industrial discharges must be licensed. According to a report by The Department of Urban Affairs and Planning (1998), in 1998 six direct discharges were licensed in the Georges River Catchment; three for oily wastes, two for chemical industry and three for sewage treatment plant effluent.

At present, these licensed effluent discharges are not a significant source of pollution. Illegal discharges, however, may be more important. Illegal discharges include unethical operators emptying a tanker load of effluent down a stormwater drain to avoid disposal costs, or a home owner pouring a can of solvent or used motor oil into the street gutter. The contribution of these illegal discharges to river pollution is unknown. These anti-social practices can be stopped only by education and significant fines.

Past use and disposal practices, both legal and illegal, are the major source of polychlorinated biphenyls (PCBs) and other chlorinated organic compounds such as the pesticide, DDT (now prohibited) in the environment. The importation and manufacture of PCBs has been severely restricted since the 1970s, but these compounds still appear in waterways. Their main sources are landfill runoff, sewage effluent and stormwater (Connell, 1981). PCBs were widely used as heat transfer fluids, in capacitors, as fire retardants and in plastics. PCBs are highly fat soluble, and so can concentrate in the tissues of fish and other aquatic animals. They can induce a range of toxic effects, including carcinogenicity, neurotoxicity and reproductive effects. They can remain stable in sediments for long periods. Humans appear to be able to tolerate PCBs better than other animals (**Section 3.1**).

Polycyclic aromatic compounds (PAHs) are formed largely by incomplete combustion of fuels. They result naturally from forest fires, but are also present in the off-gases of incinerators. Their presence in waterways is probably mainly the result of atmospheric deposition, but they can also be present in industrial wastes and runoff from waste disposal sites (Harrison, 1996). PAHs can cause cancer and reproductive effects.

Agricultural and domestic runoff

Fertilisers add nutrients, mainly phosphorus (phosphate) and nitrogen (nitrate, ammonia, urea) to the river via water runoff. Nutrient enrichment of a waterway is called *eutrophication*. All plants and animals need nitrogen and phosphorus for growth and survival, but excessive concentrations can cause uncontrolled algal growth, which can lead to low dissolved oxygen concentrations in the water and the death of fish and other aquatic animals. When algae dies, it can release highly toxic substances and the dead plants consume dissolved oxygen from the water (**Section 3.1**). As well as runoff from agricultural land, leaching of manure from pastures, piggeries and poultry farms, and fertilisers from domestic gardens and lawns will also contribute nutrients to runoff. Nitrogen is highly soluble, and as much as 50% of fertiliser nitrogen applied to crops is lost to water. Phosphorus (as phosphate) tends to be adsorbed to the aluminium in soil clay, so it is more immobile in soils and enters the water mainly from soil erosion (Harrison, 1996). Erosion of river banks is a major contributor of phosphorus to riverwater.

Elevated concentrations of either nitrogen or phosphorus could stimulate excessive plant growth, dependent on a range of local factors. Increased bacterial activity in bottom sediments (eg, by an increase in water temperature) can also result in the release of nitrogen and phosphorus (Connell, 1981). In general, the contribution of agriculture and domestic gardens to the nutrient load in the Georges River is only a small fraction of that contributed by stormwater (Department of Urban Affairs and Planning, 1998).

Agricultural and domestic runoff, as well as sewerage system overflows, can add pesticides and herbicides to the river. Operators treating houses for white ant control can accidentally drill into stormwater drains and inject the pesticide into the drain, when it will be washed into the river with the next rain. Organophosphate pesticides such as chlorpyrifos, diazinon and malathion are commonly found in riverwater samples, although at very low concentrations (Sydney Water, 1997). They are very toxic to some aquatic animals, although they degrade quite quickly in the environment.

Waste disposal sites

The Sydney metropolitan area has traditionally used the Georges River Catchment for waste disposal. In the early years, such disposal sites rarely had any facilities for storing leachate water (Department of Urban Affairs and Planning, 1998). Most sites in the catchment will accept only non-putrescible wastes, but the large Lucas Heights Waste Management Centre (backing onto Mill Creek) accepts putrescible waste. This waste facility now has effective measures for collecting runoff water. The Kelso tip, Bankstown, has recently closed (Bankstown City Council, 1998), but was used from the 1940s as an all-purpose dumping ground. It may have received dangerous waste in the past. Groundwater samples collected near the tip are monitored routinely for pollutants. The samples show high contamination with phosphorus, ammonia and phenols.

Tip leachates often contain high levels of suspended solids, bacteria, toxic heavy metals (eg, zinc and copper), ammonia, sulphides, phosphates, phenols and other organics, detergents and PCBs. The leachates must be carefully controlled and retained to avoid contamination of the river. The groundwater underlying the tip can also be contaminated, leading to river pollution.

Marinas and boating

Marinas can be a source of heavy metals, fuel and toxic organic compounds from the antifouling and painting of boats, and from boat maintenance. Since the banning in Australia of tributyltin antifouling paints in 1989 (Batley *et al.*, 1989), copper-based antifouling paints have been commonly used.

In addition to antifouling paints, boats can contribute copper from fittings, zinc from sacrificial anodes, fuel, sewage and general garbage thrown overboard. Increasing boat usage in the Georges river has been a significant source of pollution.

River bank and soil erosion

Although stormwater drains (urban runoff) contribute up to 90% of suspended solids to the river (EPA, 1994), it is likely that for some more pristine areas a major input still results from river bank erosion and runoff from agricultural land. In 1991 it was estimated (Water Board, 1991) that the total annual load of suspended solids to the Georges River was 8,400 tonnes. Sewage overflows contribute only a few percent of the total suspended solids load to the river (Sydney Water, 1997). In addition to suspended solids, the release of soil by erosion can add significant amounts of phosphorus and heavy metals to the river. Increased boating activity causes wave action which also leads to river bank erosion.

Warner and Pickup (1973) reported that aerial photographs taken in the 1940s of Georges River showed that the banks were more stable and the channels narrower and deeper than when the same areas were photographed in the 1950s and 1960s. Flooding occurred in the 1960s with greater frequency and with greater magnitude than in the previous 30 years (**Section 3.2**). This increase in flooding has been the result of urbanisation, dredging and sand mining.

Dredging and sand mining

During the 1950s and 1960s, large quantities of aggregate were extracted from areas near the Georges river for construction in Sydney (Department of Urban Affairs and Planning, 1998). Sand mining occurred for over 30 years at Chipping Norton, but ceased in 1993/4. Suction-mining of sand formed the large man-made lake at Chipping Norton. During the early years of sand mining at Chipping Norton, the operations released large quantities of suspended solids to the river, as well as organic matter, sulphuric acid from pyrite, and some nutrients. However, much more stringent environmental controls were instituted in later years, and a sampling trip in June 1999 by Riverkeeper volunteers found no evidence of acid pollution in Chipping Norton Lake. Samples of sediment and water taken in the lake showed no indication of acidification, with pH values between 7.2 and 7.6. Also, heavy metal concentrations in a water sample from the lake were below the ANZECC criteria values (**Section 3.1**). The Chipping Norton Lake Authority has carried out major improvements to the environment of the lake and to the facilities for community use (Chipping Norton Lake Authority, 1998).

Dredging has several deleterious effects on the river (Warner *et al.*, 1977). It can greatly increase water turbidity, at least temporarily, over a considerable distance, and during heavy rain the dredged material stored near the river banks can be washed back into the river, again increasing turbidity. Channel enlargement by dredging results in further river bank erosion and silting up of river channels downstream of the dredging. Phosphorus may also be released from storage in dredged sediments. Seagrass beds, vital to the ecology of the river, can be destroyed by dredging (**Section 3.2**).

Land development

The population of the Georges River Catchment has increased by about 400% in the past 50 years (**Figure 1**). The banks of the river, in particular, have been extensively and intensively developed. This development has involved massive land clearance and destruction of native vegetation, resulting in a large increase in erosion and the contribution of suspended solids to the river (Department of Urban Affairs and Planning, 1998). As much as 10 tonnes of soil may be lost from a building site in a major storm (Sutherland Shire Council, 1997). For example, the development of the suburb of Kareela caused significant siltation of Oyster Bay, and Kogarah Bay, because it acts as a silt trap, is suffering rapid siltation (Sinclair Knight Merz, 1999) (**Section 3.2**) . In 1997, 41% of construction sites in Sutherland Shire had effective sediment control measures, compared with 22% in 1996 (Sutherland Shire Council, 1997). Another consequence of urban development has been the destruction of mangrove areas and salt marshes (**Section 3.2**). Since 1994, it has been an offence under the Fisheries Management Act to cut, damage, remove or destroy mangroves or any marine vegetation. Nevertheless, mangrove stands continue to be removed.

Loss of habitat

Mangroves, seagrass beds and salt marshes are vitally important to the ecology of a river. Mangroves are the great purifiers of an estuary. They remove excess nutrients from the water and their litter detoxifies heavy metals by sequestering them as insoluble sulphides. Grey Mangroves in Sydney produce about 730 grams of litter/m^2 /year; this litter provides cover and food for benthic animals (worms, crabs, etc) which in turn support the wide range of the early forms of fish and other animals which inhabit mangrove areas (Department of Urban Affairs and Planning, 1998). Mangroves act as a nursery, and provide protection and food, for the juvenile forms of many fish species which have hatched offshore. The Grey Mangrove (*Avicennia marina*) and the River Mangrove (*Aegiceras corniculatum*) occur upstream to Milperra in the estuarine sections of the Georges River (EPA, 1994; Department of Urban Affairs and Planning, 1998).

Massive destruction of mangroves occurred in Sydney before governments recognised their importance. They were considered smelly and unsightly, and were cleared for filling of the marsh area for garbage tips, housing development, playing fields and golf courses. Although they are now protected, mangrove stands are still being cleared, both legally and illegally. They are affected by pollutants such as oil and by excessive wave action.

Wetland salt marshes are also important to the health of an estuary. In the Georges River, salt marshes exist upstream to East Hills (EPA, 1994). Significant wetland salt marshes exist in Mangrove Island (8.5 ha), Oyster Bay (7.0 ha), Edith Bay (0.9 ha), Lime Kiln Bay (11.0 ha), Gungah Bay (3.3 ha), Neverfail Bay (0.7 ha) and Oatley Bay (4.2 ha) (Sinclair Knight Merz, 1999). The dominant plant species in these salt marshes is *Sarcocornia quinqueflora* (EPA, 1994).

Mangroves and salt marshes form a natural barrier between land and water. They support a wide range of animals including fish, shellfish and birds (Department of Urban Affairs and Planning, 1998). Salt marshes are also threatened by urbanisation. They are sensitive to increases in sedimentation and to river changes that alter the tidal limits.

Seagrasses are a major source of detritus and provide an important fish habitat, especially for juveniles. They also stabilise the sediment, in much the same way that plants and trees stabilise soil on land, and they are involved in the recycling of nutrients (Larkum and West, 1990). Seagrasses grow in shallow-water ecosystems, and their distribution and growth is regulated by a variety of water quality factors, including temperature, salinity, nutrient availability, substrate character, turbidity and light. Seagrasses need an adequate level of water clarity; increased turbidity and sedimentation reduce clarity and affect the health and productivity of seagrass communities (Devlin, 1999). Excessive nutrient input (eutrophication) to a waterway decreases water quality and stimulates algal growth, reducing water clarity. Several studies have related the decline of seagrasses to nutrient loading of the water (Devlin, 1999). Other threats to seagrasses include sedimentation (smothering), pollution, increased wave action, dredging, and destruction by boat anchors (Department of Urban Affairs and Planning, 1998). Once impacted, seagrass colonisation and regrowth can fail or be very slow (Devlin, 1999). Attempts to recolonise seagrass areas by plantings are usually unsuccessful. The loss of seagrass beds can bring about drastic changes to a marine ecosystem, with a shift to a lagoonal system dominated by high turbidity and algal growth or a bare sandy/silty substrate. These changes cause a considerable loss of biodiversity (Devlin, 1999).

Several scattered areas of the seagrass *Zostera capricornia* exist in the Lower Georges River (State Pollution Control Commission, 1978; West *et al.*, 1985). There is evidence from aerial photographs that a much wider distribution existed in earlier years (**Section 3.2**).

All natural water systems have a defence against pollutants called *assimilative capacity*. Some toxic pollutants such as heavy metals or PCBs can be removed from the water column by adsorption on suspended particles which then carry them to the bottom sediment where they can be stored or biodegraded safely (Karr, 1991). Heavy metals can be made less bioavailable by complexation with natural organic matter (eg, humic and fulvic acids) in the water (Florence and Morrison, 1992). Estuaries, in particular, have a high assimilative capacity, because when fresh water from upstream mixes with the incoming seawater, the increased salt concentration causes suspended matter in the freshwater to precipitate, carrying much of the pollutant load with it. In this way, the sensitive nearshore coastal zone is protected from dangerous pollutants and excess nutrients which could cause eutrophication and algal blooms (Morrison, 1999). Only when the assimilative capacity of a water body is exceeded does toxicity occur. However, the concept must be applied carefully since some subtle ecological changes can occur as the assimilative capacity value is approached (Campbell, 1986).

Most environmental scientists support *The Precautionary Principle*. This principle states that "Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Anderson, 1999). Although the precautionary principle has sometimes been interpreted in an extreme manner to oppose some benign development projects, it nevertheless should be a guiding principle in assessing development or discharge applications that might affect the Georges River.

3. Changes in the River

The most recent data are compared here with historical data in an attempt to assess changes that have occurred with time in the Georges River in water and sediment quality, commercial fish catch and oyster production, habitat, and the geomorphology (ie, nature, or structure) of the river.

3.1. Water and Sediment Quality

Few reliable sets of water data for the Georges River are available that are more than 30-40 years old, although some older nutrient and salinity results are still useful. Even fewer data are available on sediment quality. The Upper Georges River (Liverpool Weir to Salt

Pan Creek) has, traditionally, been most affected by pollution. The tributary creeks usually have poorer water quality than the river, but the Woronora River is always less polluted than the Georges River (**Section 2**). The main factors in improvement of water quality in the Georges River were the drop in nutrient levels after the upgrading in March 1983 of the Glenfield Sewage Treatment Plant for partial phosphorus removal from its effluent and, in August 1985, the diversion of sewage from the Liverpool and Glenfield treatment plants to the Malabar ocean outfall (Rish, 1992). The cessation of sand mining in 1993/4 (and the earlier upgrading of the facility) also improved river water quality. However, increasing urbanisation, urban runoff and sewage overflows have counteracted these improvements in pollution.

Water quality: The changes with time in some water quality parameters are discussed below. The results are compared, for each parameter, with the guideline value (ie, suggested maximum value) published by the *Australian and New Zealand Environment and Conservation Council* (ANZECC) (ANZECC, 1992). Note that one microgram (μ) is one-thousandth of a milligram (mg), or one-millionth of a gram.

Nutrients (nitrogen and phosphorus)

Excess nutrients in water (eutrophication) can result in algal blooms, leading to low dissolved oxygen and the release of toxic substances as the algae die. These changes can cause the death of fish and other aquatic animals and the destruction of seagrasses (Valiela *et al.*, 1997). Because of high nutrient levels in parts of the river in the early 1980s (**Tables 1** and **2**), algal blooms and the growth of noxious weeds were quite common (Urban Affairs and Planning, 1998). The indicative concentration ranges set by ANZEEC for protection of aquatic life in freshwater streams are:

Total phosphorus – 10-100 μg/L
Total nitrogen – 100-750 μg/L

For estuaries, the indicative concentrations are:

Phosphate-phosphorus (PO_4-P) – 5-15 μg/L
Nitrate-nitrogen (NO_3-N) – 10-100 μg/L
Ammonium-nitrogen (NH_4-N) - <5 μg/L

Under low river flow (no rain) conditions, phosphorus is progressively removed from the water to the sediment (ie, it is not conservative) (State Pollution Control Commission, 1979). At the beginning of a rain storm, the first flush of water from stormwater drains can carry a heavy load of nutrients. The results for changes in phosphorus and nitrogen levels (**Tables 1** and **2**) relate, however, to the *average* concentrations measured over a year (Rish, 1992; Sinclair Knight Merz, 1999; Sydney Water, 1998). The three sampling sites selected (1972-1990) are *Glenfield* (freshwater section, and downstream of the Glenfield Sewage Treatment Plant), *Milperra* (estuarine, Upper Georges River), and

Lugarno (estuarine, Lower Georges River). The data for 1998 are for sampling sites close to these three sites. The only earlier data for phosphorus is a mean value of 16 μg/L total phosphorus for samples taken at Milperra during 1943-1952 (State Pollution Control Commission, 1979). A university study (Leonard, 1977) of the water quality of Mill Creek, found a mean total phosphorus of 100 μg/L for 1975-1977, and quoted a mean phosphorus concentration from CSIRO analyses of 9,000 μg/L for 1941-1945. Presumably the improvement in Mill Creek water quality in the 1970s was the result of the control of leachates from the Menai waste disposal site. Menai tip opened as a sanitary depot in 1939, and was taken over by Sutherland Shire Council in 1965 for a waste disposal site.

Sediment quality: No data are available for nutrients in sediments. Both nitrogen and phosphorus can be released from sediments, which may cause eutrophication. However, in the anoxic layers of sediment, *denitrification* occurs, where nitrate is reduced to nitrogen gas and nitrogen oxide gas, thus reducing the potential risk of eutrophication. Denitrification is mediated by sediment bacteria, but if toxic substances such as pesticides, pathogenic bacteria or unbound heavy metals are present in the sediment, the bacteria may be poisoned and denitrification prevented (Flemer *et al.*, 1998).

Conclusions: The great improvement in nutrient concentrations in the Georges River after 1985 (**Tables 1** and **2**) is clearly the result of the upgrading of the Glenfield Sewage Treatment Plant and the diversion of sewage to the ocean outfall in 1981-1985 and, to a lesser extent, the cessation of sand mining in 1993/4 (Rish, 1992). Between 1985 and 1994, the average annual contribution of wet weather sewerage system overflows to the load of total phosphorus in the river was 8%, 24%, and 8% for the Headwaters, Upper, and Lower Georges River, respectively (Sydney Water, 1998). Similar contributions were found for nitrogen. The single mean result of 16 μg/L total phosphorus for Milperra from samples collected between 1943 and 1952, suggests that nutrient levels in the river were even lower 50 years ago. In 1998, both mean total phosphorus and total nitrogen values meet the ANZECC indicative values. There are times, of course, when individual water samples may contain higher values. At Lugarno during 1998, total phosphorus was <50 μg/L in 86% of samples taken during dry weather, and in 77% of samples during wet weather (Sinclair Knight Merz, 1999).

Chlorophyll a

Chlorophyll *a* is the major algal pigment, so its concentration is an indication of algal density, or biomass. Since chlorophyll *a* constitutes about 1.5% of the dry weight of organic matter, the algal biomass can be estimated by multiplying the chlorophyll *a* concentration by a factor of 67.

The ANZEEC indicative values for chlorophyll *a* concentrations are (no value is given for rivers):

Freshwater (lakes and reservoirs) – 2 - 10 μg/L
Estuarine waters – 1 - 10 μg/L

Data for chlorophyll *a* in Georges River water samples from 1975 to 1998 are shown in **Table 3** (Rish, 1992; Sydney Water, 1998). Although the mean values for the sites chosen did not exceed the ANZECC criteria, some individual samples had high levels of chlorophyll *a* (Rish, 1992), presumably caused by algal blooms.

Conclusions: Average chlorophyll *a* concentrations were low over the period studied, although the ANZECC guideline was exceeded in some individual samples and samples may not have been collected during some algal blooms. In 1998, chlorophyll *a* levels were lower at all sampling sites in the river than in the 1980s.

Faecal coliforms

Faecal coliforms and other bacteria and viruses are contained in human faeces. The presence of faecal coliforms in a water sample is therefore indicative of sewage contamination of a waterway. These bacteria are a danger to the health of people using the river because they can be concentrated in edible shellfish such as oysters. The ANZECC guidelines for faecal coliforms are:

ANZECC – (primary contact, ie, swimming) – The median bacterial content in samples of fresh or marine waters taken over the bathing season should not exceed 150 cfu/100 mL (minimum of 5 samples taken at regular intervals not exceeding one month, with 4 out of 5 samples containing < 600 organisms/100 mL)

The faecal coliform data are shown in **Table 4** for 1969 to 1998 (Rish, 1992; Sydney Water, 1998b; 1998c). Note that because cfu/100 mL data for 1998 were not available, the results for 1998 are given as percent of days not suitable for swimming. The concentration of faecal coliforms in river water is highly variable. The bacteria are destroyed quite quickly in estuarine water, tend to be low in dry weather, but increase very rapidly after storms when there are sewerage system overflows. The Upper Georges River is the most affected, with nearly one-third of days in 1998 not suitable for swimming because of sewage contamination (**Table 4**). However, the Harbourwatch data for Summer 1997/8 showed that all monitored sites in the Lower Georges River complied 100% of the time for faecal coliforms, and were the cleanest sites monitored in Sydney for 1997/8 (Harbourwatch, private communication). In wet weather, an average of 73%, 90%, and 72% of the faecal coliforms present in the Headwaters, Upper, and Lower Georges River, respectively, originate from sewerage system overflows (Sydney Water, 1998).

Conclusions: Sewage contamination of the Upper Georges River is still a significant problem at some times of the year. Both sewerage system overflows and urban runoff contribute to the contamination of the river. Sydney Water (Sydney Water 1998; 1999) plans to have all the sewerage systems in Sydney upgraded by 2021 so that there will be an 80-90% reduction in wet weather overflow events. The Sydney-wide cost of overflow abatement is expected to be about $2 billion.

Salinity

ANZECC guideline value – In estuarine waters, salinity changes should be less than 5% from background values

Following a large storm, the Georges River becomes fresh almost to Salt Pan Creek, and the salinity is still less than 5 ppt (or 5 ‰) 2 km downstream of Salt Pan Creek (Sydney Water, 1997). After a storm the salinity declines are large and rapid (<24 h), and it may take four weeks for salinity to return to its pre-storm values. After an average storm, salinity equilibrates at about 5 ppt 10 km downstream of Liverpool Weir (Sydney Water, 1997).

Some marine animals cannot tolerate large, rapid and protracted declines in salinity. Water column animals such as fish can avoid the freshwater input by escaping to the lower river or Botany Bay, where a saline water lens exists along the bottom (Sydney Water, 1997). However most estuarine fish can tolerate a fairly wide range in salinity. Bivalve molluscs (eg, mussels) can avoid low salinities by burrowing into the sediment or closing their shells. Nevertheless, studies in the Hawkesbury River showed that floods caused significant changes in community structure (Sydney Water, 1997). Benthic organisms upstream of Salt Pan Creek are those most at risk from an increase in flooding.

Salinity data in the Georges River from 1941 to 1999 are shown in **Table 5** (State Pollution Control Commission, 1979a; Public works Department, 1990; unpublished Riverkeeper measurements, 1999). The SPCC (State Pollution Control Commission, 1979a) concluded in 1979 that "The average salinity of the Georges River is lower now than it was in 1941 to 1954. The lowered salinity is more pronounced in the middle and lower reaches". This SPCC study examined the long-term data statistically and took into account variations in rainfall over the study period. There is insufficient evidence to conclude that the salinity of the river has declined further since 1976, as the data have not been examined statistically. However, if there was no significant decrease in rainfall from 1976 to 1999, it is likely that a further decline would have occurred, because the increase in urbanisation would have led to a greater input of fresh water via urban runoff.

Conclusions: The average salinity of the Georges River is probably lower now than it was in 1941-1954. Several factors could be involved in this reduction in salinity (State Pollution Control Commission, 1979a).

- Siltation and land reclamation causing a reduction in the input of seawater to the river with each tidal cycle,
- Increases in the volume of freshwater input from the sewage treatment plants (before 1985),
- Increases in the volume of stormwater runoff because of increasing urbanisation,
- Differences in rainfall during the measurement periods.

Further decreases in salinity and increases in the frequency of flooding in the Georges River may occur as a result of increasing volumes of urban runoff from continuing urbanisation and population growth.

Turbidity

ANZECC guideline value – Turbidity should not vary more than 10% from the seasonal mean.

Turbidity is a measure of the clarity of a water and is related to the concentration of suspended matter in the water. Suspended matter has two main deleterious effects in aquatic systems. It decreases light penetration into the water, and so interferes with photosynthesis and plant growth. It also affects aquatic animals by clogging and abrading their gills and other membranes. Bivalve filter feeders such as oysters and mussels have to expend more energy discriminating between food and non-food particles (Sydney Water, 1997). Stress to an animal increases with time of exposure to a particular level of suspended solids (Newcombe and MacDonald, 1991). Unfortunately, there is no consistent relationship between turbidity (measured by light scattering) and total suspended solids (TSS), so results from investigators reporting turbidity and TSS cannot be compared. Some overseas regulatory bodies have given 25 mg/L TSS as a maximum concentration for protection of aquatic life (ANZECC, 1992).

In a survey of the literature, Sydney Water (1997) found that the first chronic effects of TSS on fish and invertebrates occurred between 250 mg/L and 1,000 mg/L. Sydney Water (1997) calculated a *stress index* for exposure of aquatic organisms to TSS. The stress index is calculated as the natural logarithm of the product of TSS (mg/L) and time of exposure (hours). For long-term protection of 95% of species, a stress index of 7.7 was calculated.

The relationship between turbidity units and TSS depends on the light-scattering ability of the suspended particles, so is site and time dependent. State Pollution Control Commission (1979b) found that in water samples taken at Como Bridge in 1977, TSS (mg/L) was approximately twice the turbidity value in NTU units. However, this relationship did not apply at Liverpool Weir. This report found turbidity values of between 2 NTU and 50 NTU in the Upper Georges River and its tributary creeks during 1977, with corresponding TSS values of 2-30 mg/L. These workers concluded (in 1977) that sand mining at Chipping Norton did not contribute significantly to TSS in the river, since any TSS from this source settled within 24 hours. The Water Board (1991) determined that the annual loads of suspended solids in the Headwaters, Upper, and Lower Georges River were, respectively, 700, 1,200 and 850 tonnes, and that urban runoff contributed 100%, 90% and 90%, respectively to these loads, with the remainder originating from sewage overflow. In June, 1999, after moderate to heavy rain in the previous 24 h, the Riverkeeper Program found turbidity values of 3-33 NTU in the river between Baldface Point and Little Salt Pan Creek, with the highest value (33 NTU) being measured in Mill Creek. In the river itself, the highest value was 8 NTU. In a later sampling run from the same sites, but after a dry period, turbidity ranged from 0.4 to 6.0 NTU.

Conclusions: Stormwater drains (urban runoff) are by far the main contributor to suspended matter in the river, and Prospect and Cabramatta Creeks are the main sources of TSS. Compared with the relatively coarse nature of TSS derived from river bank and sediment erosion, urban runoff contains fine solids that create high turbidity and take a long time to settle, thus exacerbating their effect (State Pollution Control Commission, 1979b). Recovery of the upper section of the river to dry weather turbidity (<10 NTU) conditions after more than 25 mm of rain is slow, varying from 1-2 weeks at Liverpool Weir and 3-4 weeks in Prospect Creek (State Pollution Control Commission, 1979b). The lower reaches of the river clear much more quickly.

Using a stress index of 8.0, and an average exposure time of 7 days (168 h), the maximum acceptable TSS for protection of aquatic organisms can be calculated as 18 mg/L (≈ 15-40 NTU).

With increasing urbanisation and population growth, urban runoff and the frequency of floods will increase, leading to higher levels of fine suspended solids in the river for longer periods. At present there is no conclusive evidence that TSS in the Georges River itself represents a risk to aquatic organisms, although significant effects could result from the higher TSS in some of the tributary creeks.

Dissolved oxygen

ANZECC guideline values – Dissolved oxygen should not be less than 6 mg/L, or 80-90% saturation, determined over a diurnal cycle

Because dissolved oxygen in water varies diurnally, spot measurements are not particularly useful. Organic pollutants of a wide variety can consume dissolved oxygen, causing the death of fish and other animals if oxygen consumption is excessive. However, many natural events can also cause fish deaths by depleting the water of oxygen. Fish are often killed during floods as a result of natural, oxygen-consuming materials (leaf litter, manure) being washed into the river. Algal blooms also consume oxygen as the plants die, and cold water overlying anoxic sediments can become depleted in oxygen and, if an inversion occurs and this water rises to the surface, fish kills can occur.

Sydney Water (1997) presented data showing that with a dissolved oxygen concentration of 6.0 mg/L or higher, there will be 100% survival of fish. At a concentration of 3.0 mg/L, only 10% of fish would survive. Benthic animals are most at risk from low dissolved oxygen; mobile species can escape to more oxygenated areas.

The Upper Georges River, as well as Salt Pan and Prospect Creeks, experience dissolved oxygen concentrations below 6 mg/L after heavy rainfall, principally as a result of organic matter in urban runoff consuming oxygen (Sydney Water, 1997).

Heavy metals

The main toxic heavy metals that are likely to be found in the water or sediments of the Georges River are copper (Cu), lead (Pb), cadmium (Cd), zinc (Zn) and nickel (Ni). Mercury and silver are more toxic, but are unlikely to be present in significant amounts. The ANZECC (1992, 1997) guidelines for *total* metal in waters and sediments , plus the criterion for tributyltin (TBT) are shown below:

Metal	**Freshwater** (µg/L)	**Seawater** (µg/L)	**Sediment** (mg/kg)
Cu	2-5	5	65 - 270
Pb	1-5	5	75 - 218
Cd	0.2-2	2	1.5 – 9.6
Zn	5-50	50	200 - 410
Ni	15-150	15	21 - 52
TBT	0.008	0.002	0.005

The guideline values for freshwaters depend on the hardness of the water. The harder the water, the more metal can be tolerated. The two values for sediments represent high and medium protection, respectively.

Toxic heavy metals can originate from urban runoff (Florence and Morrison, 1992), from sewage, from industrial wastes, and from mining operations. Urban stormwater drain sediment typically contains (in mg/kg) Cu – 50; Pb – 500; Cd – 2; Zn – 500 (Florence and Morrison, 1992). These metals originate from automobile tyres, brake linings and exhausts, and building guttering. EPA (1994) reported that over 90% of the lead entering the Georges River originated from urban runoff.

It is important to understand that heavy metals associated with suspended particles have very low toxicity. Only the dissolved fraction of total metal in water (ie, the metal in the water that passes through a 0.45 µm filter when the water is filtered) is likely to be toxic to aquatic organisms (Sydney Water, 1997). However, usually only part of the dissolved fraction is toxic. Dissolved metal can be bound to natural complexing agents, such as fulvic and humic acids, in the water, and these bound metal species have low toxicity (Florence and Morrison, 1992). The most toxic metal species is the free metal ion, which may represent only a few percent of the total dissolved fraction. ANZECC has recognised the need to take into account this effect of trace metal *speciation* on toxicity, and its new guidelines, to be released this year, will allow the use of speciation data.

The very low concentrations of toxic heavy metals in natural waters are difficult to measure accurately, and the contamination-free collection of samples for analysis is also difficult. For these reasons, early water quality data for heavy metals are either non-existent or unreliable. Sediments are easier to analyse because of their higher metal concentrations.

During 1999, volunteers from the Georges River Riverkeeper Program have been collecting water samples from the river from Baldface Point to Little Salt Pan Creek. The filtered samples are analysed by CSIRO, Lucas Heights for a range of heavy metals, including those listed above, using a sophisticated axial ICP-AES spectrometric technique. The samples are collected on the out-going tide, and one suite of samples was collected after a moderate-to-heavy rainfall event. In no case were the ANZECC guidelines exceeded. Even a water sample collected from Chipping Norton Lake had dissolved heavy metal concentrations below the ANZECC limits.

Heavy metals in sediments can be toxic to organisms that live in the sediment (benthic organisms). However, as with water, only a fraction of the metal in the sediment is likely to be toxic, because most of the metal is bound (mostly as sulphides) in non-toxic forms (Sydney Water, 1997). One method used to determine the toxic metal fraction in sediments is to measure the metal that can be dissolved from a sediment sample by acid and the amount of sulphur (as H_2S) that is evolved simultaneously. If the mole ratio of acid-volatile sulphur to simultaneously extracted metal (AVS/SEM) is greater than one, then the sediment usually has little or no toxicity, because it means that the metals are all bound as non-toxic sulphides. Sydney Water (1997) measured AVS/SEM ratios for Cu, Pb, Cd, Zn and Ni in sediment samples collected both upstream and downstream of Chipping Norton sewage treatment plant. Most samples showed AVS/SEM > 1, but a few samples, both upstream and downstream of the treatment plant, had ratios less than one.

Birch *et al.* (1996) measured heavy metal concentrations in sediments (15-cm cores) collected in Botany Bay and in the Lower Georges River. Copper concentrations were less than 50mg/kg between Lime Kiln Bay and Neverfail Bay, in Oyster Bay, and between Tom Ugly's Bridge and Captain Cook Bridge. Other areas had 50-100 mg Cu/kg, while sediments in the upper reaches of Salt Pan Creek contained 500-1,500 mg Cu/kg. Lead concentrations were either <100 mg/kg or 100-200 mg/kg for most of the lower river, although the upper reaches of Salt Pan Creek had 200-400 mg/kg. Zinc was 200-500 mg/kg over the whole lower river, but again, the upper reaches of Salt Pan Creek had higher concentrations, 500-1,000 mg/kg, which exceeded the guideline values.

Sydney Water (data base, 1998) analysed sediment samples (0-5 cm) from Chipping Norton, Fairfield and Glenfield for a wide range of organic and inorganic constituents. At Chipping Norton, copper ranged from 5 to 50 mg/kg, lead from 15 to 100 mg/kg, cadmium from 0.1 to 0.8 mg/kg, zinc from 40 to 300 mg/kg, while nickel ranged from 5 to 20 mg/kg. Birch *et al.* (1996) calculated that the background (pristine) metal concentrations in Sydney Harbour sediments were (mg/kg), Cu – 4-28; Pb – 12-65; Zn – 18-123. Van Metre and Callender (1996) used similar values of 30 mg/kg for copper, 75 mg/kg for lead, and 110 mg/kg for zinc as the undisturbed concentrations in Lake Livingston (Texas) sediment.

Tributyltin (TBT) is a highly effective antifouling substance for boats, and it was used throughout the world for that purpose. However, research overseas and in Australia (Batley *et al.*, 1989; 1991) showed that minute amounts of TBT from antifouling paints were responsible for low growth, shell thickening and mortality in commercial oysters. In 1989 in New South Wales, the use of TBT anti-fouling paints was prohibited on vessels under 25 m in length. TBT-caused oyster toxicity rapidly declined after this ban. In 1988, Batley *et al.* (1991) found TBT concentrations in oysters from the Georges River ranging from 2 to 112 μg/kg, whereas in 1991, oysters from the same locations had only <0.2 to 7.0 μg TBT/kg.

Oysters, mussels, cunjevoi and other filter feeders concentrate, from the water, a wide range of heavy metals (as well as viruses and bacteria) in their flesh. The concentration of a particular metal in the flesh of, for example, an oyster, is an integrated measure of the concentration of that metal in the water in which the oyster is growing. **Tables 6** to **8** show the results for copper, lead, and zinc, respectively, in oysters collected in Georges River between 1973 and 1991 (Batley *et al.*,1991; Brown and McPherson, 1992). Both copper and zinc appeared to increase in concentration from 1973 to 1988, but decreased in 1991, so that the concentrations in 1991 are similar to those measured in 1973. Lead decreased markedly from 1973 to 1987, presumably the result of increasing use of unleaded fuel.

The National Health and Medical Research Council (Anon, 1983/6) recommend that the concentrations of copper, lead and zinc in oysters for human consumption should not exceed 70, 2.5 and 1,000 mg/kg wet weight, respectively. In 1991, these limits appear to have been met in the Georges River.

Conclusions: In the Lower Georges River, toxic heavy metals in water, sediment and oysters do not appear to be a problem. However, in some of the tributary creeks, particularly the upper reaches of Salt Pan Creek, sediment guidelines are exceeded to a significant degree. The toxicity of these high-metal sediments should be measured using bioassays and the AVS/SEM ratio technique. Sediments analysed by Sydney Water at Chipping Norton also had metal concentrations that were within the guideline values.

PCBs, PAHs, and pesticides in sediment

Polychlorinated hydrocarbons (PCBs) are persistent in the environment, and are accumulated by aquatic organisms (**Section 2**). In sediments, they are dechlorinated and destroyed by bacteria, providing that no toxicants, such as pesticides or weakly bound heavy metals, are present to inhibit the bacteria. The half life (the time for half the concentration to disappear) of PCBs in a marine sediment is about six years (EPA, 1995). Roach and Runcie (1998) measured PCB concentrations in several fish species caught at Chipping Norton, Prospect Creek and Salt Pan Creek. The concentrations in fish muscle (mg/kg, wet weight) ranged from 1.7 to 1.8 at Chipping Norton, from 3.4 to 10.1 at Prospect Creek, and from 0.3 to 1.1 at Salt Pan Creek. The Maximum Residue Limit (MRL) set by the Australian Food Authority for PCBs in fish is 0.5 mg/kg (Roach and Runcie, 1998).

The suggested limit for total polycyclic aromatic hydrocarbons (PAHs) in marine sediments is 4 mg/kg and in marine waters is 3 μg/L (ANZECC, 1992; Sydney Water, 1997, Appendices). Sydney Water (Sydney Water, 1997, Appendices) found a mean concentration of 1.5 μg/L total PAH in both stormwater and sewer overflow water. The half life of PAHs in marine sediments is 0.6-6 years (EPA, 1995; Neff, 1979).

Roach and Runcie (1998) measured concentrations of a range of pesticides in fish muscle from fish collected in Georges River. They found that chlordane ranged from 0.005 mg/kg in Salt Pan Creek to 0.11 mg/L in Prospect Creek. The MRL for chlordane in fish muscle is 0.05 mg/kg (Roach and Runcie, 1998). Another pesticide measured by Roach and Runcie (1998) was DDT. The concentrations of DDT in fish muscle ranged from 0.03 mg/kg at Chipping Norton to 0.4 mg/kg in Prospect Creek. The MRL for DDT in fish muscle is 1.0 mg/kg. In general, sea mullet and yellowfin bream accumulated the highest concentrations of PCBs and pesticides, while luderick and whiting accumulated the least (Roach and Runcie, 1998). Chlordane has a half life of about two years in marine sediments, while DDT has a half life of about 9 years (EPA, 1995).

Organophosphorus pesticides such as malathion and chlorpyriphos were not detected in significant concentrations in fish muscle from fish collected in Georges River (Sydney Water, 1997). In estuarine waters, malathion has a half life of less than one week, and chlorpyrifos has a half life of about one week (Lacorte *et al.*, 1995).

Conclusions: Although the maximum accepted concentrations of PCBs and some pesticides were exceeded in some locations in the Georges River, the risk to human health does not appear to be significant, considering the large safety factors that are incorporated into the regulatory criteria. Sydney Water (1997) found that the average recreational angler in the Lower Georges River consumed 5 kg/yr of fish flesh from fish caught in the river, while a more regular angler consumed 13 kg/year. Based on these figures, and using the combined maximum concentrations of all the organic compounds found in significant concentrations in fish collected in the river, Sydney Water (1997, Appendices) calculated, using the worst case scenario, that the increased lifetime cancer risk to the average angler from eating the fish caught over the whole river (including the most polluted areas such as Salt Pan Creek) was 0.6%, and to the regular angler was 2%. For fish caught below Kangaroo Point, the corresponding increased risks were 0.01% and 0.03%, respectively. These small increased risks of cancer from fish consumption from the Georges River should be put into context with the health benefits of eating fish. Eating fish regularly lowers your risk of cancer by 20 - 40% (World Cancer Research Fund, 1997) as well as reducing the risk of heart disease by 15 - 30% and childhood asthma by over 30% (Florence and Setright, 1996; Tognoni, 1999). A recent study of workers exposed to PCBs found no increase in breast cancer, even though many of the workers had high concentrations of the chemical in their blood (Kimbrough *et al.*, 1999). It appears that the risk of cancer from PCB exposure may have been overestimated in the past. Nevertheless, it would be prudent not to eat fish caught in the most polluted areas, such as Prospect Creek and the upper reaches of Salt Pan Creek.

Bioassays (toxicity tests)

To validate the toxicity assumptions made from the results of analyses on sewage overflow water and Georges River water and sediment, Sydney Water carried out extensive, direct measurements of toxicity on these waters and sediments using a range of bioassays (Sydney Water, 1997). A bioassay is the ultimate measure of toxicity, because it directly measures the toxicity of a water or sediment using organisms selected for their high sensitivity to the toxicants being tested. River water and sediment samples from Ingleburn Weir, Fairfield, Glenfield and Chipping Norton were subjected to bioassay. No significant toxicity was observed for receiving waters at any site, in either dry or wet conditions. Also, no sediment sample exhibited toxicity. The fact that these sensitive bioassays showed no toxicity for water or sediment indicated that the chemical-based risk assessments made by Sydney Water were conservative and over-estimated the risk. Surveys by Sydney Water (1997) of the aquatic organisms in the river sediment showed that relatively few species are present in the river at these places, with similar numbers upstream and downstream of the sewage treatment plants. Sydney Water believes that this situation is consistent with the effects of stormwater in an urban environment.

3.2 Changes in Habitat

Aerial photographs taken from the 1940s to the present time show that there have been major changes in the geomorphology of the Georges River (ie, its nature and structure) during that time. Banks have eroded and channels have become wider and shallower (Warner and Pickup, 1973; Warner *et al.*, 1977). Warner *et al.* (1977) calculated that 1,600,000 cubic metres (about 4 million tonnes) of soil was eroded from the Upper Georges River during 1959-1973. Sedimentation has also increased, with the result that the depth of many bays in the river has decreased (Sinclair Knight Merz, 1999). The reclamation of wetlands for housing, playing fields, golf courses and waste disposal has been an irreversible loss to the river. These changes have been brought about by the following factors:

- **Increased urban runoff.** Over 90% of the sediment load entering the river originates from this source, and the amount will continue to increase in proportion to population increase. This represents a huge additional input of sediment to the river, compared to that in the early years of settlement, causing siltation of channels and bays, and the smothering of seagrasses. The sediment in urban runoff has a fine particle size, and is very effective in covering aquatic vegetation. Additionally, during floods, the increased volume of water travelling down the river as a result of urban runoff causes major erosion of river banks and increases the residence time of the freshwater in the estuary. This further adds to the sediment load. The ratio of estuary volume to the volume of water discharged by a river determines the residence time of the freshwater (Morrison, 1999). This freshwater residence time, which can have profound effects on the ecology of the river, can be altered by damming, dredging, channel modification, and urban runoff (Morrison, 1999).

- **Dredging and sand mining**. Dredging widens channels and deepens them temporarily. However, river banks are eroded and undermined by dredging, leading to siltation and the need for further dredging (Warner *et al.* 1977). In the early years of sand mining in the upper river, dredging operations caused many problems (Warner *et al.*, 1977). One mitigating factor was that sand entering the river from mining was coarse and settled quickly.
- **Housing development**. The development of the river bank for housing has led to the destruction of riverside trees, causing a loss of bank coherence and increasing the risk of erosion.
- **Boating**. The large increase in the number of boats using the river, and a general lack of adherence to speed limits has increased bank erosion, especially at high tide.

Before the diversion of the Glenfield and Liverpool sewage treatment plants in the mid-1980s, large amounts of nitrogen and phosphorus from sewage entered the Georges River. Although the situation is much better now (**Table 1** and **2**), considerable damage to the ecology of the river must have occurred over several decades from these discharges. Valiela *et al.* (1997) showed that as the nitrogen loading of an estuary increased, macroalgal growth rates doubled, algal biomass tripled, seagrass beds were lost and herbivore abundance decreased. Nitrogen loading causes stress to the plants as their biochemical systems try to metabolise the extra nitrate. Seagrasses under nitrate stress are more susceptible to disease (Devlin, 1999). The increased turbidity from urban runoff decreases photosynthesis and causes additional stress to the plants (Devlin, 1999). Another effect of high nitrogen loading is that some species of seagrass can cope better with excess nitrate than others. Because each seagrass species offers a different type of habitat, a decrease in seagrass area and changes in the ratio of different seagrass species will affect fish numbers and composition (Morrison, 1999). On the southern shore of Botany Bay from 1945 to 1990 there has been a marked decline in the abundance of *Posidonia australis*, while the area covered by *Zostera capricorni* has actually increased (Larkum and West, 1990). However, it is not clear if this change is the result of some natural cycle or, more likely, *Posidonia* being more susceptible than *Zostera* to dredging, trawling and to excess nutrients entering the Bay from Georges River (Larkum and West, 1990).

There is a limited amount of information on seagrass meadows in the Georges River. In 1978 and 1983 the areas of seagrass found were essentially all *Zostera capricorni* (State Pollution Control Commission, 1978; West *et al.*, 1985). Aerial photographs taken in the early 1950s indicate that at that time the distribution of seagrasses in the river was more extensive than at present (State Pollution Control Commission, 1978). West *et al.* (1985) found from field measurements in 1983 that the total area of seagrass in the Georges River was 0.27 km^2. They also found, at that time, 2.0 km^2 of mangroves and 0.25 km^2 of salt marsh. Small patches of seagrass were found in Kogarah Bay, Neverfail Bay, at the entrance to the Wononora River, near Edith Bay, near The Moons at Lugarno, and at the entrances to Salt Pan and Little Salt Pan Creeks (West *et al.*, 1985). Aerial photographs (from the Department of Land and Water Conservation) taken in 1998 showed that all these patches of seagrass were still present (and some may even have increased slightly in area), with the exception of Kogarah Bay, where they have decreased in area considerably.

There is a need for up-to-date mapping of seagrass beds, mangroves and salt marshes in the Georges River. If they were given suitable training, this field work would be a suitable project for Georges River Riverkeeper volunteers.

3.3 Changes in Fauna and Flora

Georges River is rich in flora and fauna, although no early data could be found to enable present inventories to be compared with populations registered 40 or 50 years ago. In 1998, Oatley Bay was found to contain 54 species of birds and Gungah Bay 55 species (Sinclair Knight Merz, 1999). The freshwater regions of the Georges River are an important habitat for a variety of bird species, and function as a riparian corridor for birds. The river above Glenfield is rich in macroinvertebrate species (Department of Urban Affairs and Planning, 1998). Some threatened species in the Georges River include the Green and Golden Bell Frog, the Red-crowned Toadlet, the Blue-billed Duck, the Eastern Bristlebird, the Wooly Wattle, and the Pink Pimelea (Sydney Water, 1998).

High nutrient levels during the 1980s caused algal blooms and infestations of noxious aquatic weeds, including *Salvinia molesta* and Alligator Weed. With sufficient nutrient input, both these weeds can double their mass in a week and are difficult to eradicate (Department of Urban Affairs and Planning, 1998). By competition, they can destroy seagrasses and other desirable aquatic plants.

3.4 Changes in Fish and Oyster Production

Production of the Sydney Rock Oyster, *Saccostrea commercialis*, in the Georges River was severely affected by the appearance, in 1996, of the QX (Queensland Unknown) disease. This disease is caused by a protozoan, and affects the oysters in the summer months (Department of Urban Affairs and Planning, 1998). The origin of the QX disease is still unknown. In winter months, the Georges River oysters have always been subject to the disease Winter Mortality, also caused by a protozoan. Production of oysters in the Georges River is still continuing, but at a greatly reduced rate. The number of oyster farmers now is about half of that in the early 1990s. In 1998, 71,000 dozen oysters were harvested from the river.

No separate commercial fish catch data are available for the Georges River. The statistics available from NSW Fisheries are for Georges River and Botany Bay combined, so are of limited use for this study, since the bulk of the fish catch comes from Botany

Bay. Nevertheless, it is useful to examine the fish catch in Botany Bay/Georges River since it can give an idea of the change in productivity of these waters. Data on total fish catch are of limited use for assessing fish stocks since the amount of fish caught depends on how many fishermen are operating and how often they fish. The key statistic is weight of fish catch per fisher-day of effort.

The commercial fishing effort in New South Wales increased sharply after World War II, remained fairly constant until 1970, then increased again. The effort peaked in 1979/80 then declined until 1991/2 (Pease and Grinberg, 1995). In Botany Bay/Georges River, the number of registered commercial fishers increased to a maximum of 120 in 1986/87, then declined steadily to 62 in 1997/98 (NSW Fisheries data bank). **Figure 3** shows the total catch of finfish from Botany Bay/Georges River from 1954/55 to 1997/8, while **Figure 4** shows the total finfish catch from the same area per fisher-day of effort for 1984/5 to 1996/7 (NSW Fisheries data bank). No data were available for days of fisher effort until 1984/5. It is evident from **Figures 3** and **4** that there has not been a marked decline in the catch of finfish from Botany Bay/Georges River from 1954/55 to 1997/8, and that since 1984/5 the catch of finfish per fisher day of effort has been reasonably constant. There have been declines in the catch of some species of fish, but increases in others.

4. Conclusions

This assessment of recent and historical data on the Georges River has revealed the following main points:

- Water and sediment quality in the river deteriorated from the 1950s and was poorest in the late 1970s to the mid-1980s. Since then there has been a general and marked improvement in all water quality parameters with the result that regulatory body guideline values are now complied with for most of the year and in most parts of the river. Some guidelines are exceeded after heavy rain, especially for faecal coliforms. Upstream of Lugarno, even in 1998, faecal coliform counts were too high to permit swimming for one-quarter to one-third of the year. Some of the upper reaches of the creek tributaries of the Georges River, eg, Salt Pan and Prospect Creeks, still have poor water and sediment quality. No acidification or heavy metal problems were found in the water and sediments of Chipping Norton Lake.
- Sensitive bioassays carried out on water and sediments from the Upper Georges River found no evidence of toxicity towards aquatic organisms.
- Heavy metal concentrations in oysters taken from the Georges River now meet guideline criteria for the protection of human health.
- Although the PCB concentrations in fish caught in some of the more polluted areas of the river and its estuaries (especially Prospect Creek) exceeded guideline food values, the health risk of eating fish caught anywhere in the Georges River itself is very small, and is greatly outweighed by the beneficial health effects of fish consumption.
- Seagrass meadows in the Georges River have probably decreased since the 1950s, but, with the exception of Kogarah Bay, the patches of seagrass that existed in the

early 1980s are still present today. Massive destruction of Georges River mangroves has occurred this century.

- The total commercial catch of finfish in Botany Bay/Georges River has not declined markedly since the 1950s, and the finfish catch per day of fisher effort stayed almost constant from 1984 to 1997.
- Before the upgrading and diversion of the sewage treatment plants at Liverpool and Glenfield in the mid-1980s, nutrients and other pollutants from these plants may have caused considerable damage to the ecology of the river, including the irreversible loss of some seagrass. However, it is now increasing population and urbanisation in the Georges River catchment that are the main threats to the river. The increase in roads, houses and impervious paved surfaces has led to a large increase in urban runoff in the past 50 years. This input of huge volumes of fresh, polluted water containing suspended solids has had a major impact on the river, including a decrease in average salinity and an increase in the frequency and extent of flooding. Urban runoff contributes about 90% of the total suspended solids entering the river. This material smothers seagrass beds and causes siltation of bays. Sewerage system overflows also contribute to the pollution of the river but, compared to urban runoff, their effect is minor, except for faecal coliforms and phosphorus.
- Several factors, including increasing input of suspended solids, housing development, mangrove clearance and dredging have caused a serious loss of habitat (seagrasses, mangroves, salt marshes) for the early life forms of aquatic animals.

5. Need for Additional Data and Research

The following additional data would be useful in assessing the health of the Georges River and in helping to plan for its protection and rehabilitation.

- No in-field inventory of the areas of seagrasses, mangroves and salt marshes in the Georges River has been made since the early 1980s. For future protection of these resources, it is important to have regular updates on their status. With suitable training, this is a project that could be carried out by volunteers from the Georges River Riverkeeper Program.
- Good quality aerial photographs of the Georges River are available from the 1960s. With some training, Riverkeeper volunteers could use these photographs to measure changes in river banks, sedimentation, river channels, river depth, seagrass meadows, mangrove areas and other characteristics of the river, and to continuously update these data.
- There is no knowledge of the nutrient content of Georges River sediments, or of their denitrification rates (ie, the rate of destruction of nitrate in a sediment). These data are important to an assessment of future risks of eutrophication. The nutrient contents could be measured within the Riverkeeper Program, but denitrification rates would have to be determined by a water research laboratory.
- CSIRO at Lucas Heights is developing novel, improved techniques for assessing the toxicity of sediments. The Riverkeeper Program can become involved in this

research by collecting sediment samples from the river for inclusion in the testing program.

- Separate data are not available for commercial fish catches in the Georges River. Such data would be useful in assessing changes in the productivity of the river.
- Assessment and trials of sediment traps for stormwater drains would allow information to be obtained on the best methods for intercepting sediment before it reaches the river.
- Experience has shown that attempts to re-establish seagrass beds are seldom successful. However, now that nutrient levels in the river have decreased, and are likely to decrease further once the sewage treatment plants are upgraded to reduce wet-weather overflows, the time is ripe for initiating research on new ways of planting and maintaining seagrasses.

6. Rehabilitation of the River

Rehabilitation of the Georges River effectively began 10-15 years ago with a marked improvement in river water quality, principally as a result of the upgrading and diversion of the sewage treatment plants at Liverpool and Glenfield. Further improvement in water quality can be expected in the next 10-20 years as Sydney Water completes its program to reduce sewerage system overflows by 80-90%. Because urban runoff is now by far the major contributor to pollution of the river, continued rehabilitation will depend on our ability to control this prolific source of freshwater, suspended solids, nutrients and heavy metals. The introduction of more sediment and litter traps, bank stabilisation, tree and shrub planting and the establishment of constructed wetlands (Kinhill, 1999; Sinclair Knight Merz, 1999) seem to be the main courses of action to help contain the problems caused by increasing amounts of stormwater entering the river. A program to minimise the area of new water-impervious surfaces would also help to control rainwater runoff. Footpaths, parking lots and similar areas could be paved with water-permeable materials rather than concrete or bitumen, and householders should be encouraged to do the same.

The Georges River Riverkeeper Program , by educating the community who live near the river and use it for recreation, will play a major role in river rehabilitation. Education is needed to convince land developers and builders to respect the river and make every effort to prevent pollution from building sites and to maintain river bank vegetation. Some people still regard a stormwater drain as a sink for disposal of all kinds of noxious materials. This must stop, and penalties for illegal disposal of waste down stormwater drains should be rigorously enforced. The boating and fishing community must also cherish the river, avoid using it as a sewer and for waste disposal, and adhere to posted speed limits.

Although the Georges River can never be restored to a pristine condition, we can be cautiously optimistic about the future of the river, despite the enormous pressures on it from increasing population and use. The degradation in water quality that occurred over three decades has now been largely contained, and we can expect it to improve further in the future as long as we are vigilant, have the will to protect the river, and are prepared to commit the necessary funds.

7. Acknowledgments

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8. Glossary of Terms and Abbreviations

Algae: are simple aquatic plants that grow by utilising nutrients and light (photosynthesis). They include single-cell microalgae such as diatoms, to multi-cell macroalgae such as the large-leaf seaweeds. An algal bloom occurs when excess nutrient input to a waterway (eutrophication) causes rapid growth of algae. When the nutrient or light supply runs out, the algae die. In so doing they can release highly toxic chemicals, and the dead algae consume dissolved oxygen from the water, posing a threat to fish and other aquatic life.
Anoxic: means depleted in oxygen. The first 1 or 2 cm of river sediment can be well oxygenated (ie, *oxic*), whereas deeper layers are usually anoxic.
ANZECC: is the Australian and New Zealand Environment and Conservation Council.
AVS/SEM: as applied to a sediment sample, is the ratio of sulphur that is evolved (as H_2S) when a sample is treated with acid, to the metal that is dissolved from the sample at the same time. It stands for acid-volatile sulphur/simultaneously-extracted metal.
Benthic: benthic animals are those that live in or on the sediment at the bottom of the water body. Examples are polychaete worms, crabs, and amphipods.
Bioassay: is a test for toxicity of a chemical using a living animal as the test subject. There are now limitations on the use of fish for bioassays. Prawns, worms, amphipods and algae are commonly used as test organisms.
Catchment area: is the land area which drains to a river, lake or reservoir.
Cfu: colony forming units.
Chlorophyll *a*: is the major green pigment found in plants such as algae. It captures light for photosynthesis. Its concentration in water is an indirect measure of the concentration of algae.
Denitrification: is the process in sediments whereby bacteria catalyse the conversion of nitrate to nitrogen gas and N_2O gas. This is a natural way by which nitrate stored in sediments is destroyed and prevented from causing eutrophication.
Detritus: are organic debris from decaying plants and animals.
EPA: is the NSW Environment Protection Authority.
Eutrophication: is a process resulting from a rapid and substantial increase in the nutrient load of a waterway. It can cause excess growth of algae, leading to an algal bloom.
Faecal coliforms: are bacteria present in virtually all warm-blooded animals. In human faeces, faecal coliform bacteria comprise 97% *E. coli*. Faecal coliform bacteria are an indicator of sewage contamination of a waterway.
Finfish: are fish with fins, such as bream, luderick, whiting, etc.
Geomorphology: (of a river). Is the structure, or shape of a river, including the banks and channels.
Heavy metal: is a loose term meaning a group of metals including iron, manganese, copper, lead, mercury, etc. Many, but no all, heavy metals are toxic.
Macroinvertebrate: are organisms more than one millimetre long and without a backbone.
Megalitre (ML): is one million litres.
Microgram (μg): is one-millionth of a gram, or one-thousandth of a milligram (mg).

MRL: is maximum residue limit. The maximum acceptable concentration of a toxic substance in a food.
NHMRC: is the National Health and Medical Research Council.
NTU: nephelometric turbidity units.
Nutrients: are chemicals needed to sustain life. For algae, they include nitrogen (often in the form of nitrate) and phosphorus (often in the form of phosphate), as well as trace elements such as iron, manganese, zinc, copper, silicon, etc.
PAHs: are polycyclic aromatic hydrocarbons. They are formed by incomplete combustion of coal and other organic fuels. They can appear in waterways as a result of atmospheric deposition, or from pollution by industrial wastes or sewage treatment plants. They are cancer-causing.
PCBs: are polychlorinated biphenyls. Their use is now restricted, but they still appear in sewage, industrial wastes and in leachates from waste dumps. They were used in transformer oils, heat transfer fluids, plastics and a range of other materials. They are cancer-causing. However, recent studies indicate that their cancer-causing ability in humans has been overestimated because humans seem to be more resistant to PCBs than the animals used to test their toxicity.
Photosynthesis: is the process by which green plants use light energy absorbed by their chlorophyll to convert carbon dioxide and water to oxygen and organic compounds such as sugars.
ppt: is also expressed as ‰. It means parts per thousand (ie, % x 10). Open ocean seawater has a salinity of about 35 ppt, or 35 ‰, which means it contains 3.5% salt.
Riparian areas: of a river, are the areas immediately adjacent to the river bank.
Salinity: is the concentration of salt in water. Open ocean seawater has a salt concentration of about 3.5%, or 35 ppt, or 35 ‰.
Sedimentation: is the deposition of sediment on the bottom of a waterway.
Substrate: is a material on which an organism is growing or is attached to.
Tributyltin: is an organic tin compound which is highly effective in preventing the growth of organisms on boats (ie, it is an anti-foul). However, it was banned from use on small vessels because of its toxicity towards oysters.
Wetlands: is an area that is flooded often enough to support aquatic plants.

9. References

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Table 1. **Changes in Total Phosphorus Concentrations (µg/L) in Georges River Waters (expressed as annual mean values*)**

Site	1972	1980	1990	1998
Glenfield	320	4,220	19	40
Milperra	76	776	84	37
Lugarno	220	92	43	35

* 95% confidence levels are approximately 50%.

Table 2. **Changes in Total Nitrogen Concentrations (mg/L) in Georges River Waters (expressed as annual mean values*)**

Site	1977	1980	1990	1998
Glenfield	4.4	24	0.47	0.53
Milperra	1.7	2.8	0.93	0.50
Lugarno	0.53	0.56	0.64	0.27

*95% confidence levels are approximately 50%.

Table 3. **Changes in Chlorophyll *a* Concentrations (µg/L) in Georges River Waters (expressed as annual mean values)**

Site	1975	1980	1990	1998
Glenfield	9	7	2	4
Milperra	10	5*	2	3
Lugarno	4	7**	3	2

*1985, ** 1981. The 95% confidence levels are about 100%.

***Table 4.* Changes in Faecal Coliforms Counts (cfu/100 mL) in Georges River Waters (expressed as annual mean values[*])**

Site	1969	1975	1980	1990	1998[#]
Glenfield	19	10	34	330	23
Milperra	560	150	29	830	32
Lugarno	14	7	6	110	18

[*] From Rish (1992). The range of results for faecal coliforms is very large (see text)
% of days not suitable for swimming because of sewage contamination

***Table 5.* Changes in Salinity (ppt) in Georges River Waters (expressed as annual mean values[*])**

Site	1941-54	1971-76	1980	1999
Oatley Bay	31	28	-	27
Como Bridge	32	28	30	-
Salt Pan Cr.	25	22	22	14
Alfords Point	23	19	-	17
Liverpool Weir	2	2	1	-

[*] The differences in salinity for the Georges River between 1941-54 and 1971-76 were statistically different (State Pollution control Commission, 1979a)

***Table 6.* Mean Copper Concentrations (mg/kg wet weight) in Oysters from Georges River**

Site	1973	1978	1987/88	1991
Oyster Bay	44	51	56±2	37±4
Double Bay	-	-	95±1	64±1
Mangrove Is.	-	-	71±3	62±2
Lime Kiln Bay	45	64	69±5	55±3

***Table 7.* Mean Lead Concentrations (mg/kg wet weight) in Oysters from Georges River**

Site	1973	1987*
Oyster Bay	1.3	0.3
Hurstville Bay	-	0.6
Lime Kiln Bay	1.0	0.5
Salt Pan Cr.	1.0	-

* The standard errors for the 1987 results are about ±20%

***Table 8.* Mean Zinc Concentrations (mg/kg wet weight) in Oysters from Georges River**

Site	1973	1978	1987/8	1991
Oyster Bay	470	550	875±19	440±57
Double Bay	-	-	770±90	760±2
Mangrove Is.	-	-	650±45	670±0
Lime Kiln Bay	640	780	920±130	510±2

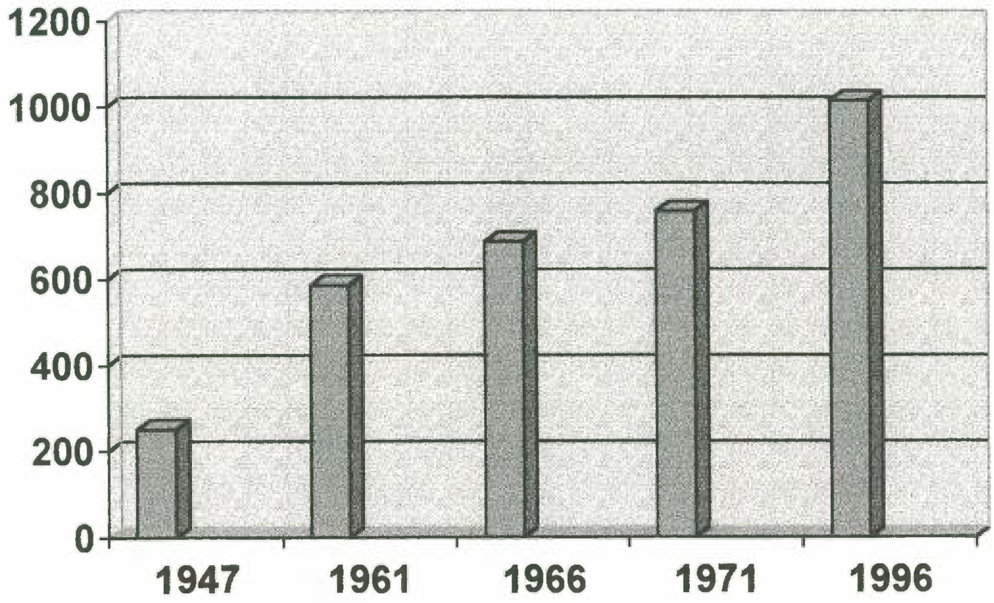

Figure 1. Combined Populations (in 1,000s) of the LGAs of Sutherland, Fairfield, Bankstown, Campbelltown, Canterbury, Liverpool and Rockdale from 1947-1996

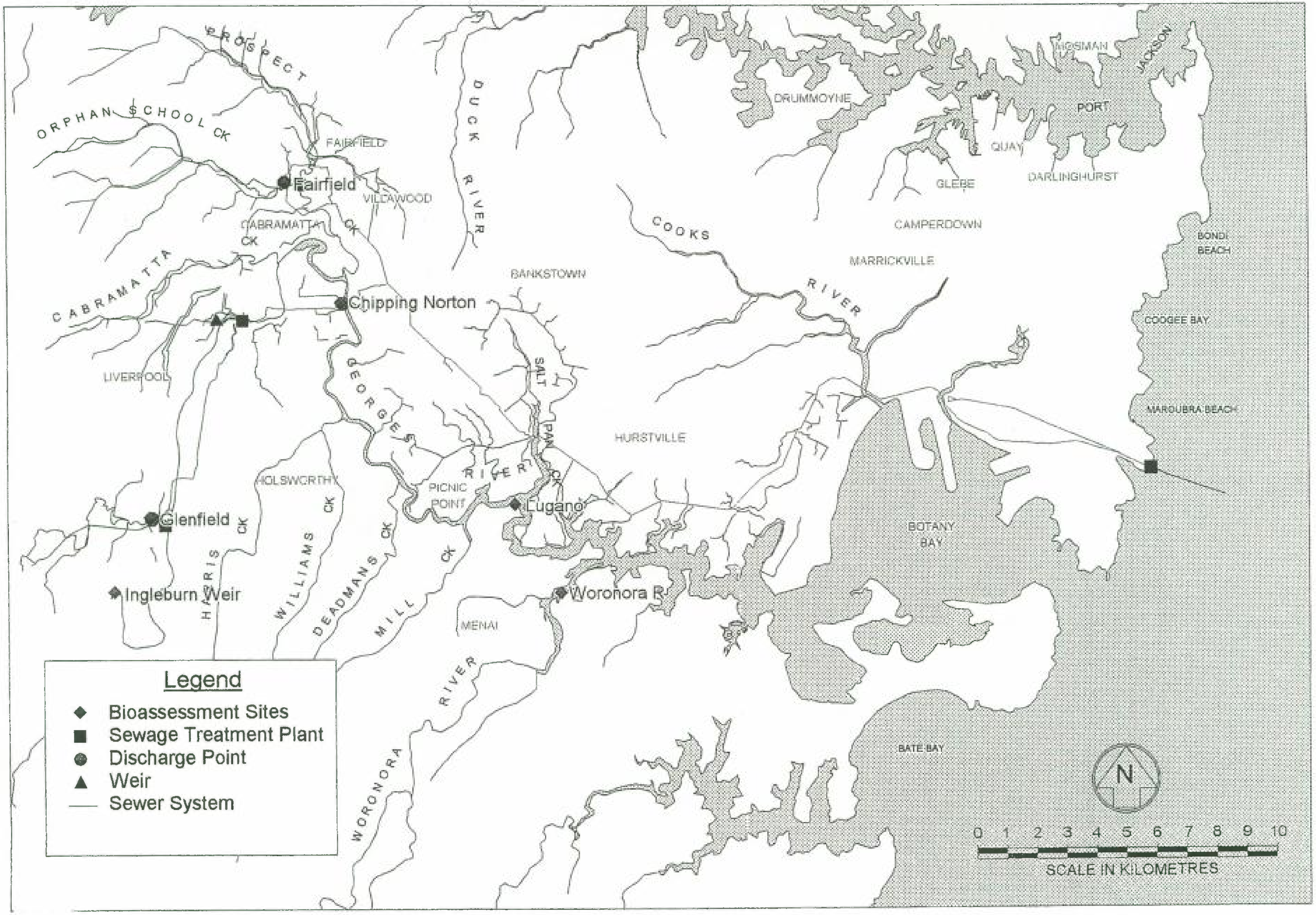

Figure 2. The Georges River

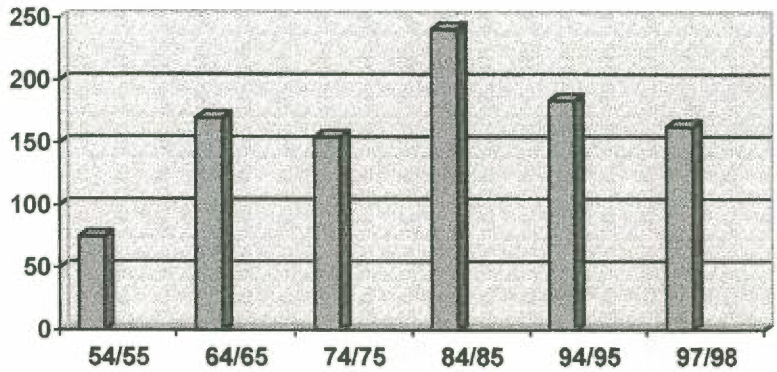

Figure 3. **Total Catch (tonnes) of Finfish in Botany Bay/Georges River for 1954-1998**

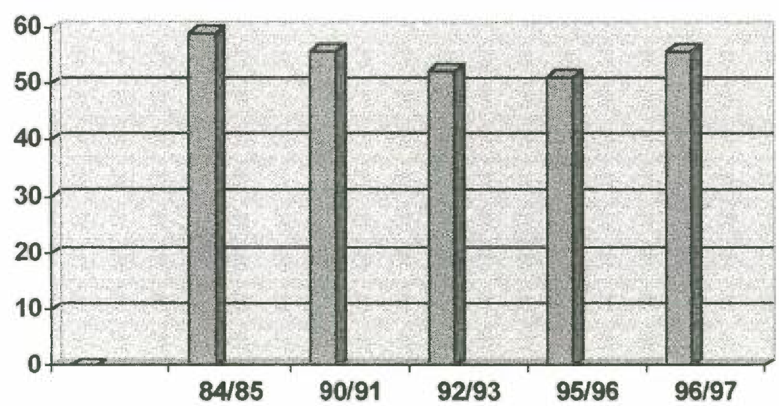

Figure 4. **Ratio (kg/day) of Total Finfish Catch to Total Days Fished for Finfish in Botany Bay/Georges River from 1984 to 1997**