Water quality

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Key messages

- Strict water quality controls are in place to protect human health and aquatic ecosystems from chemical, and biological pollutants.
- In general, control of pollutants at their source is more effective than remediation because of their persistence in the environment and concentration through the food chain.
- Elevated levels of salinity, nutrients, metals, pathogens, and organic contaminants (e.g. pesticides) are the main causes of poor water quality in Australia. Pollutants are derived from a wide range of sources including agriculture, industry, and urban areas.
- Sediment layers at the bottom of waterways are a major sink for nutrients and contaminants, which can be released into waters and become toxic under certain conditions.
- New contaminants, for example pharmaceuticals, are continually emerging and much monitoring and research is focussed on detecting their presence and toxicity in aquatic environments.

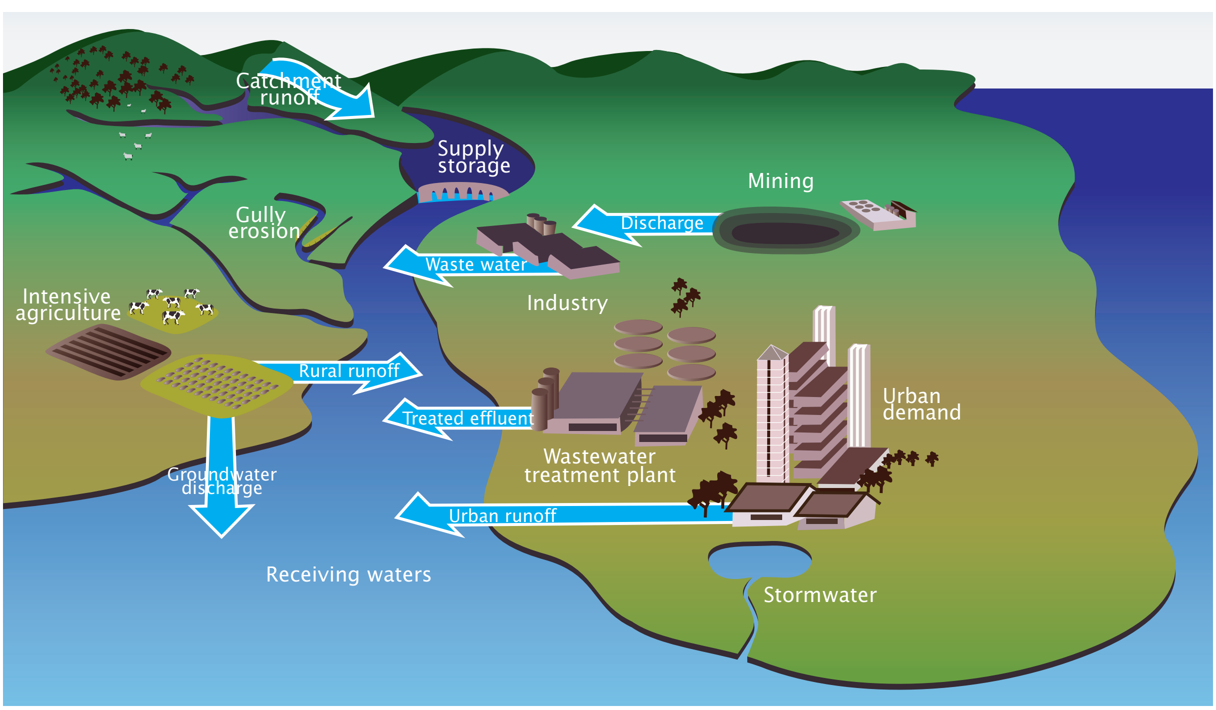
It is not only the quantity of water that matters, but the quality of the water has to be maintained for it to be useful. Maintaining supplies of potable quality water for human health is of paramount concern, either through water treatment or the protection of sources such as the largely pristine water supply catchments that provide for much of Sydney, Melbourne and Perth. Pollutants such as metals and pathogens may also enter the food chain, so the quality of irrigated water and that of fisheries have long been of concern. Poor quality irrigation and stock water can also reduce agricultural productivity. Finally, natural organisms are quite sensitive to some contaminants, so to conserve aquatic ecosystems the highest water quality needs to be maintained. For example, the pollution criteria for copper in the Australia and New Zealand water quality guidelines[1] is 0.0013 mg/L for freshwater ecosystems, compared with 2 mg/L for drinking water.

Streams, rivers, lakes, and groundwater naturally contain chemical and biological constituents. Natural waters contain essential nutrients of phosphorus, nitrogen, cations and trace metals and biological constituents, such as algae, which are essential requirements for fish and invertebrates. The physical properties of water, including its temperature and the degree of light penetration, also influence aquatic organisms. Water released into rivers from the depths of large dams can be so cold and deprived of oxygen as to be lethal to organisms for tens of kilometres downstream. Consequently, dam release valves have been re-engineered to take water from higher up in the dam.

Native ecosystems have become adapted to an enormous range of natural water quality across Australia, from the clear waters of rainforest streams to the naturally turbid waters of Cooper Creek in western Queensland or the hypersaline lakes of the arid regions. It is the changes to natural water quality, through the pollution of water, which threatens human health and other life. Pollution can result from changes in the naturally occurring concentration of some components in waters, such as when nutrient levels become too high and trigger the toxic growth of algae, or when oxygen levels become too low. Of course, pollution also occurs from manufactured constituents, such as pharmaceuticals, which are not normally found in water.

Managing pollutants in a river basin or groundwater system involves several steps.[2] The first is to define the uses and environmental values of water and risks to them from pollution. Then the sources of pollution and transport pathways should be identified. In large catchments with multiple land uses, there can be many possible sources, and for chemical and biological pollutants, the pollutants can be transformed as they pass through the environment. For example, herbicides can degrade into harmless constituents, so they may only be pollutants close to the source. Targets for improved water quality are then set, along with management actions to achieve them. Monitoring of water quality is used to identify new pollution risks and to help evaluate the effectiveness of the management strategies.

Water quality from point source pollution has improved in recent decades as a result of strong regulations that control pollution at its source from industrial plants, hospitals, sewage treatment



▲ ***Figure 5.1***: *There are many potential sources and pathways of pollutants to waterbodies.*

plants, and mine sites. Diffuse pollution of waters from catchment land use is much harder to tackle, and poses the most extensive pollution problems today. Salt, nitrogen, phosphorus, and suspended sediment are diffuse pollutants resulting from a wide range of agricultural and urban land uses that have degraded water quality across much of Australia. There are many possible sources of these pollutants in each catchment (Figure 5.1), making them hard to control. Being natural constituents of water, the levels required to prevent ecological damage are hard to determine and highly variable, although much progress has been made.

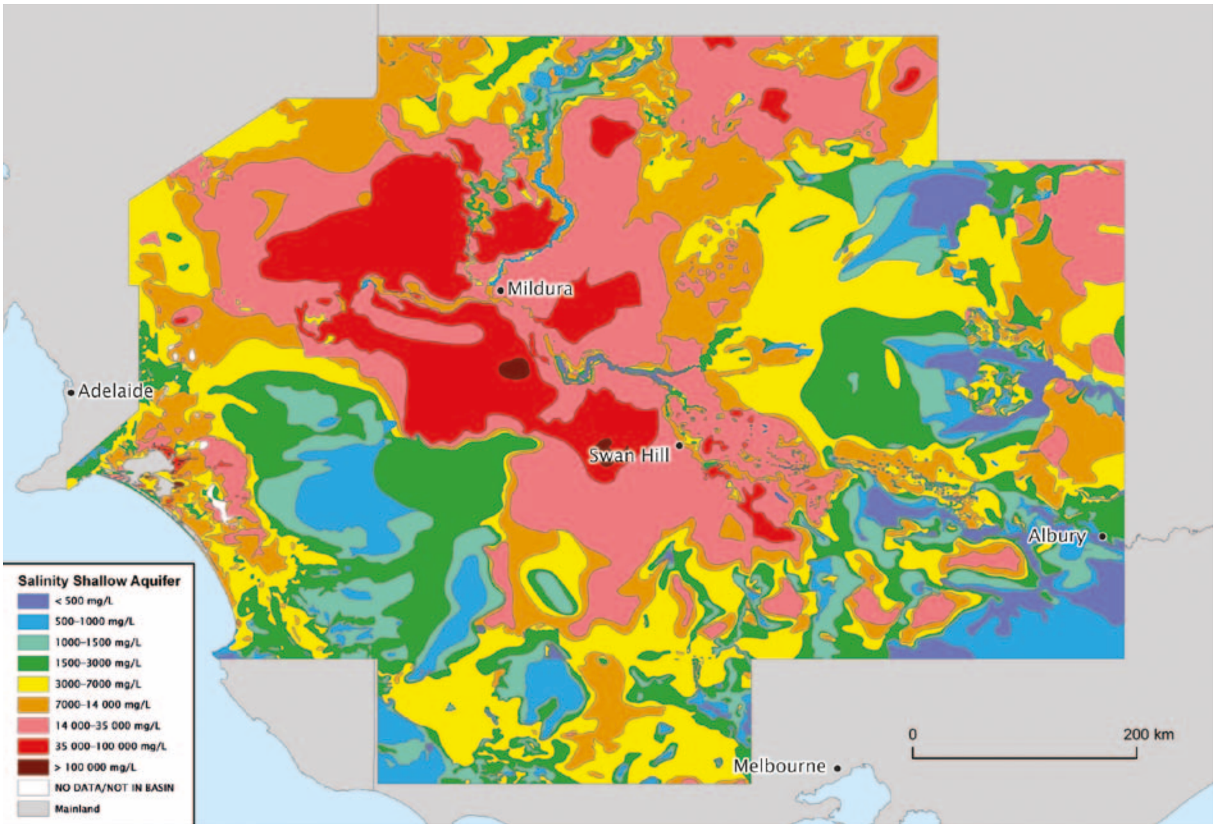
Salinity

Land use-induced increases in salinity affect about one-third of rivers in agricultural regions and cost about $3.5 billion a year in lost production and treatment.[3,4] Salinity has an impact on the potable use of water, including supplies for Adelaide obtained from the Murray River, and the use of water for irrigation and stock (Table 5.1). Although most adult Australian fish can tolerate salinity, juvenile fish (such as Murray cod), are particularly sensitive to salt.[5]

Table 5.1 Indicative salt concentrations above which agricultural production or quality of use declines. Sea water has a concentration of about 30 000 mg/L.

Water use	Salt concentration (mg/L)
Drinking water	500
Irrigation of fruit and vegetables	500–1500
Irrigated pastures	800–3000
Dairy cattle	3000
Sheep	6000

The ultimate source of salt is from rainfall, which contains small amounts of ocean spray, even far inland. The salt accumulates deep in soil over many millennia, especially in regions where rainfall is fairly low (300 to 600 mm/year). Geochemical and isotopic evidence is unequivocal that the source of salt is from marine aerosols and rainfall, even though some rocks were deposited under the sea. That salt is being mobilised and transported to rivers with the rise in groundwater levels under current land use regimes. Under the natural cover of forest and woodland there was very little groundwater recharge (0.1% to 1–2% of the annual rainfall) and correspondingly little discharge of groundwater into rivers. Clearing of trees reduced evaporation, increased recharge up to 10 times, causing groundwater levels to rise. This mobilised the salt stored in soils and



▲ ***Figure 5.2**: Map of groundwater salinity in the shallow aquifers of the Murray Basin, south-east Australia. Large areas of very saline groundwater in the central Murray Basin leak slowly into the Murray River.*[6]

increased its discharge into rivers. Salinity is also a result of rising saline water tables under irrigation areas and mining can directly discharge saline water into rivers. Much of the salinity in the lower Murray River comes from naturally saline groundwater that has risen in level as a result of clearing of the mallee woodlands and introduction of irrigation (Figure 5.2).

Salinity loads in rivers can be reduced by revegetation of catchments and promoting pastures with deep roots that use more water, but very large areas need to be revegetated.[5] Salt interception schemes are used to pump highly saline groundwater or surface drainage waters into evaporation or storage basins, preventing them from reaching rivers,[7] and improved irrigation practices reduce the recharge of saline groundwater. Maintaining discharges of freshwater from tributaries is also important for providing dilution of saline groundwater, so there is a salinity management imperative for the maintenance of environmental flows in the Murray–Darling Basin. Salinity management has also employed a cap and trade system, as proposed for carbon, as a means to allow new uses of water while preventing any increase in salt pollution, such as to control salt loads from mining in the Hunter River catchment NSW.[8]

A paradox of salinity is that, although it is a symptom of a dry continent, it expresses itself more in wet years. Much has been achieved in recent years in revegetation, drainage, and salt interception to alleviate salinity, but the millennium drought provided a reprieve through lower recharge. It was during the relatively wet early 1970s when the salinity problem began to manifest over large areas, and the exceptional rainfall and flooding in eastern Australia in 2010–11 is being carefully monitored to assess whether salinity returns as a result of rises in water tables and the drainage of salt from floodplains that have been dry for over a decade.

Blue-green algae in Chaffey Reservoir near Tamworth, New South Wales. Photo: Brad Sherman, CSIRO.

Algal blooms

Algae are a natural and essential component of water ecosystems. They photosynthesise, providing food for animals and include phytoplankton, cyanobacteria, diatoms and seaweed. However, many rivers, lakes, and coastal waters have become enriched in nitrogen and phosphorus – a process known as eutrophication – as a result of agriculture and urban discharges. Eutrophication leads to the overly rapid growth of algae (algal blooms) and the predominance of blue-green algae, which can excrete toxins that are hazardous to animals and people if they are consumed, inhaled, or contact the skin. Equally rapid decomposition of the blooms consumes dissolved oxygen in the water, leading to fish kills.

An increased frequency and consequences of algal blooms in the 1980s and 1990s stimulated a concerted effort to better understand their causes and to reduce their occurrence. It was revealed that, although rivers have chronically high levels of nitrogen and phosphorus, it is the local conditions of light, turbidity, and water stratification that are important triggers of algal blooms.[9] Many of Australia's river pools and reservoirs become stratified under warm conditions with low inflows. The bottom layer of water and sediments becomes oxygen deficient, changing the chemistry of the sediment, causing phosphorus and nitrogen to dissolve into the water, and stimulating algal blooms.[10] Turbid waters are more prone to toxic algal blooms because the toxic algae float and out-compete algae deeper in the water that receive even less light.

It became clear that managing the local conditions was more effective in the short term than reducing the runoff of sediment, nitrogen, and phosphorus, even though that helps in the longer term. Environmental flows can be used to flush and dilute nutrients and algae and reduce periods of low or no flow. In reservoirs prone to algal blooms, water is now mechanically stirred to increase oxygen and reduce stratification,[10] and in urban areas the treatment of sewage and reductions in stormwater runoff reduce nutrient loads. Alternatively, phosphorus can be removed from waterbodies, using products such as Phoslock™, which is a clay that has been modified to bind phosphorus tightly so that it is not released, even under anoxic conditions.[11]

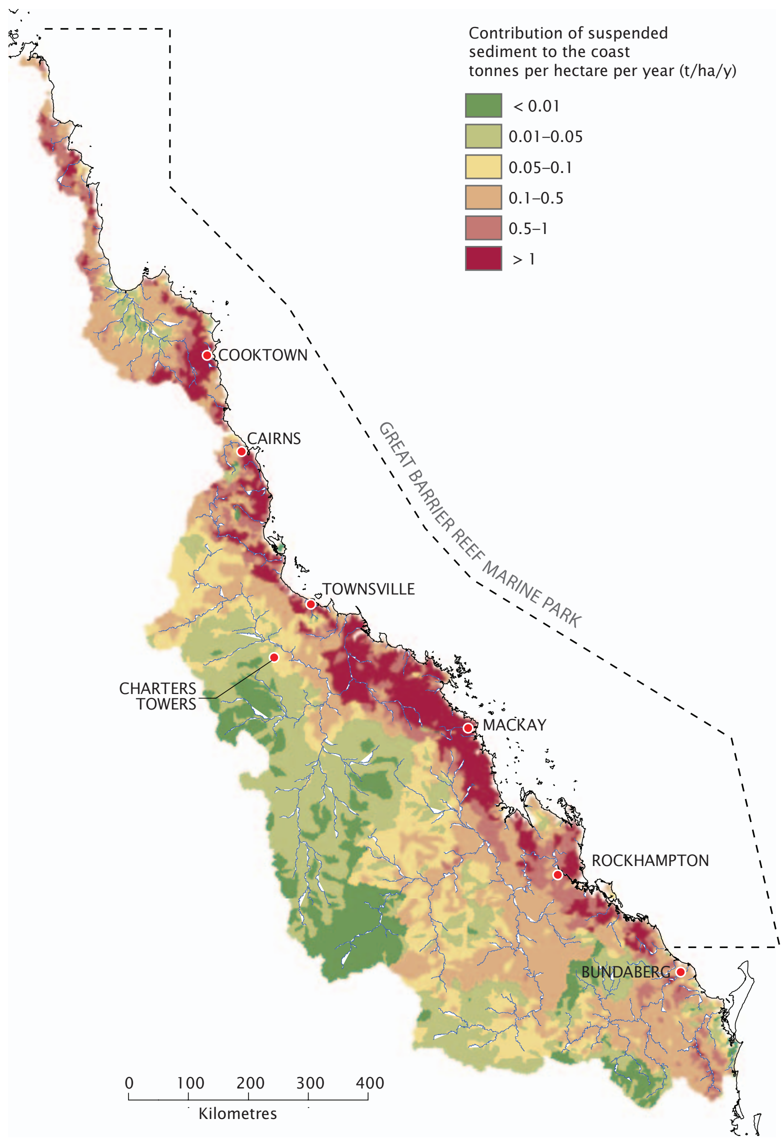
Sediments

A peculiarity of Australia is the very low natural loads of sediment and nutrients in rivers, as a result of its extreme geological stability. The clearing of native vegetation and the development of agricultural land uses changed that, increasing the loads of sediment by 10 to 50 times – particularly in the years immediately following clearing.[4,12] Sediment is relatively easy to remove in town water supplies, but it can have significant ecological impacts. Sediment is transported during storms and is deposited as flows wane. The deposits can smother the bed, covering more suitable habitats, and killing plants and other organisms. The deposited sediments may re-suspend, causing high turbidity, or metals and nutrients contained in the sediment can be released into the water under some conditions. Metals contained in sediment can concentrate in the food chain when sediment is consumed by organisms such as worms, shellfish, and small crustaceans.

Sediment is an ideal example of a pollutant with diverse sources. Sediment erodes from all landscapes, but not uniformly. Typically about 70–80% of the sediment reaching estuaries is derived from just 20% of the upstream catchment area.[13] Thus, catchment management to control sediment pollution can be targeted at these hotspots once they are identified by catchment sediment modelling (Figure 5.3). Further targeting can occur by identifying the erosion processes that are responsible. Agricultural land is the obvious source of erosion, but tracing of sediment sources using the chemical composition of sediment has revealed that accelerated erosion of riverbanks and gullies is responsible for up to 90% of the total sediment yield from a catchment.[12,14] By identifying the source of sediment, management can be much more effectively targeted to the precise sources. The most effective means of reducing erosion is to restore adequate vegetation cover by rehabilitating degraded riparian zones or improving farming practices.

Recycled water complex at Bolivar, South Australia. Photo: Greg Rinder, CSIRO.

Remediation of polluted sediments may be required if biological communities are severely impacted. Remediation of contaminated sites can simply involve dredging and licensed disposal of contaminated sediments, excavation and incineration on-site, capping of affected areas with barrier materials that prevent water infiltration and transport of contaminants, or the application of sophisticated clean-up technologies that use chemical procedures (e.g. oxidation or reduction) to destroy or extract the contaminants. Bioremediation, using microbes to degrade the pollutants, can be used for some contaminants. Two of the biggest sediment remediation activities in Australia are currently underway at Homebush Bay in Sydney Harbour (the source of historical dioxin contamination), and Newcastle Harbour, where oil and metal contamination levels are high.



▸ ***Figure 5.3**: Results of catchment sediment modelling for the catchments draining to the Great Barrier Reef. The model shows which of the more than 5000 sub-catchments contribute the most sediment to the coast. Catchments close to the coast and with intensive land use are predicted to be the highest contributors because sediment from inland catchments is trapped before reaching the coast or those catchments have a lower erosion rate as a result of less rainfall and less intense land use.*[13]

Estuaries and coastal waters

It is the combined impacts of sediment, eutrophication, and other pollutants that have had major impacts on estuaries and coastal waters including the inshore areas of the Great Barrier Reef.[15] Increased nutrient inputs, particularly nitrogen combined with increased turbidity, have led to growth of algae on seagrass beds or on corals, resulting in decline of seagrass and corals and the predominance of algae. High turbidity from re-suspension of sediments reduces light levels, thus favouring algae over seagrass and coral. Examples of seagrass bed decline include Port Phillip Bay, Moreton Bay, and the coastal waters around Adelaide and Perth. Seagrasses are an important food source and a nursery for fish and prawns. When seagrass is lost, the underlying sediments are exposed and move under currents, making for slow recovery. It has taken up to 20 years in other parts of the world for seagrass meadows to regrow once suitable conditions were re-established.

Recovery of seagrass beds requires a combination of reducing sediment and nutrient inputs and restoring seagrass. Sources of nitrogen in coastal waters near Adelaide include a wastewater treatment plant, discharge from major industries, and stormwater runoff. Large-scale recovery of seagrass meadows along Adelaide's coast will require intervention, by providing appropriate settlement substrates for seedlings, transplanting of mature stock, or the harvesting and planting of germinated seedlings. Similar management controls would be needed to restore seagrasses in Perth and Moreton Bay.

Organic chemicals and pesticides

More than 20 000 human-made industrial and household chemicals are used routinely in Australia. These can enter waterways as runoff, through deposition from the air, or by direct discharge of treated wastewaters from sewerage plants and industry. Industrial discharges are usually licensed to protect the environment, and can include organic as well as chemical contaminants. Because of the sheer number of substances, it is not practical to set water quality guidelines for all of them. Guidelines are in place for organic chemicals that are discharged in high volumes or are particularly toxic.

Chemicals found in waterways include pesticides, herbicides, antifouling paints, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons. Commercial fishing in Sydney Harbour is currently banned due to the build-up of toxic organochlorine chemicals in fish and prawns. These contaminants originate from former industrial sites, are leached from contaminated soils, or are deposited in the Harbour through eroded sediments. From the sediments, they accumulate in the tissues of the aquatic organisms.

Pesticides can be broadly grouped into chemicals used to control weeds, insects and fungi (i.e. herbicides, insecticides, and fungicides). In common with most developed countries, Australia continues to be a large user. Pesticides find their way into waterways either as spray drift or in

Aerial spraying, Virginia, South Australia. Photo: Greg Rinder, CSIRO.

runoff. In some cases, they are even used to control water weeds. As well as targeting unwanted weeds and pests, these chemicals are also a hazard to aquatic organisms, even at very low concentrations. Residues from the use of now-banned compounds such as DDT, chlordane, and dieldrin are remarkably persistent and can still be found in both water and sediments.

Reducing the pollution from pesticides and other chemicals can be achieved in three ways: replacing them with less persistent chemicals; recycling or storing water onsite to prevent discharge into waterways; and reducing use through new agricultural and industrial practices. The original persistent pesticides have now been replaced by ones that degrade more rapidly after performing their desired function. Glyphosate (or 'Roundup™') is now the most common herbicide in Australia and degrades within a few days.

Historically, the cotton industry was one of the biggest users of pesticides, and was associated with numerous fish kills from the use of endosulfan (a pesticide that is toxic at parts per trillion concentrations) but all three treatment mechanisms have greatly reduced the risks. Endosulfan is gradually being replaced by the less persistent chlorpyrifos and cypermethrin, and water used in cotton growing is now retained on the farm, although there is still risk from aerial spray drift. The use of genetically modified strains of cotton, commercially available in Australia since 1996,[16] have reduced insecticide use by as much as 80% compared with conventional cotton.[17] These new varieties contain proteins from a soil bacterium that confer insecticidal properties to the whole plant.

Pathogens

Pathogens are disease-causing organisms that end up in waters due to the discharge of sewage effluents or as diffuse inputs from animal wastes. They comprise a wide range of living microorganisms including bacteria, viruses, and protozoa. Very stringent regulations apply to ensure that drinking water supplies are adequately treated and are free from microbial contamination.[18] These include managing pathogen sources and pathways of transport within the catchment, and multiple treatments (see future urban water supplies chapter). For instance, animal wastes from grazing livestock can represent a significant source of pathogens to water reservoirs, which is why many of Australia's urban water supply catchments have strict land use restrictions and largely retain natural vegetation cover, thereby maintaining very high water quality.

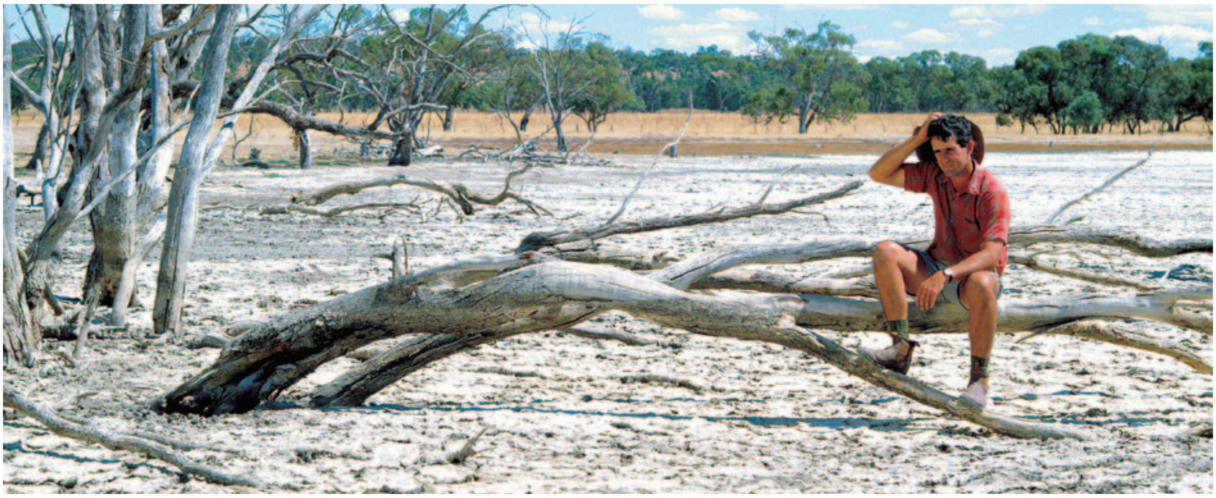
Because there is a very wide range of potential pathogens, routine analysis of each pathogen is not feasible, so indicators such as fecal matter are used to monitor microbial water quality. Currently, microbial tests are slow to perform and at best take 15–24 hours because they rely on culturing the bacteria. This leaves a delay before contamination can be managed. A major goal, therefore, is to develop rapid analytical techniques for pathogens and indicator organisms to enable a more rapid response. This could be most useful for applications in potable recycling.

Metal contaminants

Metal contamination from point sources include mining and mineral processing activities, as well as from specific industries with metal-containing wastes, such as fly ash from coal combustion. Many Australian examples are largely associated with historical contaminations, when regulatory controls were poor or non-existent. Examples include the lead/zinc smelter at Lake Macquarie (New South Wales), lead smelting at Port Pirie (South Australia), zinc refining in Hobart (Tasmania), and copper mining and processing near the King River and Macquarie Harbour in western Tasmania.[19] These extreme cases had serious impacts on aquatic ecosystems. In addition, metals accumulated to alarmingly high concentrations in some organisms. For example, in the 1970s, oysters from the Derwent River in Tasmania were grossly contaminated with zinc discharged from a local smelter and were unfit for human consumption.[20] Metals, unlike most organic contaminants, are persistent and do not break down with time, so prevention at source is preferable to remediation, which can be both very expensive and slow.

Active mining sites in many areas of Australia contribute low concentrations of metals such as copper, lead, zinc, nickel, and uranium to local waters, but such releases now have to meet strict regulatory control and only in extreme cases do concentrations exceed water quality guidelines. Typically mining wastes are retained in sealed tailings dams and are not discharged to the environment.

Urban and residential areas are diffuse sources of trace concentrations of metals (parts per billion levels) to waters, which can lead to a complex mixture of contaminants. For instance, stormwater runoff from roads carries zinc from tyres and copper from brake linings. Dissolved zinc is borne by rainwater washing galvanised metal roofs and quantities of dissolved copper



Rising groundwater tables affecting salinity, Griffith, New South Wales. Photo: Bill van Aken, CSIRO.

originate from the slow leaching of water pipes. Many metals are essential nutrients for humans and aquatic organisms, particularly copper (Cu), cobalt, zinc, and iron. Although organisms are reasonably tolerant of higher than normal iron concentrations, excesses of the other metals can be quite toxic even at part per billion concentrations. Metal toxicity is largely associated with certain chemical forms of the elements: in particular, the free metal cations (e.g. Cu^{2+}).[21] Analyses that determine only the bioavailable and potentially toxic fractions of metal contaminants are now being used to better specify the risks to ecosystem health and ensures that industry is not subjected to unnecessarily strict discharge controls.

Acid sulfate soils

The polluting effects of acid sulfate soils were realised when fish kills and fish disease (e.g. red spot ulceration) were observed. Acid sulfate materials are found naturally and typically form under waterlogging of organic sediment (such as mangrove mud), which causes iron sulfides to form. Left undisturbed, these soils are harmless, but when excavated or drained, the sulfides within the soil react with the oxygen in the air to form sulfuric acid. The acid can dissolve metals such as aluminium and, if discharged to rivers and estuaries, the combination of metals and acidity can kill plants and animals, contaminate drinking water and food such as oysters, and corrode concrete and steel.

Acid-forming soils can be found at many coastal locations and are particularly prevalent in northern New South Wales and Queensland, associated with organic mangrove sediments. The millennium drought exacerbated the problem of acid sulfate soils in the Lower Lakes and wetlands along the Murray River, where the drop in water levels exposed sulfidic materials. Acid formation was mitigated by careful management of water levels and the addition of lime to some rivers and creeks that drain into the Lower Lakes. Recent re-flooding of the acid materials seems to have occurred without harmful acid discharge.

Groundwater contamination

Groundwater contamination occurs through accidental spills and other unintended releases of chemicals, which move downwards through soils into underlying groundwater. It can pollute drinking water supplies, irrigation water, and ecosystems, where groundwater discharges to surface waterbodies. The slow movement and lack of mixing and dilution in groundwater can preserve high concentrations of pollutants for decades and at distances well away from the initial source so, again, prevention is the most effective management option.

Groundwater pollutants include organic liquids such as petroleum fuels and industrial solvents (e.g. perchloroethene, which was used for many years by the dry-cleaning industry and in plastics manufacturing). Petroleum fuels are less-dense than water so they float on the groundwater table. Some solvents are denser than water and sink below the water table towards the base of aquifer systems. Both types of organic liquids slowly dissolve into groundwater over decades to centuries.

Remediation of groundwater pollution can be achieved by biodegradation; for example, by using bacteria that can consume organic contaminants such as benzene, but they require the correct chemical conditions – such as an abundance of oxygen, nitrate or sulfate. Establishing an artificial barrier across the leading edge of a pollution plume can reduce contaminant transport. Such barriers are expensive to install, but low ongoing costs make them financially attractive. Permeable reactive barriers allow some throughflow of water but contain active ingredients that can degrade or immobilise contaminants.[22]

Removal of service station fuel tanks which can leak into groundwater, Perth, Western Australia. Photo: Bill van Aken, CSIRO.

Monitoring water quality in Lake Wivenhoe, Brisbane, Queensland. Photo: CSIRO.

Emerging contaminants

New chemicals are introduced continually, but only a small proportion of them are routinely monitored in water. The release of emerging chemical or microbial contaminants may have gone unrecognised for long periods until new, more-sensitive analytical detection methods were developed. Studies in the United States of America and Europe show that a broad range of chemicals found in residential, industrial, and agricultural wastewaters commonly occur as mixtures at low concentrations in rivers and streams. The chemicals detected include human and veterinary drugs, natural and synthetic hormones, detergent metabolites, plasticisers, insecticides, and fire retardants. Similar results are now being found in Australia. The presence and significance of such contaminants is particularly pertinent to water recycling.

Low levels of certain pharmaceuticals in the environment could affect aquatic life through patient use of prescription and non-prescription medicines, especially if there is little degradation or removal during sewage treatment. Veterinary chemicals may enter waterbodies through animal excreta and farm runoff. Dilution can reduce the concentration of these contaminants to below levels of concern, but the problem is exacerbated by Australia's low discharge rivers and streams.

Much recent effort has focussed on organic contaminants, which can disrupt animal reproduction or growth by modulating, mimicking, or interfering with hormones. These compounds are called endocrine disrupting chemicals. They include hormones created in the body, synthetic hormones (such as those manufactured for birth control), and industrial/commercial compounds that can have some hormonal function (such as alkylphenols, pesticides, pharmaceuticals, and phthalates). Natural estrogen is excreted from the female body in a deactivated form, but, during the process of sewage treatment, chemical changes occur that restore estrogen to its original chemical form and biological activity. A major challenge in this area is to understand how very dilute mixtures of bioactive contaminants interact with living organisms, and how interactions between contaminants may magnify biological effects.

Nanomaterials represent a new class of contaminants. They have an extremely varied composition and, because of their small size, may possess chemical and physical properties that are unlike their equivalent macro-sized forms. There is a good deal of research activity in Australia and overseas dedicated to evaluating the potential impact of these new materials on aquatic environments and to determine if they require their own water and sediment quality guidelines.

Further reading

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