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REPORT No. 56

THE EFFECTS OF LAND USE ON WATER QUALITY

(water quality

THE EFFECTS OF LAND USE

ON

WATER QUALITY

An Australian Perspective

PREPARED BY D.E.J. GARMAN

FOR THE WATER RESEARCH FOUNDATION

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by

D.E.J. GARMAN.

This report was prepared by Dr. D.E.J. Garman for the Water Research Foundation. Dr. Garman is a Research Officer with the Water Resources Commission of New South Wales to whom the Foundation extends its sincere appreciation.

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WATER RESEARCH FOUNDATION OF AUSTRALIA

This Report is the fifty sixth of a series of technical reports issued by the Foundation dealing with interesting and informative subjects associated with the conservation, use, control and treatment of water.

The opinions expressed by the author of this paper do not necessarily present the views of the Foundation on the subject. The Foundation believes however that the writer has approached his subject in a professional manner.

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THE EFFECTS OF LAND USE ON WATER QUALITY

1. INTRODUCTION

The purpose of this paper is to examine the impacts of land use and changing land use in Australia on the water quality of lakes, rivers, esturaries and groundwaters and to discuss the areas which require further research and investigation.

Although there is extensive overseas literature on this subject, (e.g. DNDE 1980), much of this may not be directly applicable to Australian conditions, in terms of population and land use. The emphasis on control of pollution from point sources, which is a feature of Australian States' pollution control legislation and its enforcement, further reduces the relevance of many papers in categories such as agricultural industries - including feedlots, piggeries and abattoirs; septic tanks in major urban areas; mining; and some urban development. Legislation to control point sources of pollution has now been enacted in all States.

Thus the major emphasis in this paper will be on pollution from non point or diffuse sources with some attention being drawn to intermittent point sources.

Water quality is a single component in a multifactor natural resource system. Development or change in the resource system must lead to some impact on water quality due to the resulting close interaction on parts of the hydrologic cycle. In many cases the demographic and economic uncertainties of a change are very much greater than the uncertainty in assessment of the impact on water quality. However as great an uncertainty as the social effects lies in the problems associated with the impact of changes in water quality on other natural systems. Although some of the ramifications of the effects on biological systems will be mentioned, the assessment of total biological impact is little studied and understood. How much impact we are prepared to allow in terms of man's role as a competing biological entity is a philosophical question which will not be entered into here. The tolerance and adaptability of other biological species to man's activities has not been extensively studied.

It is becoming increasingly apparent to many people that the fresh-unpolluted water resources of the earth are limited. To allow them to become "polluted" will mean an increasing commitment of energy and resources to recover one of the most essential minerals to man. Thus preservation and protection are better than cure and the side benefits which accrue can be seen to be considerable in terms of enhancement of life in its broadest sense.

To lay a basis for the following discussion a brief survey of land use - water quality interactions is summarised in Table 1. The table has been prepared with the assumption that discharges from point sources have been controlled so that there is minimal impact from these on the receiving waters. Thus only diffuse or intermittent point sources are considered.

The land uses which can be readily identified are:

- changes in urbanisation including subdivision;
- changes in agricultural practice or introduction of agriculture;
- other changes in land use e.g. for provision of

  reservoirs
  recreation
  industrialisation
  national parks
  forestry and related activities
  access roads

TABLE 1

SUMMARY OF LAND USE - WATER QUALITY INTERACTIONS

(Assuming control of point source discharges)

	Surface Waters									Underground Waters							
	Salinity	Eutrophication	Deoxygenation	Colour	Bacterial	Sedimentation	Turbidity	Pesticides	Chemical	Salinity	Eutrophication	Deoxygenation	Colour	Bacterial	Turbidity	Pesticides	Chemical
Urbanisation	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*
Agriculture	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*
Industrialisation inc. mining	*			*		*	*		*	*			*				*
Forestry	*	*		*		*	*	*		*							
Reservoirs	*	*	*		*												
National Parks	*	*			*		*	*									

Interactions may be beneficial or deleterious (see text)

The aim of this document will be to summarise the effects of the following aspects of water quality and to comment on their relevance to Australian conditions:

salinity
eutrophication
deoxygenation
colour
bacterial contamination

pesticide contamination
chemical pollution
suspended sediment loads

Increases in salinity of water, usually in the form of increased concentrations of sodium chloride, can make water unsuitable for human consumption or domestic use.

It can render it unsuitable for irrigation due to the absorption of salts by plants, changes in the water-root uptake because of increased osmotic pressure and accumulation of salt in soils. Salt sensitive plants may be unproductive and yields affected in other crop species. In extreme cases the water may also be unsuitable for stock use.

Eutrophication is caused by the addition of nutrients, particularly nitrogen and phosphorus, to water so that increases in plant growth occur. The term is usually used to infer that excessive undesirable growth (such as an algal bloom) takes place.

The consequences of this are that extremes of oxygen concentration occur from day to night and undesirable, sometimes toxic, algae occur. Fish kills, stock deaths, minor gastrointestinal complaints and skin irritation have been attributed to the presence of these algae.

Colour changes can occur because of increasing amounts of organic or inorganic compounds. Organic compounds such as oils from eucalyptus species or synthetic chemicals may increase colour values. So will inorganic compounds such as iron salts which could be mobilised by sediment transport.

Bacterial contamination - this generally refers to contamination of waters by possible pathogenic organisms. An accepted indicator of the presence of these is the organism Escherichia coli (E. coli) which can show if faecal pollution of water by warm blooded animals has occured. The interpretation of the results showing the presence of this organism however requires great care and usually a great deal more bacterial identification work than usually reported. The presence or absence of

E. coli organisms does not necessarily indicate the respective presence or absence of pathogenic organisms but rather is useful for monitoring faecal pollution.

Pesticides and herbicides - the greatest concern is usually expressed about the presence of chlorinated hydrocarbons compounds which may be persistent for long periods of time.

Most other pesticides have shorter term persistancy and cause less serious long term problems. The chlorinated hydrocarbons because of their stability may cause problems by accumulation in plants and animals. These compounds can be carcinogenic, teratogenic or have other undesirable side effects in many organisms. Despite this knowledge of specific interactions the extent of detrimental effects of compounds such as DDT are not known.

Chemical pollution - for the purpose of this discussion chemical pollution refers to the presence of chemicals other than those specified above, and not naturally occuring.

Particular problems have been identified as those relating to polyaromatic hydrocarbons and other organic compounds usually associated with industrial processes and not generally found in the environment, and heavy metals derived from mining and processing activities.

The impact and fate of many of these compounds have not been identified. Teratogenic and carcinogenic properties have been ascribed to many of these compounds but their action at very low concentration is not well understood.

As with pesticides, the effects of heavy metals may result from bioaccumulation. Heavy metals may remain in a toxic form and unlike many pesticides are not necessarily converted to less toxic forms by bacteria. At high concentrations the metals may be toxic while at lower concentrations there may be effects on fertility, viability of eggs and larvae of susceptible species and cause undesirable physiological effects.

The elements generally referred to as heavy metals include, arsenic, barium, cadmium, chromium, copper, lead, manganese, mercury and zinc.

Erosion and sedimentation - The loss of soil from land can lead to a number of problems for water quality. The soil particles themselves can cause increased turbidity and also sedimentation on the river bed and in dams.

Turbidity changes the optical properties of water and markedly reduces the productivity of waters. Some animals dependent on visual acuity for survival are unable to live in turbid waters and many plants die under turbid condition. Turbid reticulated water is generally unacceptable to consumers.

Suspended sediment can smother plants and deleteriously change the bottom characteristics of water ways. Bed loads may increase and their redeposition may cause loss of capacity in storages.

Adsorption of chemicals on to sediment is also the major mechanism for their transport. Nutrients, heavy metals, pesticides and other chemicals have all been identified as being closely associated with sediment.

Deoxygenation - inorganic and organic compounds can require oxygen for their conversion to other compounds. Their rate of conversion and therefore oxygen demand depends on the bacteria present and the temperature. A measure of the possible oxygen demand is often assessed using the biochemical oxygen demand test (BOD) over 5 days. While the test is intended to show the oxygen demand from organic carbon compounds, unless precautions are taken it may also show oxygen demand by inorganic compounds.

Low oxygen concentrations may stress aquatic life and in the absence of oxygen, anaerobic bacteria can cause obnoxious taste, odour, and colour characteristics.

1.1 Australian Research

A review of the "Effects of land management on quantity and quality of available water" was undertaken as a research project for the Australian Water Resources Council (Boughton 1970) and summarises most of the available literature from overseas and surveys the limited activities in this sphere in Australia at that time.

The Inventory of Water Resources Research in Australia (AWRC 1979) lists about 80 projects which are directly concerned with the effects of land use on water quality. A breakdown of these topics into separate classifications is given in Table 2 together with the type of organisations undertaking the research projects.

TABLE 2

Investigations of the interaction between land use and water quality presently in progress in Australia.

(Source: Inventory of Water Resources Research in Australia 1979).

Classification	No. of Projects
Urbanisation	11
Subdivision	4
Spills	2
Land Use (general) (including urban watersheds and eutrophication)	10
Agriculture	8
Forestry, clearing and associated mining	20
Irrigation	6
Recreation	1
Dams	5

Movement of pollutants	6
Rainfall	10
Burning	1
	84

This listing is however apparently incomplete as a number of organisations and research studies are not listed. For Victoria alone this number could amount to as many as 80 projects (Bolto 1980 pers. comm.), although not all of these would be directly related to land use and water quality.

The significance of this table in terms of research effort applied will be discussed later in the paper. It is sufficient to note that a significant amount of effort is being applied to investigating this problem in Australia.

2. EFFECTS OF URBANISATION ON WATER QUALITY

Water quality problems which arise from urbanisation are often of minor significance in terms of water resource preservation. They are generally related to aesthetic and recreational considerations although some more significant problems have been found.

Australia is fortunate that the majority of its population lives near the coast because it has meant that many problems of urbanisation which have been experienced in Europe and America have had a much smaller impact here. These problems have been associated with the need to dispose of sewage, urban stormwater and industrial wastes to rivers great distances from the ocean often using international rivers as waste receivers. While treatment of large volumes of sewage to extremely high standards has recently become feasible the capital costs involved have deterred many overseas authorities from embarking on this course. Traditionally major Australian cities have outfalled their treated or partially treated sewage to the oceans. The one significant exception to this is the Werribee Sewage Farm in Melbourne.

The purpose of this section is not to examine the impact of these methods of disposal on water quality but to look at the trends in population development which have changed generally accepted views on urban growth and water quality, to review the problems which could arise and those which are already being encountered.

The metropolis of Sydney has typically experienced some of these problems. Expansion of the residential zone in the outer western suburbs and the creation of new towns some distance from the ocean has meant that the sewage is no longer readily able to be discharged directly to the ocean through existing ocean outfall systems. In many cases rapid expansion of smaller existing sewage treatement works has occurred. These works discharge to the rivers or upper reaches of estuaries and in the absence of adequate dilution or nutrient removal facilities, problems of eutrophication have occurred. Inadequate planning of this development has meant that only now are significant results being obtained which could provide data for strategies to solve some of these problems (SPCC 1977, 1979).

In addition to this, problems have occurred from sewer overflows in areas which are generally considered adequately provided for in terms of sewage reticulation. Recently the contamination of shellfish from this source in the Sydney region led to a number of serious gastric illnesses. Decontamination facilities are now provided to ensure that this type of contamination does not occur again.

It has been assumed by many designers of such sewerage systems that sufficient dilution of overflows exists under all conditions. The problems of small overflows may be confined to ones of dilution but if they are of sufficient number or size, difficulties such as those recorded in the Lane Cove River may result [SPCC 1980(a)].

In wet weather conditions the pollutant load of runoff from the urban area draining into that river may be many times that of the sewer overflows and the dilution is generally very large. However, it is possible for the sewage overflow to operate because of wet weather conditions at the head of the sewerage system while at the point of surcharge some kilometres away, the absence of wet weather runoff and therefore dilution has resulted in significant pollution of an estuary when it may be in demand for recreational use.

The matter of location of sewer overflows, the provision of treatment if necessary and the definition of their impact on water quality are subjects which have received little attention until this recent study.

While again there have been many studies published overseas on the effects of urban runoff on water quality very little has been reported for Australia. The types of pollutants are very broad and include street litter, decaying vegetation, rubber and metals from vehicles, hydrocarbons, industrial fallout and chemicals applied to parks and gardens (Brown et al. 1979).

Reports of studies have contained a certain amount of extrapolation (MMBW 1973) or only deal with briefly sampled investigations (Brown et al. 1979) or have shown results which differ considerably in quality characteristics to runoff found for other catchments (Corderey 1977). Data for nutrient loads from urban catchments around Lake Burley Griffin in Canberra (Cullen et al. 1978) have shown that those catchments did follow the classical pattern of high pollutant concentration being associated with the initial flush, with little base flow load.

However all these studies indicate that it is the antecedent weather conditions and the intensity and duration of the rainfall which are the most significant factors associated with the amount of material transported. Identification of other variables which lead to changes in water quality of the runoff have not been examined in detail although the study along these lines is presently being undertaken by Walter (1979) dealing with the Melbourne Area.

More recently exhaustive studies on these aspects in Eastern Australia have been undertaken in and around Canberra where a detailed basin study has resulted in valuable data being compiled on the effects of urban density on water quality characteristics (NCDC in press).

Parallel studies on the eutrophication of Lake Burley Griffin have also revealed important water quality characteristics of urban pollution including not only the effects of urban runoff but also the effect of sewage wastes on lake eutrophication (Cullen et al. 1978).

There have been many plans for control of urban runoff in new and developing cities. The application of storm water detention ponds and their use as recreational impoundments or aesthetic lakes in Canberra has received a great deal of attention. There the successful operation of the urban lakes or ponds appears to indicate that some degree of control of the water quality of urban runoff can be achieved.

Whether this type of treatment can be further applied to existing stormwater systems and the costs of providing these requires further study.

Design of these systems requires good hydrologic runoff data for catchment areas. Canberra's relatively high proportion of unpaved area in their urban catchments has meant that the passage of flood peaks can be more reliably estimated than for urban catchments with higher proportion of paved or covered surfaces.

The need for a better understanding of hydrological processes for design of urban stormwater systems has been identified by the Australian Water Resources Council as a matter of importance and it has funded two recent studies on this subject (Black et al. 1977; Moodie 1979).

This controlled development in Canberra is in marked contrast to that which has occurred in some of the catchments of reservoirs around Adelaide. Virtually uncontrolled development in the past has necessitated plans for extensive treatment of the water supplied to

Adelaide from these catchments which supplement the relatively poor potable quality of water provided from the River Murray. A revised management plan has recently been published by the Engineering and Water Supply Department (EWS) which is reponsible for water pollution control.

It has been argued that the costs of the provision of water treatment where there is deterioration in quality because of development in a catchment should in part by met by the developers of such land. Such imposition of costs could produce either a completely undesirable high density region or alienation of the community looking for development land. The absence of suitable data on which to base an estimate of the cost would also be a major weakness.

There have been arguments advanced that subdivision of blocks within water supply reservoir catchments must inevitably lead to deterioration of the stored waters (Williams 1977). This has in part been substantiated by experiences in South Australia.

Recent investigations in the catchment of Googong reservoir near Canberra have indicated that in catchments which had potential erosion hazards, the subdivision of the land has led to decreased erosion. This has been due to intensive tree planting, absence of intensive grazing with effectively lower rates of stock and also greater attention to the smaller areas by ecologically conscious families (Starr 1980 pers. comm).

Haughey (1979) has highlighted the problem of accidental spills of dangerous and noxious chemicals from transport systems, the worst problem being that of road transport. He has discussed the impact of these events on surface waters but a far greater hazard probably exists for underground waters where dilution and breakdown occurs at much slower rates.

There are systems for coping with problems such as accidental spills into the stormwater systems of some cities and towns located on important underground aquifers. However thoughtless hosing down may have seriously polluted the aquifers beneath cities such as Mt. Gambier in

South Australia (Wood et al. 1980). Where water resources are drawn from the same aquifers as those to which surface runoff is disposed, extensive treatment may be required to restore the quality of water for potable use.

Similar pollution of underground water by nitrogen compounds in urban waste and stormwater has also been identified. The extent of this from urban sources has not been distinguished from nitrogen from other sources such as nitrogen fixing plants including native and introduced species such as clovers.

In Western Australia the effects of groundwater pumping to maintain gardens during periods of water restrictions and to minimise water charges has led to problems with the natural lakes in the Perth Basin. The water levels of these lakes have been drawn down at times to such levels so as to damage the ecosystems associated with them. Proposals for artifically recharging these systems by using treated wastewater have been investigated. However the increasing salinity of Perth's water supply (see Section 4.2) coupled with the increase in salinity which occurs during its use - an increase of up to 300 mg sodium chloride per litre, may affect the viability of salt sensitive plants.

Reuse of waste water was practised at Angle Vale Winery using water from Adelaide's Bolivar sewage treatment works for irrigation of vines..

Effective winter rainfall provides adequate leaching of the soil to reduce salt build up in the root zone which may be caused by the salinity of Adelaide's water supply which may be quite high.

A similar hazard may exist if the use of waste water for recharge of the North Adelaide plains aquifers (Manoel 1980) is pursued. The long term salt build up may have to be closely monitored to avoid problems from this source.

3. RESERVOIRS

3.1 Reservoirs - Water and Land Use for Recreation

There is a great deal of debate on whether or not recreational use should be permitted around reservoirs, especially reservoirs which are direct sources of urban water supply. Guidelines have recently been proposed by the Health Commission of New South Wales (HC 1978). Recent reviews of these factors have also been presented (Lane 1980; Burton 1979).

The questions which need to be evaluated are:

- is there a demand for recreational space or activity?
- is there a likelihood of contamination of the water supply?
- will the use of the reservoir or its foreshores create additional management problems?

There is no simple answer to the first question. To assess whether the life style of people will be significantly improved by the provision of recreation facilities at or on reservoirs requires a type of sociological investigational procedure which is extremely complex.

The major risk identified is that of potential contamination of the water supply by micro organisms. It appears that recreational use of the water and its immediate foreshores does lead to an increase in the number of micro organisms in the water.

However what is not quantified is the increase in health risk which is associated with these increases in micro organism numbers. There do not appear to have been any epidemiological studies in Australia of health risk associated with the direct contact of recreational use of waters for swimming or indirect such as boating or fishing and most studies rely on the use of indicator organisms.

There is always a risk that contamination could occur whether or not a closed catchment policy and closed reservoir use are practised. Deliberate contamination has been threatened in some instances and it is unlikely that it could be actually prevented. There have been no reports of it actually occurring in Australia. Accidental contamination could occur but the risk depends on the degree of treatment available before reticulation.

The multiple reuse of water which naturally occurs by return of treated sewage effluent to rivers and the greater possible risk of further contamination from animals and humans before treatment and reticulation suggest that, provided there is no likelihood of direct contamination at the actual offtake point, there are no good health reasons for preventing recreational use of either the foreshores or the water.

In most cases the suitable location of swimming and boating areas and the prevention of these activities in the vicinity of the water offtake should provide more than sufficient dilution and time for die off of micro organisms. As the extent of treatment of the water supply increases greater relaxation of the restrictions could be allowed.

A degree of risk is possible if there is either a breakdown of the treatment process because of equipment failure or for industrial reasons. In these instances it would be relatively simple to restrict recreational activities until treatment had been restored.

The final point is a matter of the cost and the management difficulties associated with the degree or type of recreational use.

If recreational facilities are provided the cost of these and the associated works could become a significant proportion of the cost of building and maintaining the storage.

For example the provision of ablution facilities, boat ramps, camping areas, roads and treatment of wastes will require a considerable capital outlay. The running costs could well decide whether or not the facilities are provided. It has been reported that vandalism alone could significantly affect the running costs.

In some instances Governments have recognised this by providing specialised permanent staff to undertake the day to day operations. This has appeared to work well at New South Wales Water Resources Commission storages where staff of the National Parks and Wildlife Service provide these services. In the cases where similar support is not given a decision would be required to determine whether or not the authority concerned would be prepared to subsidise the provision of these facilities through the income derived from its clients or whether charges would be levied on users at an "at cost" basis.

A policy of recreational use of water supply reservoirs should be on a step wise basis and should be accompanied by detailed water quality monitoring programmes and possibly accompanied by an epidemiological investigation.

If there is sufficient demand shown by potential users in the absence of Government subsidy for this the cost should be borne directly by the users.

3.2 Reservoirs - their Impact on Surface and Underground Waters

The secondary effects of reservoirs can be important in terms of the resultant quality in the surface waters downstream.

The most obvious effect is the storage of water under a variety of flow conditions to give a mixture which is generally more representative of high flows in the river prior to impoundment. This is generally a beneficial impact.

However the storage can also create lowered water temperatures downstream. Where the stream is used for trout fishing this can have a beneficial effect provided oxygen concentrations can be maintained at high level. However for Australian native species lowered water temperatures can inhibit their breeding and discourage their presence. Temperature differences can be as much as 12° lower than ambient in summer when breeding would be expected. This coupled with variations in flow patterns related to water supply requirement, can disrupt the ecology of the river for many kilometres. With a 12° difference in temperature at a flow of 1000 ML/day it requires about 100 km to achieve temperature equilibrium for a number of N.S.W. Water Resources Commission storages.

Similar results have been reported for Lake Hume on the Murray River (Walker et al. 1978).

These effects can be ameliorated by the use of destratification, providing both better temperature and oxygen regimes downstream or the incorporation of multilevel offtakes in the outlet structure (Burns 1977, Bowles et al. 1979).

While storages generally decrease the salinity downstream in some cases they increase it. Where a storage can affect the groundwater and it is saline, the resultant pressure increase in the aquifers can induce saline accessions to the river downstream.

Problems of this nature were anticipated for the Chowilla Dam project which was subsequently defered for various reasons. Saline water interception works are proposed to mitigate such a problem in the Rufus River caused by stored water in Lake Victoria (Maunsell 1979).

Other effects related to the trophic status of reservoirs are well reviewed by Wood (1975). While there are many monitoring programmes in Australia a compilation of the adverse effects in Australia and other recommendations contained in the report have still to be undertaken.

4. EFFECTS OF AGRICULTURE ON WATER QUALITY

If point source discharges are controlled the major impac which could influence water quality are:

- erosion and sedimentation resulting from clearing (overstocking;
- increased salinisation of land and the subsequent effect on water quality;
- leaching of fertilizer derived nutrients to surface an underground waters;
- forestry activities.
- deposition of herbicides and pesticides in water;

The quality aspects of agricultural runoff and drainage have recently been reviewed for the United States by a special task committee (Kelman 1977).

While there have been a number of papers which have related various aspects of agricultural runoff to water quality the absence of a single comparable publication on this subject for Australia indicates both the absence of suitable source material and the lack of interest in this subject by many authorities and academics until quite recently.

4.1 Sediment

Sediment has been identified as the most important water pollutant from agriculture. Sediment not only represents a loss of soil and subsequent loss of cropland but it also transports nutrients, pesticides, pathogens, organic and inorganic matter. Of the load washed into streams each year, about 2 billion tonnes, in the United States it has been estimated that half reaches the oceans or estuaries (Kelman 1977).

Loss of nutrients from agricultural areas to watercourses not only creates problems for the water but also for the productivity of the land, which in Australia generally already has a low nutrient status (Jackson 1966).

Loss of sediment from major catchments has received only limited attention in Australia. There is also little information on the water quality changes associated with this.

Papers in this field in Australia have been mainly concerned with small rural catchments and the effects of soil conservation measures. The characteristics of sediment transport with changes of flow have been particularly well investigated by some workers, although not directly related to land use (Loughran 1978, Geary 1979).

The extent of instrumentation and data collection required to understand the processes involved in changes in runoff and erosion with different watershed management procedures formed the subject of a recent report by the Water Research Foundation of Australia - Project 77/389, (1980).

There are few data on sediment loss from arid zones although such investigations have been extensively undertaken overseas. Similarly the loss of sediment from Australia's major river basins have only been the subject of a few papers (e.g. Kriek 1976). This latter report also illustrates the problems associated with estimation of sediment loads. A series of sediment-flow relationships have been developed for major sites within the Hunter River Basin and an attempt at relating these to known regions of soil erosion has been made.

Another estimation of sediment transport has been undertaken from the Shoalhaven River (McAlister et al. 1977) using an investigation of sediment grain size in the river bed.

The difficulties with the interpretation of such data are that if processes other than catchment erosion - such as stream bank erosion, are significant, the data can seriously misdirect the remedial measures.

However, it has been reported that 51% of the total area used for agricultural and pastoral purposes in Australia is in need of some form of soil conservation treatment under existing land use. Only 0.5% of this total area in Australia has received treatment although 29% is assessed as requiring treatment (DEHCD 1978) by soil conservation works and the remainder requires the incorporation of sound land management practices.

While not all this area would produce significant impact on water quality the areas involved are considerable - 2667 000 km^2 in the non arid zone and 1850 000 km^2 in the arid zone. These were the areas identified in June 1975 and represent, it is claimed, considerable progress since soil conservation activities commenced in the 1930's (DEHCD 1978).

4.2 Dry Land Salinsation

Dry land salinisation may affect as much as 200 000 ha of semi arid and sub humid country in Australia (Mabbut 1978). It is common in south western Australia but also occurs in Victoria and other eastern States. The figures quoted in an earlier publication are 9700 km^2 in the non arid zone and 1100 km^2 in the arid zones (DEHCD 1978).

Mulcahy (1978) has reported that evidence of this kind of salinisation in south Western Australia was first noticed through its effects on water quality. The first reports date from 1897 and indicated increasing salinity in water supplies.

The major problem resulting from this salinisation in Western Australia is the increased salinity of the water supply to Perth although the effects on agriculture are also significant.

There is considerable evidence that the salinity of streams in the region was considerably lower before the Europeans arrived and that the salinisation has occurred in recent years due to reduced evapotranspiration brought about by removal of the tree cover through land clearing for pastoral activities, logging, and mining operations.

The rising groundwaters have mobilised salt from the lower strata. The origin of this salt, mainly sodium chloride, is from cyclic salts in rainfall which have been reactivated by the interruption of the hydrologic cycle.

Peck (1978) has reviewed the effects of salinisation on land and streams throughout Australia although the areas quoted may now be underestimated and the extent of water quality impairment is not well documented.

In Victoria it has been estimated that "primary" dryland salinisation affects 122 000 ha with saline flows commonly occurring. Primary salting refers to that which was present under natural conditions and secondary salting to that which derives specifically from changes in land use. Since primary salting may be exacerbated by land use changes there is overlap of these arbitary classifications. Secondary salinisation affects about 85 000 ha (Mitchell et al. 1978).

A review of dryland salting in Victoria has been recently undertaken (Jenkin 1979, 1980). Although the equivalent detail is not recorded of the effects on water quality in the region, some reports are available (Graham, Fricke 1979).

In the Hunter River Valley of New South Wales significant areas of salinised soils have been identified and groundwater accessions can at times impair the quality of water in the River in the lower reaches under low flow conditions. Here the salinity appears to be derived from connate salts associated with marine sediments (WRC in preparation). Land clearing may have allowed watertables to rise and exacerbated saline flows to streams.

4.3 Irrigation and Salinisation

Water quality problems are often associated with irrigation.

There are many irrigated regions throughout Australia but the long established large scale developments along the Murray River in south eastern Australia are the ones most intensively studied.

These problems have arisen as a result of rapidly rising groundwaters through irrigation in these semi-arid regions where the soils and groundwater naturally contain high concentrations of sodium chloride. The geology, geomorphology, land use and agricultural practices have been the subject of an Australian Academy of Science symposium (AAS 1974) and a symposium organised by the Royal Society of Victoria (RSV 1978).

More recently an evaluation of engineering works to ameliorate some of the water quality and other problems was undertaken by Maunsell and Partners for the River Murray Salinity Study Steering Committee (Maunsell 1979).

The main irrigation problems in the Murray Valley can be summarised as:

- high watertables and land salinisation in the Riverine Plains and

- high river salinities in the Mallee zone.

High water tables adversely affect plant growth and thus agricultural productivity and where the groundwaters are saline the problem is exacerbated (Maunsell 1979).

Accessions of saline drainage flows and groundwaters to the river increase the salinity of river waters which may create problems further downstream.

The report states that the total annual salt load in the water flowing to South Australia as measured at Lock 6 is reckoned to be about 1.1 million tonnes of which 250 000 tonnes comes from drainage inflows, a similar amount from groundwater inflows and the remainder, about 600 000 tonnes, from tributary inflows.

A further 500 000 tonnes of salt is added to the river in South Australia of which nearly 300 000 tonnes is diverted at irrigation and water supply offtakes (Maunsell 1979).

Under regulated flow conditions the majority of salt additions above Lock 6 from drainage returns come from Victoria, while the largest proportion of saline drainage returns are contributed by South Australia.

The effects of the disposal of saline drainage waters together with more saline tributary inflows, and groundwater accessions, both natural and irrigation induced, throughout the Murray River Basin means that excellent headwater quality of about 50 S/cm has, in 1968 reached as high as 1640 S/cm at Murray Bridge, in the lower reaches of the Murray in South Australia, under low flow conditions.

The report proposed an expenditure of $75.24 million over 5 years mainly (79 percent) to be spent on interception and disposal works as well as drainage works.

Even though the data available and the work undertaken both by State authorities were extensive, the number of assumptions used in the final analysis by the authors indicates that further research is still required before unequivocal recommendations can be made concerning the best ways of dealing with a number of aspects of the problem. Even so the report is probably the best available with the data resources presently at hand.

Typical needs identified by the consultants were the crop yield response to salinity, salt tolerance of crops and the urban effects of saline water supplies. If these factors were more clearly enumerated they might change the cost benefit ratios used for proposed works to mitigate the deterioration in water quality.

Similar problems could arise in many other irrigation areas. Intensive monitoring is required to anticipate the time when problems will actually occur and early investigation of solutions to the problems which will be posed are required. Among the problems will be those of disposal of saline drainage and tailwaters to river systems.

Even now, to keep groundwaters at sufficiently low levels beneath the root zone of plants to maintain efficient crop production, it is necessary to remove groundwater by sub-surface drainage in intensively irrigated areas in Australia. Where salinity problems also exist the problems are compounded, although no water quality problems as significant as those in the Murray River System have been reported elsewhere in Australia.

4.4 Nutrient Exports from Agriculture

The absence of suitable data on nutrient levels in general severely limited the conclusions which could be made during an assessment of eutrophication in Australia (Wood 1975).

More recently Cullen et al. (1978) have reviewed the available data in the Canberra region with particular reference to Lake Burley Griffin. Their study was ostensibly related to an urban lake but only 3% of the catchment of Lake Burley Griffen was urbanised although it received a significant impact from a sewage treatment works.

Buckney (1979) has undertaken a less detailed study of chemical loading in small rivers in South Australia and an assessment of the potential eutrophication of two reservoirs in New South Wales has been recently undertaken (Banens 1978). Both studies lack detailed data from wet weather conditions.

A study of the Yarra River was recently carried out in Victoria but also this lacked significant wet weather data (Campbell 1978).

The report by Cullen et al. (1978) presents a further asessment of eutrophication in Australia with particular emphasis on sources and sinks of nitrogen and phosphosrous.

Generally speaking, the periods of collection of data have been relatively short and the type of weather experienced during the study period may therefore only be representative of a small proportion of that prevailing in the long term.

As with urban runoff, the antecedent conditions and intensity of rainfall will have a significant effect on the transport of nutrients, especially with respect to the amount of adsorbed nutrients on suspended material.

Other sources of nutrients which have been largely overlooked have been the groundwaters associated with irrigated areas. Very high concentrations (up to 40 mg N per litre) have been reported for shallow groundwaters in the Murrumbidgee Irrigation Areas in New South Wales (Kelly 1980). The origins of these high concentrations may not be invariably related to agricultural practice. A perched water table close to the irrigation area and associated with land which had not received any form of agricultural attention had nitrate nitrogen concentrations of 45 mg/L. The land was however covered with the well known nitrogen fixer <u>Acacia sp.</u> or wattles (Kelly pers. comm. 1979).

In practice it is possible, though nevertheless somewhat undesirable, to tolerate high loads and concentrations of nutrients in water provided they do not cause problems.

For rivers, and irrigation supply and drainage systems it is the amount of algae or rooted macrophytes which can be tolerated. In the case of lakes this may not be so and questions which need to be answered are:

- at what levels are eutrophic lakes a problem for their respective uses;

- what are the most effective management decisions which would enable the eutrophic state to be changed.

In more recent times considerable effort has gone into the asesssment of eutrophication in stored waters. The original theories of for example Vollenweider (1976) have been subjects of much discussion and proposed modification but they are generally accepted as being suitable formulae for assessment of potential eutrophication in storages (Cullen et al. 1978).

The general application of these theories to reservoirs in Australia has not been comprehensively reported on although a number of papers have attempted such studies but based on limited data.

The real value of any such theory lies in the ability to predict whether or not water released from the reservoirs will create problems or whether the application of the reservoirs for such uses as recreation will be impaired.

The secondary effects of eutrophic reservoirs have many water quality implications; the most obvious is the effects on downstream water quality and the quality of water in the storage itself. General benefits of such large impoundments have been surveyed in a recent publication (WRC 1979) but some of the more subtle but nevertheless extensive impacts on water quality have not been considered in much detail, in part due to the absence of data.

For urban water supply reservoir systems for instance, an assessment of eutrophication may indicate the degree of treatment which may have to be provided, but it would be unlikely that an authority would be prepared to commit extensive capital funds to water treatment on the basis of the eutrophication assessment alone. The provision of a detailed monitoring programme before and after storage commences is the only effective way at present to determine the treatment factors required and, provided the funds are available, over-treatment will generally be the preferred option.

For releases of water for irrigation the degree of eutrophication is largely unimportant although for highly eutrophic storages some secondary impacts - fish kills, unpleasant odours and loss of wildlife may influence decisions on this subject. The high nutrient concentrations may also promote weed growth in irrigation channels with resulting increased costs to water users.

For recreation the aesthetic effects may be more important but fish kills and other problems would certainly lead to complaints.

Nevertheless however successful these theories of eutrophication may be they do not provide the fundamental overview of the best control measures which could be applied to achieve a nominated (or tolerable) eutrophic state.

The options open to management are at present - although the best management practice has yet be defined, (Weir 1975).

- control of fertilizer use in the catchment;
- provision for pre-impoundment nutrient harvesting;
- provision of nutrient harvesting in the reservoir;
- other control measures such as destratification (Burns 1968).

Many of these options are only just being explored and other possibilities such as reservoir operation (Imberger et al. 1980) and biological control are still unknown quantities as management tools.

4.5 Forestry

The effects of logging and clear felling have received a great deal of attention in Australia. This concern has been reinforced in recent times by poor management in some areas being cleared by the wood chip industry. This can lead to problems of salinisation, soil erosion and changes in water yields.

Changes in water yield and water quality as a result of forestry operations have been well reviewed (Langford and O'Shaughnessy 1977) as have the effects of clear felling on salinisation in western Australia (Mulcahy 1978). This latter aspect is considered under the section on salinisation. Wood (1975) reviewed the literature with respect to the effects of forestry on eutrophication of lakes and streams.

Recent work by the New South Wales Forestry Commission has shown that correctly managed forest operations can have a much less significant impact on water quality compared with other variables such as soils, geology, rainfall intensity and steepness of catchment (Cornish 1979).

4.6 Pesticides

The long term effects on water quality are generally restricted to pesticides which do not break down readily such as organo-chlorine compounds. These compounds are generally not very soluble in water and they are largely transported through adsorption on sediment. In this form their direct effects on water quality are small and it is the secondary effects of biological accumulation which are important.

A study of the effects of pesticide use in the lower Namoi Valley in north western New South Wales has been prepared as a combined effort by a number of government authorities and co-ordinated by the State Pollution Control Commission of New South Wales. This report is the first major study of the broadscale effects of intensive pesticide use in Australia (SPCC 1980b).

The conclusions from the study at Wee Waa in the Namoi River Valley mentioned above are of interest in terms of the effects on water quality from broad scale agricultural use of pesticides [SPCC 1980 (b)]. These are:

- residues of DDT and its metabolites in the natural waterways are mainly confined to the cotton growing area during regulated flow conditions.

- proper care in the handling of chemicals should prevent contamination from this source.

- no evidence was obtained in this study to indicate overland transport of DDT by surface drainage flows and floodwaters are an important pathway for pesticide residues in the Lower Namoi Valley.

- residue levels of DDT and its metabolites in the water and sediments of the Namoi River do not increase from season to season even after heavy and prolonged DDT applications. In Gunidgera Creek, where there is a lower through-flow than in the Namoi River, residue levels in sediments increased in non-flood periods.

- during heavy local rains some residues of DDT and its metabolites have been flushed from taildrains into the Namoi River. More importantly, during major summer floods residues have been flushed from creeks and taildrains into the Namoi River and carried downstream into the Barwon River. Residue levels previously recorded in the Namoi River System outside the cotton area are not likely to be exceeded in future floods (SPCC 1980).

The conclusions regarding pesticide concentrations and their effects on fish and birds were less precise and in general the absence of other biological information restricted the interpretation of the data collected.

Other reports of pesticide pollution from agricultural practices have arisen from orchards in the Preston River in Western Australia (Anon. 1980) and in the Murray River (Walker et al. 1979).

5. OTHER LAND USES WHICH AFFECT WATER QUALITY

Other significant factors which have been shown to have effects on water quality are caused by roads, through increased erosion and providing sources of oil, lead and other chemical pollution related to motor vehicles. In areas where there is significant snowfall there may be effects from the use of salt to de-icing roads. This has been the subject of a study in New South Wales national parks (Robins 1979) to investigate the effects of human visitation on water quality.

The effects of industrial discharges on the quality of rainfall have been shown to be significant in the overseas literature. In Australia major impacts have been recorded around Queenstown in Tasmania before controls were imposed. However since legislation has restricted the discharge of pollutants to the air, records of significant effects have been few. Many other local examples of air pollution have been recorded but there have been few reports on the effects of this on the water quality of rivers or rainfall.

An exception to this might be the discharge from the Mount Isa mine in Queensland where the plume extends many hundreds of kilometres under fine weather conditions (Milne et al. 1980) and could even affect the quality of rainfall in Indonesia (Milne pers. comm. 1978).

The effects of bush fires (Smalls 1978) have been often quoted as releasing significant amounts of nutrients to the aquatic environment and resulting in large scale erosion with consequent turbidity in water bodies. A combination of controlled burning and effective fire minimisation management techniques might have lessened the impact on water quality. This is presently being investigated by CSIRO Division of Land Use Research (AWRC 1979, CSIRO 1979).

6. DISCUSSION

This paper has outlined some of the impacts of land use on water quality. A need for more background data for Australia has been stressed to further identify and document problems, but rather than spend available funds on investigation programmes alone, options for control should be considered at a very early stage.

Soil erosion has been identified as the single most important mechanism for transporting pollutants to water and is an indicator of poor land management, especially in non irrigated regions. Salinisation of dry land areas ranks high as a major potential hazard for water quality. While the effects of salinisation on water quality are being studied widely throughout Australia sediment transport investigations are poorly supported and reported, although the extent of soil erosion has been recently summarised (DEHCD 1979).

In irrigated regions the secondary effects of salinisation and water-logging, and the impact of pesticides transported through return of tailwaters to rivers could be partly controlled either by more careful use of water and tailwater and drainage water recycling. The effects on water quality have been extensively reported only for the River Murray System although most authorities controlling irrigation have extensive records for other regions.

Pesticide pollution may not be as great a problem as previously thought although the ultimate fate of persistent pesticides is not well documented.

Eutrophication is claimed to be a significant water quality problem but there is inadequate documentation to assess the extent of the problem.

For the urban situation there is likely to be a great deal of resistance to increased water and drainage rates to implement programmes of urban stormwater quality management and treatment of sewage overflows for existing settlements. For new development, planning guidelines to minimise problems of runoff including minimising changes in catchment hydrology could possibly be implemented at little increased cost during the construction phase. It will take more detailed investigation of not only the quality of runoff water but also the impact of this quality before the public is convinced that changes involving major capital expenditure are desirable.

In Australia the concept of initial control of point source waste discharges has been successfully applied by regulation. This is the preferred approach because it minimises costs of investigation and optimises the control process.

In the United States an equivalent to this for non point source pollution has arisen from the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92 - 500). Section 208 of that Act is concerned with land use management for prevention of water pollution (Pisano 1976). It has been recognised that public participation and acceptance of this Section of the Act would be the basic ingredient for success of such a programme (Garner 1977) and best management practices (USDA 1978) were an integral part of such plans (e.g. Brown 1979, Frere 1977, Seitz and Spitze 1978).

The difficulties are to decide the best management practice for each situation, measure the effectiveness of the controls proposed, and implement the best management practice where a significant problem is identified.

Documentation of best management practices needs to be made more readily available and key factors for the recognition of the need for implementation of these are required to be published for Australia. However, it appears that for Australia, basic investigations are still needed to promote the greater awareness required to obtain the financial and other resources required to minimise the adverse effects of land use on water quality.

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