

Land use and management of water supply catchments

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Summary

Complex interactions characterize the impact of land use on water supply catchments. Catchment managers have an unenviable task in trying to balance the interest of water users with that of catchment landholders. The objective of catchment management is to adjust and manage land use in a catchment so that as far as possible an appropriate quality and quantity of water and suitable distribution throughout the year can be ensured at a minimum cost to the community.

Assessment of the necessary adjustment to the complex interactions between land use and water quality, land use and hydrology, and the balance between water treatment and catchment protection is largely subjective. Some guiding principles are proposed for use in catchment assessment and management.

Mechanisms for catchment management which may be used to achieve an acceptable solution include legislation, education and extension, physical catchment protection techniques, re-afforestation, control of land disturbance from roads etc., nutrient and pesticide control, and alternative water supply options. Future research needs are outlined.

Introduction

A catchment may be defined as an area of land which absorbs or discharges water to a particular point of a stream, storage or aquifer.

Catchment vary greatly in size, physical characteristics and the land uses practised on them. However, in all catchments, land use has some effect on the quantity, distribution and quality of water discharged. These land uses may include forestry, agriculture, urban, industrial, mining, infrastructure and recreational use. All these land uses must be considered in catchment management.

Water produced from catchments may be used for electricity generation, mining, industrial, irrigation or for stock or domestic supply. Catchment management is necessary where water is used for any of these purposes. The greatest area of potential conflict between land use and water production is likely to occur where water is harvested for domestic supply.

Examples of areas where the effect of land use on water production or quality is currently of concern are the Collie catchment in Western Australia, the Lal Lal catchment in Victoria (King 1977a), and the North Pine catchment in Queensland (Webber 1975). Interest in catchment management for water supply will increase as most new sources of water will have to tap catchments in which agricultural use at varying intensities already occurs (Local Government Department Queensland 1975). The demand for high quality water for domestic supply will increase as the population expands.

This paper concentrates on the effect of agricultural land use on domestic water supply catchments.

Catchment management

The objective of catchment management is to adjust and to manage land use in a catchment so that as far as possible an appropriate quality and quantity of water and suitable distribution throughout the year can be ensured at a minimum cost to the community.

The particular management objectives for a catchment can vary, dependent on its hydrologic characteristics, the particular use for which the water is required, the type and intensity of land use, and, for domestic supply, on the degree of treatment applied.

For example, where a domestic supply is required, a water authority would ideally take water from a stream of relatively uniform flow. The management objective would be to protect and maintain this regular flow, especially if the catchment lacked potential storage sites. If stream flow is irregular, a storage would be necessary and the management objectives would then be to prevent sedimentation and pollution of the storage and keep the irregularity of flow to a minimum.

(a) Water treatment and catchment management

The flexibility of land use management in domestic water supply catchments can vary according to the degree of water treatment applied and the period of detention in the storage. Management options could range from virtual non-use of the land for purposes other than water production where the water is untreated, through some flexibility in use with partial treatment, to much flexibility in use with full water treatment. Even with full treatment, some land use management may be necessary to ensure that accelerated erosion does not cause sedimentation of the water storage or result in excessive turbidity or in the excessive addition of other pollutants, which could greatly increase the cost of treatment.

High water quality can be achieved either by conservative land use policies which could involve constraints on present and future land use or land management, or by water treatment, the cost of which is a charge on the consumers. Some pollutants such as salts, however, are very difficult to remove with conventional treatment and changes in land use may be the only economic means of achieving high water quality.

Where land in catchments has been committed to particular uses before water storages are constructed, it would be reasonable for the level of catchment protection applied to be based on the capability of the land to withstand the current or intended use and the appropriate water treatment applied. Land in the immediate environs of a storage or stream would normally require a high level of protection.

If a desired level of water quality protection cannot be achieved by water treatment except at an uneconomic cost, and it is considered that a change in land use or management gives a less costly solution, then it would be reasonable for the water consumer to meet the cost of most land use changes.

(b) Effect of land use on catchment hydrology

In most water supply catchments, precipitation exceeds actual evapotranspiration on an annual basis. In other catchments we can manipulate the vegetation to reduce evapotranspiration.

The disposition of precipitation can be expressed as

$$P = E + T + I + R$$

Where P = Precipitation E = Evaporation

T = Transpiration I = Infiltration R = Runoff

The effect of vegetation on catchment hydrology is highly complex and varies with the type of vegetation, its density, utilization and stage of growth. Changes in either vegetative cover or soil characteristics can result in major changes in catchment hydrology affecting both the quantity of water discharged and its distribution throughout the year. For example, in an extreme situation such as following wildfire or gross overgrazing, a catchment can be changed from one providing a sustained yield of clean water to one giving infrequent flood flows highly charged with sediment. The reverse is the effect of sowing improved pastures in small catchments of farm dams, which often results in increased water use in the catchment and insufficient runoff to fill the dams.

Experimental evidence on the effect of different kinds of pastures and crops on catchment hydrology is sparse. There are a number of reasons for this, including the long-term nature of the work as catchments must be calibrated before superimposing treatments, and the difficulty of applying results generally as each catchment has its own unique hydrologic characteristics as a result of the interaction of factors such as size, shape, length, topography, geology, climate, soil, vegetation and existing land use.

Generally there is an increase in the quantity of surface discharge with conversion from forest to pasture or crop (Wu 1979) but a change in vegetation type can also lead to a decrease in runoff. An example of this comes from the Parwan Experimental Area near Bacchus Marsh, Victoria, where Dunin and Downes (1962) showed a reduction in surface runoff following conversion of native perennial pastures to an improved annual pasture of Wimmera rye grass and sub clover. Donald (1970) also reported increased depletion of water from the whole of the soil profile by improved pastures of phalaris and sub clover compared with a native *Danthonia-Stipa* spp pasture. A greater amount of water was required to recharge the soil profile under the phalaris pasture.

On cropland, soil moisture use and surface detention will vary throughout the growing period. Rotation of crops with pasture to retain soil structure, replenish organic matter and hence maintain infiltration capacity is important. Soil conservation techniques on sloping land such as contour banks, strip cropping and stubble mulching, will also reduce the rate of surface runoff and generally also the quantity.

(c) Effect of land use on water quality

This section concentrates on the effect of agriculture on water quality and some of the factors that can modify the effects. Rainfall on rural upland areas is relatively free of contaminants but water from catchments always contains some dissolved or particulate material. Some of the processes by which runoff from catchments becomes contaminated are as follows. As surface runoff moves through forest land, it will accumulate some sediment and via seepage flow it will absorb some nutrients from the soil. Water passing over grazing land on the steepest slopes, gathers nutrients and biological contaminants from animal excreta. On cropping land on lesser slopes it may accumulate more sediment, colloidal material, fertilizer residues and perhaps some herbicide or pesticide residues.

(i) Sediment and turbidity

Sargeant (personal communication) in a study of streams to Westernport Bay in Victoria, found that the suspended solid load per unit area of subcatchment was significantly related to land characteristics. He found that clearing native vegetation from soils on parent materials older than Tertiary Age increased sediment yield by about two and a half times. Australian soils often have highly dispersible clays, particularly where formed on sedimentary rocks or prior soils.

Consequently those soils are generally erosion prone and erosion often results in high levels of suspended sediment and turbidity in the receiving waters. Generally the highest levels of suspended sediments and turbidity result from storms and this is particularly important in northern and eastern Australia where a high proportion of rain falls as storms. High intensity rainfall has a high erosivity and accordingly much of the sediment arises from various forms of soil erosion during storms (Wischmeier and Smith 1978). Sediment is generally the most important pollutant from agriculture, and soil erosion from cropland is the major source of sediment in the USA (Kelman 1977). Tracks, roads and land disturbance associated with farming practices are also important sources of sediment.

Sediment is not only a physical pollutant itself but also carries pesticides, nutrients, organic and inorganic matter, pathogens, heavy metals and other pollutants into water. For example, sediment is estimated to contain 0.1% nitrogen, 0.08% phosphorus, and 1.25% potassium. Therefore for every tonne of sediment there would be 1.0 kg of nitrogen and 0.8 kg phosphorus carried into the water.

High turbidity in water reduces light penetration and therefore lowers biological productivity in water bodies. However, under conditions of low turbidity (because of reduced erosion or flocculation due to high salinity) and in the presence of sufficient nitrogen and phosphorus eutrophication of storages will occur.

Soil conservation practices can reduce sediment yield. For example, in the Eppalock catchment in Victoria, an intensive soil conservation program involving pasture improvement and erosion control partially restored the hydrologic balance and reduced sedimentation of the reservoir from 617 000 m³/yr to 706 000 m³/yr in the first seven years of the project. Even where gross soil erosion is not evident, sediment and turbidity may still cause problems to water users. The dilemma is often that an acceptable soil loss to the farming community is unacceptable as a water pollutant to domestic consumers.

(ii) Nutrients

Nitrogen and/or phosphorus are most commonly the limiting factors for aquatic growth in lakes or storages. Agricultural runoff is the greatest contributor of nitrogen and phosphorus to water (Kelman 1977). The major sources of these nutrients are applied fertilizer, animal excreta, mineralization of organic compounds, and legumes.

Phosphorus is generally carried into water adsorbed to clay colloids, except in sandy soils where it may be dissolved and enter directly into the drainage water. Nitrogen is more soluble and enters water primarily in a dissolved form. Dissolved phosphorus in agricultural runoff rarely exceeds 5% of the most recently applied application (Olness et al. 1975). As part of the National Eutrophication Survey in the USA (Environmental Protection Agency 1974) a comparative study of 143 catchments showed that, in general, streams draining agricultural catchments had about 11 times higher phosphorus concentrations than streams draining forest areas.

In the Onkaparinga catchment in South Australia linear regressions of rate of transport of nitrogen and phosphorus on turbidity showed that turbidity changes accounted for about half the variation in total nutrient load (Buckney 1979). Soil conservation practices which reduce turbidity levels should assist in reducing nutrient loads.

Other factors which will affect the yield of nutrients relate to farm management practices such as form of fertilizer applied and the rate, time and method of application. Surface-applied granular fertilizers are more susceptible to being washed into streams than fertilizers placed below the surface.

Intensive animal industries such as beef feedlots or piggeries can be a major source of nutrient and biological pollution. Because of the large generation of animal wastes, the difficulty of adequately controlling pollution from these sources, and the potential effects on public health, it is good practice to exclude intensive animal industry from domestic water supply catchments.

Atmospheric loadings of nutrients may also be a significant input to a catchment. This can be reduced by air pollution controls.

(iii) Salinity

The rising salinity levels of streams is a critical water quality problem. This problem although recognized for some time has only recently received due attention. Over-clearing of native forests in particular land types with geologies susceptible to salting and excessive irrigation without adequate drainage especially where there is a saline groundwater table cause salinity.

The source of salt are parent material, atmospheric accessions and saline groundwater. The reasons for the development of salinity are:-

- clearing native forests on slopes, allowing increased water percolation and through-flow of water with movement of salts into valley floors and drainages.

- clearing forests on aquifer intake areas increasing deep percolation and raising saline groundwater levels
- applying excessive irrigation water and causing a rise in saline groundwater levels
- wet seasons which have caused a rapid increases in area affected by salinisation, an effect not reversed by dry seasons (Jenkin 1979).

The effects of rising salinity may be a reduction in agricultural productivity (particularly in downstream irrigation areas); bare areas on slopes and valley sides which become sheet eroded; increased runoff causing gully erosion; high salinity in streams and storages giving lower quality water for stock and domestic supply; and flocculation of turbid waters which may increase the rate of eutrophication.

The dilemma is to establish an agricultural system which is productive and profitable and is also in hydrological balance. Where the water is sufficiently valuable, agriculture may become a non-acceptable use and the land purchased for other uses such as for re-forestation, as is the current situation in some domestic water supply catchments in Western Australia (Sadler and Williams 1979).

(d) Pesticides, herbicides and other toxic chemicals

Much of the productivity gains in agriculture have been through the growing use of agricultural chemicals such as herbicides, insecticides and fungicides. In the United States the usage of pesticides was 450 x 10⁶ kg in 1970 and this has continued to grow at the rate of 3-4% per annum (Kelman 1977). Their use has become a controversial public issue following episodes such as the use of Agent Orange in Vietnam and the dioxin contamination in Italy.

Pesticides vary enormously in their toxicity, persistence, and ability to accumulate in food chains. Losses into water of most chemicals are generally less than 0.5% of the total applied volume, unless heavy rains follow the application when up to 1.5% may be lost. There are exceptions, however. The persistent organochlorines tend to consistently lose about 1% of the applied dose. Soil surface applied, wettable powder formulations may lose up to 5%, and DDT, 2-3% (Wauchope 1978).

Some pesticides, because of their ionic nature, such as the organochlorines, paraquat, and the arsenicals, are adsorbed onto clay minerals. Soil conservation measures will help to reduce the losses of these chemicals. Others with solubilities greater than about 10 ppm are mainly lost in runoff water so soil conservation measures will only help where runoff is reduced. Although pesticide concentrations are often 2-3 times higher in the sediments than in water, most of the pesticides are lost in the water, simply because there is more water than sediment.

The effects of pesticides in water are fairly well known. Fish-kills and accumulation of persistent chemicals in the food chain have caused great concern. Other possible effects are mammalian toxicity, birth defects, cancer, and sub-lethal effects on other non-target organisms.

Management practices which result in changes in soil pH can also release heavy metals into water. Further information is required on what happens to pesticides in water bodies. That is, how do they dissipate or concentrate, how do they enter food chains, and are there synergistic or other additive effects.

Catchment Management Principles

Seven principles are proposed, which apply to catchment land use and management.

- (i) Each catchment has unique hydrologic characteristics and it should be considered as an entity before changes in land use or management are made

The hydrologic characteristics of a catchment are the result of the complex interaction of climate, geology, physiography, soils, vegetation and land use.

(ii) Critical areas within a catchment should be identified and efforts concentrated on their protection.

This calls for three stages:

- studying and understanding the processes relating to water production operating in the catchment
- determining the desirable standards of water supply - quantity, distribution, quality; a knowledge of the purpose of the supply and of the present hydrologic characteristics of the catchment
- when these standards have been determined, the prediction of the consequences of land use changes for different land types on the status of the water supply.

These critical areas are usually of three types:-

- prime water source areas such as perennial springs
- aquifer intake areas
- areas of inherent ecological weakness or erosion hazard

(a) Prime water source areas often occur along the edge of stream channels or where bedrock rises above the surface. These areas, which may amount to less than 10% of small catchments, may yield up to 90% of the overland flow. Overland flow is the most susceptible to gross pollution as pollutants on the surface may be carried directly to the stream or storage.

(b) Aquifer intake areas are of special importance where underground sources are used for town water supply. Identification of these intake areas and a knowledge of the consequences of land use change on their function will allow appropriate management for avoiding problems such as the build-up of nitrates and the movement of salts.

(c) Areas of inherent weakness or hazard can be identified by using information from land resource studies (Jeffrey et al. 1979). Inherent weaknesses and hazards of individual land units, such as high erodibility of soil, slope instability, flooding, water logging or salting, can be delineated and appropriate treatment applied.

Having identified these particular soil associations or land types as providing most of the sediment, the catchment manager can then concentrate on these areas.

(iii) Planning for multiple use in water supply catchments should be a multidisciplinary exercise.

Planning for multiple use requires the input of expertise from a number of technical disciplines. Wherever possible, land use planning proposals and catchment protection schemes should be developed simultaneously. This ensures that all of the community's requirements from the land are considered and their relative claims evaluated in a consistent manner. Further, the data base needed for both kinds of planning can be gathered and used most efficiently by joint planning. Close involvement of landholders and other local expertise at an early stage is essential if changes in land use or in management practices are to be identified, accepted and implemented.

(iv) Public participation in the planning process should commence at an early stage especially where it is apparent that changes in land use or management will be required.

Extension programs involving local Government as well as catchment landholders are necessary to explain the reasons for catchment management, the location of critical areas, and how the necessary catchment protection requirements can be integrated with current land use without affecting landholders' incomes (where this is possible). If, however, the changes will result in increased costs, either directly or, indirectly through inconvenience or additional time, then government incentives or compensation should be considered.

(v) Where changes in existing land use or practices are necessary on private land for catchment protection and these are more than good land husbandry, and this will result in added costs, then

compensation or incentives should be applied in addition to extension as a means of achieving the desired change.

The basis for this principle is that prior use confers prior right of use, but only if the land is used within its capability for that kind of production. It follows that the cost of any additional works or constraints to allow the harvesting of water of a suitable quality, should be borne by the user of the water.

(vi) Other technical and economic options must be compared to altering the land use mix or land management practices so that the optimum public benefit can be achieved.

The effects of attempting to manipulate the land use mix to protect water quality or yield must be analysed in detail before statements of intent are made. Other methods of control such as water treatment and alternative sources or water must be fully evaluated in comparison to land use or management changes. In certain situations, water treatment may be the most appropriate course, and in others it may be better to abandon a water supply source that is inadequate or polluted and concentrate on highly protected water supply catchments that supply several communities.

A mechanism whereby the interests of the water user and the catchment landholders with respect to land and water management, costs and controls, can be reconciled, should be established. This process should preferably avoid litigation as court costs can add substantially to the total community costs of coming to a satisfactory solution.

(vii) Potential future water quality problems and catchment management requirements should be adequately investigated and the results made public before a decision is made on the site of a reservoir or off take in a particular location.

Often construction authorities base their location decision on site characteristics alone. Future water quality problems and catchment management difficulties and the options for water treatment are considered after the decision has been made to build a storage at a particular site.

The full range of implications of choosing a particular site including social, political, economic, and organizational factors need to be considered and made public before the decision to construct a major storage or off take is made.

Mechanisms for catchment management

1. Legislation

Legislators have given catchment managers legislation through which they can influence catchment land use. For example, in Victoria the statutory responsibilities of the Soil Conservation Authority, Environment Protection Authority, State Rivers and Water Supply Commission, Town and Country Planning Board, Public Health Commission, Local Government Bodies, Melbourne Metropolitan board of Works, Labrobe Valley Water and Sewerage Board, and other water supply authorities can be brought into play under different sets of circumstances.

The Soil Conservation Authority has been given the primary role in water supply catchments in determining and co-ordinating catchment land use and management in the State; it basically has four catchment management processes defined in its Act.

Catchment Proclamation - This defines an area as a water supply catchment and gives it legal status.

Land Use Notice - This is an interim device specifying those changes in land use which must be approved by the Authority.

Land Use Determination - This involves the determination of land use which will not result in deterioration of water supply values and is binding on Government departments and statutory authorities managing public land.

Before a determination is made, the Authority must consult with the Land Conservation Council on which the land managing organizations and the public are represented.

Land Use Conditions - These are applied to private land and require a landholder to use his land in conformity with a Land Use Determination. Land use conditions can only be imposed after the Authority has consulted with its local District Advisory Committee on which there are a majority of elected landholders and with the Minister's approval. Any capital or financial loss to landholders resulting from these conditions is apportioned and paid by the Authority.

The Authority also influences land use in the catchment by undertaking land capability investigations and in advising local government and other planning bodies on zoning certain land uses away from critical areas within the catchment. Increasingly the tendency is for joint planning exercises with planning authorities to consider other community needs than just water supply protection. These joint planning operations should lead to better planning as well as to better protection of water supply catchments.

2. Education and Extension

Demonstration of water quality problems and ways in which they can be overcome is a valuable means of gaining acceptance by the community of the need for catchment management. Development of guidelines for control of land disturbance or the prevention of pollution from intensive animal industries are useful extension aids.

Extension programs which promote broad area land management practices which are also financially beneficial to the landholder by preventing soil or fertility loss are likely to be successful. However, it is unlikely that this method alone will achieve adequate control. Where additional costs to the catchment landholder are involved in applying controls above normal good land husbandry,

then incentives may be necessary. In this situation, they may be justified because most benefits from the improved water facility accrue to downstream users and the public generally.

3. Physical Catchment Protection Techniques Broad area catchment protection

(a) Forest land

Much catchment land is forested. While most of this would be public land, a portion is generally privately owned and contained in farming properties.

In general the best catchment protection for steep land is for it to remain in forest. This is for both soil protection and to maintain catchment hydrology.

Where forest utilization occurs, management guidelines can be applied to minimize land disturbance and soil erosion. These should include conditions covering extraction of timber, log landings, buffer strips along streams and water courses, and stream crossings.

The most appropriate catchment treatment for some cleared steep land with poor pasture cover is reforestation.

(b) Grazing land

On sloping land used for grazing management, practices which ensure retention of an adequate soil protective cover will be the most important means of preventing erosion, retaining infiltration capacity,

regulating flow and minimizing erosive flows. This will also help prevent downslope movement of annual excreta and applied nutrients.

Where climate and soils are suitable, the introduction of improved deep rooted perennial grasses such as phalaris will assist in retaining hydrologic balance. Initial soil protection will be aided by sowing on the contour with an implement such as a chisel seeder.

(c) Cultivation land

On land used for cropping, management practices such as the use of pasture phase in rotation add organic matter, retain structure, infiltration capacity and provide soil protection.

Where possible the use of minimum tillage or no-till techniques may be useful to reduce soil or nutrient loss.

Reduction of fallow length should be practised, consistent with its effect on crop yields, so that the period of exposure to rains of high erosivity is reduced. Where fallowing is necessary on sloping ground, soil conservation practices such as the retention of vegetative trash on the surface, contour or graded banks and waterway systems can be used to reduce the speed and volume of surface discharge. This will reduce the amount of soil movement.

The prediction of gross surface erosion from cultivated areas by means of the Universal Soil Loss Equation would be a useful aid in determining where to apply soil conservation practices.

(d) Control of land disturbance

This refers to major disturbance from non-agricultural uses such as extractive industries, industrial and mining development. Roads and track construction applies to all these situations and also occurs on farms. They are a major source of sediment and turbidity in many water supply catchments. Correct road location is important to avoid hazards to water supply such as steep slopes and erodible soils, and also to reduce interception and concentration of overland flow and allow for effective disposal of road drainage. Where slopes will allow, ridgeline locations are the most suitable.

Techniques are available to reduce the hazard from erosion and sedimentation during construction and to allow stabilization and revegetation of disturbed areas after construction is complete.

(e) Vegetation buffer or filter strips

These are vegetated strips of land retained along major drainage lines, streams and around water storages to prevent the transfer of sediment, plant nutrients or other pollutants directly into a storage reservoir. This technique is commonly used in Australia. Doyle et al. (1977) in the USA showed that forest and grass buffer strips 4 m wide were effective in reducing levels of faecal bacteria and concentration of NH₄, NO₃, P and K in surface runoff.

While this technique can be successfully applied to the immediate environs of a storage reservoir and on public land along major streams, maintenance and control of vermin and noxious weeds, providing access and alternative watering points, can be a problem where buffer strips are used along drainage lines on farming land.

4. Nutrient and Pesticide Control

Sediment from surface erosion is the major means of transport of nutrients and pesticides. Hence, surface erosion and runoff prevention practices should reduce the movement of both these pollutants.

Application of surface applied fertilizers such as superphosphate, should be avoided when there is a risk of heavy storm rains as significant movement can occur during this period. Fertilizer placement beneath the surface and the use of slow release fertilizers will reduce potential pollution.

Both pesticides and herbicides should be avoided on buffer strips especially when the risk of heavy rainfall and overland flow is greatest. Care should be taken with disposal of chemical containers and in washing out application equipment.

5. Alternative Water Supply Options

In some situations other water supply options will be more cost effective in achieving good water quality than changing land use and management and implementing pollution control. This may involve assessment of the water treatment options or alternative sources of water. For example, it may be possible to tap groundwater which is unpolluted or to pipe water from a more distant catchment.

Future research needs

There is an urgent need for more research into catchment management in Australia. Catchment managers are placed in the unenviable position of making decisions in the public interest which may affect the livelihood of landholders. A sound scientific basis for catchment management is needed, but there is a dearth of information.

Catchment management research broadly fits into the following categories:

- Land use/water quality interactions
- Land use/hydrology interactions
- Water quality changes in water bodies
- Water treatment options
- Catchment modelling
- Socio-economic considerations

These are considered in the above order.

Possibly the most important research objective is to be able to predict the relationship of a water quality problem to particular mixtures of land uses. Further research is required into the level of pollutants which may be generated from various kinds of land uses and management practices (King 1977b). At present it is difficult to relate the management practices of an individual landholder to a potential or existing water quality problem in a reservoir.

If the catchment manager is required to justify imposing restrictions on an individual landholder, he rarely has sufficient scientific evidence. Research into non-direct land use contributions of pollutants is also required, such as the contribution of pollutants washed out of the atmosphere. For example, in the Latrobe Valley, an industrial area in Victoria, the nitrogen content of the streams is approximately equal to that contributed by the rainfall.

It is recognized that the hydrologic cycle and the cycle of dissolved chemicals are different. There is a need to define these pathways and processes.

Comparative catchment studies are required to relate land forms and soil types to the chemical constitution of water. The natural contribution to water from different land types with various land uses must be distinguished as it is only the contribution from land use that can be meaningfully altered by catchment management.

Also little is known of the role of vegetation in water quality deterioration. For example, *Trifolium* spp. and other legumes may contribute a significant amount of nitrogen to water, and some species of *Eucalyptus* are known to contribute exudates to water which cause significant colour problems.

We are still a long way from understanding the relationship between land use and catchment hydrology. More instrumented catchments are needed which record rainfall and runoff data before and after a change in land use. This research is time-consuming and costly but necessary in order to provide the data for dynamic modelling, which would enable management guidelines to be developed.

Once pollutants enter a stream we need to know how much the aquatic and riparian vegetation can assimilate or contribute to the water and how the uptake of pollutants by the stream and its biota can be promoted. Research is required into the effectiveness of vegetated buffer strips along streams and around reservoirs.

In reservoirs and underground aquifers we need to know more about the behaviour of pollutants and their chemical reactions.

Whilst it is claimed the simplest solution to catchment problems lies in water treatment because the technology is now so advanced, such technology is still not completely effective, can be extremely costly and may be subject to human error. An important area of research is in the comparison between the efficiency of water treatment and the efficiency of a range of land use control measures and their various combinations.

It is only recently that water quality modelling has been combined with the hydrologic models. The prediction models developed by Aston and Dunin (1979) for land use and hydrology in the Shoalhaven catchment give a useful lead. More research is required to develop predictive models which will indicate the likely effect of land use controls on catchment hydrology and water quality.

Although many of the problems facing a catchment manager are related to political, social and economic factors rather than technical ones, there has been little research in these areas.

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