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AN EVALUATION OF COSTS OF REDUCING PHOSPHORUS TO CONTROL ALGAL BLOOMS IN AUSTRALIAN WATERWAYS

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INTRODUCTION

Nutrient pollution is a widespread problem in most countries of the world. Nutrients enter waterways from many sources but agriculture, intensive animal industries, sewage treatment plants and industrial production represent the main sources. The two most important nutrients in water pollution are nitrogen and phosphorus. Technical innovations in agriculture have intensified nutrient pollution. Most of the new crops developed in research institutes were fertiliser responsive and their increased use exacerbated nutrient pollution. Part of the nutrients applied to crops enter waterways through return irrigation, run-off and natural drainage. Nitrogen fertilisers increase the nitrate content in waterways incurring external costs through drinking water contamination and eutrophication. Excess phosphorus in water which cause algal blooms that have affected Australia's water quality represent another important nutrient pollution problem (Herath,1995).

Nutrients from agriculture is a diffuse or non-point source while nutrients from treated sewage effluent is a point source. In general, control of point source nutrients is easier than the control of non-point nutrients. The Australian Environmental Council has recommended that phosphorus concentrations should not exceed 50 ug /l in lakes used for recreational purposes. The existing licence limits for nitrogen and phosphorus are given in Table 1.

Table 1: Existing Licence Limits

Parameters	Range	50 Percentile mg/L	90 Percentile mg/L	Not to be Exceeded mg/L
Nitrogen (ammonia)		15	20	25
Nitrogen (total)		20	25	30
Phosphorus (total)		3	5	6

Source: Albury City Council, 1992

Reduction of nutrients is an imperative to improve water quality in Australia. However, serious informational constraints exist in implementing abatement policy. The non-point nature of most nutrients and the complex mechanisms by which they enter waterways make it difficult to identify the contribution of individual producers to nutrient levels. Further, problems still exist in assessing the value of damages caused and the benefits of nutrient reduction. The aim of this paper is to explore the actual costs involved in reducing nutrients in water particularly phosphorus both from point and non-point sources.

POINT NUTRIENT REDUCTION

An important point source of nitrogen and phosphorus is the sewage effluent discharged into the water ways Intensive animal industries such as cattle feedlots, piggeries, poultry farms, fish farms and dairy farms are other point sources which generate organic waste containing high concentrations of phosphorus and nitrogen.

Removal of Phosphorus from Treated Sewage Effluent

Sewage treatment plants are the most common method of sewage disposal in most city and municipal council areas in Australia. In sewage, the major sources of phosphorus are human excrement, laundry detergents and industrial waste. Phosphorus is present as dissolved inorganic or organic phosphorus and particulates. Domestic wastewater contains around 15 mg/ l of phosphorus and roughly 70% of it occur in the dissolved inorganic form. In general, raw sewage goes through several stages of treatment and the quality of the effluent depends largely on the nature of treatment.

The principal methods of phosphorus removal are (a) chemical removal (b) physical removal and (c) biological removal. Chemical removal is the most common method where alum or iron salts are added to precipitate the phosphorus which is removed with the sludge. In general, only about 90% of the phosphorus can be removed by chemical treatment (Switzenbaum, 1981). Ferrous iron in the form of waste pickle liquor is used because it is cheaper and is also effective. This is used in the treatment plant at Penrith with varying degrees of success (Davis, 1985). Lime is also used but several factors affect the effectiveness of lime. The amount of lime needed increases as we remove more and more phosphorus and the marginal costs of removal will rise sharply. For example, the lime required to remove phosphorus concentration from 2.5 mg/l to 1.5 mg/l is three times the lime required to remove phosphorus from 5 mg/l to 4 mg/l. The lower Molonglo treatment plant in Canberra uses lime but augments this with ferrous chloride to achieve an effluent total of 0.15 mg/ l .

The physical processes used for phosphorus removal are ultrafiltration, reverse osmosis and ion exchange (McGregor,1990). These methods produce a reject stream which needs to be further treated chemically. The physical methods basically intercept phosphorus in the influent wastewater. Biological removal of phosphorus is done by modifying the activated sludge process which increases the number of phosphorus accumulating organisms in the biomass. Biological removal has been very successful in South Africa where effluent phosphorus levels of around 1 mg/l have been achieved. In Australia, the plants at Penrith, Wodonga and Bendigo have been built for biological removal of phosphorus while the plants at Albury and Ballarat have been modified (McGregor, 1990; Brett, 1990; Oorschot and Crockett,1994).

Some indicative costs of physical and chemical control methods are given in Table 2. The reverse osmosis and ion exchange processes are prohibitively expensive compared to chemical treatment. The capital cost of the reverse osmosis process for a plant of 44 L/s is more than 30 times that of chemical treatment. These physical processes are thus not relevant to Australia under these circumstances. Biological removal can be an effective alternative to even to chemical removal of phosphorus. The main advantage being the saving of costs. For example, the treatment plant in

Canberra spends nearly $ 900,000 per year for the purchase of chemicals. Barnard (1986) estimated the saving in chemical costs alone for the city of Johannesburg to be around $ 1,000,000.

Table 2: Costs of Physical and Chemical Removal of Phosphorus from Sewage Plants

Plant size	Chemical	Systems	Reverse	Physical Osmosis	Systems Ion	Exchange
L/s	Cap Cst	Op Cst	Cap Cst	Op Cst	Cap Cst	Op Cst
	$US	$US/ML	$US	$US	$US	$US/ML
44	35,000	16.0-30.0	1,200,000	270	480,000	410-3200
220	105,000	16.0-30.0	3,200,000	240	-	-
440	190,000	15.8-29.3	4,800,000	210	-	

Source: McGregor, 1990

The NSW Water Board plans to reduce the phophorus content by 90% over the next five years through a rationalisation of plants. The total discharges of phosphorus will be reduced to about 63 Kg of Phosphorus per day reducing it to about 12-23% of the present level. These figures also imply that the concentrations of phosphorus will be reduced from levels as high as 11.7 mg /l to about 0.3 mg/l in most plants by the year 2000. Upgrading sewage treatment plants is an expensive method and also the indivisibility of plants require discrete jumps with high costs. Costs will involve both fixed as well as variable costs. Some costs of reducing sewage phosphorus in the Hawkesbury-Nepean are given in Table 3.

The marginal operating costs increases with increased reduction of phosphorus. This is true both for fixed and operating costs. To reduce phosphorus from 1 mg/ l to 0.3 mg/ l requires $ 219 per kg of phosphorus removed and to reduce it from 0.3 mg/l to 0.1 mg/l results in a marginal costs poof $ 705 per kg of phosphorus removed. There is a steep increase in the marginal costs of phosphorus removal. Chemical dosing can achieve about 90% removal of phosphorus from secondary effluent at a moderate cost of about $ 20.00 per kg of phosphorus removed. Achieving higher levels of removal involves progressively higher costs. The incremental costs to reduce concentrations from 1 mg/ L to 0.3 mg /L by double dosing and filtration is of the order of $ 200.00 per kg of phosphorus removed.

The Albury city council evaluated five alternatives to reduce phosphorus. The costs can vary due to different processes and different circumstances. It is worthy of note that the total land disposal option which reduced the phosphorus to zero is the most expensive. This is mainly due to the need for large extents of land which may be costly. Also the environmental consequences of land disposal should be carefully evaluated. In land disposal, the ability of soils to withstand long term loadings of salts and nutrients and whether such accumulations can later enter waterways through run-off etc are important considerations. Costs of refining sewage treatment works for phosphorus removal in plants in Canberra are given in a report by the National Capital Development Commission shows similar trends (NCDC, 1981).

Table 3: Costs of Reducing Phosphorus in Sewage Treatment Plants Discharges, NSW

Concentration of Phosphorus (P)	Capital ($/EP)	Operating ($/EP)	Capital $/kg P removed	Operating $/kg P removed
P < 2 mg/L	374	60	-----	-----
P < 1 mg/L	594	66	2,390	66
P < 0.3 mg/L	930	85	5,290	285
P < 0.1 mg/L	1,087	115	8,600	990
Wetland Reduction (from 2 mg/L to 1 mg/L	200	12	2,109	131

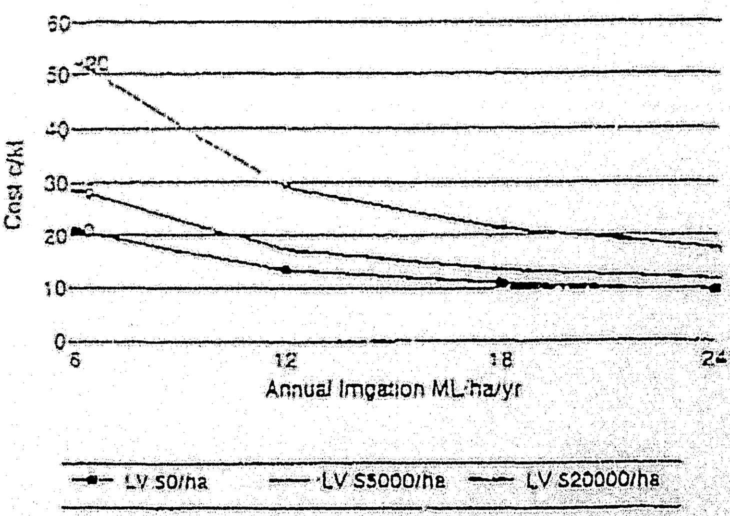
Source: EPA, 1994

Reuse Options of Sewage Effluent

The other alternative often suggested is to develop water reuse mechanisms so that the nutrients in effluent could be reused. There are two advantages in such schemes. Firstly, it will reduce pollution of waterways and secondly will provide a source of nutrients and water for use where it is required (Anderson, 1992). The effluent could be used in plantations or forestry located in the vicinity of treatment plants. Figure 1 shows the costs of reuse of water for a tree plantation. For inland sites with high evapo-transpiration rates and low land values, reuse may be more cost effective than chemical dosing in reducing nutrient discharges. For coastal areas with low evapotranspiration and high land values, the reverse may be true.

Figure 1.

Tree Plantation Costs



There is a general perception that Australia being an arid continent should have good opportunities to reuse effluent. Pitt, Urie and Wrigley (1992) examined a range of agricultural reuse options for an area in Victoria with a wet winter and dry summer and an average annual rainfall of 870 mm. The economic analysis concluded that selected horticultural and food crops and some speciality animal husbandry enterprises may be profitable.

Phosphorus from Animal Industries

Cattle Feed Lots

The Australian feedlot industry is an important component of Australia's total cattle kill and accounts for 25% of beef production whose value exceeds one billion dollars annually. Table 4 gives an idea of the structure of the feedlot industry. The large feedlots account for 46% of the total feedlot pen capacity although the number of large feedlots is small. Investments in the cattle feedlot industry brings considerable economic gains to rural Australia due to the demands placed on foodstuffs, plant and equipment and grain production etc. The number of feedlots is increasing due to the freeing up of the Japanese market. New facilities are being established and it is estimated that by 1995, the total pen capacity will be about 1.1 million, an increase of about 130% (Murray Darling Basin Commission, 1992).

Cattle feedlots produce a large volume of waste water and thus have important environmental implications. But most feedlots are sited on the basis of economic factors and hence they are found closer to the main grain growing areas. Environmental factors have not played a part in the siting of feedlots. It is difficult to estimate the nutrient contribution with a high degree of accuracy. Estimates show that the feedlots located in the Murray Darling Basin discharges about 1620 tonnes / year of total phosphorus and 7200 tonnes of nitrogen / year (MDB,1992).

Table 4: Estimated Number and Pen Capacity of Cattle Feedlots in Australia, 1990

Feedlot Capacity Range	Number of Feedlots	Total Pen Capacity (head)	Share of Total Feedlot Pen Capacity %
0-50 head	140	6,400	1
50-399 head	284	42,950	9
400-999 head	106	56,705	12
1,000-1,999 head	42	49,320	10
2,000-4,999 head	37	105,999	22
over 5,000 head	22	223,520	46
Total	631	484,885	100

Source: Tucker, et. al., 1991

Control of pollution from feedlots including nutrients is approached through a set of governmental regulations. These regulations require diversion banks, catch drains, sedimentation basins, retention ponds and land disposal areas so that pollution of waterways is controlled. However, most feedlots do not adhere strictly to these guidelines although some of the recommended structures are present in most feedots (Young, et. al., 1994; Ridley, 1994). The percent of feedlots having these different control structures is given in Table 5.

Table 5: Commercial Feedlots with Various Effluent Structures

Structure	Proportion of Pen Capacity %
System of Drains	87
Sedimation Pond	74
Retention Ponds	76
Equipment for Land Disposal of Waste	61

Source: Young et. al., 1994

Studies which specifically deals with the costs of reducing phosphorus from feedlots are virtually non-existent. One way of determining the costs of control of phosphorus is to estimate the costs of complying with the regulations recommended for feedlots. Broad estimates made from two feed lots by Young et. al. (1994) given in Table 6 shows the relative magnitudes involved. The table gives the annual costs to upgrade the effluent drainage systems. The estimates were made by multiplying the portion of pen capacity in the Basin which lacks each structure by the weighted annualised unit cost of each structure. The values are estimates of the opportunity costs of capital. However, one should be careful in interpreting these results because of the poor data base on which they are based. Similar studies with better data from a larger sample will help establish the generality of these results.

Table 6: Costs of Installing Control Mechanisms to Reduce Phosphorus Pollution

	Annualised Unit	Cost ($)	at an
	Interest	Rate	of
	5%	8%	10%
Cost of Upgrading Effluent Drainage Systems	194,180	256,380	301,510
Total Annual Costs	4,917,220	4,979,420	5,024,550

Source: Young et. al.,1994

Another approach is to reuse effluent from cattle farms. Table 7 gives costs of reuse of treated effluent in two dairy farms in the Berriquin irrigation district by the Department of Water Resources. Here again the sample is small and the costs are to be used carefully.

Table 7: Effluent Reuse in Dairy Farms

	Water recycled	Capital costs	Operating costs (per year)
Dairy Farm 1	15%	$29,000	$1445
Dairy Farm 2	5%	$10,950	$1305

Source: EPA, 1994

Fish Farms

Aquaculture as a human economic activity transforms resources into commodities and, in so doing, produces wastes. Fish farms discharge water into the river system with additional waste products. These wastes consist of organic solids and dissolved organic and inorganic nutrients, such as nitrogen and phosphorus. The main sources of these wastes are faecal and urinary wastes and unused fish feed. In general, aquaculture effluents are characterised by large volumes and low concentrations of wastes compared to other industries. However, effluent concentrations can vary a great deal from farm to farm, and depends on the amount of water used, the system of management etc. For example, in Australia, the trout farms have a higher amount of nutrients because of the high throughput of water.

In the MDB the most significant fish farms are located in Victoria and NSW. There are 18 fish farms in the Victorian part of the MDB with a throughput of about 275 ML/ d. They have been identified as a major point source of nutrients particularly under low flow conditions when the risk of blue green algae is highest (Murray Darling Basin Commission, 1992). Most of these farms are located along the Goulburn River. The contribution of phosphorus and nitrogen by fish culture is indicated by the difference in the nutrient content in the effluent and the influent. On average the nitrogen content in water increases by about 0.5 mg/ l and total phosphorus by 0.07 mg/ l (MDB, 1995). An EPA study of the Rubicon River showed that fish waste caused a 300% increase in the nutrient concentrations felt even five kilometres downstream (Ash, 1994). Another study by the EPA, Victoria of three fish farms along Goulburn River indicates that the loads discharged from fish farms did not differ between high and low categories. The percentage incresse of load in the Goulburn River due to fish farms was high during low flows. The nitrogen and total phosphorus increased by 7-55% and 20-348% respectively (EPA Victoria,1993). NSW has a larger number of fish farms and more than 40 are located along the MDB. Data are sketchy for NSW, but limited evaluations have revealed phosphorus levels of 0.38 mg/ l and 0.13 mg/ l in Tumut River and an Albury fish farm respectively.

In Victoria, trout and salmon farms are licensed because of the very high discharge volumes and significant suspended solids. In 1993, 25 trout/salmon farms in Victoria were licensed. The amendments to the EPA regulations effective from January 1994 requires any fish farm discharging more than 0.2 Ml/ d to be licensed. Presently native fish farms, yabby farms and warm water species are exempt from licensing because their water discharges are relatively low. The pollutant concentrations required by the licence is that the maximum and median levels of total phosphorus should be 0.2 mg/l and 0.1 mg/l (Ash,1994).

The actual costs of phosphorus pollution have not been estimated in Australia. Folke, Kautsky and Troell (1994) examined salmon farming and nutrient pollution in the Nordic countries. They found that salmon farms are an important source of phosphorus and contributed heavily to eutrophication. They estimated that the total production of phosphorus from salmonoid production in Nordic countries in 1994 of 200,000 tonnes is equivalent to the phosphorus produced by 1.7 million people. They concluded that salmon farming is ecologically as well as economically unsustainable.

The Pig Industry

Piggeries are usually covered and the run-off from them is low. A large number of piggeries is located in the MDB. In the Queensland part of the MDB there are about 100 piggeries with over 500 pigs. In the NSW part there are around 300 piggeries (MDB, 1992) Some piggeries such as the Bunge Meat Industries in Albury and Corowa are very large with about 185000 pigs. Most piggeries have waste management systems of their own. The Bunge piggery has its own waste disposal system where solid waste is composted and the effluent after treatment is used for irrigation of crops such as maize, flood irrigation and spray irrigation (Barclay, Kelly and O'Shea, 1994). In the Victorian part of the MDB there are about 130 piggeries with over 500 pigs.

Estimates of nutrient inputs from piggeries into the waterways in Australia are not available. On certain assumptions, the equivalent human populations of pigs in terms of phosphorus generation are 2.6 and 1.8 for phosphorus and nitrogen respectively. Significant nutrient problems from the piggeries are unlikely if the regulations are adhered to. The costs of removal of phosphorus from piggery sources are not available. The costs of reducing phosphorus in pig farms in the Netherlands using several alternative approaches were estimated by Leneman, Giesen and Berentsen (1993). Their results show that of the many alternatives, measures to reduce phosphorus by reducing the phosphorus content in the diet is the lowest cost alternative. The study further shows that measures to reduce ammonia volatilization from pig farms are costly. For pig farms, manure processing at central plants combined with measures in the pig house is very effective in reducing emissions.

REMOVING NON-POINT PHOSPHORUS

Removing Agricultural Phosphorus

Agricultural phosphorus come mainly from return irrigation and drainage water. One way to reduce the phosphorus is to use interception channels and re-use the drainage water . Numerous other approaches which to some extent is farm specific can be adopted and some of these may be of low cost but effective. Some of the methods are (a) conservation tillage (b) contouring and terracing (c) buffer strips. The costs involved in some of these approaches in the US are given in Table 7.

Johnsen (1993) analysed several approaches to reduce phosphorus run-off from non-point sources in the Norwegian lakes. On the basis of his results he recommended that planned fertilising and a tax on phosphorus in the order of 150% should be implemented as nationwide measure. In addition a ban on spreading manure outside the growing season and on tillage in the autumn is recommended in areas with run-off to water sources where run-off is a problem. The abatement of nitrogen pollution in France due to excess manure shows that a nitrogen tax would have some effect. They will differ among different farms of varying efficiency . The elasticities of nitrogen tax estimated by Bonniueux and Rainelli (1993) show it to be 0.36 while the elasticity among less efficient farmers it is 0.46. A tax is also expected to increase the opportunity of organic fertiliser and would push farmers towards more efficient practices at the micro level.

Table 8: The Cost and Effectiveness of Agricultural Run-off Controls

Type of Measure	Sediment Load Reduction	Phosphorus Load Reduction	Unit Costs (US$) per acre per year
Sediment controls (cropping):			(1990 $)
*Conservation tillage	30%-90%	35%-90%	18
*Conturing/terracing	50%-90%	35%-75%	35
*Sediment/water retention	60%-70%	40%	30
*Buffers/filter strips	70%-90%	50%	3
Intensive animal production			(1986 $) 800-1,700/100
*Run-off controls(BMP)	NA	70%-90%	animals (1983 $) 50-600/acre
Grazing lands:			(1991 $)
*Land management system(BMP)	Less than 1 ton per acre per year	greater than 90%	$6 per acre

Source: EPA,1994

Point -Non point Trading

Point non-point trading implies granting point sources the option to bring non-point sources of phosphorus under control. The advantage here is that it permits flexibility to adopt low cost control methods. The marginal cost data on increased point source control of phosphrus in sewage plants which increases steeply imply supporting agricultural activities in Table 7 instead of more point source controls may be economical. The absence of detailed costs of control of point and non-point sources constrain point-non point trading but merits attention (Letson,1993).

CONCLUSIONS AND IMPLICATIONS

The control of phosphorus in Australian waterways to reduce algal blooms is expensive and only the most economically efficient methods should be used . A serious dearth of relevant cost data thwarts the estimation of the most economically efficient levels. Regulations which are used now are not not efficient and the costs of adhering to them are high. The phosphorus from sewage effluent is removed economically to a certain degree but marginal costs rise rapidly with further controls. Efforts should be made to obtain relevant data to introduce the most efficient policies for control. The results obtained from such studies while providing insights to efficiently control phosphorus will be useful in reducing other types of pollution as well.

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