Goulburn Broken Water Quality Working Group

NUTRIENTS IN IRRIGATION DRAINAGE WATER FROM THE GOULBURN AND BROKEN CATCHMENTS

ISSUES PAPER

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HydroTechnology
A Business Unit of the Rural Water Corporation
590 Orrong Road
Armadale Victoria 3143

Telephone: (03) 508 2609
Facsimile: (03) 508 2264
Ausdoc DX21

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GLOSSARY OF TERMS

AEAM	Adaptive Environmental Assessment and Management
AHD	Australian Height Datum.
ABS	Australian Bureau of Statistic's.
BDAC	Bamawn Drainage Advisory Council.
BOD	Biochemical Oxygen Demand.
CIB	Customer Information and Billing.
CMSS	Catchment Management Support System.
DAP	Di-Ammonium Phosphate.
EPA	Environment Protection Authority.
FRP	Filtered Reactive Phosphorus.
GMW	Goulburn Murray Water.
g/pig/yr	grams per pig per year.
ha	hectare.
ISIA	Institute of Sustainable Irrigated Agriculture.
kg	kilograms.
kg/cow/yr	kilograms per cow per year.
kg/ha	kilograms per hectare.
kg/yr	kilograms per year.
km	kilometre.
L/min	Litres per minute.
MDBC	Murray Darling Basin Commission
mg/L	milligrams per Litre.
ML/yr	Megalitres per year.
mm	millimetres.
N	Nitrogen.
NO_x	Oxidised Nitrogen.
PIVOT	Phosphate Co-operative.
REN	Register Entry Number.
RWC	Rural Water Corporation.
S	Sulphur.
SIR	Shepparton Irrigation Region.
SIRLWSMP	Shepparton Irrigation Region Land and Water Salinity Management Plan
SPAC	Salinity Program Advisory Council
SPG	Service Point Group.
TKN	Total Kjeldhal Nitrogen.
TN	Total Nitrogen.
TP	Total Phosphorus.
VDIA	Victorian Dairy Industry Association.
WWMC	Waranga Western Main Channel.
WQWG	Goulburn\Broken Water Quality Working Group

EXECUTIVE SUMMARY

INTRODUCTION

In its development of an algal bloom management strategy for the Murray Darling Basin, the Murray Darling Basin Commission (MDBC) identified the Goulburn and Broken catchments as a significant source of nutrients to the River Murray and one of three river basins for which the development of nutrient management strategies was a high priority.

The Goulburn/Broken Water Quality Working Group (WQWG) was convened through the auspices of the Salinity Program Advisory Council (SPAC) to oversee the development of a nutrient management strategy for the Goulburn and Broken catchments.

The WQWG, through involvement of key stakeholders in the catchment, have identified five major sources of nutrients that required further investigation:

- irrigation drainage
- runoff from dryland areas
- effluent from sewage treatment plants
- urban stormwater runoff
- effluent from intensive animal industries.

HydroTechnology, in conjunction with Water EcoScience, have carried out a study of nutrients discharged to surface waters in irrigation drainage.

SCOPE OF THE STUDY

The objectives of the study were to:

- identify the nutrients, and the sources of these nutrients, being discharged to irrigation, community and farm drains
- identify the problems associated with these discharges
- evaluate the options to reduce nutrients that reach the River Murray at Echuca.

All effluent and discharges associated with dairying were to be included, while other intensive animal industries were not a part of this study. All point sources discharging to irrigation drains were also to be considered.

Within these broad objectives key study areas were identified:

- description of the drainage system
- existing and potential problems including:
    - the sources of nutrients that reach irrigation drains
    - the impact of nutrients on receiving waters, now and in the future
    - drain management
    - nutrient “hot spots”
    - farm management practices
    - land use information

- other catchment issues (eg. salinity)
- current drain diversion licences and practices
- environmental values
- nutrient control options - costs, benefits where identifiable, barriers to implementation, cost sharing with respect to identification of polluters and primary and secondary beneficiaries
- current and future monitoring and research.

GENERAL DESCRIPTION OF THE STUDY AREA

The Goulburn and Broken catchments cover approximately 2.4 million hectares in northern Victoria, incorporating both dryland and irrigated agriculture.

While the study area in this issues paper is limited to irrigation areas within the Goulburn and Broken catchments, extensive reference is made to the Shepparton Irrigation Region (SIR) throughout this report. Available information for areas west of the Campaspe River (Campaspe West, Bamawm and Lockington) presents an opportunity to add to the understanding of nutrient sources, impacts and control strategies that may be applicable to the neighbouring catchments.

Irrigated Agriculture in the Shepparton Irrigation Region

The SIR covers approximately 500,000 ha of land of which 487,000 ha is taken up as farm holdings. Of the farm holdings, only 430,000 ha is suitable for irrigation and only approximately 295,000 ha (69%) of this is presently under irrigation. Irrigation water within the SIR is supplied primarily from the Goulburn System and partially from the Murray System via Yarrawonga Weir.

Within the SIR, most irrigation is carried out using the border check system (97% in 1992/93). Irrigation products in the SIR include grain crops, lucerne, fodder crops, annual pasture, perennial pasture, grapes, stone and pome fruit, vegetables and other miscellaneous crops. Of the 295,000 ha of irrigated land, the largest proportion is used for pasture production (259,600 ha 88%), whilst a further 8,900 ha (3%) is used for horticulture and the remainder is made up of grain crops, lucerne, forage crops and vegetables (23,600 ha or 8%).

A census based on land under irrigated culture, carried out for the 1987/88 irrigation season, determined that of the 7,300 farms in the SIR, 3,600 (49%) where mixed farms, 3,100 (42%) dairy, while 650 (9%) where classified as horticultural farms. Overall dairy farming produces the major farm output, followed by livestock industries.

Irrigation Drainage

Irrigation drainage consists of two main categories: surface and sub-surface. An effective drainage system for irrigation areas is essential to prevent or alleviate problems of salinity and waterlogging which are often caused by intensive irrigation on a large scale.

In 1989, high water tables existed over 188,000 ha (36%) of the SIR, and are projected to extend to 274,000 ha (55%) within 30 years if no action is taken.

In the Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP) a program was developed to provide surface and/or sub-surface drainage systems to all irrigated farms within the SIR and effectively control groundwater levels. Subsequent refinements to the drainage program resulted in a proposal for 268,000 ha to be serviced by surface drainage in addition to the 183,000 ha that are already serviced. This involves the construction of an additional 310 km of arterial drains and 1,990 km of community drains.

In the sub-surface drainage program within the SIRLWSMP, protection will be provided to 85,000 ha via the installation of public groundwater pumps, some of which dispose to evaporation basins. A further 85,000 ha will be serviced through management arrangements and salt disposal opportunities for both existing and future private groundwater pumps primarily used for irrigation. Implementation of tile drainage and low capacity groundwater pumping programs will protect an additional 11,200 ha.

Both the existing nutrient loads in drainage water disposed to the River Murray and the potential loads from large scale proposed drainage works highlight the importance of assessment of nutrient sources and management options.

NUTRIENTS IN IRRIGATION DRAINAGE

Nutrient concentrations in irrigation drainage are usually much lower than sewage or effluent from intensive animal industries. However, when compared with criteria for fresh surface waters the concentrations are usually much higher.

A program to monitor the contribution of nutrients from the SIR to nutrient loads in the River Murray commenced in 1990, based on 9 monitoring sites. Median concentrations at these sites vary between 0.07 to 0.7 for total phosphorous (TP) and 0.6 to 2.4 mg/L for total nitrogen (TN). These results indicate that irrigation drainage water at <u>all</u> drain monitoring sites is in a "degraded" condition. The results also show that:

- channel outfall water is low in both TN and TP
- in the major arterial drains a high proportion of TP is in soluble form (25%-50%)
- most of the nitrogen is in organic matter
- the Deakin Main Drain and Murray Valley Drain 6 have high concentrations of both TP and TN and both catchments should be targeted as priority areas for nutrient reduction strategies.
- the Rodney Main Drain has the lowest median concentration of both TP and TN of all the monitored arterial drains.
- Broken Creek at Rice's Weir has median levels for TN and TP that are comparable to those measured in the Rodney, Lockington and Bamawm irrigation drainage systems.

The results from this monitoring program also indicate that there are considerable differences in the nutrient loads from year to year due to the variations in annual flow in response to rainfall. Correlations between nutrient concentration and flow do not exist. Of all the monitored drainage catchments, the Deakin Main Drain produces the largest nutrient loads and these often exceed the combined load of all other monitored outfalls.

Using the data for 1993/94, which was wetter than the long term average due to spring flooding, it has been estimated that the total loads leaving the Goulburn and Broken catchments from irrigation drainage were:

- 169,000 kg of TP, or 27% of the 615,000 kg from the total Goulburn Broken catchment (equal to 19% of the 912,000 kg measured in the River Murray at Torrumbarry).
- 619,000 kg of TN, or 12% of the 5.1 million kg from the Goulburn and Broken catchment (equal to 9% of the 7.1 million kg measured in the River Murray at Torrumbarry).

Total future drained loads as a result of extended surface drainage based on the current drainage strategy, under 1993/94 climate conditions, were estimated to be:

- 203,000 kg, TP, an increase of approximately 20%
- 820,000 kg, TN, an increase of approximately 32%

The impacts of drainage on receiving waters were examined using the Rodney Main Drain outfall to the Goulburn River. Percentage reductions in phosphorous concentrations in the Goulburn, for ceasing discharge from the Rodney Drain, generally reached 30% in the summer months for FRP and 20% for TP, indicating a significant impact of irrigation drainage on the potential for algal growth in the receiving waters.

SOURCES OF NUTRIENTS IN IRRIGATION DRAINAGE

In estimating the nutrient inputs to the irrigation drainage system both diffuse and point sources must be considered. Diffuse sources are primarily the runoff from agricultural land, while point sources include:

- towns
- sewage treatment plants
- industry
- intensive animal industries
- dairy shed effluent

Farm export rates

Farm export rates through drainage inlets have been estimated for the irrigation and non irrigation periods, by combining estimates of water applied, percentage runoff and runoff concentrations for the major land uses. The estimated rates are summarised in the following table:

IRRIGATED LANDUSE	ESTIMATED EXPORT RATES (kg/ha)			
	Irrigation season		Non-irrigation period	
	TP	TN	TP	TN
Perennial pasture	5.24	13.1	0.30	0.8
Annual pasture	1.22	3.0	0.15	0.4
Crops	1.77	6.7	0.12	0.5
Vegetables	1.62	8.1	0.15	0.8
Fruit - surface drainage	0.23	4.5	0.04	0.8
Fruit - subsurface drainage	0.18	90.9	0.02	7.6

These export rates do not consider the increase in nutrient concentration and load after fertiliser application. For example, in the two irrigations after phosphorus fertiliser application to perennial pasture it is estimated that an additional 3.12 kg/ha/yr of phosphorus could be exported. This represents 36% of the total TP load exported in a year.

Diffuse and Point Sources

Using landuse distribution information, these unit export rates have been used to estimate the potential loads to the drainage system, assuming full access across the study area to drainage and no losses between the irrigation bay and the drain. These estimates have been primarily used to establish the relativity between sources.

The estimation of all potential inputs and outputs to the irrigation drainage system for the Goulburn and Broken catchments shows:

- Diffuse sources are the major inputs into the drainage system for TP and TN: 1,243,000 kg/yr TP and 2,291,000 kg/yr TN, compared with point sources of 22,000 kg/yr TP (2% of total) and 270,000 kg/yr TN (11% of total).
- For the Deakin Main Drain there are also significant industrial point source inputs.
- Other less significant inputs include dairy shed effluent, groundwater pumping and towns in the Deakin Main Drain catchment.
- Dairy shed effluent is generally the main point source of both TN and TP.

The major proportion of the diffuse nutrient load is derived from irrigated perennial pasture, representing 84% of the potential TP load and 74% of the potential TN load during the irrigation season. Irrigation season loads represent over 90% of the potential annual input to the irrigation drainage system.

Sources of nutrients versus Export to the River Murray

For the 7 monitored catchments, the ratio of the measured nutrient load at the drain outlet versus the potential load entering the drainage system varies between 1:1.5 (Murray Valley Drain 6) to 1:22 (Toolamba Depression) for TP and 1:1.2 to 1:12 for TN. While some component of the estimated loss may be parameter error, the ratios also appear to indicate that there are significant nutrient losses within the drainage system. These losses possibly reflect drain density (ie. drain length per unit catchment area), and standard of drain construction, which influence both the volume of water entering the drainage system and the retention time in the drains. However, the nutrient dynamics in the drains is poorly understood and it is not clear whether the magnitude of such losses would continue indefinitely or reduce or cease at some point in the future.

FARM MANAGEMENT PRACTICES

The greater majority of agriculture practices within this region centre around the dairy industry, with significant areas of intensive horticultural cropping and to a lesser extent, what is commonly termed "mixed" farming, which is generally a combination of irrigated pasture for animal production and cropping within the one property. These combinations are dynamic, responding rapidly to the relative profitability of each commodity.

Animal industries within the Goulburn and Broken catchments consist primarily of dairy cattle, sheep and beef cattle, with smaller enterprises of pig and poultry farming. The dominant industry in the study area is dairy farming, which display a general trend of intensification in terms of both numbers of animals within the catchment, and the density of dairy cattle per unit area. Over the 2,257 dairy farms in the SIR, the average number of cows per farm is 133. In terms of intensity of dairy cattle numbers, areas surrounding the townships of Bamawm, Katunga, Kyabram, Stanhope, Tatura and Tongala all have dairy cattle populations in excess of 11,000.

Irrigation methods, within the study area, can be broadly categorised into four types: Flood (Border Check), Furrow, Sprinkler (Over tree and Under tree) and Micro Drip (Trickle). Flood irrigation covers 98% of the total area.

The majority of irrigators base their decision to water on their own experience and the appearance of the crop or pasture. This sacrifices some yield component to water stresses that show no visible symptoms. Current irrigation scheduling in the SIR sees farmers watering every 7-10 days, well below optimum irrigation levels for clover production.

Management practices

Management practices identified as having potential to reduce nutrient loading to irrigation drains, although largely unquantified, include:

- The development of a property according to a well designed whole farm plan .
- Installation of a water re-use system and management to minimise tailwater and rainfall run-off. Target minimisation of tailwater to the first irrigation after sowing and the first two irrigations after fertiliser application when run-off concentrations can be ten times the background nutrient levels.
- Maintaining an optimum rotation length for pasture production of 20 days to ensure dry matter production levels are optimal and supplementary fertiliser inputs are kept to a minimum.
- Optimise timing of fertiliser to the crops nutritional requirements to increase the uptake by plants.
- Optimise timing of fertiliser with respect to the irrigation cycle to increase fertiliser adsorption, minimising nutrient accession to drains and below the root zone.
- Ensuring effective management of dairy shed effluent through appropriate storage and disposal methods.

Management practices most likely to reduce the volume of run-off water include: the installation of water re-use systems, minimisation of tail water and changing to alternative forms of irrigation technology, notably trickle irrigation for horticulture. Management practices with potential to reduce the concentration of nutrients in irrigation drains include: optimal timing of fertiliser application, short watering after fertiliser application and installation of buffer strips at the end of bays. The major obstacle for these last two options is the value of the land taken out of production through implementation of such a management action. In the case of buffer strips, further research needs to be performed in this area before realistic percentage reductions could be hypothesised for soil types and conditions encountered in the study area.

DRAINAGE SYSTEM MANAGEMENT

Within examination of existing drain diversion licenses, and assessment of existing practices and potential for nutrient management, it has been established that:

- Drainage water is a valuable source of water and nutrients suitable for re-use.
- Drainage diversion incorporates issues of security of supply, equity, landholder costs, administration of policy, pricing and compatibility with irrigation supply, salinity and environmental plans, amongst other issues.
- Existing licenses are weighted in number and volume towards relatively low volume diverters.
- Drain flows leaving the study area are significantly greater than licensed diversion volumes.
- A study in the Bamawn system has shown that while total diversion may be close to licensed volume (eg 1993/94), there are many diverters using much less water compared to their licensed volume over a full season. At the same time many diverters use much more than their licensed volume. To significantly increase diversion in this system, the short duration high flows need to be targeted, with a reduction in volume tied up with unused or low usage licenses.
- To limit the problems already existing with security and management of diversion, a few high volume diverters would be preferable to many low volume diverters.
- The spatial and temporal distribution of flows, over a full season, and over a longer time period of many years, needs to be quantified to assess security of supply.
- The issues of high volume diverters and risks to security of supply lead to a requirement for storages for diversion, targeting irrigators who also have access to wheel water to provide regularity of supply during dry seasons.

Clearly, the implementation of this option for nutrient load reduction will need to resolve a number of complex issues such as security of water supply, water quality (eg. salinity), equity issues, and investment confidence.

The implementation of this option will require a systematic approach on a sub-catchment basis that accounts for the following factors:

Volumes, Reliability, Distribution. Use a combination of mapping of sources and sinks of water, monitoring, and system analyses possibly including system modelling.

Landholder attitudes. Consider the need for clear economic benefits to farmers, and the link between security of supply and potential for adoption.

Evaluate feasibility of options. Consider environmental impacts, pumping and gravity options, and soil types for re-use dams.

Water Supply Pricing and Policy. Target maximising drain diversion in typical years and removal of underutilised commitments. Consider use of meters, shorter license agreements, cost sharing linked to security of supply, and cost penalties for underutilisation.

Of particular importance will be the security of supply issue, where it is recommended that cost sharing and rating bases make allowance for variations in security. Encouragement of adoption is required with the aim of maximising drain diversion in typical years and removing underutilised commitments.

Elements of a successful strategy can be found in the Bamawn system, downstream of Dargan's Bridge:

- There are several large diverters with licenses of the order of 2,000 ML in total, and a co-operative system of 5 landholders exists, increasing the regularity of demand.
- A weir exists in the drain to store water, and one property has two water harvesting dams of 240 ML and 80 ML capacity.
- Although not relevant to drain diversion, also a number of wetland systems exist - Murphy's Swamp and Richardson's Lagoon.

DRAIN MAINTENANCE AND MANAGEMENT

Generally, the cycling of nutrients in drains is poorly understood, making it difficult to confidently relate drain maintenance and management practices to nutrient benefits.

The maintenance of drains to their best possible condition conflicts with the use of drains for nutrient management. Weed control in drains is necessary because excessive vegetation decreases hydraulic efficiency through increased friction, and limits the available head for farm drainage outfalling into the irrigation drainage system. However, less retention time in drains most likely reduces any nutrient stripping ability they afford. Deliberate use of weeds in drains as a nutrient control strategy is not generally promoted because of these level of service issues. However, the buffer strip concept could be logically extended to the use of grass swales placed either on the drain verge or within the drain itself. The growth could be harvested for animal feed or removed at intervals, along with the nutrient rich sediments for application as a mulch. These strategies would have to be researched extensively to more accurately determine the potential benefits.

OTHER CATCHMENT WATER QUALITY ISSUES

Salinity

Activities within the SIRLWSMP that will impact on drain water quality include:

- environmental management of wetlands
- farm programs including re-use schemes may result in increased drain salinities, potentially restricting drain diversion. However, re-use schemes and improved irrigation management will reduce nutrient loads in drains.
- increased sub-surface drainage, particularly the public pump program, will increase drain salinities during the irrigation season, and possibly reduce surface runoff.
- increased surface drainage will generate increased nutrient loads to the River Murray. Increased drain lengths may however restrict nutrient export through longer retention times, and hence greater nutrient losses. Any reduced level of service in arterial drains will also increase retention times. Further specific monitoring and assessment along drains is required in the area of nutrient dynamics.

Pathogens

There has been almost no investigation on the pathogens carried by irrigation drainage and how long they persist, and the current and possible future occurrence of pathogens carried by irrigation drainage is an area that should be investigated further. Disease organisms existing in irrigation drainage in the study area include Johnès Disease and Leptospirosis. However management practices for these organisms are well understood and should be followed.

Other Issues

Levels of *biocides* in irrigation drainage are thought to be low and are usually below the level of detection of the analytical methods used.

Little information is available on *heavy metal levels* in irrigation drains. Although heavy metal concentrations in irrigation drainage is likely to be low some testing should be considered to confirm this.

Biological decomposition of the organic matter may lead to the depletion of oxygen, which favours mobilisation of sediment bound phosphorus into the water column and availability of phosphorous for uptake by aquatic plants and algae.

Environmental flow regimes in the River Murray may impact on nutrient concentration and loads and algal growth patterns. Four major types of Environmental Flows have been identified, being Sustaining Flows, Spring Flushing Flows, Channel Forming Flows and Flooding Flows.

NUTRIENT REDUCTION OPTIONS

Perennial pasture is the major source of nutrients that reach the River Murray and fundamentally therefore must be a primary focus for nutrient management. However, evaluation of issues and practices from a farm to whole catchment scale will be required to establish the best mix of management options to reduce nutrient export from the irrigation areas.

Available Nutrient Reduction Options

A number of options were considered at a preliminary level, although identification and implementation of other options based on opportunities and local features that are specific to individual catchments is recommended:

OPTION	DESCRIPTION
Change Irrigation Methods	Change current irrigation techniques from predominantly flood irrigation to another more directed method. The aim is to reduce flow, and hence nutrient load, leaving the farm and entering the drain. Improve irrigation scheduling with on farm storages to better match crop water requirements and hence reduce runoff, and therefore nutrient loads.
Constructed Wetlands and Vegetated Drains	Install wetlands (either on farm or adjacent to irrigation drains) and vegetated drains to serve as nutrient sinks
Containment of Dairy Shed waste on farms	Utilise storages for dairy shed wastewater for a source of nutrients to be used on the farm.
Dilution/Flushing Flows	Flush rivers with good quality water to increase flow and reduce nutrient concentrations and hence reduce the potential for algal growth. Flushes would be based on monitoring of critical indicators and risk assessment of an algal bloom.
Drain Design	On a site specific basis, utilise drain design features to reduce concentration of nutrients or increase diversion for re-use - eg drain dimensions to allow easier diversion for re-use, a series of swales along a drain to act as nutrient sinks, drain dimensions to increase retention time (hence related to level of service offered by drain).
Drain Diversion	Install storage dams on farms to divert drainage water for irrigation. Increase drain diversion without dams.
Drain Maintenance	Protect and manage existing drains to stop livestock access and prevent erosion. Hence reduce nutrient load to drains carried in sediment.
Economic Policies	Change water supply and pricing policies to conserve and re-use water and nutrients.
Fertiliser application Techniques	Look at the timing, type and method of application to maximise crop uptake of fertilisers, reducing concentration and load leaving the farm.
Installation of Riparian or Buffer Strips	Place vegetation as a barrier between tail water and farm drains, reducing the concentration and load in the tail water
Irrigated Woodlots	Use irrigation drainage to irrigate commercial tree plots, reducing flow and nutrient load in the drainage system.
Minimise Tail Water	Install fully automated irrigation systems, laser grade and improve pasture to ensure full utilisation of irrigation water. Hence reduce load leaving the farm.
Reduce Channel outfalls	Reduce channel outfalls to increase effectiveness of drain diversion. Reduction in nutrient load associated with reduced outfalls likely to be minor.
Re-use Systems	Installation of farm re-use systems to collect and re-use irrigation tailwater, thus minimising the nutrient enriched water discharged to irrigation drains
Sediment Management	Remove sediment from drains, re-use dams, and apply to farms as a source of nutrients. Remove sediment stockpiles from drain banks
Storage of Drainage Water, Changed Discharge Timing	Install large storage facilities to hold irrigation drainage to protect receiving waters during times of low flow - discharge at times of high flow. Hence reduce concentration in receiving waters at critical times.
Sub-surface drainage	Install sub-surface drainage to encourage greater recharge, and hence less runoff. Hence reduce flow and load entering drain (disposal of sub-surface drainage water, possibly at a lower concentration of TP and higher concentrations of TN and salinity, is required - eg evaporation, to drain)
Tile Drainage and re-use	Install tile drainage to reduce groundwater flow to drain and re-use for irrigation. Hence reduce concentration in drains (particularly for TN)
Transfer Drainage Water back to supply system	Transfer irrigation drainage to local irrigation supply systems, and possibly to other catchments or irrigation regions. Hence reduce flow, and therefore load in the drainage system.

Costs and Nutrient Load Reductions of Options

Unit costs for nutrient load reductions were identified for a number of the options. A base case interest rate of 8% was adopted, and 4% and 10% were also used to test sensitivity of results to interest rate:

Strategy	8%		4%		10%	
	Net Cost /P removed ($/kg)	Net Cost /N removed ($/kg)	Net Cost /P removed ($/kg)	Net Cost /N removed ($/kg)	Net Cost /P removed ($/kg)	Net Cost /N removed ($/kg)
Wa: Wetlands, harvesting (40ha)	17	7	13	5	19	8
Wa: Wetlands, no harvesting	20	8	15	6	24	10
Wb: Wetlands, harvesting (40ha)	10	4	8	3	11	4
Wb: Wetlands, no harvesting	10	4	7	3	12	5
Dairy shed pondage systems (40 ha, 120 cows)	0.5	0.1	-0.9	-0.1	1.3	0.2
Whole farm planning, 100% re-use, 40 ha farm	43	24	30	17	51	28
Whole farm planning, 50% re-use, 40 ha farm	93	51	67	37	111	60
Re-use only, 100%, 40 ha farm	2	1	-1	0	2	1
Re-use only, 50%, 40 ha farm	10	6	6	3	9	7
Tailwater Management	0.6	0.1	-1	-0.1	1	0.2
Drain diverter (20ML storage = 400ML)	-3	-1	-8	-3	-1	0
Drain diverter (50 ML storage =1000ML)	-6	-2	-9	-4	-4	-2
Drain diverter (100 ML storage = 2000ML)	-7	-3	-10	-4	-6	-2
Drain diverter no storage, 400 ML licence	-11	-4	-13	-5	-10	-4

Note **Wa**: Wetland assuming "high" capital costs,
Wb: equivalent wetland with respect to benefits, with "low" capital costs if site conditions are suitable

The results indicate cost effectiveness of targeting drainage diversion using storages, which attract significant benefits in terms of normal irrigation water saved, as well as reduced fertiliser costs through the re-use of nutrient rich water.

Water re-use systems are also ranked high, with relatively low capital and ongoing costs, and benefits from both water and fertiliser retained on the farm. However, performance of the re-use system in capturing tailwater is critical in achieving the low net costs.

Important issues in assessing the effectiveness of options include:

- differences exist in transferring local reductions at different locations in the drainage system through to the River Murray. There may be greater net benefits from targeting options to the bottom of catchments, where a more direct correlation exists between the direct nutrient load or concentration reduction and the eventual load export to the River Murray.

- the potential level of adoption and the likely magnitude of effect of options varies: eg dairy shed pondage systems will not have the scope for large scale load reductions across the area compared with some other options.

For drain diversion, use of 20 ML storages filled 20 times per year may be the most practical and economically viable solution, based on adjoining farms sharing a storage.

Preferred Package of Nutrient Reduction Options

The nutrient reduction options can be considered in two categories:

- **Reduce the concentration of nutrients** in the drains, and hence the loads to the River Murray
- **Reduce the flow** in the drains, and hence the loads to the River Murray

In the short term, a preferred package of options should be directed towards reducing the summer concentrations in the River Murray and consequently the loads in the drainage system during the irrigation season. In the longer term, these preferred options must also reduce the total annual loads being exported to the River Murray, in effect encompassing nutrient issues for the lower reaches of the Murray.

Options have been considered at the farm scale, the irrigation drain scale and the catchment scale:

(i) Farm Scale Options

In general, farm scale options should be focussed on:

- perennial pasture, identified as the major source of nutrient loads reaching the River Murray
- farms with high concentrations of animals
- the lower catchment areas, where a more direct relationship is likely to exist between reduced nutrient load from the farm and reduced nutrient load to the river system.

Within the above framework, the options that are considered to have particular merit in reducing nutrient export in irrigation drainage are generally related to developing best management practices. These options include:

- automation of irrigation to minimise the water leaving irrigation bays
- tailwater management after fertiliser applications
- installing re-use dams to reduce tail water leaving the farm, and encouraging improved irrigation scheduling and efficiency and better timing of fertiliser applications
- installing buffer strips between the bay and the drain
- adoption of appropriate timing of fertiliser applications to minimise concentration of water leaving the farm.

Education programs are essential to explain that options for reducing nutrients leaving farms will also provide other productive benefits as well as reducing nutrient loss.

It will also be necessary to indicate that one measure on its own is unlikely to achieve either the farm management or nutrient reduction benefits that might be achieved when all factors are considered together.

(ii) Irrigation Drain Scale Options

The nutrient reduction options most likely to succeed at this scale include:

- drainage diversion with particular emphasis on high volume diverters possibly utilising storages
- drain design where local conditions are favourable
- the possible installation of constructed wetlands after careful consideration of their location and inclusion only as part of a drain management strategy.

(iii) Drainage Catchment Scale Options

The main options to consider at the drainage catchment scale are most likely to focus on:

- economic instruments: eg. decreasing the costs of drainage water, establish nutrient targets to be set for individual catchments, decrease length of diversion licenses, cost sharing, drain water price linked to quality, financial penalties.
- institutional arrangements, ensuring coordination is obtained across salinity, environmental and drainage strategies.
- education about the necessity for nutrient reductions.

Within all of the above options, across the various scales, there can be considered to exist three tiers of options based on a level of certainty to offer the most cost effective benefit to the River Murray. Confidence in benefits are greatest for those options in tier 1:

Tier 1

drain diversion
education programs
economic policies: financial and cost sharing
water re-use
tailwater minimisation : automated watering, water use efficiency, targeting fertiliser applications
dairy shed waste containment
control of point sources
transfer of drainage water into the supply system

Tier 2

wetlands: constructed or modified
local drain design
buffer strips

Tier 3

reduce channel outfalls
irrigated woodlots
sediment management from drains

IMPLEMENTATION OF PREFERRED PACKAGE OF OPTIONS

Key features of the prescription for implementation have been identified:

- *Education Program*: Generate Information Packs; Use Workshops & Meetings; Initiate the Implementation Process in the Deakin Main Drain and the Murray Valley Drain 6 catchments; Develop a priority list for other areas. At the same time, the adoption of options should be encouraged across the whole study area.

- *Develop a strong link between Whole Farm Plans and nutrient reduction options:* Re-use dams are an essential part of whole farm plans and should be encouraged for nutrient management, water and drain management, salinity, and effluent management. Other Best Management Practices for which nutrient benefits have not been well defined should be incorporated into the Whole Farm Plan process.

- *Implementation of Re-use/Drain Diversion Systems:* Establish sources of drainage water; Understand landholder attitudes; Establish confidence in the security of supply and benefits to the farmer; Address environmental issues and engineering feasibility; Establish policy and operational instruments to encourage adoption and maximise drain diversion in typical years and remove underutilised commitments.

- *Implementation of other elements of the Package of Options:* Identify and take opportunities for site specific solutions/nutrient reduction activities, driven by local issues, cost, local interest, community and environmental benefits.

- *Initiate Monitoring and Investigations to fill significant knowledge gaps*.

- *Develop an Accounting System:* Develop effectiveness monitoring and potential Victorian or MDB compliance requirements.

- *Community Feedback:* Activate regular reporting of achievements: Implementation progress in terms of works and measures, Monitoring and related Research and Investigation.

KNOWLEDGE GAPS AND IMPEDIMENTS TO IMPLEMENTATION

There are a number of significant knowledge gaps in our understanding of how nutrients behave in the irrigation drainage system in the study area. These include:

- Nutrient cycling on farms.
- The benefits of BMP’s on farms.
- Farmers attitudes to the different BMP’s.
- Nutrient cycling in the drainage system.
- An accurate description of Landuse for the irrigation areas in the SIR that is easily manipulated.
- The cost sharing, funding and institutional arrangements for nutrient reduction options.
- The short and long term ability of engineered systems and biological options (eg. swales, wetlands and weedy drains for nutrient stripping).

INTRODUCTION

Blue green algal (cyanobacteria) blooms in waterbodies of the Goulburn and Broken River catchments in recent years have caused considerable problems for resource managers and the urban, industrial and recreational users of the affected waters. In its development of an algal bloom management strategy for the Murray Darling Basin, the Murray Darling Basin Commission (MDBC) identified the Goulburn and Broken catchments as a significant source of nutrients to the Murray River and one of three river basins for which the development of nutrient strategies was a high priority (MDBC, 1994).

A community based steering committee known as the Goulburn\Broken Water Quality Working Group (WQWG) was convened through the auspices of the Salinity Program Advisory Council (SPAC) to oversee the development of a nutrient management strategy for the Goulburn and Broken catchments. The development of this strategy will play an important part in identifying the management options that may be used to reduce the incidence and severity of algal blooms in the catchment.

The WQWG used the Adaptive Environmental Assessment and Management (AEAM) process to centralise and utilise the many sources of information and expertise relating to catchment management issues available both within and outside the Goulburn and Broken catchments (Cottingham, 1994). The preparation and use of a water quality model assisted in identifying the major land uses and activities occurring in the catchment that contributed to nutrients in surface waters. Gaming of the model by key stakeholders in the catchment identified five major sources of nutrients that required further investigation:

- irrigation drainage
- runoff from dryland areas
- effluent from sewage treatment plants
- urban stormwater runoff
- effluent from intensive animal industries.

The contribution and issues relating to each of the above nutrient sources has been investigated and described in Issues Papers prepared by consultants on behalf of the WQWG. This report presents the findings of the investigation of nutrients discharged to surface waters in irrigation drainage.

Objectives and Scope of the Study

The objectives of this consultancy were to prepare a report for the irrigation areas of the Goulburn and Broken catchments that:

- identifies the nutrients, and the sources of these nutrients, being discharged to irrigation, community and farm drains

- identifies the problems associated with these discharges

- evaluates the options to reduce nutrients that reach the River Murray at Echuca.

All effluents and discharges associated with dairying were to be included as part of this investigation while other intensive animal industries were not a part of this study. All point sources discharging to drains were also to be considered.

Within these broad objectives key study areas were identified:

- description of the drainage system

- existing and potential problems including:
    - the sources of nutrients that reach irrigation drains
    - the impact of nutrients on receiving waters, now and in the future
    - drain management
    - nutrient "hot spots"
    - farm management practices
    - land use information

- other catchment issues (eg, salinity)

- current drain diversion licences and practices

- environmental values

- Nutrient control options - costs, benefits where identifiable, barriers to implementation, cost sharing with respect to identification of polluters and primary and secondary beneficiaries

- current and future monitoring and research.

Methodology

To meet the objectives outlined in Section 1.1, ten tasks have been undertaken as part of this consultancy. These tasks were:

Task 1: Identify and quantify diffuse sources of nutrients that reach the irrigation drainage system.

Task 2: Identify and quantify point sources of nutrients that reach the irrigation drainage system.

Task 3: Determine the current and future level of impact of nutrients in irrigation drainage on the receiving waters.

Task 4: List farm management practices that influence nutrient discharge to irrigation drainage.

Task 5: Review current drain diversion practice and the extent and status of existing licences.

Task 6: Identify issues in relation to drain management and maintenance.
Task 7: Explore other catchment issues that relate to nutrients.

Task 8: Determine a priority listing for options to reduce nutrients entering drains and removing nutrients from drains on the basis of cost benefit analysis. This includes the identification of the beneficiaries of nutrient reduction strategies and the basis of cost sharing of the options.

Task 9: Identify strategies to facilitate the implementation of nutrient reduction strategies.

Task 10: Identify the adequacy of monitoring and research and advise on further work to manage irrigation drainage nutrients and to develop proposals for implementation.

4

1. GENERAL DESCRIPTION OF THE STUDY AREA

- **The Study Area**

The Goulburn and Broken catchments (Figure 2.1) cover approximately 2.4 million hectares in northern Victoria. The land use and activities in the basin are diverse, including major tourism, dryland agriculture and forestry in the upper catchments, and irrigated and dryland agriculture, food processing and textile industries in the lower catchments. Major urban centres include Shepparton, Benalla, Kyabram and Tatura.

In this issues paper, the study area consists of all the irrigated land in the Goulburn and Broken catchments. This consists of the Murray Valley, Shepparton, Central Goulburn irrigation areas and part of the Rochester irrigation area (Figure 2.2). In total, these four irrigation areas make up what is known as the Shepparton Irrigation Region (SIR).

While the study area is limited to irrigation areas within the Goulburn and Broken catchments, extensive reference is made to the SIR throughout this report. Available information for areas west of the Campaspe River (Campaspe West, Bamawm and Lockington) presents an opportunity to add to the understanding of nutrient sources, impacts and control strategies that may be applicable to the neighbouring catchments. Such information includes drain flows, salinities, nutrient concentrations and loads, together with the associated catchment characteristics, and some detail on drain diverters including actual volumes diverted.

- **Climate**

The irrigation areas within the Goulburn and Broken catchments experience a Mediterranean climate of hot, dry summers, where evaporation exceeds rainfall, and cool, wet winters. Winter and spring frosts are also common. Overall the climate becomes slightly drier and warmer moving from the east to the west and the south to the north. Average monthly temperatures in the irrigation areas vary between 7.5°C to 22°C and the average annual rainfall varies between 380 mm to 500 mm with ranges of ±180 mm. Evaporation exceeds rainfall for over nine months of a year and averages approximately 1350 mm/yr (SPPAC, 1989). The large variation in rainfall results in both periodic flooding and drought. Above average rainfall in autumn and spring produces waterlogging in many soils in the irrigation areas due to low grades and heavy soil profiles. Irregular thunderstorms in summer can produce significant and intense rainfall.

Figure 2.1: The Goulburn and Broken catchments.

Figure 2.2: The irrigation areas within the Shepparton Irrigation Region..

- **Topography**

The irrigation areas within the Goulburn and Broken catchments are located on the flood plains of the Goulburn River, Campaspe River and the minor streams that are located between the two rivers. Prior stream areas have produced many depressions and wetlands. The riverine areas are very flat with slight slopes varying from 1:1500 to 1:4000 with a north-west fall towards the Murray River (SPPAC, 1989; MDBC, 1992). The riverine plains are susceptible to periodic flooding due to the flat grades and the higher rainfall in the upper catchment. Drainage is often poor and after flooding, large areas can remain inundated for a number of months (RWC, 1992a).

- **Soils**

Soils found in the SIR generally fall into two groups: red-brown earths and grey-brown soils of heavy texture. The first group includes the coarser surface sediments historically deposited close to ancestral rivers and stream courses. The second group were deposited further out on the flood plains (RWC, 1992a). In general, the soils have shallow top soils over heavier clay subsoils with low permeability to water; characteristics which limit their agricultural versatility. Only the lighter soils near the prior streams, East Shepparton Fine Sandy loam and Shepparton Fine Sandy Loam, are generally suited to horticultural production (MDBC, 1992). The soils of the irrigation areas in the Goulburn and Broken Catchments have been classified into six categories (Table 2.1) based on their suitability to support different crops (DAV, 1962).

- **Irrigated Agriculture in the Shepparton Irrigation Region**

The irrigation system within the SIR is approximately 100 years old and has been progressively expanded as additional water has been stored and made available for irrigation purposes (MDBC, 1992). Irrigation development within the SIR was initially controlled by Irrigation Trusts under the Water Act of 1883. The Rodney Irrigation Trust was the first to be established under the new Irrigation Act of 1886 while the Ardmona Trust commenced its operation in 1887. By 1889 there were 25 Irrigation Trusts operating in northern Victoria. Irrigation development in the region expanded with the completion of Waranga Basin in 1902, and in 1905 the State Rivers and Water Supply Commission (later the Rural Water Commission of Victoria 1984, then the Rural Water Corporation 1992, now Goulburn Murray Water) was formed to cover the Irrigation Trusts established in Victoria. Further irrigation development in the region intensified with the construction of Lake Eildon and the enlargement of Waranga Basin between 1919 and 1924 and, more recently, the construction of “Big Eildon” (existing Lake Eildon) in 1955.

Irrigation water within the SIR is supplied primarily from the Goulburn system and partially from the Murray System via Yarrawonga Weir. The main storage for the Goulburn system is Lake Eildon, from which water is diverted to serve irrigation areas to the east and west of the Goulburn River. The East Goulburn Main Channel diverts water to the Shepparton district, while both the Stuart Murray and Cattanach channels at Goulburn Weir are used to supply the irrigation districts to the west of the Goulburn River. Both channels supply water to the Waranga Basin with part of the Central Goulburn area being supplied from channels which have offtakes from the Stuart Murray Canal. The main outlet from the Waranga storage basin is the Waranga Western Main Channel (WWMC) which supplies the Central Goulburn and Rochester irrigation areas to the west.

Table 2.1: Classification of Soils in the Irrigation Areas (DAV, 1962).

Soil Type	Soil Characteristics	Location	Supported Crops
Sandmount Sand, Broken Sand East Shepparton, Fine Sandy Loam, East Shepparton Sandy Loam	Permeable, deep, brown sandy soils, no clay subsoil Brown sandy soils overlying red-brown clay sub-soils	Adjacent to many existing water courses, also between Shepparton and Waaia	All horticultural crops, perennial and annual fodder crops and cereal crops
Katamatite Loam, Youanmite Loam Shepparton Fine Sandy Loam, Shepparton Sandy Loam, Shepparton Loam	Brown loams overlying permeable clay sub-soils Brown soils overlying moderately permeable red-brown clay sub-soils	Adjacent to many existing water courses, also near Girgarre, Kyabram, Mooroopna, Katamatite, Toolamba	All horticultural crops except citrus, perennial and annual crops
Lemnos Loam, Lemnos Sandy Loam, Erwen Loam	Brown soils overlying red heavy clay and variable clay layers below 1 metre	Widespread across most of the irrigation area	Stone and pome fruits, tomatoes, annual and perennial pasture
Goulburn Loam, Dunbulb Loam, Orrvale Sandy Loam, Orrvale Loam	Prior stream beds with brown soils and permeable subsoils	Widespread across much of the irrigation area, although less prevalent than Lemnos Loam etc.	Pome and stone fruit, annual and perennial pasture
Congupna Clay Loam, Coomboona Clay, Yuga Clay	Heavy soils in low lying areas	Widespread in low lying areas across the irrigation areas, especially along prior water courses	Annual pastures and cereals
Congupna Clay, swamps, river frontage	Low lying, heavy textured soils and pitted soils	Widespread in low lying areas across the irrigation areas, especially along prior water courses	Not recommended for irrigation

Supplies to the WWMC are sometimes supplemented from the Campaspe River at peak times. To the north east, the Murray Valley irrigation area is supplied by water from the Murray River via Yarrawonga Weir and then the Yarrawonga Main Channel (MDBC, 1992).

The SIR covers approximately 500,000 ha of land of which 487,000 ha is taken up as farm holdings. Of the farm holdings, only 430,000 ha is suitable for irrigation and at present only approximately 295,000 ha (69%) of this is presently under irrigation (SPPAC, 1989).

Within the SIR, most irrigation is carried out using the border check system (97.3% in 1992/93). The remaining irrigation water within the region is distributed via either furrow, moving irrigator, over tree sprinkler, under tree sprinkler or micro/drip systems. Most of the pressurised systems in the area are used for horticultural crops and occupy approximately 3% of the total area irrigated (RWC, 1992b).

Irrigation products in the SIR include grain crops, lucerne, fodder crops, annual pasture, perennial pasture, grapes, stone and pome fruit, vegetables and other miscellaneous crops (MDBC, 1992). Of the 295,000 ha of irrigated land, the largest proportion is used for pasture production (259,600 ha 88%), whilst a further 8,900 ha (3%) is used for horticulture and the remainder is made up of grain crops, lucerne, forage crops and vegetables (23,600 ha or 8%) (SPPAC, 1989).

A census based on land under irrigated culture, carried out for the 1987/88 irrigation season, determined that of the 7,300 farms in the SIR, 3,600 (49%) where mixed farms, 3,100 (42%)

dairy, while 650 (9%) where classified as horticultural farms. Overall dairy farming is the major farm output, then livestock industries, followed by agriculture and horticulture (SPPAC, 1989; RWC, 1992a).

- **Irrigation Drainage**

Irrigation drainage is excess water that arises from irrigated agriculture. It includes surface runoff from irrigation and rainfall, irrigation supply outfalls, groundwater and water that is intercepted as it percolates through the soil profile beyond the root zone. Other sources of water that may also contribute to irrigation drainage include: dryland runoff, runoff from roads, urban runoff and stormwater, sullage, sewage and discharges from other point source inputs. Irrigation drainage consists of two main categories: surface and subsurface. Surface drains are constructed to enhance the removal of surface water.

An effective drainage system for irrigation areas is essential to prevent or alleviate problems of salinity and waterlogging which are often caused by extensive irrigation. These problems have long been recognised by governments, engineers, scientists and farmers. However, with the implementation and early development of the irrigation system in the SIR the importance of an effective surface drainage system was not acted upon and as a consequence much of the irrigated area was installed without an adequate drainage system.

At present, high water tables underlie some 188,000 ha (36%) of the SIR and are projected to extend to 274,000 ha (55%) within 30 years if no action is taken. Rising water tables within the SIR will have devastating environmental and sociological impacts if nothing is done. Environmental impacts could lead to destabilisation of river banks due to saline seepage, high salinity concentrations within water systems (causing the death of aquatic flora and fauna), while saline seepage into streams would kill riparian vegetation and precipitate bank erosion and bed widening. The estimated socio-economic impacts of both salinity and watertable increases would result in associated losses of $27M (1989 values) in the year 2000 to $40M within 30 years.

- **Surface and Sub-surface Drainage**

The development of the surface and sub-surface drainage system in the SIR did not begin until the irrigation system was well established and the detection of some early signs of increases in groundwater levels and salinisation were observed. A strategy developed in the 1950's began to address the problem of the development of surface drainage system for the irrigated areas. A stated long term objective of the Rural Water Corporation (RWC) was to provide surface drainage to all irrigated farms within the SIR. However, this objective could not be realistically achieved as the cost to complete the drainage system was estimated to be $450 M (1989 values) while recent rates of expenditure prior to 1994/95 were of the order of $2 M annually. This meant that a new strategy was required to satisfactorily complete the surface drainage system in the SIR and this new drainage program was developed as part of the Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP) (SPPAC, 1989).

The Surface Drainage Program as outlined in the SIRLWSMP proposed a number of programs to effectively and responsibly tackle the salinity problem and in so doing: "*manage the salinity of* *the land and water resources in the Shepparton Irrigation Region in order to maintain and, where feasible, to improve the social well being, environmental quality and productive capacity of the Region*" (SPPAC, 1989). The SIRLWSMP stipulated that the full development of surface drainage in the SIR is an essential and integral component of any salinity control strategy. The direct benefit from this strategy is that it will reduce accession to the groundwater (hence reducing salinisation) by up to 19% and also indirectly benefit a number of other issues concerning the SIR, viz:

- reduce road construction and maintenance costs
- improve water use efficiency
- provide incentives to carry out other management measures which also reduce accession
- redirect community energies which would otherwise be lost in arguments concerning drainage
- provide provision of infrastructure for disposal of saline groundwater removed by pumps to move toward salt balance in the Region

At the time of the development of the SIRLWSMP, RWC arterial drainage serviced 183,100 ha (36%) of the 500,000 ha of land in the SIR while a range of sub-surface drainage activities covered another 20,000 ha (SPPAC, 1989). In the SIRLWSMP, a program was developed to provide surface and/or sub-surface drainage systems to all irrigated farms within the SIR and effectively control groundwater levels (Table 2.2). In the plan it was identified that new arterial drains be constructed for an additional 74,000 ha while a further 236,000 ha would be serviced by community drains (SPPAC, 1989). Other proposed surface drainage strategies included water harvesting and drainage course declarations. In its response to the SIRLWSMP the Victorian Government requested that the surface water program be reviewed. A major redevelopment of the strategy was undertaken and this is discussed further in Section 2.7.5.

Table 2.2: Surface Drainage Strategies as proposed in the Shepparton Land and Water Salinity Management Plan (SPPAC, 1989).

Surface Drainage Strategies	Area Drained ha	%
Existing RWC arterial drains	183,000	35
New RWC arterial drains	74,000	14
Community drains	236,200	46
Water harvesting, with channel discharge	13,400	3
Water harvesting, without channel discharge	12,700	2
Length of Drainage Course Declarations (km)	343	-

Arterial Drains

Arterial drains are owned and maintained by Goulburn Murray Water (GMW), (previously the Rural Water Corporation of Victoria). These drains are usually earthen, open cut, fenced longitudinally with title to the land within the fenced area being purchased by GMW and constructed to provide a high standard of service and to minimise maintenance costs. Typically they are constructed for areas which are intensively irrigated, have high value production, where outfall is required from groundwater pumping or private drains and to provide environmental protection for sensitive wetland areas.

These drains were initially designed to accommodate a 1 in 10 year flood, however a review of these standards recommended that a design standard of 1 in 2 year be adopted for pasture area drains, based on appropriateness and cost effectiveness. For horticultural areas with a higher land value, it was recommended to retain a 1 in 5 or 1 in 10 year design standard. Typical capital costs for new arterial drains are $130,000 per kilometre.

Community Drains

Community surface drains are constructed and maintained by community working groups. They are generally designed to remove in five days, the runoff from a 24 hour rainfall event of 50 mm, which on average would occur 1 year in 2. These drains are an essential component of the SIRLWSMP as they enable excess water to be removed.

Although these community surface drains are smaller in size than the GMW drains they are still designed and constructed to the same standards. There is however, some flexibility in the design of these drains due to their often site specific nature and purpose. Capital costs for new community drains are approximately $20,000 per kilometre.

Drainage Course Declarations

Drainage course declarations enable coordinated programs to be developed to ensure waterways (drains and channels) are cleared of man-made obstructions to allow water to pass efficiently, especially higher flows. They are particularly advantageous where there are high flows entering the irrigation area and the natural drainage line is not well defined, or where minor flows are diverted to an appropriate outfall and there is a need to protect the natural overflow route. Typically they will only provide minimal drainage improvement at low flows, even with the removal of obstructions.

Water Harvesting

The concept of the water harvesting drainage option, as outlined in the SIRLWSMP, involves the use of large community storages and the incorporation of pumps to re-use irrigation water by either outfalling to the GMW channels or re-use by the landholder on whose property the storage is located. Of the two options, the community pumping scheme (ie, outfalls to channels) is preferred however, this is only a interim measure until irrigation outfalls to GMW arterial drains and community drains is possible.

Drainage Catchments in the Shepparton Irrigation Area

In 1990, the Government in its response to the SIRLWSMP, requested that a review of the surface water strategy be carried out. HydroTechnology (1994a) developed a draft report on the Shepparton Region Surface Drainage Strategy which details the current status of drainage in the SIR and the works necessary to provide drainage to all irrigated properties in the Shepparton Region. Management of surface drainage in the SIR is sub-divided into 24 drainage systems (see Figure 2.3). The revised Shepparton Region Surface Drainage Strategy (HydroTechnology, 1994a) has determined an economic and funding analysis required to implement the full extent of surface drainage in each catchment and in turn the SIR. A summary of the areas requiring drainage in the revised strategy (length and cost) for both GMW and community drains for the 24 drainage catchments in the SIR is outlined in Table 2.3.

Table 2.3: The area of each sub-catchment, the area requiring drainage and the length and cost of both arterial (GMW) and community drains in the revised surface water strategy.

Catchment	Area of Catchment (ha)	Area Requiring Drainage (ha)	GMW Drains		Community Drains	
			Length (km)	Cost ($,000)	Length (km)	Cost ($,000)
Lockington[1]	20,440	5,400	0.0	0	76.8	1,152
Bamawm[1]	14,920	1,740	0.0	0	17.0	255
Wharparilla[1]	9,470	2,830	0.0	0	24.7	37
Campaspe[1]	11,180	7,395	2.3	276	58.6	879
Strathallan	9,240	4,360	0.0	0	25.0	375
Deakin	46,230	20,560	19.7	2,561	160.5	3,210
Corop Lakes	48,620	38,850	41.0	4,810	135.0	2,025
Tongala	14,930	2,160	0.0	0	14.1	282
Mosquito	45,990	29,275	66.3	9,622	326.2	8,037
Coram	7,100	1,660	0.0	0	19.1	382
Wyuna	22,750	13,070	2.9	272	150.3	3,006
Rodney	17,230	10,680	10.7	1,550	110.0	2,409
Coomboona	15,360	8,900	0.0	0	63.3	1,583
Ardmona	9,420	3,460	0.5	50	40.6	1,015
Toolamba	8,740	4,410	0.0	0	74.9	1,873
Kialla	17,110	5,050	0.0	0	51.5	1,358
Shepparton	9,800	540	0.0	0	2.4	36
Tallygaroopna	37,110	27,500	43.0	5,590	199.4	4,432
Invergordon	19,180	5,480	0.0	0	24.4	488
Kaarimba	8,900	5,830	2.4	312	48.0	960
Barmah/Nathalia	55,200	27,340	47.9	6,227	188.1	3,762
Strathmerton	33,630	8,310	9.0	1,170	72.5	1,340
Muckatah	40,040	33,190	64.0	8,320	105.6	2,112
TOTALS	522,590	267,990	309.7	$40,760	1988.0	$41,008

Source: HydroTechnology (1994a).

[1] These catchments are west of the Campaspe River and are outside the study area.

Within the SIR 17 irrigated sub-catchments are currently monitored for continuous flow and salinity to determine the quality and quantity of water leaving the catchments. At 8 sites, nutrients are also monitored on a fortnightly basis. Another seven dryland and urban sub-catchments have also been defined while an additional five monitoring sites have also been established in order to determine a flow and salt balance throughout the system.

Figure 2.3: The 24 drainage systems in the Shepparton Region Surface Drainage Strategy (HydroTechnology, 1994a).

These monitored catchments form an integral part of the analysis to determine the surface and sub-surface salt and nutrient generation and movement within the SIR. Figure 2.4 is a map showing the locations of the monitoring sites and their catchment boundaries.

Sub-surface Drainage

Sub-surface drainage is used to protect crops from elevated or perched water tables. The type of sub-surface drainage depends on economic factors and on the size and hydrogeology of the area to be protected. Sub-surface drainage is mainly restricted to small-scale, high value enterprises due to the to the high capital and running costs. Sub-surface drainage includes tile drains, mole drains, spear points, tubewells, shallow and deep groundwater pumps. In the sub-surface drainage program within the SIRLWSMP protection will be provided to 85,000 ha via the installation of public groundwater pumps and evaporation basins, a further 85,000 ha will be serviced through management arrangements and salt disposal opportunities for both existing and future private groundwater pumps while implementation of tile drainage and low capacity groundwater pumping programs will protect an additional 11,200 ha.

Disposal of irrigation drainage is often a problem particularly when it is highly saline. The Murray Darling Basin Commission has developed a Salinity and Drainage Strategy that enables the Discharge of drainage water from irrigation areas that suffer from salinisation and waterlogging to the Murray River. These discharges are made in exchange for contributions to works to reduce salinity of the river further downstream. The Drainage Strategy also has implications for nutrients in irrigation drainage and these are discussed in later sections of the report.

Figure 2.4: The locations of the monitoring sites and their catchment boundaries.

NUTRIENTS IN IRRIGATION DRAINAGE

In 1994, a major review of nutrients in irrigation drainage in the Murray Darling Basin was published by CSIRO Division of Water Resources (Harrison, 1994). The primary objective of this review was to collate and analyse available data on levels of nutrients in irrigation drainage within the irrigation areas of the Murray-Darling Basin and to relate the levels of nutrients found in irrigation drainage with land use and other characteristics within the irrigation areas.

In this report, Harrison (1994) found it difficult to categorise nutrient levels in irrigation drainage due to the lack of suitable criteria for comparison. Nutrient concentrations in irrigation drainage are usually much lower than in sewage or intensive animal industry effluent and when compared with criteria for fresh surface waters are usually much higher. Draft Australian Water Quality Guidelines for fresh water (ANZECC, 1992) recommend ranges for total phosphorus and total nitrogen "*...at or above which problems have been known to occur, depending upon a range of other factors*". For lakes and reservoirs these ranges are 0.005-0.05 mg/L-P and 0.1-0.5 mg/L-N while for rivers and streams the ranges are 0.01-0.1 mg/L-P and 0.1-0.75 mg/L-N. The Victorian Environmental Protection Authority (EPA, 1983) recommends a total phosphorus level of 0.1 mg/L-P for streams not discharging directly to lakes and 0.05 mg/L-P for those that discharge to lakes. The State of the Environment Report (OCE, 1988) on inland waters in Victoria developed criteria for assessing nutrients ranging from "excellent" at <0.01 mg/L-P and <0.2 mg/L-N to "degraded" at >0.1 mg/L-P and >1.0 mg/L-N.

The criteria finally adopted by Harrison (1994) were chosen to highlight relative differences between irrigation drainage arising from different sources and areas. The low levels for TP and TN were based on the above EPA figures and the degraded category defined in the State of the Environment Report. The moderate and high levels were chosen to further highlight these differences. These criteria are summarised in Table 3.1. Harrison (1994) stressed that these criteria do not represent environmentally safe target levels for nutrients discharging to receiving waters. *"These target levels are under deliberation elsewhere and are likely to be less than the "low" levels selected for the purposes of this re port*" (Harrison, 1994).

Table 3.1: Criteria selected for nutrients in irrigation drains (Harrison, 1994).

Criteria	TP mg/L-P	FRP mg/L-P	%P FRP/TP%	TN mg/L-N	NO_x mg/L-N
Low	<0.1	<0.01	<10	<1	<0.5
Medium	0.1-0.5	0.01-0.05	10-50	1-5	0.5-2.5
High	>0.5	>0.05	>50	>5	>2.5

Parameters are defined as follows:
TP - Total Phosphorus (digested) mg/L as phosphorus.
FRP- Filtered Reactive Phosphorus (0.45 micron filter, no digestion) mg/L as phosphorus
%P - Percentage of TP present as FRP.
TN - Total Nitrogen (sum of Total Kjeldahl Nitrogen (digested) and Oxidised Nitrogen) mg/L as nitrogen.
NO_x - Oxidised Nitrogen (reduction followed by nitrite analysis) mg/L as nitrogen .

To analyse nutrient data against land use Harrison (1994) plotted the median nitrogen value against the median phosphorus values for individual monitoring sites categorised as either pasture, horticulture or mixed crop. Figure 3.1 is a plot of the median total phosphorus and median total nitrogen concentration for irrigation drainage arising exclusively from horticultural areas and for drainage arising from predominantly pasture areas. Each triangle represents a sample site on an irrigation drain for a particular study. The smallest triangles represent a single sample for a particular site graduating to the largest triangle which represents the median values for an individual set containing over 400 observations. This data clearly shows that drainage arising from irrigated horticulture is often high in total nitrogen and relatively low in total phosphorus. Conversely, drainage arising from irrigated pasture is generally high in total phosphorus but relatively low in total nitrogen. Harrison (1994) found that *"there is almost no overlap between the two groups of data"*.

Figure 3.1: Total Phosphorus versus Total Nitrogen for pasture and horticulture (after Harrison, 1994).

Nutrients in Irrigation Drainage in the Shepparton Irrigation Region

A number of studies of nutrients in irrigation drainage in the SIR have been conducted. Sullivan et al. (1989) measured algal and nutrient levels (TP and NO_x) on a weekly basis (Program 1) from July 1985 to May 1988 at the Deakin Main Drain 500 m upstream of its outfall to the River Murray and at two sites in the River Murray (one upstream and one downstream of the Deakin Main outfall). During this same period, thrice-yearly monitoring (Program 2) was undertaken on 6 occasions at 12 sites on the Deakin Main Drain and its spurs and for 3 RWC groundwater pumps.

In the first sampling program, Sullivan et al. (1989) found that at the outfall of the Deakin Main Drain the concentration of TP and TN generally varied between 0.5 and 1.2 mg/L and 0.5 and 2.6 mg/L, respectively. (Note: Median concentrations of TP and TN were not presented in this report). For TP there was no clear seasonal pattern in concentration but for NO_x the concentrations were lower between January and May in each year. On all but several occasions they found that both the TP and TN loads in the Deakin Main Drain were low relative to that in the River Murray. In their analysis, Sullivan et al. (1989) assumed that the flow in the River Murray at Torrumbarry was equivalent to the flow in the river adjacent to the Deakin Main Drain. Unfortunately, this assumption fails to account for the inflows to the River Murray from the Campaspe River and the flows from the Torrumbarry Weir pool into the National Channel during the irrigation season.

In the second sampling program, Sullivan et al. (1989) found that under low flows in the drain the concentration of TP varied form 0.003-2.5 mg/L at the 12 sampling sites, and under high flows from 0.003-3.4 mg/L. It was found that "*the highest concentrations were generally found in the sites furthest from the Murray, and this effect was most apparent under conditions of low flow*". Under high flows this effect was less apparent though the concentrations at the outfall site were consistently lower than those further upstream. Oxidised nitrogen concentrations under low flows varied from 0.003-0.82 mg/L and under high flows from 0.003-0.83 mg/L. Concentrations of NO_x were similar but variable along the length of the drain although relatively low concentrations were found at the outfall site.

A program to monitor the contribution of nutrients from the SIR to nutrient loads in the River Murray commenced in 1990 (Barling, 1993; HydroTechnology, 1995). The objectives of this monitoring program are primarily to quantify current nutrient levels in irrigation drains in the SIR and the current level of impact of irrigation drainage on the water quality (nutrients) in the River Murray.

A summary of the results from this monitoring program are presented here and a more detailed analysis is presented in Barling (1993) and HydroTechnology (1995). Table 3.2 lists the sites that have been, or are, currently monitored for nutrients. The characteristics of each sampling site are listed in Table 3.3 and are described below. These sites include six constructed irrigation drains, a community drainage scheme, a naturally but poorly drained depression and a channel outfall. Initially, nutrient samples were collected on a weekly basis but the sampling frequency is now fortnightly. All nutrient samples are currently analysed for NO_x, TKN, FRP and TP.

Table 3.2: Station number, location and the date monitoring commenced.

Station Number	Description	Monitoring Period
405714	Central Goulburn No.9 Outfall	April 1990 to August 1994
405720	Rodney Main Drain, Wells Creek	April 1990 to present
405730	Toolamba Depression	September 1991 to present
406263	Mullers Creek, Murray Valley Highway	April 1990 to present
406704	Deakin Main Drain Outfall	April 1990 to present
406750	Bamawm Main Drain @ Dargan's Bridge	September 1993 to present
406758	Bamawm Main Drain @ Richardson's Lagoon	September 1993 to present
407712	Lockington Main Drain, Murphy Swamp	April 1990 to present
409712	Murray Valley Drain 6	April 1990 to present

Table 3.3: Catchment characteristics for each nutrient sampling site.

Sampling Site	Area (ha)	Drain Diverters	Groundwater Pumps	Other Features
Central Goulburn No. 9 Channel outfall (405714)	-	-	Yes	Groundwater pumping into the channel system. Flood pumping into the channel system.
Rodney Main Drain, Wells Creek (405720)	26,780	Yes	Yes	Ardmona Retarding Basin, Central Goulburn 6 No. 14 outfall, Main Drain Inlet from Mosquito Depression
Toolamba Depression (405730)	2,200	No	Yes	Natural depression with low gradients and poor drainage.
Mullers Creek (406263)	7,750	No	No	Community drainage scheme constructed in June and July, 1992 and January, 1993 Echuca Wastewater Treatment Plant
Deakin Main Drain Outfall (406704)	56,114	Yes	Yes	Timmering-Woolwash Depression, Mosquito Depression.
Bamawm Main Drain @ Dargan's Bridge (406750)	22,000	Yes	Yes	Regulated diversion roster.
Bamawm Main Drain @ Richardson's Lagoon (406758)	-	Yes	Yes	Downstream of Murphy Swamp and the junction of the Lockington and Bamawm Main Drains
Lockington Main Drain (407712)	20,467	Yes	Yes	-
Murray Valley Drain 6 (409712)	18,343	Yes	Yes	Only one groundwater bore is currently operational

Central Goulburn No. 9 Channel Outfall

The Central Goulburn No. 9 channel (CG9) is one of the major channels that offtakes from Waranga Basin. Except for a few minor spurs, the monitoring point on the CG9 is the major outfall for this network of channels (personal communication, Gale, 1992). The CG9 does however, receive a substantial amount of water from spur channels off the Central Goulburn No. 8 channel (CG8). The 3/8, 4/8, 10/8, 12/8, 14/8 and the 16/8 (prior to February 1990) channels all flow into the CG9 channel (personal communication, Gale, 1992). There is also a considerable amount of flood pumping (ie., pumping from flooded farm land into the channel system) and groundwater pumping into both the CG9 and CG8 channels.

Flood pumping occurs following heavy rains in winter and spring. Records from the pumping log for the Tongala district office of the RWC confirm that most pumping occurs after larger (> 25 mm) rainfall events when the antecedent soil water content is high. Records of flood pumping are only kept for a short period (typically several months) and they are kept primarily for operational purposes (eg., if problems develop in the system a farmer can be contacted and requested to discontinue pumping). No records are kept on exactly when, how long, and how much water is pumped into the irrigation channels.

There are at least 10 groundwater pumps that discharge into the CG8 and CG9 channels. During the irrigation season groundwater pumping only represents a small proportion of the flow in these channels but during the non-irrigation period when the flows are reduced it will represent a higher proportion.

Rodney Main Drain

The Rodney Main Drain catchment at Wells Creek has an area of 26,780 ha and includes the Rodney Main Drain, the Undera Main Drain and the Ardmona Main Drain. A link also exists between the start of the Rodney Main Drain and the Mosquito Depression known as the "Main Drain Inlet" where up to 220 ML/d can be diverted provided that the capacity of the Rodney Main Drain is not limited. During periods of low flow, all of the flow in the Mosquito Depression at the "Main Drain inlet" is diverted into the Rodney Main Drain. However, after heavy rains when flow in the Mosquito Depression is high, the inlet to the Rodney Main Drain may be throttled down or closed completely based on its available capacity. This situation does not occur all that often, although for example, it was necessary on several occasions in the spring of 1992 (personal communication, Gundrell, 1993). During summer, the Mosquito Depression does not flow and any runoff from irrigation is either re-used or lost through evaporation or seepage. Another major source of flow into the Rodney Main Drain is the Central Goulburn No. 6 channel No. XIV (CG6 No. 14) outfall which discharges into the Rodney Main Drain just upstream of the Wells Creek gauging station. This is the major outfall for the Central Goulburn No. 6, 7 and 8 channels.

Other factors that may influence the water quality at the outlet of the Rodney Main Drain is the presence of a flood retarding basin on the Ardmona Main Drain. There are also 37 groundwater bores that discharge to the Rodney Main Drain or to channels that outfall to the Rodney Main Drain and there are 36 drainage diverters upstream of the Wells Creek gauging site who are licensed to divert 4,409 ML/yr.

Toolamba Depression

The Toolamba Depression is a natural depression that drains a 2,200 ha catchment that adjoins the Goulburn River. The natural fall along the depression is only 1:5000 and the drainage efficiency of irrigated land is not high. Water quality monitoring at the drainage outfall commenced in September, 1991.

Mullers Creek

Mullers Creek is a depression in the landscape that drains to the River Murray and provides natural drainage for both storm flow runoff and irrigation runoff for a 7,750 ha catchment west of Echuca. In June and July, 1992 and then in January, 1993 a community drain was constructed along the Mullers Creek drainage depression. In many areas minimal works were required as there was already sufficient fall and flow capacity in the creek and as a result the majority of earthworks was devoted to increasing the continuity along the creek.

There are no groundwater pumps or drain diverters in the Mullers Creek catchment however, the Echuca Wastewater Treatment Complex is situated in the catchment and occasionally discharges treated effluent to Mullers Creek approximately 4 km upstream of the RWC gauging station and water quality sampling site. Treated effluent is added to the creek at a maximum dilution rate of 1:7. Barling (1993) estimated that the Echuca Wastewater Treatment Complex contributed 375 kg of TN and 130 kg of TP to Mullers Creek in 1992/93 and HydroTechnology (1995) estimated that 10,590 kg of TN and 3,946 kg of TP was discharged to the creek in 1993/94. Table 3.4 lists the median concentrations in Mullers Creek pre and post community drainage.

Table 3.4: Median concentrations in Mullers Creek pre and post establishment of community drainage.

Sampling Period	Median Concentration (mg/L)				
	NO_x	TKN	TN	FRP	TP
Pre-Community Drain (24/4/90 - 31/5/92)	<0.003	1.100	1.102	0.010	0.067
Post Community Drainage (1/6/92 - 30/6/94)[1]	<0.003	1.600	1.602	0.027	0.190

[1] The post community drainage median concentration omits the data for the period 9/10/92-3/11/92 and 15/8/93-15/10/93 when the Echuca Wastewater Treatment Plant was discharging treated effluent into Mullers Creek.

Deakin Main Drain

The Deakin Main Drain outfall at Echuca has an large catchment area and at present the area serviced by drainage is thought to be 56,114 ha. This consists of the Deakin Main Drain, the Rochester Drain 6 and a portion of the Mosquito Depression which is gradually being increased as the RWC drainage system is extended towards Tatura. There is also a contribution from the Timmering-Woolwash Depression (109,000 ha) to the south which has poorly developed drainage system. However, irrigation tailwater runoff is not the main source of runoff from the Timmering-Woolwash Depression. Runoff comes predominantly from the influx of flood water from upland dryland areas. There are however, extremely low gradients in the Timmering depression and because of the low flow velocities and the substantial attenuation in the upstream wetlands, peak outflows to the Deakin Main Drain occur typically some weeks after flood-producing storms. Accordingly, discharges to the Deakin Main Drain are inordinately low for a catchment of this size, and rarely exceed some hundreds of megalitres per day (Ian Drummond and Associates Pty Ltd, 1992a,b).

Ian Drummond and Associates Pty Ltd (1992b) have estimated historic outfalls from the Timmering Depression into the Deakin Main Drain using a hydrologic model for the periods 1973-1976 and 1988-1990 and these are listed in the Table 3.5. Flows in the Mosquito Depression Main Drain at Curr's Road (406756) have been recorded since 18 September 1992 and the annual flows for 1993 and 1994 are also listed in Table 3.5. These results show that both the Timmering and Mosquito Depressions make a significant contribution to flows in the Deakin Main Drain in wet years and appear to be a smaller proportion of the flow in average and dry years.

Table 3.5: Annual flows measured at the Deakin Main Drain outfall (406704), estimated annual inflows to the Deakin Main Drain from the Timmering Depression and annual flows measured at the Mosquito Depression (406756) for the periods 1973-76, 1988-90 and 1992-93.

Year	Annual Flows (ML/yr)		
	Deakin Main Drain outfall	Timmering Depression[1]	Mosquito Drain
1973	N/A	107,826	N/A
1974	N/A	54,582	N/A
1975	N/A	47,640	N/A
1976	N/A	4	N/A
1988	57,516	23,775	N/A
1989	43,333	10,793	N/A
1990	39,406	291	N/A
1993	81,585	N/A	9,923
1994	45,622	N/A	654

[1] These are estimated flows not measured flows.
[2] N/A = Not Available

There are 39 groundwater bores in the Deakin catchment that discharge to irrigation drains or channels. There are also 164 drain diverters across the Deakin drainage network that are licensed to divert 24,070 ML/yr. Approximately, 109 diverters are located on the Deakin Main Drain, 41 diverters on the Mosquito Depression and 14 diverters on the Rochester Drain 6 system.

Lockington Main Drain

The Lockington Main Drain at Murphy Swamp has a catchment area of approximately 20,500 ha. In this catchment there are no groundwater bores licensed to discharge to the Lockington Main Drain and there are only 5 drainage diverters with a license to pump 572 ML/yr. Between the monitoring site and the junction of the Lockington Main Drain and Bamawm Main Drain there is 1 additional diverter with a license volume of 123 ML/yr.

Bamawm Main Drain at Dargan's Bridge and at Richardson's Lagoon

The Bamawm Main Drain at Dargan's Bridge has a catchment area of approximately 22,000 ha. and includes a significant part of the Campaspe West irrigation area. There are 16 groundwater bores in the catchment and 62 drain diverters with a licensed diversion volume of 8,947 ML. The Lockington Main Drain flows into the Bamawm system upstream of Murphy Swamp and Richardson' Lagoon. Between the Dargan's Bridge and Richardson's Lagoon monitoring stations there are an additional 6 drain diverters that have a license to divert 2,398 ML/yr.

Murray Valley Drain 6

The Murray Valley Drain 6 catchment discharges directly to the River Murray near the Barmah State Forest and has an area of 18,343 ha. There are 51 groundwater bores within the catchment and there are also 38 drain diverters who are licensed to divert 3,297 ML/yr. This catchment has the highest drain density of all the monitored catchments.

Table 3.6 lists the median concentrations at the sampling sites for the full period of record and these are plotted in Figures 3.2 and 3.3 against the low, medium and high concentration ranges (see Table 3.1) for irrigation drainage specified by Harrison (1994) together with the median levels in the Broken River at Rice's Weir (404210), the River Murray at Torrumbarry Weir (409207) and the Goulburn River at McCoy's Bridge (405232). The Broken Creek acts as a conduit for a substantial amount of irrigation drainage from both the Murray Valley and Shepparton Irrigation areas, and as such, it has much higher median concentrations than the River Murray or the Goulburn River.

Table 3.6: Median concentrations for the period July 1990- June1994.

Sampling Site	Median Concentration (mg/L)				
	NO_x	TKN	TN	FRP	TP
Central Goulburn No. 9 (405714)	0.140	0.400	0.630	0.006	0.038
Toolamba Depression (405730)	0.062	2.300	2.377	0.034	0.320
Mullers Creek (406263)	<0.003	1.300	1.302	0.014	0.110
Rodney Main Drain (405720)	0.150	1.000	1.125	0.042	0.170
Deakin Main Drain (406704)	0.480	2.000	2.440	0.280	0.660
Bamawm Main Drain @ Dargan's Bridge (405750)	0.285	1.500	1.830	0.235	0.525
Bamawm Main Drain @ Richardson Lagoon (405758)	0.098	1.600	1.765	0.140	0.390
Lockington Main Drain (407712)	0.058	1.400	1.495	0.110	0.310
Murray Valley Drain 6 (409712)	0.210	1.500	1.811	0.310	0.620
Broken Creek @ Rice's Weir (404210)	0.073	1.300	1.311	0.056	0.290
Murray River @ Torrumbarry (409207)	0.024	0.600	0.605	0.011	0.068
Goulburn River @ McCoy's Bridge (405232)	0.180	0.800	0.985	0.018	0.100

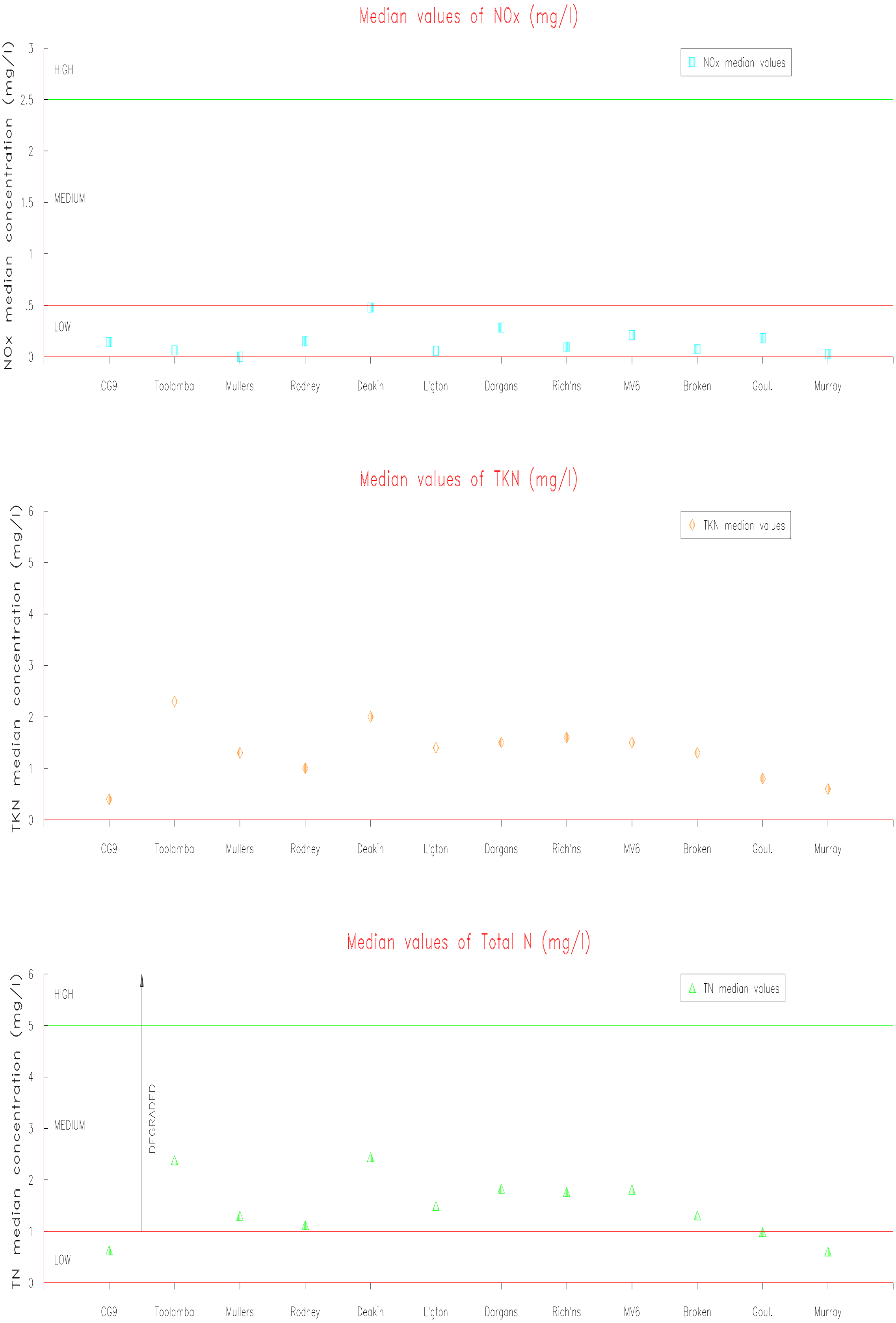
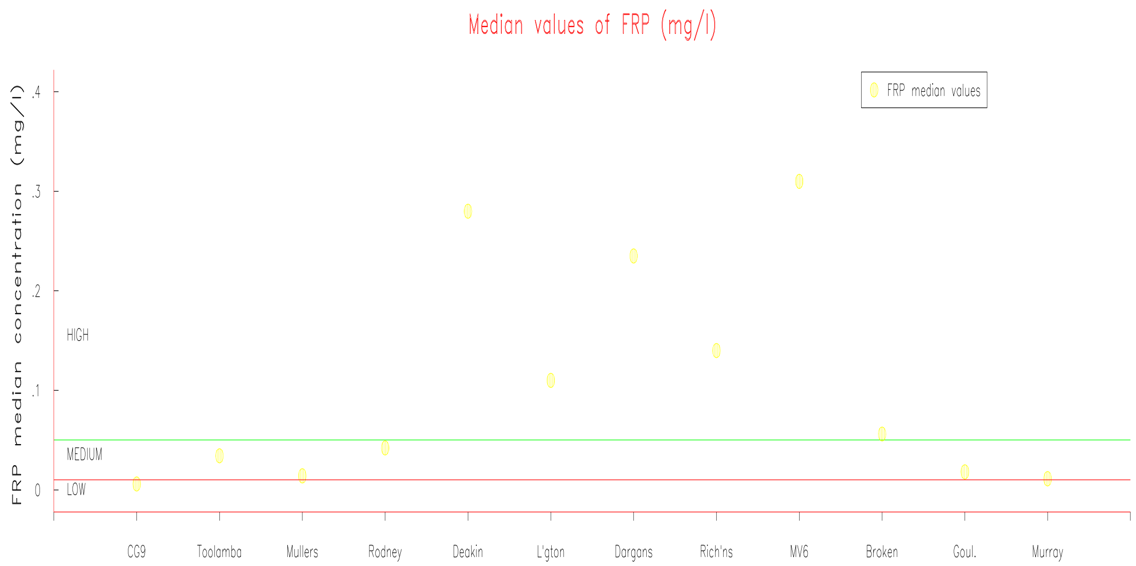


Figure 3.2: Median values (mg/L) of NO_x, TKN and TN.



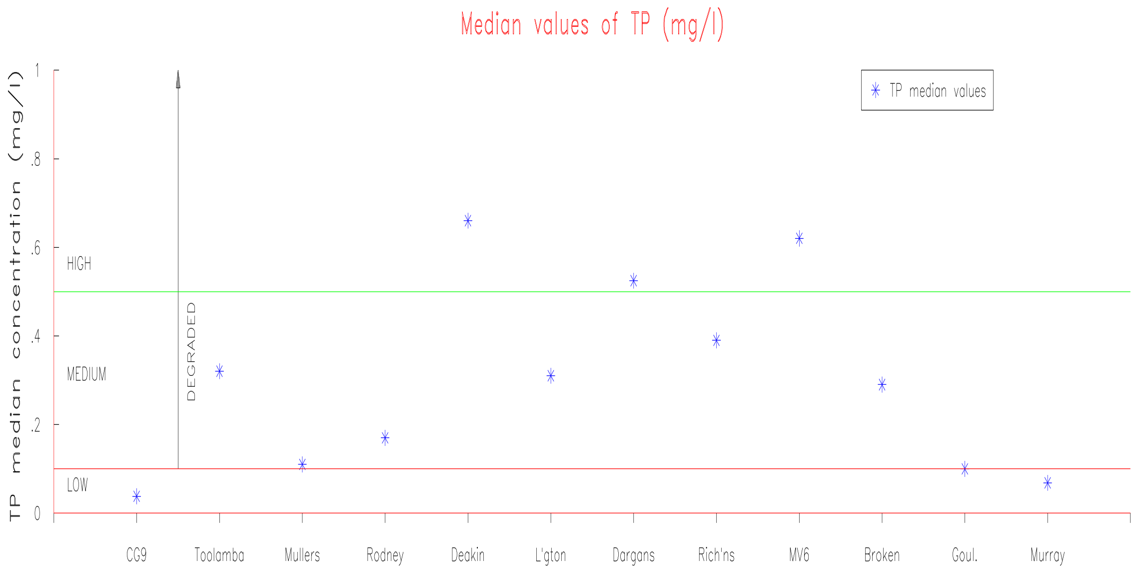


Figure 3.3: Median values (mg/L) of FRP and TP.

These results indicate that there is considerable variation in the median concentrations between the sampling sites. Based on the criteria in Table 3.1 irrigation drainage water at all drain monitoring sites is in a "degraded" condition based on the median concentration of TN (>1 mg/L) and based on the median concentration of TP. The results also show that:

- channel outfall water is low in both TN and TP
- in the major arterial drains a high proportion of TP is in soluble form (25%-50%)
- most of the nitrogen is in an organic from (ie., TKN)

- the Deakin Main Drain and Murray Valley Drain 6 have the highest concentrations of both TP and TN and both catchments should be targeted as priority areas for nutrient reduction strategies.

- the Rodney Main Drain has the lowest median concentration of both TP and TN of all the arterial drains.

- Broken Creek at Rice's Weir has median levels for TN and TP that are comparable to those measured in the Rodney, Lockington and Bamawm irrigation drainage systems. It would appear that irrigation drainage from both the Murray Valley and Shepparton Irrigation areas has a major impact on the water quality in Broken Creek.

To complement the regular sampling program, Barling (1993) sampled a further 27 sites in irrigation drainage system on a one-off basis in April, 1991 to look at the spatial variability in nutrient concentration and load across the SIR. Barling (1993) found that the water quality was "degraded" at 19 of the 27 sites sampled based on the concentration of TN (> 1 mg/L) and at 24 of the 27 sites based on the concentration of TP (mg/L). In general, the concentration at the drain outlets were generally lower than the concentration measured further upstream.

A pilot study of four drain sites in the Campaspe West Irrigation Area is currently being undertaken to provide information for the Campaspe West Salinity Management Plan. The aim of the study is to establish nutrient levels within the drainage system (Hooke, personal communication, 1995). The four sites and their median concentrations for TN, FRP and TP are listed in Table 3.7. All sites have been monitored on a monthly basis since November 1994.

Table 3.7: The sampling sites in the Campaspe West Irrigation Area and the median values of TN, FRP and TP for the period from November 1993 to June 1994.

Sampling Site	Number of samples	Median Concentration (mg/L)		
		TN	FRP	TP
Drain 5 at Northern Highway (406741)	8	3.065	1.600	1.700
Drain 3 at O'Donnell Road (406744)	6	2.750	0.735	1.450
Bamawm Main Drain d/s of WWMC (406751)	7	2.128	0.078	0.320
Drain 11/1 at Foster Road (406753)	6	2.985	1.085	1.750

Nutrient Loads from Irrigation Drainage

Barling (1993) and HydroTechnology (1995) have calculated monthly and annual nutrient loads for all monitored irrigation drains that discharge to the Murray or Goulburn Rivers. This data indicates that there are considerable differences between from year to year due to the variation in annual flow in response to rainfall (HydroTechnology, 1995). For example, the rainfall at the Tatura Post Office for the 1990/91, 1991/92, 1992/93 and 1993/94 years was:

- 439 mm (91% of the long term average, 484 mm)
- 361 mm (75% ")
- 666 mm (138% ")
- 585 mm (121% ").

The annual loads for all drain outfalls are listed in Table 3.8 for 1990/91, 1991/92, 1992/93 and 1993/94. This information shows that the Deakin Main Drain produces the largest nutrient loads of all the monitored drainage catchments and often exceeds the combined load of all other monitored outfalls. On this basis, it is the number one priority catchment for the development of a nutrient management strategy. The data in Table 3.8 also suggests that the number two priority catchment would be Murray Valley Drain 6.

Table 3.9 lists the catchment area for each monitoring site and the length of arterial and community drains in each catchment except for the Bamawm Main Drain at Richardson's Lagoon. It should be noted that the area of the Deakin Main Drain does not include the Timmering-Woolwash Depression or the Mosquito Depression. Similarly, the area of the Rodney Main Drain does not include an allowance for flows entering the drain from the Mosquito Depression. Table 3.10 lists the annual flow per unit area while Tables 3.11, 3.12, 3.13 and 3.14 list the annual loads per unit area and per unit length of drain. The Deakin and Rodney Main Drains have only been included for comparative purposes in dry years. In calculating the unit export rates for Mullers Creek the estimated contribution from the Echuca Wastewater Treatment Plant has been subtracted from the annual load in Table 3.8.

Table 3.8: Measured annual loads (kg) exported from monitored irrigation drainage outfalls in the SIR.

Sampling Location	Year	Flow (ML/yr)	Annual Load (kg)				
			NOx	TKN	TN	FRP	TP
Toolamba Depression (405730)	1990/91	-	-	-	-	-	-
	1991/92	393	12	264	276	12	48
	1992/93	679	48	1,608	1,656	96	312
	1993/94	782	86	1,934	2,020	90	325
	Average	**618**	**49**	**1,269**	**1,317**	**66**	**228**
Mullers Creek[1] (406263)	1990/91	1,081	24	1,128	1,152	12	84
	1991/92	1,297	12	1,728	1,740	12	132
	1992/93	4,265	60	7,920	7,980	444	1,116
	1993/94	5,003	3,435	15,139	18,576	3,302	4,458
	Average	**2,912**	**883**	**6,479**	**7,362**	**943**	**1,448**
Rodney Main Drain (405720)	1990/91	45,710	7,608	58,500	66,108	3,324	12,360
	1991/92	44,989	9,300	55,236	64,536	2,076	9,252
	1992/93	54,254	7,824	76,140	83,964	5,100	15,744
	1993/94	56,710	9,366	92,838	102,279	5,147	17,570
	Average	**50,710**	**8,525**	**70,679**	**79,222**	**3,912**	**9,705**
Deakin Main Drain[2] (406704)	1990/91	40,115	15,516	93,240	108,768	15,012	32,352
	1991/92	44,371	25,020	98,364	123,384	15,024	30,744
	1992/93	73,179	31,320	173,652	204,972	31,536	56,496
	1993/94	74,470	34,342	171,174	205,518	30,727	60,431
	Average	**58,034**	**26,550**	**134,108**	**160,661**	**23,075**	**45,006**
Lockington Main Drain (407712)	1990/91	11,842	1,284	18,984	20,268	1,536	4,320
	1991/92	12,998	2,268	22,788	25,056	1,872	5,088
	1992/93	20,315	2,388	36,540	38,916	4,884	9,852
	1993/94	22,015	2,610	42,399	45,009	4,365	10,298
	Average	**16,792**	**2,138**	**30,178**	**32,312**	**3,164**	**7,390**
Bamawm Main Drain @ Dargan's Bridge (406750)	1990/91	-	-	-	-	-	-
	1991/92	-	-	-	-	-	-
	1992/93	-	-	-	-	-	-
	1993/94	29,609	7,073	42,517	49,590	9,510	16,654
	Average	**29,609**	**7,073**	**42,517**	**49,590**	**9,510**	**16,654**
Bamawm Main Drain @ Richardson's Lagoon(406758)	1990/91	-	-	-	-	-	-
	1991/92	-	-	-	-	-	-
	1992/93	-	-	-	-	-	-
	1993/94	28,675	4,377	50,407	54,784	6,579	15,194
	Average	**28,675**	**4,377**	**50,407**	**54,784**	**6,579**	**15,194**
Murray Valley Drain Drain 6	1990/91	32,350	8,136	64,320	72,468	12,240	23,064
	1991/92	27,046	5,664	43,056	48,720	10,704	17,640
	1992/93	32,365	7,260	62,712	69,972	15,804	27,300
	1993/94	35,797	9,849	70,524	80,374	20,522	34,340
	Average	**31,890**	**7,727**	**60,153**	**67,884**	**14,818**	**25,586**
Goulburn River at McCoy's Bridge (405232)	1990/91	2,100,133	564,468	1,793,676	2,358,156	43,848	193,032
	1991/92	1,561,829	841,080	1,468,788	2,309,856	29,124	133,896
	1992/93	3,147,271	591,168	2,575,992	3,167,148	62,028	283,152
	1993/94	3,913,363	508,962	3,979,798	4,488,760	86,248	435,510
	Average	**2,680,649**	**626,420**	**2,454,564**	**3,080,980**	**55,312**	**261,398**
River Murray = Torrumbarry Weir + National Channel	1990/91	6,632,009	689,832	4,383,024	5,070,420	122,748	566,100
	1991/92	4,823,280	1,019,364	3,358,812	4,376,064	73,560	364,860
	1992/93	8,176,124	624,060	5,885,652	6,508,488	189,948	764,412
	1993/94	8,358,547	635,883	6,419,196	7,055,079	223,427	912,362
	Average	**6,997,490**	**742,285**	**5,011,671**	**5,752,513**	**152,421**	**651,934**

[1] This includes the contribution from the Echuca Wastewater Treatment Plant.

[2] In wet years the load measured at the Deakin Main Drain includes contributions from both the Mosquito and Timmering Woolwash Depressions.

Table 3.9: Catchment area (ha) and current drain lengths (km).

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6
Area (ha)	20,467	22,000	7,750	56,114	26,780	2,200	18,343
Drain Length (km)							
- GMW	125	191	0	451	126	0	155
- Community	27	0	44	5	18	0	5
Total drains (km)	152	191	44	456	144	0	160
Area/drain length	135	115	176	123	186	N/A	115

Table 3.10: Annual Flow per unit area (ML/ha) for 1990/91, 1991/92, 1992/93 and 1993/94.

Year	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain[1]	Rodney Main Drain[1]	Toolamba Depression	Murray Valley Drain 6
1990/91	0.58	-	0.14	0.71	1.71	-	1.76
1991/92	0.64	-	0.17	0.79	1.68	0.18	1.47
1992/93	0.99	-	0.55	1.30	2.03	0.31	1.76
1993/94	1.08	1.35	0.65	1.33	2.12	0.36	1.95
1990-1994	0.82	1.35	0.38	1.03	1.88	0.28	1.74

[1] Included for comparative purposes only since he total load may include contributions from outside the defined catchment.

Table 3.11: Annual TP load per unit area (kg/ha) for 1990/91, 1991/92, 1992/93 and 1993/94.

Year	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain[1]	Rodney Main Drain[1]	Toolamba Depression	Murray Valley Drain 6
1990/91	0.211	-	0.011	0.577	0.462	-	1.257
1991/92	0.249	-	0.017	0.548	0.345	0.022	0.962
1992/93	0.481	-	0.127	1.007	0.588	0.142	1.488
1993/94	0.503	0.757	0.066	1.077	0.656	0.148	1.872
1990-1994	0.361	0.757	0.055	0.802	0.513	0.104	1.395

[1] Included for comparative purposes only since he total load may include contributions from outside the defined catchment.

Table 3.12: TN per unit area (kg/ha) for 1990/91, 1991/92, 1992/93 and 1993/94.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain[1]	Rodney Main Drain[1]	Toolamba Depression	Murray Valley Drain 6
1990/91	0.990	-	0.149	1.938	2.469	-	3.951
1991/92	1.224	-	0.225	2.199	2.410	0.125	2.656
1992/93	1.901	-	1.030	3.653	3.135	0.753	3.815
1993/94	2.199	2.254	2.397	3.663	3.819	0.918	4.382
1990-1994	1.579	2.254	0.950	2.863	2.958	0.599	3.701

[1] Included for comparative purposes only since the total load includes contributions from outside the defined catchment.

Table 3.13: TP per unit drain length (kg/km) for 1990/91, 1991/92, 1992/93 and 1993/94.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain[1]	Rodney Main Drain[1]	Toolamba Depression	Murray Valley Drain 6
1990/91	28.4	-	1.9	70.9	85.8	N/A	144.2
1991/92	33.5	-	3.0	67.4	64.3	N/A	110.3
1992/93	64.8	-	22.4	123.9	109.3	N/A	170.6
1993/94	67.8	87.2	11.6	132.5	122.0	N/A	214.6
1990-1994	48.6	87.2	9.7	98.7	95.4	N/A	159.9

[1] Included for comparative purposes only since the total load includes contributions from outside the defined catchment. [2] N/A = not appropriate since the Toolamba Depression has effectively no drainage.

Table 3.14: TN per unit drain length (kg/km) for 1990/91, 1991/92, 1992/93 and 1993/94.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain[1]	Rodney Main Drain[1]	Toolamba Depression[2]	Murray Valley Drain 6
1990/91	133.3	-	26.2	238.5	459.1	-	452.9
1991/92	164.8	-	39.5	270.6	448.2	-	304.5
1992/93	256.0	-	172.8	449.5	583.1	-	437.3
1993/94	296.1	259.6	181.5	450.7	710.3	-	502.3
1990-1994	212.6	259.6	105.0	352.3	550.2	-	424.3

[1] Included for comparative purposes only since the total load includes contributions from outside the defined catchment. [2] N/A = not appropriate since the Toolamba Depression has effectively no drainage.

Estimation of Current Loads for the Total Irrigated area in the Goulburn and Broken Catchments

In assessing the current impact of the irrigation areas in the Goulburn and Broken catchments on the River Murray, the 1993/94 year has been used as an indicator. It should be noted however, that there was higher than average rainfall during the 1993/94 year and higher than average flows in both the irrigation drainage system and in the River Murray. A simplistic approach has been adopted because ultimately any estimate will only be of low to medium accuracy and should be used as an indicator rather than an absolute measure. The problem with any estimation process is that there is presently no clearly defined links between the catchment and nutrient export. Export rates are based on some complex and as yet unquantified relationship between: land use, drain length, drain density, drain type, rainfall, point source inputs and special features (eg, wetlands, swamps). On this basis, the specific treatment of the available data sets is as follows:

There are three types of drainage catchment that must be considered and these are:

- monitored catchments, flow and nutrients
- monitored catchments, flow
- unmonitored catchments

Monitored Catchments, flow and nutrients

The loads exported from monitored catchments for the 1993/94 season have been quantified by HydroTechnology (1995) and are listed in Table 3.7. In total, these outfalls exported approximately 167,800 ML, 112,700 kg of TP and 390,200 kg of TN. The monitored outfalls on the Deakin Main Drain, Rodney Main Drain, Murray Valley Drain 6 and the Toolamba Depression measure the loads currently exported from the Deakin, Corop Lakes, Mosquito, Rodney and Ardmona catchments and part of the Toolamba and Strathmerton catchments as shown in Figure 2.3.

Monitored Catchments, flow

There are however, additional sites outfalls to the River Murray on Warrigul Creek and Murray Valley Drain 3 that are monitored for flow and salinity as part of the Shepparton Salt Load monitoring program. These drains essentially measure all the flow exported from the Tongala, Coram, Wyuna catchments and most of the remainder of the Strathmerton catchment. To estimate the nutrient loads exported from these sites it was assumed that:

- Murray Valley Drain 3 nutrient levels are the same as the median concentrations measured at Murray Valley Drain 6. For the 1993/94 season the median concentrations in Murray Valley Drain 6 were: TP = 0.80 mg/L and TN = 1.795 mg/L.

- Warrigul Creek is situated between the Deakin and Rodney Main Drains. However, both drains have special features and have the highest and lowest median concentrations of all monitored arterial drainage systems (see Table 3.6). On this basis, neither data set was thought to be representative of the water quality in Warrigul Creek and values of TP = 0.4 mg/L and TN = 1.6 mg/L were adopted after examining the concentrations at other sites (similar to Bamawm and Lockington).

The estimated loads for Murray Valley Drain 3 and Warrigul Creek for the 1993/94 season are listed in Table 3.15.

Table 3.15: The estimated loads exported from Warrigul Creek and Murray Valley Drain 3 in 1993/94.

Site	Flow (ML/yr)	Concentration (mg/L)		Load (kg/yr)	
		TP	TN	TP	TN
Murray Valley Drain 3 (409711)	8,134	0.800	1.795	6,507	14,601
Warrigul Creek (405297)	35,948	0.400	1.600	14,379	57,517
Total	44,082	-	-	20,886	72,118

Unmonitored Catchments

Catchments in Figure 2.3 that are east of the Campaspe River and have unmonitored areas include: Strathallan, Coomboona, part of Toolamba, Kialla, Shepparton, Tallygaroopna, Invergordon, Kaarimba, Barmah/Nathalia and Muckatah. Subtracting the area requiring drainage in Table 2.3 from the total area suggests that 215,000 ha is currently drained. It is known however, from Table 2.2 (and allowing for the catchments that are west of the Campaspe River) that the area serviced by RWC drainage in the Goulburn and Broken catchments in 1990 was approximately 148,000 ha and since then another 11,400 ha has been constructed (MDBC, 1994). Therefore, approximately 160,000 of the 215,000 ha (~74%) is currently drained. The remaining 55,000 ha includes areas that are to be serviced by subsurface drainage and other areas that do not require drainage. An assumption that this ratio applies uniformly to all 18 subcatchments is considered valid for the level of accuracy within this exercise and hence the area currently serviced by drainage and not monitored in one form or the other is assumed to be 71,000 ha. This area is serviced predominantly by arterial drains and assuming that these generate the same unit flow and nutrient export rates as the Lockington Main Drain (i.e. for 1993/94, flow = 1.08 ML/ha, TP = 0.5 kg/ha, TN = 2.2 kg/ha) then this 71,000 ha is estimated to contribute 76,680 ML of irrigation drainage, 35,500 kg of TP and 156,200 kg of TN. It must be remembered however, that these numbers are of low to medium accuracy and could vary by up to 50%.

Table 3.16 lists the TP and TN loads for all three types of catchments for the 1993/94 season, giving an estimate of the total volumes and load exported from the study area. On the basis of the data, information on loads for catchment type 1 is good, type 2 is satisfactory and type 3 of low accuracy. Table 3.16 indicates that the total load estimates are reasonable given that catchment type 3 represents only 20%-30% of the total load. On this basis , it is estimated that 169,000 kg of TP and 619,000 kg of TN where exported from irrigation drainage in the Goulburn and Broken catchments in 1993/94. This compares with an estimated load of between 40,000-200,000 kg of TP and 250,000-600,000 kg of TN from the AEAM model.

Table 3.16: TP and TN loads exported from catchments monitored for both flow and nutrients, for catchments monitored for flow only and for unmonitored catchments.

Catchment Type	Flow (ML/yr)	Annual Load (kg) for 1993/94	
		TP	TN
1. Monitored, flow and nutrients	167,759	112,666	390,191
2. Monitored, flow	44,082	20,886	72,118
3. Unmonitored	76,680	35,500	156,200
Total	288,521	169,052	618,509

HydroTechnology (1995) have estimated that the TP and TN loads exported from the Goulburn and Broken catchments in 1993/94 were 615,000 kg and 5,121,000 kg, respectively (see Table 3.17). This compares with an annual load measured in the River Murray (Torrumbarry Weir plus National Channel) of 910,000 kg and 7,060,000 kg, respectively. The load exported from the Goulburn and Broken catchments is calculated by summing the contributions from the Goulburn River at McCoy's Bridge, the Broken Creek at Rices Weir and the irrigation drains that outfall directly to the River Murray. These drains include: Murray Valley Drains 3 and 5, Warrigul Creek and the Deakin Main Drain. Table 3.17 lists the estimated annual loads from each of these sources.

Table 3.17: The estimated annual load exported from the Goulburn and Broken Catchments in 1993/94.

Sampling Location	TP Load (kg)	TN Load (kg)
Goulburn River @ McCoy's Bridge (405232)	436,000	4,489,000
Broken Creek @ Rice's Weir (404210)	64,000	273,000
Murray Valley Drain 3 (409711)	7,000	15,000
Murray Valley Drain 5 (409712)	34,000	80,000
Warrigul Creek (405297)	14,000	58,000
Deakin Main Drain (406704)	60,000	206,000
Total Exported	615,000	5,121,000
River Murray at Torrumbarry	912,000	7,055,000

The results in Tables 3.16 and 3.17 suggest that in 1993/94, irrigation drainage in the Goulburn and Broken catchments contributed 27% of the TP load and 12% of the TN load exported from the Goulburn and Broken catchments. The measured nutrient load in the River Murray at Torrumbarry has been included for comparative purposes only since nutrient cycling in the river prevents a direct comparison.

Estimation of Loads for Complete Drainage in the Irrigation Areas of the Goulburn and Broken Catchments

If in 1993/94, all areas under the SLWSMP had been fully drained as is proposed within the surface drainage program, additional nutrients would have been exported from these areas. Under the SLWSMP the increased area to be drained is 250,625 ha (see Table 2.3).

The estimation of total future "drained" loads is based on:

- (A) Current loads
- (B) Estimate contribution from undrained areas to these current loads
- (C) Estimate contributions from installation of drainage in the currently undrained areas.
- Net load = (A) - (B) + (C)

Contributions from undrained areas to the 1993/94 load

In assessing the future contribution from presently undrained areas, it is important to recognise that these areas already make some contribution to the total nutrient loads exported from the irrigation drainage system. This contribution increases in wet years, and is negligible in dry years.

Using 1993/94 and assuming that the major contribution from undrained areas is the Mosquito and Timmering Depressions, the data in Table 3.5 indicates that approximately 50% of the flow (37,235 ML) measured at the outfall of the Deakin Main Drain was generated from these areas. Nutrient levels in this runoff is likely to be similar to those in the undrained Toolamba Depression (TP = 0.325 mg/L, TN = 2.660 mg/L, HydroTechnology(1995)). On this basis, it is estimated that the Mosquito and Timmering Depressions contributed 12,000 kg of TP and 99,000 kg of TN to the Deakin Main Drain.

Contributions from installation of drainage in the currently undrained areas.

For the 250,625 ha presently requiring drainage, it is estimated that 46,000 kg of TP and 301,000 kg of TN (see Table 3.18) would have been exported to the River Murray in 1993/94 if this area had been drained. In arriving at these estimates, the following assumptions were adopted:

- The area serviced by arterial and community drains east of the Campaspe River is in the same proportions as the drain lengths listed in Table 2.3 (i.e., 307 to 1811). Therefore, 36,328 ha will be serviced by arterial drains and 214,297 ha by community drains.

  The export rates in 1993/94 for areas serviced by arterial drains are the same as those for the Lockington Main Drain (i.e., flow = 1.08 ML/ha, TP = 0.5 kg/ha, TN = 2.2 kg/ha).

- The export rates in 1993/94 for areas serviced by community drains is equivalent to those for Mullers Creek in 1992/93 (i.e., flow = 0.55 ML/ha, TP = 0.13 kg/ha and TN = 1.03 kg/ha). The 1993/94 export rates for Mullers Creek were not adopted because the contribution from the Echuca Wastewater Treatment Plant accounts for 89% and 57%, respectively, of the annual TP load and TN loads. This limits the data set to the first year after the construction of the community drainage scheme was completed. In this year, the export rate for TP for Mullers Creek is less than for the undrained Toolamba Depression (see Table 3.11) but it is greater than the corrected value for 93/94. However, given the limited data set, a more accurate estimate cannot be provided at this stage.

Particular difficulties in the predictions include an assumption of a linear response between the area drained and nutrient export rate and it is possibly that this is not valid due to a number of factors:

- Community drains and new arterial drains are designed for the 1:2 year event and this will increase the amount of water overtopping the drain banks and the retention time in the catchment. This potentially increases nutrient stripping.

- New drains will be located in the upper reaches of catchments, increasing drain lengths and travels times. This potentially increases nutrient stripping.

- Nutrient dynamics in drains is not understood eg. trigger points may exist with respect to uptake or release of nutrients.

- Re-use systems may be more prevalent in current undrained areas reducing the amount of nutrients reaching the drainage system.

Table 3.18: Estimated flow and nutrient load (in 1993/94 equivalents) exported from areas that are currently undrained.

	Area (ha)	Flow (ML/yr)	TP (kg/yr)	TN (kg/yr)
Arterial Drainage	36,328	39,230	18,160	79,920
Community Drainage	214,297	117,860	27,860	220,730
Total	250,625	157,090	46,020	300,650

Table 3.19 presents a summary of the loads exported from the study area assuming full drainage in 1993/94. The 1993/94 year has been used only as an indicator based on the limited amount of data and a recognition of lack of sound statistical inference from such data sets. Given the last four years of records, the loads would be expected to be higher than average (i.e., 21% more rainfall in 1993/94). Further evidence of the variability is given in the unit rates of TP and TN export in Tables 3.11 and 3.12, showing the 1993/94 rates for Lockington being double that for 1990/91 and 1991/92. Given the level of variability, a much longer data set is needed for long term meaningful averages.

Table 3.19: TP and TN loads exported from the irrigation areas in 1993/94, the current contribution from undrained areas and the predicted contribution from the additional 250,625 ha of land requiring drainage.

	Flow (ML/yr)	Annual Load (kg) for 1993/94	
		TP	TN
1993/94 exports	288,521	169,052	618,509
Existing contributions from the Mosquito and Timmering Depressions	-37,235	-12,100	-99,050
Contribution from undrained areas	157,090	46,020	300,650
Net exports for full drainage	408,376	202,972	820,109

Impacts on the Receiving Waters

Impacts on Concentration

In evaluating the impact of nutrients discharged in irrigation drainage on receiving waters, it is necessary to consider both nutrient concentration and load. Algal growth in surface waters will be affected by many factors, one of which is the availability of nutrients in the water column. Concentration is often measured to identify what form nutrients are present and whether these forms are available for uptake by plants and algae.

Monitoring of the nutrients in irrigation drainage from the Goulburn Irrigation Area (Barling, 1993; HydroTechnology, 1995) indicates that a high proportion of phosphorus (25%-50%) is present in a form that is readily available for plant and algal uptake.

For example, if all discharge from the Rodney Main Drain to the Goulburn River were to cease, then the available phosphorus in the Goulburn River at McCoy's Bridge would be greatly reduced, especially in the summer months when warm temperatures can lead to increased algal growth. In Table 3.20 the percentage reduction in the phosphorus concentration has been estimated by subtracting the phosphorus load measured in the Rodney Main Drain from the load measured in the Goulburn River at McCoy's Bridge and dividing by the flow in the Goulburn minus the flow from the Rodney Main Drain.

The results in Table 3.20 show the importance of targeting irrigation drainage flows during the summer period to minimise the potential for localised algal blooms. The results also show that winter drainage flows do not have the same local impact. However, these flows may be of great significance further downstream in the River Murray and their impact needs to be considered when developing a nutrient management strategy.

Table 3.20: Percentage Reduction in Phosphorus Concentration by Ceasing Discharge to the Goulburn River from the Rodney Main Drain.

Date	1990		1991		1992		1993		1994	
	FRP	TP	FRP	TP	FRP	TP	FRP	TP	FRP	TP
Jan			71	25	31	11	36	13	26	14
Feb			33	6	37	11	17	9	98	28
Mar			14	8	26	7	4	3	61	22
Apr			26	5	1	3	5	6	17	19
May			14	27	0	0	0	0	7	2
Jun			9	10	0	0	8	4		
Jul	4	3	0	0	0	0	1	0		
Aug	0	0	0	0	3	3	1	1		
Sep	1	1	1	2	2	2	2	2		
Oct	4	4	20	4	4	3	9	4		
Nov	23	11	28	5	8	5	83	15		
Dec	27	4	30	7	32	14	42	12		

Nutrient - Algal Count Relationships

Algal growth will be affected by a number of factors, including nutrient availability, light availability, temperature, turbidity, turbulence, mortality rates and predation. The combination of the various factors prevalent in a water body and the way these factors interact are likely to be site specific and difficult to determine. Algal species are therefore likely to respond differently to a particular set of environmental conditions. This makes prediction of the response of algae to changes in nutrient levels difficult.

An investigation of nutrient - blue-green algae relationships in the River Murray below Hume Dam (Long, 1992) using long term data collected by the MDBC indicated that blue-green algae density were related to nitrogen and phosphorus concentration and storage levels in Hume Dam. Multiple regression analysis suggested that approximately 75% of the variation in blue-green algae density between December and June was explained by the regression model:

$$BG^* = 4894.3 + 1078.5TN + 24603.3TP - 0.3424LL$$

where, BG = blue-green algae density (units/mL)
TN = total nitrogen concentration (mg/L)
TP = total phosphorus concentration (mg/L)
LL = water storage height (m, Australian Height Datum (AHD))

*BG was taken as equal to zero between July and November and when water storage was above 181m AHD.

The use of this model suggests that doubling the TN and TP concentration in the River Murray from for example 0.3 mg/L and 0.02 mg/L respectively to 0.6 mg/L and 0.04 mg/L, respectively when storage levels in Hume Dam were at 170m AHD, would result in an increase of approximately 14% in blue-green algae density.

While this is a useful model for the section of river below Hume Dam, the inclusion of water storage height and data collected at Albury means that applying the above model would be inappropriate to the River Murray near the study area.

A positive correlation between nutrient concentration and flow and a negative correlation between algal counts and nutrient levels has been recorded at Torrumbarry Weir (Sullivan et al., 1989). Sullivan et al. (1989) suggested that nutrient levels increase with increased flow, while algal numbers are reduced by dilution. As discharge recedes, algae numbers increase due to the increase in available nutrients. Then as algal numbers increase, nutrient levels decrease due to uptake by the algae. However, no predictive model such as that described by Long (1992) above was offered by Sullivan et al. (1989). As such a model could be useful for the future development of a nutrient management strategy, some further investigations of nutrient - algae count relationships in the vicinity of the Goulburn-Broken catchment should be considered.

Chlorophyll-a levels (as a measure of algal growth) are measured by the MDBC at sites including Torrumbarry Weir and Barr Creek (as is nutrient concentration at these sites). It was hoped that examining this data might identify the likely impacts of increased nutrient availability as a result of increased irrigation discharge on algal growth in receiving waters.

Simple regression analysis was used to examine any relationship between chlorophyll and nutrient levels. Unfortunately, no correlation between chlorophyll levels and the nutrient concentration at either Torrumbarry Weir or Barr Creek during the period 1982-1994 was found that might help identify the response of algae to changes of nutrient concentration in the River Murray near the study area.

Potential Changes to Biota in Response to Increased Nutrient Levels

Many native plant species are adapted to low nutrient conditions. Increased nutrient availability favours the growth of invasive native and exotic species that out-compete the low nutrient adapted species (eg the growth of combungi in drains and wetlands). If nutrient levels continue to increase and are persistent, there is the possibility that the dominant plant species may shift from macrophytes to algae (eg Lake Mokoan, Lake Burley Griffin). Such changes in plant communities are also likely to result in changes to animal assemblages.

The decomposition of organic material carried by irrigation drainage requires the utilisation of oxygen, both in the drainage water and receiving waters. This process may potentially result in low dissolved oxygen conditions (dissolved oxygen sags) in irrigation drains and the receiving zones of waters receiving the drainage. In such cases, the low availability of oxygen could result in the death or dispersal of the naturally occurring biota in the receiving waters, possibly leading to lower species diversity or changes in species dominance to opportunistic or nuisance organisms (including algae).

Lowered oxygen conditions can also lead to changes in the oxidation/reduction of the drainage water and receiving waters overlying bottom sediments. This can lead to the remobilisation of phosphorus from the bottom sediments, thus making additional nutrients available for plant and algal uptake.

SOURCES OF NUTRIENTS IN IRRIGATION DRAINAGE

In Section 3, the nutrient loads exported from the irrigation areas in the Goulburn and Broken catchments were quantified. In this section, the sources of nutrients entering the drainage system are evaluated for a "typical" year to provide an understanding of the relative magnitude of the various inputs. In estimating the nutrient inputs to the irrigation drainage system both diffuse and point sources must be considered. Diffuse sources are primarily the runoff from agricultural land, while point sources include:

- towns
- sewage treatment plants
- industry
- intensive animal industries
- dairy shed effluent

The magnitude of the loads from each of these sources are evaluated in the following sub-sections together with the impact of drain diverters who remove nutrients from the irrigation drainage system when they divert water from the drains.

Diffuse Sources of nutrients

Landuse in the Irrigation Areas of the Goulburn and Broken Catchments

One of the key parameters affecting the nutrient load in the irrigation drainage system is the agricultural activity on the adjacent irrigated land. Several sources of information were consulted to determine the landuse categories in the study area and in the sub-catchments that are presently monitored for nutrients. The three sources of data were the Australian Bureau of Statistic's (ABS) Agricultural Census for 1992 also commonly referred to as "AgStats", the RWC Culture Data for the 1991/92 irrigation season and Landsat satellite imagery for 1991/92.

The RWC Culture Data for the 1991/92 irrigation season (Table 4.1) provides an accurate record of the irrigation culture in the six irrigation districts that formed the SIR at that time. For the purposes of this study, the irrigation culture data is assumed to provide the best estimate of the overall irrigated landuse in the Goulburn and Broken catchments and is used as the baseline data set. The landuse for all irrigated land in the Goulburn and Broken catchments is assumed to be the sum of the 1991/92 culture data for the Shepparton, Rodney, Tongala and the Murray Valley irrigation districts, plus 48% of the irrigated area in the Rochester irrigation district and all the irrigated land under private diversions. The difference between the area of holdings and the irrigated area is assumed to be dryland pasture.

Table 4.1: Lands Under Irrigated Culture 1991/92

Irrigation Area	Shepparton	Rodney	Tongala	Rochester	Murray Valley	Total
Area of holdings (ha)	81,627	104,278	68,775	104,297	127,873	486,850
Water Right (ML)	182,593	245,901	139,202	173,441	256,866	998,003
Water delivered (ML)	255,909	365,249	226,074	296,694	407,119	1,551,045
Area by farm type (ha)						
Dairying	402	496	814	602	756	3,070
Other	811	680	796	720	784	3,791
Horticulture	289	120	33	14	130	586
Area Irrigated (ha)						
Perennial pasture	23,495	29,856	35,855	27,581	33,513	150,300
Annual pasture	18,704	20,957	16,162	22,231	33,423	111,477
Lucerne	339	810	253	1,629	1,960	4,991
Autumn Irrigated Fallow	105	89	105	190	118	607
Harvested Crops	756	1,939	1,263	2,583	2,373	7,225
Forage Crops	810	441	356	507	979	3,093
Grapes	61	26	3	0	133	223
Citrus	0	0	12	0	379	391
Stone Fruit	1,094	1,361	112	0	1,472	4,039
Pome Fruit	2,597	2,038	203	0	254	5,092
Other orchard Crops	131	81	75	0	283	570
Tomato	128	478	42	1,064	6	1,718
Potato	0	4	0	0	88	92
Other vegetables	50	43	16	51	65	225
Other	0	20	6	21	0	47
TOTAL	48,270	58,143	54,463	55,857	75,046	291,779

Source: RWC (1992b).

The culture data can be linked to individual parcels of land via the Register Entry Number (REN). Unfortunately, the REN's for a particular sub-catchment can only be obtained manually and this task was beyond the scope of this consultancy. In more recent surveys, culture data has now been linked to the Service Point Group (SPG) number of the customer and not to a physical unit of land. This new arrangement, substantially degrades the quality of the culture information for catchment based studies.

The ABS provides landuse information at a parish level based on data supplied by farmers in the annual Agricultural Census. The categories in the AgStats are well defined and provide a wide range of information. A number of parishes were selected for 'ground-truthing' which was carried out by touring these parishes and consulting local Department of Agriculture Extension and Research staff. ABS data is limited to farms that exceed a certain level of productivity and the unsurveyed agricultural area within a parish is not recorded. In some parishes, the unsurveyed area accounted for 40% of the total parish area. A comparison between the AgStats and the Culture Data in the SIR indicates that the total area for irrigated categories from AgStats is 15.6% less than the total irrigated area from the culture data (only 6% less for the irrigated pasture category).

For the purpose of this study, AgStats categories in each Parish were combined into the following broad commodity groupings: irrigated pastures and grasses, dryland pasture and grasses, irrigated crops, dryland crops, irrigated vegetables, dryland vegetables, irrigated fruit, dryland fruit, and *others* (= total area - sum of all other categories, and include roads and buildings, towns, crown land etc). These commodity groups were chosen based on the available information on export rates for different agricultural landuses.

Another major limitation in the AgStats data is the failure to differentiate between irrigated perennial and irrigated annual pasture which have significantly different nutrient export rates.

This problem was addressed using information from Landsat satellite imagery provided by the Institute of Sustainable Irrigated Agriculture (ISIA) at Tatura. Landsat satellite imagery provides landuse statistics at any scale (sub-catchment, parish, study area) based on the growth activity of the vegetation at specific times of the year (January and late Autumn). Due to the nature of satellite imagery and the method of interpretation, the number of categories is currently limited to six and these can be difficult to relate to categories in other data sets. These categories are: irrigated permanent pasture (vigorous), irrigated permanent pasture (less vigorous), irrigated annual pasture, horticulture, summer active vegetation and dryland. The horticulture category must be used with caution due to possible inclusion of spiny rush and problems with identifying orchards with the Tatura trellising system.

To quantify the irrigated and dryland landuse for a particular sub-catchment the following approach was used. First, the proportion of each parish within a drainage catchment was established. If a parish was located within the SIR the landuse categories were proportioned on the basis of the area of the parish within the sub-catchment. If however, some proportion of a parish was outside the SIR, it was assumed that all the irrigated land in the parish was located in the proportion of the parish within the irrigation area. Irrigated landuse categories were then proportioned on the basis of the area of the sub-catchment within the irrigation area.

After this proportioning process, the *others* category should reflect the amount of land that is not used for agricultural activity, such as roads, dams and towns and crown land. For a number of sub-catchments, the magnitude of the *others* category appeared to be high (see Table 4.2). If all of the irrigated categories in the AgStats are uniformly increased by 15.6% to match the total irrigated area from the culture data the *others* category is reduced. However, for a number of subcatchments this reduces the *others* category to unrealistically low levels as listed in Table 4.2. As a compromise measure, a percentage for the *others* category was adopted for each subcatchment as listed in Table 4.2 and the individual landuse categories were adjusted accordingly. Table 4.3 is a summary of the landuses in the sub-catchments and for complete study area.

Table 4.2: The percentage of the catchment in the *others* category for the 7 catchments monitored for nutrients.

Catchment	AgStats	Culture Data	Percentage Adopted
Lockington Main Drain	13.8	0.4	10
Dargan’s Bridge	17.4	4	15
Mullers Creek	29.8	19	25
Deakin Main Drain	31.9	21	25
Rodney Main Drain	24.4	12	20
Toolamba Depression	43.8	35	40
Murray Valley Drain 6	32.8	22	25

Table 4.3: Landuse in the 7 sub-catchments that are monitored for nutrients and for the whole Goulburn and Broken Catchment.

LANDUSE (ha)	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigated								
Perennial pasture	6,808	5,762	673	17,599	7,161	613	4,401	145,629
Annual pasture	3,875	2,003	853	8,389	4,613	276	4,300	112,297
Crops	275	329	95	366	303	77	356	12,997
Vegetables	108	13	30	216	170	0	7	11,846
Fruit	1	1	4	127	25	0	136	1,671
Dryland								
Pasture and Grasses	5,498	5,153	2,057	12,946	6,702	743	3,869	171,466
Crops	1,611	1,932	1,054	2,666	2,465	133	687	-
Vegetables	0	0	0	0	0	0	0	-
Fruit	0	0	0	0	0	0	0	-
Others = Total - sum	2,020	2,681	1,589	14,102	5,360	1,228	4,585	-
Total Area (ha)	**20,195**	**17,875**	**6,355**	**56,410**	**26,800**	**3,070**	**18,340**	**455,907**

Export rates for different agricultural landuses

In the literature, nutrient export rates from diffuse sources are generally expressed in the units of kg/ha/yr. The nutrient export rate from agricultural land varies with the amount of runoff and the concentration of TP and TN in the runoff. Unfortunately when the export rates are presented in the units of kg/ha/yr it is not clear which of these factors is important and for this reason, export rates in this issues paper are calculated from first principles using research by Small (1985), Agriculture Victoria (1994), and McNab et al. (1994) from within the study area. That is:

- Export rate = Water applied (ML/ha) x (% runoff) x concentration (mg/L)

This approach has been used because it shows the impact of different management actions on either or both the amount of runoff from irrigated land and the nutrient concentration in the runoff. For each landuse category, data has been collected on the amount of water applied, the percentage that becomes runoff and the concentration of TP and TN and this is listed in Table 4.4. Irrigation requirements for the different landuses are presented in Section 5 of this report and an average value has been adopted here. The rainfall data in Table 4.4 is based on long term averages for Shepparton while the runoff percentages and the nutrient concentrations have been obtained from reports, published papers and from discussions with researchers and Departmental extension staff in the SIR. Export rates for the irrigation season and the non-irrigation period are listed in Table 4.5. In calculating these export rates it has been assumed that the runoff factor during the irrigation season applies to both irrigation and rainfall during the irrigation season.

The export rates in Table 4.5 do not consider the increased nutrient loads exported after fertiliser application. For example, the average concentration of TP in tailwater runoff from perennial pasture for the two irrigations after phosphorus fertiliser application is approximately 15 mg/L (personal communication, D. Small and N. Austin). Assuming 0.6 ML/ha is applied in each irrigation, tailwater runoff is 20% of the applied water, and the background concentration of TP is 2 mg/L (see Table 4.4) then an additional 3.12 kg/ha/yr of phosphorus is exported after fertiliser application. This represents 36% of the total TP load exported (= 8.66 kg/ha) in a year.

Increases in the nutrient concentration occur after fertiliser application for other landuses however, given the small areas (and small loads) relative to perennial pasture, further consideration of these loads is not warranted.

Table 4.4: Water requirements, rainfall, % runoff and the concentration of TP and TN in the runoff from different irrigated landuse.

IRRIGATED LANDUSE	Irrigation season			Non-irrigation period		Concentration	
	Irrigation (ML/ha)	Rainfall (ML/ha)	% Runoff	Rainfall (ML/ha)	% Runoff	TP (mg/L)	TN (mg/L)
Perennial pasture	10	3.09	20	2.02	7.5	2.0	5.0
Annual pasture	3	3.09	20	2.02	7.5	1.0	2.5
Crops	8	3.09	20	2.02	7.5	0.8	3.0
Vegetables	5	3.09	20	2.02	7.5	1.0	5.0
Fruit - surface drainage	6	3.09	10	2.02	7.5	0.25	5.0
Fruit - subsurface drainage	6	3.09	20	2.02	7.5	0.1	50.0

Table 4.5: Nutrient export rates for the irrigation season and over the non-irrigation period

IRRIGATED LANDUSE	EXPORT RATES (kg/ha)			
	Irrigation season		Non-irrigation period	
	TP	TN	TP	TN
Perennial pasture	5.24	13.1	0.30	0.8
Annual pasture	1.22	3.0	0.15	0.4
Crops	1.77	6.7	0.12	0.5
Vegetables	1.62	8.1	0.15	0.8
Fruit - surface drainage	0.23	4.5	0.04	0.8
Fruit - subsurface drainage	0.18	90.9	0.02	7.6

Potential nutrient loads from diffuse sources

In estimating the potential nutrient loads entering the irrigation drainage system from diffuse sources during the irrigation season it has been assumed that:

- Forty percent of the area under perennial pasture is assumed to have some form of on farm re-use which is assumed to have an overall efficiency of 0.5. This represents an overall reduction in the volume of runoff and the nutrient load of 20%.
- All land within a drainage catchment is assumed to have access to surface drainage.
- There is no reduction in nutrient levels between the end of the irrigation bay and when the tailwater runoff enters the irrigation drainage system.

During the non-irrigation period (May-August) it is assumed that:

- Runoff is generated from both dryland and irrigated areas.
- The runoff factor is 7.5% for all landuses. This is based on long term monitoring data for drained catchments.
- The concentration of the runoff from the dryland categories is assumed to be the same as for the equivalent irrigated categories.
- Re-use on farms in the non-irrigation period is assumed to be zero.
- All land within a drainage catchment is assumed to have access to surface drainage.
- There is no reduction in nutrient levels before the rainfall runoff enters the irrigation drainage system.

The potential TP and TN loads during the irrigation and non-irrigation periods and over the whole year are listed in Tables 4.6, 4.7, 4.8, 4.9, 4.10 and 4.11, respectively. These tables show that the major proportion of the diffuse nutrient load is derived from irrigated perennial pasture. This is to be expected because it represents the major irrigation landuse and it has high export rates for both phosphorus and nitrogen.

Table 4.6: Estimated Potential TP load (kg) from diffuse sources during the irrigation season.

LANDUSE	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigated								
Perennial pasture	35,646	30,169	3,521	92,148	37,497	3,211	23,045	762,513
Fertiliser (perennial)	21,240	17,977	2,098	54,909	22,344	1,913	13,732	454,362
Farm re-use	-11,377	-9,629	-1,124	-29,411	-11,968	-1,025	-7,356	-243,375
Annual pasture	4,720	2,440	1,039	10,217	5,619	336	5,237	136,778
Crops	487	584	168	649	538	136	632	23,063
Vegetables	174	21	49	350	275	0	11	19,167
Fruit	0	0	1	29	6	0	31	380
TP Load (kg)	**50,891**	**41,563**	**5,753**	**128,890**	**54,311**	**4,571**	**35,332**	**1,152,887**

Table 4.7: Estimated Potential TN load (kg) from diffuse sources during the irrigation season.

LANDUSE	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigated								
Perennial pasture	89,114	75,424	8,803	230,370	93,743	8,028	57,614	1,906,282
Re-use	-17,823	-15,085	-1,761	-46,074	-18,749	-1,606	-11,523	-381,256
Annual pasture	11,800	6,100	2,598	25,544	14,048	839	13,092	341,944
Crops	1,827	2,191	629	2,435	2,018	509	2,368	86,485
Vegetables	872	105	245	1,748	1,377	0	54	95,834
Fruit	3	3	19	575	112	0	619	7,596
TN Load (kg)	**85,794**	**68,738**	**10,534**	**214,597**	**92,549**	**7,770**	**62,224**	**2,056,884**

Table 4.8: Estimated Potential TP load (kg) from diffuse sources during the non-irrigation period.

LANDUSE	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigated								
Perennial pasture	2,063	1,746	204	5,332	2,170	186	1,334	44,126
Annual pasture	587	303	129	1,271	699	42	651	17,013
Crops	33	40	11	44	37	9	43	1,575
Vegetables	16	2	5	33	26	0	1	1,795
Fruit	0	0	0	5	1	0	5	63
Dryland								
Pasture and Grasses	833	781	312	1,961	1,015	113	586	25,977
Crops	195	234	128	323	299	16	83	-
TP load (kg)	**3,728**	**3,106**	**789**	**8,970**	**4,246**	**366**	**2,704**	**90,549**

Table 4.9: Estimated Potential TN load (kg) from diffuse sources during the non-irrigation period (May-August).

LANDUSE	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigated								
Perennial pasture	5,157	4,365	509	13,331	5,425	465	3,334	110,314
Annual pasture	1,468	759	323	3,177	1,747	104	1,628	42,532
Crops	125	150	43	166	138	35	162	5,907
Vegetables	82	10	23	164	129	0	5	8,973
Fruit	1	0	3	96	19	0	103	1,266
Dryland								
Pasture and Grasses	2,082	1,952	779	4,903	2,538	282	1,465	64,943
Crops	732	878	479	1,212	1,121	61	312	-
TN Load (kg)	**9,646**	**8,113**	**2,160**	**23,049**	**11,116**	**946**	**7,010**	**233,936**

Table 4.10: Estimated Potential TP loads (kg) from diffuse sources for an average year.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigation season	50,891	41,563	5,753	128,890	54,311	4,571	35,332	1,152,887
Non-irrigation period	3,728	3,106	789	8,970	4,246	366	2,704	90,549
Total (kg/yr)	**54,619**	**44,669**	**6,541**	**137,860**	**58,557**	**4,936**	**38,036**	**1,243,436**

Table 4.11: Estimated Potential TN loads (kg) from diffuse sources for an average year

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Irrigation season	85,794	68,738	10,534	214,597	92,549	7,770	62,224	2,056,884
Non-irrigation period	9,646	8,116	2,160	23,049	11,116	946	7,010	233,936
Total (kg/yr)	**95,441**	**76,853**	**12,694**	**237,646**	**103,666**	**8,716**	**69,234**	**2,290,820**

Point sources of nutrients that reach the irrigation drainage system

Loads from towns discharging stormwater to drains

The towns that discharge to the irrigation drainage system are: Stanhope, Gigarre, Kyabram, Tongala, Tatura, Katunga, Strathmerton and Waaia (personal communication, Z. Helman, 1995). CMPS&F (1995) have quantified the loads for all towns with a population of more than 200 people. For the townships of Katunga and Waaia a population of 100 people was assumed and the loads for these towns were estimated was estimated by factoring the load from Girgarre (unsewered, 232 people). The annual loads for dry, typical and wet years for each town are listed in Table 4.12.

Table 4.12: Estimated Annual loads (kg/yr) from towns discharging to drains for a Dry, Typical and Wet year.

Township	Drainage System	Dry		Typical		Wet	
		TP	TN	TP	TN	TP	TN
Stanhope	Deakin Main Drain	697	1,093	702	1,138	709	1,237
Girgarre	Deakin Main Drain	294	460	295	479	299	521
Kyabram	Mosquito Drain	282	3,358	334	4,021	423	5,109
Tongala	Deakin Main Drain	54	646	64	773	81	982
Tatura	Mosquito Depression	141	1,684	168	2,018	212	2,562
	Sub-total	**1,468**	**7,241**	**1,563**	**8,427**	**1,724**	**10,411**
Katunga	Murray Valley Drain 6	127	198	127	206	129	225
Strathmerton	Murray Valley Drain 6	25	292	31	347	40	465
	Sub-total	**152**	**490**	**158**	**553**	**169**	**690**
Waaia	Murray Valley Drain 13	127	198	127	206	129	225
	Total	**1,746**	**7,930**	**1,848**	**9,187**	**2,022**	**11,325**

Sewage and Industrial inputs

There are only four Victorian, Environment Protection Authority (EPA) licences to discharge effluent to the irrigation drainage system but only 3 of these are currently being used. The fourth licence which exists for a caravan park has not been used since 1982.

The three licences that currently discharge to the drainage system are Bonlac, Nestle and the Kyabram Wastewater Treatment Plant. Data for Kyabram is based on the information in the draft report provided by CMPS&F (1995) for the sewage treatment plant in the Goulburn and Broken catchments. Average flows and nutrient concentration for Nestle were provided by the company. Flow information for Bonlac was provided by the company but they did not provide information on nutrient levels. In the absence of any other data, the concentration for effluent being discharged by Nestle has been adopted for Bonlac (Table 4.13).

The Echuca Wastewater Treatment complex is not in the study area but it discharges into Mullers Creek. In 1992/93, it was estimated that 130 kg of TP and 375 kg of TN were discharged to Mullers Creek while in 1993/94, 5,040 kg of TP and 10,590 kg of TN were discharged into the creek.

Table 4.13: Estimated Point source industrial inputs.

Point Source	Drainage System	Discharge (ML/yr)	TP (mg/L)	TN (mg/L)	TP Load (kg/yr)	TN Load (kg/yr)
Bonlac	Deakin Main Drain	1,004	8	22	3,212	8,833
Nestle	Deakin Main Drain	636	8	22	5,088	13,992
	Subtotal				**8,300**	**22,825**
Kyabram Sewage	Coram Drain	122	8	25	976	3,050
	Total				**9,276**	**25,875**

Intensive animal industries

Based on the information contained in the report from GHD (1995) on intensive animal industries a number of piggeries are located in the irrigated area of the Goulburn and Broken catchments. In the GHD (1995) report, the numbers of pigs are recorded at a Shire level and these numbers are significantly greater (on average 1.63 times) than the comparable ABS data.

In their report GHD (1995) calculated in an average year that the 137,600 pigs in the catchment would export 1,000 kg of TP and between 5,000 and 50,000 kg of TN. Based on the advice from GHD (personal communication, M. Muntisov) the lower value in the TN range was adopted as the present rate of export. Therefore, on average each pig in the study area exports:

- TP export = $1 \times 10^6/137,600 = 7.3$ g/pig
- TN export = $5 \times 10^6/137,600 = 36.3$ g/pig

The numbers of pigs in each catchment were calculated from the ABS Parish based data (as per the methodology used for landuse) and then factored by 1.63. The number of pigs in the irrigated area of the Goulburn and Broken catchments were estimated by area weighting the numbers in each Shire in proportion to the area within the irrigation district. Table 4.14 summarises the results.

Table 4.14: Estimated TP and TN loads from piggeries

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Number of pigs (ABS)	4,020	2,041	163	13,381	3,574	6	2,247	-
Adjusted number of pigs	6,553	3,327	266	21,811	5,826	10	3,663	88,195
TP export rate (g/pig/yr)	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
TN export rate (g/pig/yr)	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3
TP load (kg/yr)	48	24	2	159	43	0	27	644
TN load (kg/yr)	238	121	10	793	212	0	133	3,205

Dairy shed waste

To calculate the amount of TP and TN that potentially may enter the irrigation drainage system from dairy shed effluent (see Table 4.15) the following assumptions were used:

- The number of cows in each catchment are based on ABS statistics (as per the methodology used for landuse). For the whole study area, the Victorian Dairy Industry Association (VDIA) figures were adopted.
- The TP production per cow = 9 kg/yr
- The TN production per cow = 70 kg/yr
- A 300 day lactation period.
- A cow spends on average 10% of their time in the dairy shed during the lactation period and amount of waste and TP and TN dropped in this area is assumed to be in the same proportion.
- 5% of dairy sheds discharge directly into the drainage system.

Table 4.15 summarises the potential loads from dairy shed effluent.

Table 4.15: Estimated TP and TN loads from dairy shed waste.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Number of cows (ABS)	17,751	17,308	2,140	50,571	20,431	1,169	14,934	227,891
TP (kg/cow/yr)	9	9	9	9	9	9	9	9
TN (kg/cow/yr)	70	70	70	70	70	70	70	70
% of time in dairy during lactation period	10	10	10	10	10	10	10	10
Non-compliance (%)	5	5	5	5	5	5	5	5
TP load (kg/yr)	657	640	79	1,870	756	43	552	8,429
TN load (kg/yr)	5,085	4,958	613	14,485	5,852	335	4,278	65,277

Groundwater Pumping

Data on groundwater pumping from both Phase A pumps and the Groundwater pumping scheme for 1993/94 were obtained from GMW. Approximately 70 of the pumps under the Groundwater Pumping Intersection Scheme have not been located because they have no registered bore number. A number of pumps also discharge to both channels and drains and this makes it difficult to quantify the exact amount that is pumped to the irrigation drainage system. For the purposes of this study it has been assumed that all pumped water has been discharged to the drainage system. In estimating the load discharged from each pump the concentration of TP and TN in the groundwater is assumed to by 0.025 mg/L-P and 3.0 mg/L-N (HydroTechnology, 1993). Table 4.16 gives the estimated TP and TN loads from groundwater pumps in 1993/94.

Table 4.16: Estimated TP and TN loads from groundwater pumps in 1993/94.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Phase A pumps								
Number of pumps	0	3	0	4	30	7	3	96
Volume - Irrigation season	0	29	0	705	3,312	1,222	543	11,181
Volume - Non irrigation	0	7	0	313	1,158	512	188	4,021
GPIS pumps								
Number of pumps	16	13	0	35	7	4	48	495
Volume - Irrigation season	1,224	352	0	2,271	596	272	3,215	36,146
Volume - Non irrigation	115	62	0	406	124	13	493	4,332
Irrigation season (ML)	1,224	381	0	2,976	3,908	1,494	3,758	47,327
Non-irrigation period (ML)	115	69	0	719	1,282	525	681	8,353
Total Volume (ML)	1,339	449	0	3,694	5,190	2,019	4,439	55,680
TP (mg/L)	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
TN (mg/L)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
TP load (kg) - irrigation	31	10	0	74	98	37	94	1,183
TP load (kg) -non-irrigation	3	2	0	18	32	13	17	209
Total TP load (kg)	33	11	0	92	130	50	111	1,392
TN load (kg) - irrigation	3,672	1,142	0	8,927	11,724	4,482	11,274	141,981
TP load (kg) - non-irrigation	345	206	0	2,156	3,846	1,575	2,043	25,059
Total TN load (kg)	4,017	1,347	0	11,082	15,570	6,057	13,317	167,040

Drain diverters

Drain diverters remove both water and nutrients. In Table 4.17 the number of diverters and their licensed diversion volume are listed for each of the monitored catchments. To determine the impact of diverters on nutrient load the nutrient it has been assumed that in an average year they pump their licensed allocation and the concentration of the pumped water is assumed to be at the median concentration at the drain outfall. For diverters outside monitored catchments the median concentrations for the Lockington Main Drain was used (0.310 mg/L-P and 2.04 mg/L-N).

Table 4.17: Estimated potential TP and TN loads removed from the drains by diverters.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Number of diverters	6	62	0	161	64	0	34	606
Licensed diversions (ML)	695	8,947	0	24,070	4,409	0	2,314	65,435
TP (mg/L)	0.310	0.440	0.085	0.600	0.170	0.305	0.590	-
TN (mg/L)	2.04	1.70	1.20	2.39	1.15	2.04	1.81	-
TP load (kg/yr)	215	3,937	0	14,442	750	0	1,365	20,285
TN load (kg/yr)	1,418	15,210	0	55,527	5,070	0	4,188	133,487

TP and TN inputs and outputs for all sub-catchments and for the Goulburn and Broken catchments.

All potential inputs and outputs to the irrigation drainage system are summarised in Tables 4.18 and 4.19 for monitored drains and for the Goulburn and Broken catchments. This data shows that:

- Diffuse sources of pollution are the major inputs into the drainage system for TP except for Deakin Main Drain where there are also significant industrial point source inputs.

- Diffuse sources of pollution are the major inputs into the drainage system for TN. Other less significant inputs include dairy shed effluent, groundwater pumping and towns in the Deakin Main Drain catchment.

- For the 7 monitored catchments, the ratio of the measured mean nutrient load versus the predicted loads entering the drainage system varies as shown below:

	TN ratio		TP ratio	
Lockington Main Drain	1:7.5	(13%)	1:3.2	(31%)
Bamawm Main Drain	1:2.5	(40%)	1:1.4	(71%)
Mullers Creek	1:4.6	(22%)	1:1.8	(56%)
Deakin Main Drain	1:3.0	(33%)	1:1.5	(67%)
Rodney Main Drain	1:6.0	(17%)	1:1.5	(67%)
Toolamba Depression	1:22.1	(5%)	1:11.5	(9%)
Murray Valley Drain 6	1:1.5	(67%)	1:1.2	(83%)

Table 4.18: Estimated potential TP loads (kg/yr) entering the drainage system for each sub-catchment.

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Diffuse inputs								
Tailwater & rainfall runoff	54,619	44,669	6,541	137,860	58,557	4,936	38,036	1,243,436
Point inputs								
Dairy shed effluent	657	640	79	1,870	756	43	552	8,429
Piggeries	48	24	2	159	43	0	27	644
Groundwater pumps	33	11	0	92	130	50	111	1,392
Towns	0	0	0	1,563	0	0	0	1,848
Industry/sewage	0	0	0	8,300	0	0	0	9,276
Total inputs	55,356	45,345	6,622	149,845	59,485	5,030	38,726	1,265,025
Outputs								
Drain diverters	215	3,937	0	14,442	750	0	1,365	20,285
Inputs - outputs	55,141	41,408	6,622	135,403	58,736	5,030	37,361	1,244,740

Table 4.19: Estimated potential TN loads (kg/yr) entering the drainage system for all sub-catchments (kg/yr).

	Lockington Main Drain	Bamawm Main Drain @ Dargons	Mullers Creek	Deakin Main Drain	Rodney Main Drain	Toolamba Depression	Murray Valley Drain 6	Goulburn and Broken
Diffuse inputs								
Tailwater & rainfall runoff	95,441	76,851	12,694	237,646	103,666	8,716	69,234	2,290,818
Point inputs								
Dairy shed effluent	5,085	4,958	613	14,485	5,852	335	4,278	65,277
Piggeries	238	121	10	793	212	0	133	3,205
Groundwater pumps	4,017	1,347	0	11,082	15,570	6,057	13,317	167,040
Towns	0	0	0	8,427	0	0	0	9,187
Industry/sewage	0	0	0	22,825	0	0	0	25,875
Total inputs	104,780	83,277	13,316	295,258	125,300	15,108	86,962	2,561,402
Outputs								
Drain diverters	1,418	15,210	0	57,527	5,070	0	4,188	133,487
Inputs - Outputs	103,363	68,067	13,316	237,731	120,229	15,108	82,773	2,427,914

The net loads (ie inputs - outputs) in Tables 4.18 and 4.19 do not equal the measured load at the drain outfalls because: a) they represent the estimated "potential load" entering the drainage system, b) there are a many uncertainties in these calculations and c) nutrients are non conservative. There is some evidence to suggest that the concentration of phosphorus decreases along the length of a drain. Unfortunately, the nutrient dynamics in both farm drains and in the irrigation drainage system are poorly understood and it is unclear whether this decrease continues indefinitely or ceases at some point in the future.

Despite these limitations, the ratios for Toolamba indicate that the depression operates as a greater sink for water and nutrients than the constructed drains. This confirms the fact that wetlands and vegetation are an effective method of improving the quality of degraded water. At the other end of the spectrum, the ratios for Murray Valley Drain 6 are lower than the other catchments. This may imply that there are special features in this catchment that increase the efficiency of nutrient export, or alternatively, there may be a major unknown source of nutrients within this catchment that has not been considered.

2. FARM MANAGEMENT PRACTICES

The aim of the Farm Management Practices portion of this document is to present a picture of the predominant forms of agriculture practiced in the SIR together with information on stocking rates, irrigation methods and scheduling, fertiliser regimes and prevailing farm practices as they affect the above. This section then goes on to categorise these agricultural practices in terms of their likelihood of contribution (low, moderate and high) to nutrient generation in irrigation drains. Finally, recommendations are made to minimise further inputs using current best management practices.

• LAND USE

Agricultural land use within the region has been divided into a number of categories: pasture, horticulture, broadacre crops and other. The greater majority of agriculture practices (over 93%), within this region centre around the dairy industry, with significant areas of intensive horticultural cropping and to a lesser extent, what is commonly termed "mixed" farming, which is generally a combination of irrigated pasture for animal production and cropping within the one property. These combinations are dynamic and respond rapidly to the relative profitability of each commodity.

Pasture

The term pasture refers to grass and clover species which are grown and may be improved via the addition of fertilisers and soil ameliorants for the sole purpose of supplying feed for grazing animals. Pastures can be further divided into perennial pasture, annual pasture and lucerne.

Pasture production slows from late autumn to early spring and during this period there is insufficient quantity produced for adequate nutrition of sheep or cattle. In order to offset this, and avoid the costs of agistment off farm, fodder is conserved via ensilement or hay production during surplus herbage production months in the spring. Pastures are, almost without exception in this area, watered by flood irrigation.

The most common type of pasture in this region is irrigated perennial pasture, which is often referred to as permanent pasture. Approximately 57% of the area under pasture is sown to perennial pasture species. Perennial pasture is most often sown with rye grass, paspalum and white clover species. It is irrigated when required (from six days to three week intervals) throughout the irrigation season from spring through to autumn. Water use on perennial pastures in addition to rainfall is typically 8-10 ML/ha/yr. The area of perennial pasture is increasing steadily due to expansion of the dairy industry in the study area. Costs associated with sowing perennial pasture are significant and perennial pasture tends to be established when money is more freely available. Cost of seed for perennial pasture is currently $108/ha with additional costs of gypsum, superphosphate and nitrogen fertilisers running at $24/t, $200/t and $340/t, respectively.

Annual pasture, also known as 'sub-pasture' due to the prevalence of subterranean clover species as well as Wimmera rye grass, is irrigated during the spring and autumn and allowed to dry off during the summer months when it sets seed and resows itself. Annual pasture generally uses around 3-4 ML/ha/yr.

Lucerne is a leguminous plant used extensively in the irrigation regions as pasture for feed, and it is often cut and baled as hay. Water requirement for lucerne will vary, with paddocks cut five to six times per season for hay requiring around the same amount of water as perennial pasture, although the peak water demand for lucerne can be as high as 14 ML/ha/yr (Rendell, SRWSC). Within the SIR the common practice of agisting cattle on lucerne pasture necessitates an input of between 4 and 8 ML/ha/yr.

Broadacre Crops

Broadacre cropping in the study area is a minor industry relative to pasture production. Cereals are most commonly grown as a dryland crop, but when sown under irrigation, yields are observed to double or even triple. Wheat yields under irrigation, not limited by the availability of nutrients, are often greater than 5 t/ha. From time to time cereal crops, particularly winter wheat, are grazed early in the season, as the crop is able to recover if grazed prior to tillering and can go on to provide good yields if water and fertiliser are not limiting.

Irrigation of cereal crops is carried out throughout spring, with up to five irrigations required. Irrigated cereals are normally sown between April and June following a pre-sowing watering, with those destined to be grazed planted slightly earlier in the season to allow for the crop to 'catch up'. Crops are irrigated as required through late winter and early spring, then allowed to dry off before harvesting, which may occur from late September to early January. Cereal crops generally have four to five irrigations per season in the SIR. The majority of cereal crops in the SIR are watered by flood irrigation. Other methods which are occasionally used include furrow irrigation on raised beds and overhead sprinklers.

Irrigated Summer Crops

This category consists of minor crops which include maize, millet, sorghum, soybeans, saccoline and oats. These crops differ significantly in their water and nutritional requirements. Crop plantings are usually opportunistic and depend on projected crop prices, though maize is becoming increasingly important as a silage crop for supplementary feeding of dairy cows in the district.

Forage crops: millet, sorghum, saccoline and oats, are destined for animal feed, particularly for horses and cattle. These crops do not have a particularly high dollar value, and are consequently watered by flood irrigation. Sorghum is also grown for other uses, mainly syrup production. Soybeans are planted for a variety of reasons, as feed for animals, for human consumption and also as a means of improving soil fertility without the application of chemical fertilisers. Maize, generally grown for silage, is commonly planted on hills or raised beds and watered by furrow irrigation

Oilseeds

Oilseed production in the area is limited and is divided fairly evenly between canola (rapeseed) and sunflower plantings. Oilseeds are most commonly planted in the northern portions of the irrigation district around Numurkah. Canola and safflower are winter oilseed crops, whereas sunflowers are grown during summer. All are sown onto pre-irrigated paddocks, with canola and safflower usually sown in the latter part of April, and sunflowers around the beginning of November to mid December. Irrigated oilseed crops are commonly watered by the border check method.

Horticulture

Horticulture in the SIR consists predominantly of stone and pome fruit orchards, grapevines and vegetables. Peaches and pears are the major orchard crops of the region, with the majority of these being planted in the Shepparton, Rodney and Murray Valley districts (Appendix A, Figure A1). There are a small number of citrus orchards concentrated in the Murray Valley area, however the soil types prevalent over the SIR are not conducive to their growth.

Until the last decade, flood irrigation was the most common form of irrigation in the SIR. Since then there has been a trend towards watering by mini sprinklers as drip irrigation has not proven successful due to the size and depth of the root systems of orchard trees. At present around 30-35% of orchards are watered by mini sprinklers, which have the added advantage that, once integrated with neutron probes and computer controlled automatic watering, they have the potential to reduce problems associated with over watering.

Trends within the industry are to replace older trees with new ones planted closer together to take advantage of advances in irrigation and fertiliser technology. Typically, orchard trees were planted on 6 x 6 m grids, now many are planted at 6 x 3 m spacings. There are also trends to reduce pear plantings within the district in favour of apples (personal communication, A. Prater).

Vineyard production in the district is for the majority wine grapes, though table grapes are produced near Shepparton and Ardmona. Growers prefer to limit the quantity of wine grapes produced by vines, through judicious use of fertilisers and irrigation water, in order to produce lower fruit yields which are however, of a high quality. Irrigation water requirements of vines grown in the SIR vary from 2-3 ML/ha annually in the Nagambie area to 5-7 ML/ha around and north of Shepparton. This variation is due mainly to changes in rainfall, soil type and evaporation.

Irrigation of vines is mainly by overhead sprinklers, with approximately 50% of the vines grown in the area watered in this manner. However, in terms of proportion of growers using this method, the percentage is far less. The remaining area is irrigated by either flood or drippers, with the latter being the more popular. The majority of growers rely on water supply from dams on their properties and the extensive use of drip irrigation is mainly due to this constraint (personal communication, J. Whiting).

The other major horticultural industry in the study area is vegetable production, in particular tomatoes, for both processing and the fresh fruit market (Appendix A, Figure A2). Of the 2,609 ha used for vegetable farming in the 1992 census year, 2,085 ha, (over 91% of the horticultural land category) was utilised for the growing of this crop. The higher costs and returns from intensive horticultural cropping is reflected in the smaller areas under production relative to pasture and cropping activities. Trends in crop production show that the total tomato growing area is increasing, with large advances being noted in the processing tomato industry (personal communication, R. Holland).

The majority of tomato growers in the study area utilise trickle irrigation in conjunction with black plastic spread over raised beds, to minimise the need for weeding and reduce evaporation. All fresh market tomato crops are trickle irrigated, while processing tomatoes are still grown chiefly under flood irrigation (personal communication, R. Holland).

While vegetable production is scattered throughout the study area, it tends to be concentrated around towns and cities providing a good water supply to service the requirements of processing plants, eg. Shepparton and Ardmona. Aside from the tomato growing industry there are several small areas of market garden growing mainly broccoli and asparagus.

- **ANIMAL INDUSTRIES**

Animal industries within the Goulburn and Broken catchments consist primarily of dairy cattle, sheep and beef cattle, with smaller enterprises of pig and poultry farming. The dominant industry in the study area is however, dairy farming.

Dairy Industry

The general trend in the area is to an intensification of the dairy industry, with many former sheep farmers providing services to the dairy industry as the gross margins for sheep farming continue to fall (personal communication, R. O'Farrell). Not only is this industry intensifying in terms of numbers of animals within the catchment, the density of dairy cattle per unit area is also increasing. Dairy farms are now supporting far larger herd sizes in order to remain economically viable, and the incorporation of intensive techniques such as the use of calf sheds and feeding supplements on feed pads, is becoming more common (personal communication, D. Small).

Stocking rates for dairy cows depend on the area of perennial pasture and the calving pattern. Spring calving stocking rates are typically around 3 to 3.5 milking cows per hectare of perennial pasture, but with the use of feed supplements or agistment the rate may rise to 4 to 5 cows per hectare. As the dairy industry in the area inclines toward intensive animal production, so does the potential for substantial rises in nutrient exports to drains, particularly in areas where pasture dry matter production is being boosted through nitrogen fertiliser application. In Appendix A (Figure A3) and Appendix B, information on the number of dairy cattle in the SIR is provided, based on their proximity to the nearest town. This data was provided by the Victorian Dairy Industry Authority (VDIA).

There are over 297,000 dairy cattle spread over 2,257 dairy farms in the SIR giving an average number of cows per farm of 133. In terms of intensity of dairy cattle numbers, areas surrounding the townships of Bamawm, Katunga, Kyabram, Stanhope, Tatura and Tongala all have dairy cattle populations in excess of 11,000.

Beef Cattle

According to 1992 AgStats there are around 140,000 beef cattle in the SIR and this industry is much less intensive than dairying. Figure A4 in Appendix A shows the general locality of beef cattle in the SIR. Within the SIR, numbers of beef cattle are increasing, at a rate of around 4% per annum (personal communication, R. O'Farrell). In terms of intensity of beef cattle, the parishes of Bamawm, Murchison North, Shepparton and Tallygaroopna all had populations in excess of 4,000, with Bamawm having over 5,800 beef cattle resident in the parish according to the 1992 AgStats data (see Appendix C).

Beef cattle calving generally occurs during late summer to early autumn in the SIR, with calves being weaned at about 8 to 10 months of age. The largest beef enterprise in the irrigated districts is the production of vealers, which are sold for slaughter at around nine months of age. Vealer production requires abundant production of good pasture, and the irrigated pastures of the SIR are ideal for this farming enterprise.

Sheep

The majority of sheep farms in the study area fall into the 'mixed' category in that they carry one or more other enterprises, and in the SIR this is generally dairying. In the irrigation areas the sheep industry is essentially directed towards prime lamb production, with irrigated annual pasture supporting up to 6 dry sheep equivalents per hectare.

Lambing generally occurs during autumn, though there is significant late summer and early autumn lambing in the study area due to the quality and quantity of pasture in the area. Shearing occurs in spring or early summer and excess stock are sold in late spring before pastures dry off, or mid-autumn when prices are better (Reed, in Connor, 1987).

There are over 500,000 sheep in the SIR, with the parishes of Dargalong, Diggora, Molka, Moora Murchison North, Pine Lodge and Wanalta each having populations of over 15,000 animals (Appendix A, Figure A5 and Appendix C). However, within the last 6 years there has been a significant and sustained down-turn in the sheep industry. Within the SIR former sheep farming areas are now being used to support the dairy industry.

Pigs

Pig production is concentrated around areas of intensive dairying due to the historic importance of skim milk in pig rations, though cereal grain has now taken over as the major feed stuff in pig production (Lumb in Connor, 1987). The pig industry continues to intensify, due mainly to economic pressures to increase the number of animals carried per unit of land, labour or capital, and to a lesser extent to maximise animal production potential (Taverner, in Connor, 1987).

In the Goulburn and Broken catchment there are 137,590 pigs (GHD, 1995). These numbers are based on data from the local Shires. In total, it is estimated that 88,195 pigs are in the irrigated area of the Goulburn and Broken catchments (see Section 4.2.3).

- **WATER USE**

Irrigation Method

Since 1955/56 there has been an average increase in the total area under irrigation within the Goulburn Valley (Shepparton, Rodney, Tongala and Rochester Irrigation districts), of 2,141 ha/yr (Jones, 1992). With the introduction of Transferable Water Entitlements (TWE) there is potential for changes in landuse to accelerate.

Irrigation methods within the study area, can be broadly categorised into four types: Flood (Border Check), Furrow, Sprinkler (Over tree and Under tree) and Micro Drip (Trickle). Moving irrigators are only occasionally used in the study area because of the high capital and operating costs and this, together with the advent of laser grading, has resulted in their demise. A summary of areas irrigated by these methods for the regions encompassing the Goulburn Valley Area is presented in Table 5.1. The irrigation methods are listed in ascending order for potential water use efficiency. Table 5.2 lists the most common methods of irrigation for various crops.

Table 5.1: Areas under Irrigation by various methods in the Goulburn Valley Area (Shepparton, Rodney, Tongala and Rochester Irrigation Districts) (Jones, 1992).

IRRIGATION METHOD	AREA (ha)
FLOOD (BORDER CHECK)	214,596
FURROW	2,338
MOVING IRRIGATOR	132
SPRINKLER - OVER TREE	211
- UNDER TREE	1,001
MICRO DRIP (TRICKLE)	2,339
TOTAL	**220,619**

Table 5.2: Summary of major forms of irrigation for crops and pastures of the SIR.

CROP	FORM OF IRRIGATION			
	FLOOD	FURROW	SPRINKLER	DRIP
PASTURE	+			
CEREAL	+			
SORGHUM	+			
MAIZE	+	+		
SOYBEANS	+	+		
FORAGE CROPS	+			
CANOLA	+	+		
SAFFLOWER	+	+		
SUNFLOWER	+	+		
GRAPES			+	+
CITRUS		+	+	
STONE FRUIT	+	+	+	
POME FRUIT	+	+	+	
TOMATOES		+		+
OTHER VEGETABLES	+	+		+

Flood Irrigation (Border Check Irrigation)

Flood irrigation, also known as border check irrigation, is the method of choice for the majority of the SIR. The area is predominantly (>93%) pasture based and therefore, used in conjunction with laser grading, flooding paddocks is the most cost effective means of applying water. Using this method, openings are made, either via pipes or simply digging out part of a supply channel embankment, to allow water to flood from the channel and into a bay. The water is contained within the bay by formed banks located on the bay perimeter.

Furrow Irrigation

This method of irrigation is popular for a number of the higher value row crops such as sunflowers and is still common in orchards. While row crops can be sown on the flat it is fairly common practice to use hill and furrow or raised bed land-forming when sowing out bays to these crops. Water is delivered through siphon tubes leading from the supply channel to the top of each furrow.

Furrow irrigation has also been used extensively in the tomato industry, though with the enormous increases in yield brought about through using trickle irrigation, the use of this form of irrigation in the tomato industry is rapidly declining.

Due to the high value of horticultural crops, to maximise productivity farmers will not risk yield reduction due to water induced stresses of the crop. This often results in over-watering and the generation of a large amount of tail-water. Water re-use systems are recommended in this instance, to minimise both water losses and nutrients flowing to drains, as the fertiliser requirements of horticultural crops are particularly high.

Sprinkler Irrigation

Most of the pressurised irrigation systems are used for horticultural crops, though overall their contribution is small (<2%). Sprinklers are expensive relative to flood irrigation methods as they require a high initial establishment cost and ongoing maintenance of pumps, filters, sprinkler heads, hosing etc., and for this reason are more popular for crops with high gross margins (eg. fruit trees and vines) grown in areas with better quality soils (eg. riverine clay loams).

Sprinklers are considered to be a far more efficient way of irrigation than flooding methods because the irrigator can apply a uniform depth of water to the soil surface overlying the root ball. The aim of this method is to store as much of the applied water in the root zone as possible. With correct irrigation scheduling, sprinklers, and other forms of pressurised irrigation, can more readily match crop needs than flood or furrow irrigation and will lessen the likelihood of waterlogging and reduce tailwater drainage volumes.

The major forms of sprinkler irrigation are over-head and under-tree sprinklers and micro spray systems. These are permanent medium pressure systems and can be operated manually or automatically. In the SIR, sprinklers are most frequently used in orchards. While the most common orchard irrigation system is still furrow irrigation, the under-tree and micro-spray methods are gaining popularity, particularly micro-spray which allows a greater degree of control using computer controlled automatic watering. To minimise the effects of saline soils and high evaporation rates, sprinkler irrigation systems are used to apply water every night to individual trees at rates which counter the previous days transpiration and evaporation losses.

Micro Drip (Trickle Irrigation)

This method of irrigation is commonly used on vegetables and vines. The development of polythene piping, drip emitters and micro-sprinklers has enabled efficient, low pressure irrigation to be developed on a large scale. One of the major advantages to trickle irrigation is that it can be utilised on both uniform slope and undulating terrain. Costs associated with this form of irrigation are far higher than those for furrow irrigation.

Scheduling of irrigation is critical for the horticultural industry in general, but is vital for trickle irrigated crops as water is only introduced into the area of the root zone. Failure to supply adequate water in this instance rapidly reduces the yield potential as plant tissue swiftly desiccates. A bed system is still required for micro-irrigation for drainage purposes after rainfall, since the black plastic cover and the soil at or near field capacity limits the ability of the crop to utilise this rainfall and increases the amount of rainfall run-off.

• IRRIGATION SCHEDULING

The aim of efficient irrigation is to water as quickly as possible whilst ensuring sufficient water is applied without waste, and at the correct time to achieve optimum crop or pasture productivity. Over-watering results in rises to the water-table, water wastage through excessive run-off, water movement past the root zone, increased leaching, waterlogging and associated reduced crop yield, and of course additional cost to farmers for the water itself, wear and tear on pumping equipment and their own valuable time.

In the case of pastures, water should remain on bays for four hours or less. The major benefit of quick watering to dairy farmers is pasture composition. Saturated soil (waterlogged) inhibits all pasture growth, but particularly growth of clover species, the most desirable pasture component as it increases milk yield and quality (% butterfat). Under ideal conditions of rapid irrigation the clover content can be as high as 50%, however as the time of water retention on the bay lengthens toward 24 hours or more clover composition can decline to 12% or less (Mulcahey and Schroen, 1993).

A major factor in determining the level of irrigation efficiency is the farm design and layout. Uneven applications of water, coupled with poor drainage and low supply capacity significantly impede irrigation efficiency. For these reasons it is paramount to maximise the effectiveness of irrigation water through the proper implementation of a whole farm plan. A second factor in maximising water use efficiency, is irrigation scheduling according to crop requirements rather than farmer convenience.

The majority of irrigators base their decision to water on their own experience and the appearance of the crop or pasture. This sacrifices some yield component to water stresses that show no visible symptoms. Current irrigation scheduling in the SIR sees farmers watering every 7-10 days, well below optimum irrigation levels for clover production. Other pasture species, such as rye-grass and paspalum, have a greater tolerance to water stress and production losses will occur only when the irrigation cycle is greater than 7 and 10 day intervals respectively. Irrigation in a 10 day cycle incurs production losses of 50% for white clover and will result in a pasture dominated by paspalum. Since wilting in white clover does not occur until production has fallen by 80%, visual assessment is not a practical means of scheduling irrigation.

Some farmers utilise technology in the form of tensiometers or neutron probes to determine the saturation level of water in individual bays. Irrigators can also take advantage of work done to establish relationships between available soil water, plant water requirements and measured weather conditions to predict both the timing of irrigations and amount of water required. There are also a number of computer based models developed to assist in these decision making processes, notably those developed by the CSIRO; SIRAGCROP, SIRAG-Field and SIRAG-Orchard. These packages generate recommendations for irrigation scheduling for individual paddocks based on soil water budgets. Recommendations for irrigation scheduling are determined via daily weather information and long-term weather forecasts. Average water requirements for crops and orchard trees of the SIR are presented in Table 5.3.

Table 5.3: Average irrigation requirements for crops and orchard trees of the SIR.

CROP	IRRIGATION REQUIREMENT (ML/ha/yr)
PERENNIAL PASTURE	8-10
ANNUAL PASTURE	3-4
LUCERNE	8
CANOLA	4
CEREALS	4
MAIZE	6-8
SUNFLOWERS	6-8
TOMATOES - furrow irrigate - trickle irrigated	6 4.5
SOYBEANS	6-8
SUMMER FORAGE CROPS	6-8
SORGHUM	6-8
ORCHARDS	6

Irrigation with Ground Water

Ground-water pumping is a small portion of the total amount of irrigation water supplied to the study area. Ground-water represents less than 2% of the volume which is supplied to irrigators via the channel system. The maximum annual volume which a farmer is allowed to access is 9 ML/ha/yr minus the water right on the property, or if the property has no water right, 6 ML/ha/yr.

- ### FERTILISERS

The object of fertiliser application is to keep a correct balance of nutrients available for plant uptake. If more than one nutrient is lacking, the effect of supplying one of the required nutrients may not be beneficial, and could even be harmful to the crop. The general outcome of nutrient imbalance is depressed crop yields. The two nutrients in short supply in Australian soils are nitrogen and phosphorus.

Nitrogen

Under irrigation, the most likely yield limiting factor is nitrogen. Nitrogen tends to be limiting due to its extremely labile nature, ie. it is easily broken down through the action of soil bacteria and is also water soluble, and therefore easily leached out of the soil profile. Nitrogen deficiencies in pastures and crops are generally manifested by pale green or yellow foliage, premature senescence and lower than expected production.

Nitrate is the form of nitrogen most readily taken up by most plants. Nitrate is easily taken up by roots, but is also very easily washed out of the soil profile by irrigation water or rainfall, and may end up in drains or the ground-water table, leading to potential pollution problems. This can be minimised by applying nitrogen fertiliser in the irrigation water towards the end of an irrigation, when the soil water capacity is partly filled and fertiliser N is unlikely to move beyond the root zone. Within the soil profile, nitrogen is gained and lost from the soil, is absorbed by plants and returned to the soil as organic matter (see Figure 5.1 below).

Nitrogen fertilisers also differ in their susceptibility to leaching with ammonium sulphate being the least soluble of the commonly used nitrogenous fertilisers and therefore useful in areas with a high leaching potential.

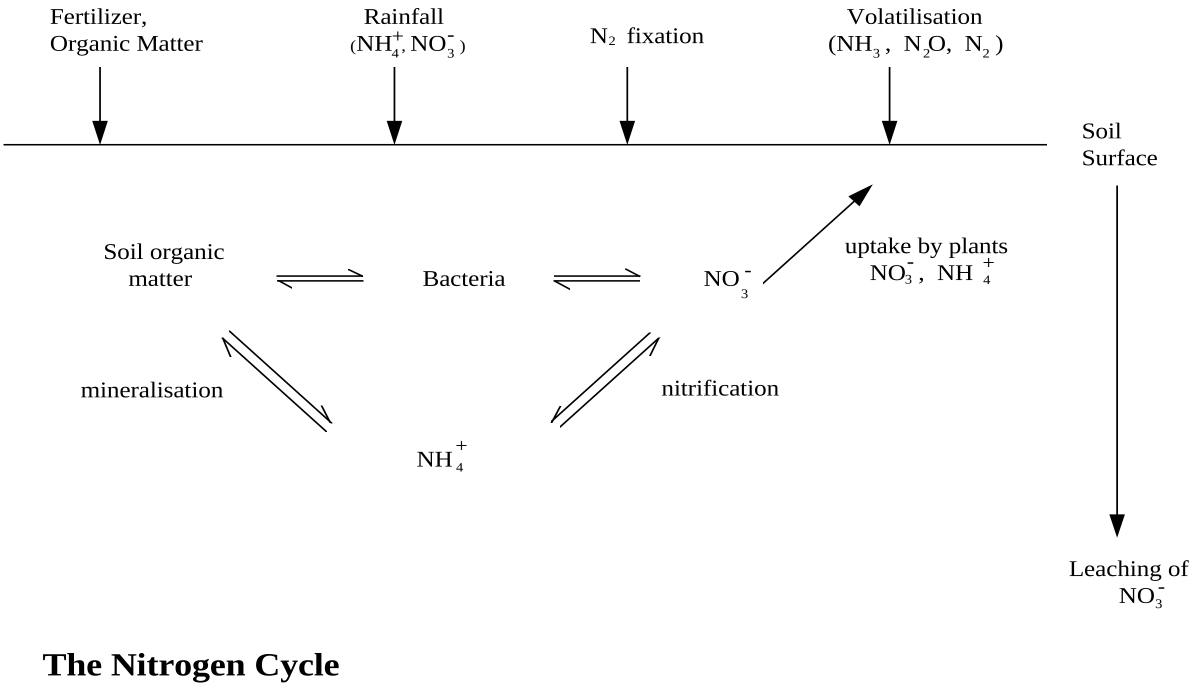


Figure 5.1: The nitrogen cycle both above and below the soil surface.

Phosphorus

Australian soils are also naturally very low in phosphorus. Since the early 1920's regular superphosphate application has ensured a build-up of this element in many agricultural soils beyond crop requirements. Phosphorus is less mobile than nitrogen and remains tightly bound to soil particles.

In the soil, organic phosphorus is converted into inorganic forms through the action of bacteria, and becomes available to plants. These inorganic phosphate residues are able to accumulate within the soil profile and are adsorbed onto the surface of clay particles Clay soils have the capacity to absorb more phosphorus than sandy soils. Acidic soils bind phosphorus far more strongly than neutral to alkaline soils. Phosphorus deficiency, when it occurs, is characterised by stunted growth of plants.

Potassium

Potassium is the third major nutrient for plant nutrition. It also, adsorbs onto the surfaces of clay particles, though it is not as strongly bound as phosphorus and can be readily leached from the soil profile, particularly from sandy soils. Potassium is a major constituent of clay minerals, and consequently is in abundance in clay soils. It is usually deficient in sandy soils, particularly when rainfall or irrigation intensity is high and the potential for leaching is significant.

Potassium is required in large amounts by crops such as potatoes, carrots and other root vegetable crops. Rates of 100 kg kg/ha for potatoes and 120 kg/ha for carrots are not uncommon and 50 to 80 kg/ha are often applied to tomato crops. Symptoms of potassium deficiency include: scorching and withering of edges or tips of older leaves, bluish green coloration of stems of potato plants which develops to a bronze colour before the stem collapses completely, and white discolouration of the tips of barley leaves. In tomato fruit, a deficiency in potassium causes soluble solids content to drop, making the fruit unsuitable for some processing procedures.

Forms of Fertiliser

The following gives a brief description of the fertilisers commonly applied to crops and pastures in the study area. Further information relating to fertiliser recommendations for individual crops and elemental analysis of fertiliser types can be found in Appendix D.

Phosphate Fertilisers

Phosphorus (P) contained in rock phosphate is principally present in forms not immediately available to crops. To overcome this, rock phosphate is treated with sulphuric acid which converts P to available forms, and has the additional advantage of adding Sulphur (S) to the mix. Many Australian soils are also deficient in S but due to long standing and regular fertilisation with superphosphate containing sulphur as an 'impurity' this deficiency is not common.

With the development of Double and Triple super, which contain far less contaminant sulphur, many crops are now exhibiting S deficiency, which manifests itself as reductions in crop yield and vigour. Double and Triple Super were developed primarily to reduce freight costs. Double Super provides the same amount of Phosphorus as Single Super, with a 48% reduction in volume while an application of 0.43 t of Triple Super will supply the same amount of P as 1 tonne of Single Super. Further development has led to the release of superphosphate products with added Sulphur.

The recent increase in the use of Di-Ammonium Phosphate (DAP) is related to both cost and the need to increase irrigated pasture production for stock, particularly under drought conditions, when sources of feed are more limited. DAP, at 20.1% P, contains almost as much phosphorus as Triple Super with the added advantage of supplying 18% Nitrogen which will increase the dry matter production of pastures. DAP (approximately $350/t), is similar in price to Double ($276/t) and Triple Super ($315/t), (personal communication J. Morrow). DAP is also being used quite extensively in orchards in the study area. Again this is due to the increase in yields from the additional nitrogen for a similar cost input.

Nitrogen Fertilisers

In the past, the common agricultural practice of fallowing paddocks between cropping resulted in little perceived need for nitrogenous fertilisers. Increased cropping, even continuous cropping, has resulted in high demands for nitrogen (N) inputs and advisory officers recommend N application to increase both yield and quality of pastures, broadacre and horticultural crops.

There are numerous nitrogenous fertilisers available, including; urea, ammonium nitrate, sulphate of ammonia, potassium nitrate and nitrate of soda. (See Appendix D for elemental composition and notes on various nitrogenous fertilisers). However, around 90% of the nitrogenous fertiliser used is applied in the form of urea (cheapest source), with a little ammonium nitrate used in the area and DAP becoming popular and making up most of the residual amount.

It is now becoming common practice to apply N fertiliser in split applications. There are several advantages to this practice. It allows farmers to apply a 'starter' amount of N fertiliser at sowing, assess the crop potential further into season and decide, if risk factors are low, to attempt to manipulate crop yield or protein content. It also creates less likelihood of N accessions to groundwater and drainage water as the smaller amounts of fertiliser applied are more likely to be utilised by the developing crop.

Other Fertiliser and Soil Conditioners

Potassium fertilisers, particularly potassium nitrate, are used quite extensively in the horticultural cropping area. Tomato crops have a very high requirement for potassium as it affects the soluble solids content of the fruit. See Appendix D for elemental analysis of potassium fertilisers: muriate of potash, sulphate of potash and nitrate of potash, and soil conditioners: lime and gypsum.

Fertiliser Application Regimes

In order to realise maximum production, the nutrients removed by pasture and cropping must be replaced at a rate equal or greater to that exported by grazing or harvesting. The following table contains information from a flier produced by the Phosphate Co-operative (PIVOT) and relates crop and animal types to the removal of nutrients from the soil.

Whereas the information in Table 5.4 details nutrient removal from various agricultural industries, it is based upon nutrient concentration present in the product and does not take into account nutrient lost due to run-off, volatilisation, trash refuse of broadacre crops, etc. In order to maintain and/or improve paddock fertility, and animal condition higher inputs of nutrients are required. See Appendix E for information regarding general fertiliser recommendations for individual crops and pastures in the SIR.

Table 5.4: Nutrient removal from the soil by selected agricultural commodities.

COMMODITY	N kg/ha/yr	P kg/ha/yr	K kg/ha/yr	S kg/ha/yr
Wheat	21	3.0	5	1.5
Barley	20	2.7	5	1.5
Oats	17	2.5	4	1.8
Beans	41	4.6	12	2.0
Peas	41	4.5	10	2.4
Lupins	51	4.5	9	3.0
Canola	40	7.0	9	10.0
Sunflowers	25	4.3	9	4.0
Pasture Hay	30	3.0	15	2.0
Cereal Hay	20	2.0	18	1.4
Lucerne Hay	27	3.0	16	2.5
Stone Fruit (per ha)	85	9.0	65	-
Pome Fruit (per ha)	70	11.0	79	-
Vines	8	1.3	8	-
Citrus (100 trees)	43	4.3	30	-
Wool (5 kg greasy)	1	0.02	0.1	0.20
Meat (50 kg live-weight)	3	0.40	0.2	0.40
Milk (1000 litres)	6	1.0	1.4	0.6

Table 5.5 lists the application rates of fertiliser N and P to pastures and crops grown in the SIR. These application rates are not the recommended rates by Agriculture Victoria, but following consultation with agricultural extension staff, industry representatives and farmers, are the best estimates of what is likely to be applied by the majority of farmers.

Table 5.5: Typical fertiliser application rates in the SIR.

CROP/PASTURE	Typical application rate	
	N kg/ha/yr	P kg/ha/yr
Perennial Pasture	25	40
Annual Pasture	-	20
Lucerne	-	25
Wheat	60	25
Barley	60	25
Oats	60	20
Sorghum	100	30
Maize	200	30
Soybeans	0	30
Summer Forage Crops	100	30
Canola	50	20
Safflower	50	20
Sunflower	80	25
Grapes	75	60
Citrus	100	20
Stone fruit	300	30
Pome Fruit	100	30
Tomato	200	20
Potato	200	40

Fertiliser losses in irrigation tailwater

A substantial amount of work on the loss of nutrients in tailwater following fertiliser application has been undertaken by researchers from ISIA Kyabram and Tatura campuses for a variety of crops (Small, 1985; Austin et al., 1994; Agriculture Victoria, 1994; McNab et al., 1995; Mundy, 1995). Nutrient concentrations in run-off post fertiliser application are typically 5 and 7 times greater than background nutrient levels for N and P, respectively. This work has shown that there is an initial increase in the nutrient concentration (up to an order of magnitude higher) after fertiliser application and then an exponential decrease in the nutrient concentration with time.

In the first two irrigations after fertiliser application a significant proportion of the total nutrient load is exported. For example, the average concentration of TP in tailwater runoff from perennial pasture for the two irrigations after phosphorus fertiliser application is approximately

15 mg/L (personal communication, D. Small and N. Austin). Assuming 0.6 ML/ha is applied in each irrigation, tailwater runoff is 20% of the applied water, and the background concentration of TP is 2 mg/L then an additional 3.12 kg/ha/yr of phosphorus is exported after fertiliser application. This represents 36% of the total TP load exported from an irrigation bay in a year and typically 3-4% of the applied superphosphate-P. These results highlight the importance of minimising tailwater runoff at this time and this could be achieved by:

- short watering for the two irrigations after fertiliser application. This would incur a loss of productivity on the unwatered portion of the bay.
- automation of the irrigation process to finish watering once the crop's water requirement has been met.
- reuse systems to collect the tailwater.

Each of these options is explored further in Section 9.

- **WASTE MANAGEMENT FROM DAIRY FARMS**

Table 5.6 lists the amounts of nutrients excreted by various stock animals, their populations and the total tonnage of nutrients produced per year within the SIR. Intensive animal industries are not considered in this issues paper and are discussed at length by GH&D (1995) in the Intensive Animal Industry project brief. Effluent from dairy sheds is part of this brief and is discussed below.

Table 5.6: Manure production for selected animals, its nutrient composition and total nitrogen and phosphorus loads generated for the irrigation areas in the Goulburn and Broken catchment

ANIMAL	NUMBER	TP (kg/animal/yr)	TP (T/yr)	TN (kg/animal/yr)	TN (T/yr)
SWINE	88,195	3.6[1]	318	10.8[1]	953
CATTLE	437,714	9.0[1]	3,939	70.0[1]	30,640
SHEEP	524,442	1.5[1]	787	10.0[1]	5,244
TOTAL NUTRIENTS			**4,952**		**36,837**

[1] Department of Agriculture (1983), AWRC (1974).

At the present time, dairy farmers must retain all effluent from dairy sheds within the boundaries of their properties. As part of the nutrient management strategy for the Goulburn and Broken catchments, guidelines are being developed to assist farmers in developing efficient and effective methods for treatment and/or disposal of dairy shed effluent within the boundaries of their properties.

A herd of 120 milking cows will, in the course of one year, produce around 2.9 ML of effluent. This comprises manure and urine, and the washing water from holding yards, pits and the milk room. In addition, a further 1.9 ML of water arising from storm water and rain from the dairy shed roof and water from the plate cooler will have to be considered, a total of approximately 4.7 ML of effluent requiring storage, treatment and in the case of uncontaminated rain water and plate cooling water, re-use (Mulcahey and Schroen, 1993).

These figures are only average values and there is considerable variation in the volume of dairy shed waste produced due to differences in individuals cleaning habits, condition and size of the dairy shed, breed of dairy cattle etc. Figures quoted in a dairy yard wash survey (Crocos in Wrigley, 1993) show a huge variation in the amount of water used for washing down yards, and the amount did not correlate to the number of animals in the milking herd. It is therefore not cow number, but amount of waste water generated during winter which determines the size of the effluent system required.

Method of yard cleaning can change the daily volume of water required by 50%. Volumes are determined primarily by water volume and/or pressure. The most efficient yard cleaning system is a high flow (220-270 L/min) at low pressure (100-140 kPa), (Mulcahey and Schroen, 1993).

A survey undertaken in the Mount Lofty Ranges (South Australian Dairy Farmers Association, 1993) determined that wash-down water contained levels in the range of 47-625 mg/L TN and 22-90 mg/L TP. An average milking cow generates 30-70 kg of manure each day, of which an average of 4.2 kg is excreted in the milking shed (Mulcahey and Schroen, 1993). Milk spilt in the dairy shed also contribute to waste water nutrient concentration. Milk contains significantly more nutrients than comparative amounts of faeces or urine. The fertiliser equivalent of milking shed waste-water for a 100 cow herd based on the manure production of 500 kg cows fed on green pasture spending 2 hours per day in the milking shed and holding yard areas is shown in Table 5.7.

Table 5.7: Fertiliser equivalent for fresh dairy cattle wastes produced at the milking shed area (for 100 cows per year) and assuming 300 days lactation.

100 cows	Average kg daily	kg/year	Nutrient availability, equivalent kg of fertiliser
N	19.2	5,760	12,522 kg urea
P	2.5	750	8,241 kg superphosphate

Table 5.8 lists six methods of disposal and/or treatment of dairy shed effluent, together with the advantages and disadvantages of implementing each system. The list is not exhaustive, and there are various adaptations of these six in use throughout the dairy industry. In selecting a system, farmers need to consider:

- costs of implementation (labour, materials, equipment, energy)
- local conditions (soil type, climate, salinity, water table height etc.)
- future development (changing markets, increasing herd size, dairy remodelling etc.)
- pollution risks (run-off from re-use areas, flood, pump or sump failure etc.)

In addition the advantages of mechanised versus gravity systems needs to be appraised in considering the overall simplicity of a system and the likelihood of its sustainability. Systems which fail, commonly do so because of they are not simple to operate and maintain, or because they are outgrown by the numbers of cows in the herd (Crocos, in Wrigley 1993).

Table 5.8: Systems of Dairy shed effluent removal and/or treatment (from Wrigley, 1993).

SYSTEM	BENEFITS	PROBLEMS
Application direct to land	- uses majority of nutrients - re-use of solids and liquids - soil conditioner - cheap if gravity feed used	- likely to cause pollution of surface & ground-water - no facility for storage - requires large land areas - is labour intensive - may encourage spread of disease - reduces palatability of pasture
Holding pond storage followed by land application	- allows controlled release of waste water & land application scheduling - removes solids - makes pumping easier - storage during wet weather - provides supplementary irrigation reservoir	- safety of children and stock compromised by deep water - smell - cost more than direct application - sludge must be managed - inappropriate for high water-table areas - waste movement a problem - pervious soils must be lined
Two pond system and irrigation	- less land required - less likely to affect environment - better quality waste water - water re-use possible - no odour in treated effluent	- safety of children and stock compromised by deep water - odour present during treatment - aerobic ponds lead to significant land loss - construction of 'turkey nests' necessary if water table high - greater nutrient loss - sludge must be managed - pervious soils must be lined - algal blooms may occur in aerobic ponds
Manure cart or vacuum tanker	- may improve soil structure - possible to spread waste over entire farm - solid and liquid re-use - maximises re-use value of nutrients	-- odour - labour intensive - unsuitable for large herds - unsuitable for use during wet periods - high capital cost
Wetland/Off-site discharge	- also serves as wildlife habitat - waste not applied to pasture - system may remove 30-40% of N & P from waste water - requires small area of land	- nutrients lost from farm system - expensive to set-up - not effective for removal of P as this remains in sink - unsuitable for sandy soils
Closed water system	- no discharge - water recycled through wash-down system	- potential disease problems - build up of nutrients and pathogens

• MANAGEMENT PRACTICES

Whilst the aims of agricultural research and development in the past have been focused on increasing food production per unit land area, environmental quality issues have forced a re-evaluation of these objectives and sustainable agricultural practices are now being developed. Management Practices are a collection of procedures used to maximise productivity, but at the same time consider and minimise impacts to the environment.

Whole Farm Plans

Whole farm irrigation planning is the process of redesigning the supply, delivery and removal of irrigation water from a farm (Campbell, 1991). In the context of this definition the plan encompasses the entire farm rather than each individual bay. In addition to the engineering concerns of water movement upon the farm, other farm activities; stock management, maintenance and access to laneways and farm buildings, nutrient management, environmental features and economics are considered. Potential exists to utilise whole farm plans to minimise the impacts of nutrients in drains. By 1992 there had been 1,688 Whole Farm Plans completed in the Goulburn Valley, accounting for 29% of farms in the study area (personal communication, D. Lawler).

Re-use Schemes

Water re-use schemes can be divided into two categories: farm and regional re-use systems. In the case of farm schemes, drainage from one paddock is diverted to irrigate further crops or pasture. These schemes may be either unplanned and opportunistic, or may be part of a comprehensive whole farm plan, incorporating new drainage lines and a re-use dam. Regional re-use generally refers to the practice of drain diversion, removal of water in irrigation drains prior to final discharge to a watercourse. This already occurs in many irrigated areas of Australia. In the St George Irrigation Area in Queensland it is encouraged to the point where there is no discharge from the drainage system to surface waters unless there is a significant rainfall event (Harrison, 1994).

In the SIR, during high water allocation years, around 20% of applied irrigation water runs off to farm drains and is lost, though in drought years this percentage is significantly reduced due to a greater care being exercised by irrigators. At present around 41% of farms in the SIR employ some level of re-use system. The major factors influencing adoption of re-use systems on a farm include the cost of installation and operation, and the poorer quality of reclaimed water.

In summary, once in place a re-use dam can be used to:

- avoid losses of tail-water.
- irrigate the re-cycled water at the time a farmer requires, rather than the time dictated by availability of water in the supply channels.
- store excess irrigation water if scheduled cut off is delayed.
- provide drainage in areas not serviced by GMW or community drainage.
- reduce reliance on GMW water supply.
- store and re-apply dissolved fertiliser at the next irrigation.

Laser Grading

In 1977 agricultural lasers were introduced to Australia, and the first property to be graded was at Bunbartha near Shepparton (Hall et al. 1983). Advisory Officers for the GMW and the Department of Agriculture recommend a slope of 1 in 800 (0.13%) for optimal irrigation of perennial pasture (Rendell and Fowler, 1984). On flatter slopes water tends to pond at the end of the bay and waterlogging is common because of the slowness to drain. Steeper bays require more frequent irrigation, but this is offset by increased crop productivity and the ability to work the bay when required.

Soil types of the SIR are most often heavy clays or clay loams (Rendell and Fowler 1984). Excess water remains on the surface of these soils and either evaporates or takes a long time to infiltrate causing scalding and waterlogging. In addition, during a wet year, these flatter paddocks will not drain away after rainfall, making any planned work on the paddock very difficult.

Buffer Strips

Buffer strips are areas of vegetation, generally grasses, used as a filter for sediment and nutrients attached to sediment particles (Barling and Moore, 1992). Research into the effectiveness of buffer strips (Weston et al., 1986) installed between non-dairy grazing and intensive horticultural land, and collecting streams demonstrated that as long as the buffer strips were at least 5 m wide, and were correctly installed and maintained to prevent channelling, a reduction in nutrient runoff of 90% could be expected. Though buffer strip effectiveness is primarily dependant on width, the type of vegetation, its density and height, the slope of the land and volume of water passing through the strip are also variables. Removal of sediment from the flowing water is achieved through reductions in the flow velocity. Unfortunately, with irrigated pasture a large proportion of the nutrients are in soluble form and these may not be removed.

Further research needs to be performed in this area before realistic percentage reductions could be hypothesised for soil types and conditions encountered in the SIR, and the mobilisation of sediment, and consequently nutrients, following storm events also needs to be examined. However, there is potential for nutrient reductions to drains to be made through the use of buffer strips. The major obstacle to be overcome would lie in the value of land taken out of production through implementation of such a management action, and buffer strip size would have to be minimised and perhaps planted with a crop which has intrinsic value, such as timber, or could be utilised as a wind-break. The use of several small buffer strips, approximately 1 to 1.5 metres wide placed strategically within bays could also be studied to determine if this strategy was more effective than a single buffer strip at the end of a bay.

Potential Nutrient Reduction Practices - Pasture and Dairy

The following are a list of management practices, either already practiced within the farming community to some extent, or which have been suggested by researchers in the area, that have potential to reduce nutrient loading to irrigation drains. Most of these management practices remain unquantified in terms of their effect on nutrient loads.

- Increase water use efficiency - develop and implement a well designed farm plan, irrigation scheduling, irrigation automation.
- Minimise irrigation tailwater runoff particularly for the two irrigations after fertiliser application and after sowing - short watering, automation, water re-use system.

- Minimise rainfall run-off by installation and appropriate management of water re-use systems.

- Maintain an optimum rotation length for pasture production of 20 days to ensure dry matter production levels are optimal and supplementary fertiliser inputs are kept to a minimum.

- Boost pasture production and obtain the best yield increment by applying nitrogen fertiliser to pasture within a week after grazing.

- Avoid spreading fertilisers, dairy shed effluent or other forms of waste too close to farm and regional drains.

- Undertake plant and soil testing in conjunction with sound agronomic advice to accurately determine fertiliser requirements.

- Timing of application of fertiliser could be an important factor in minimising nutrient accession to drains and needs further investigation.

- Wet up the soil before applying fertiliser to ensure that the soil is not dried out and cracked. Rather than being adsorbed through the upper portion of the soil profile the fertiliser will enter the deep cracks and pass beyond the root system.

- Apply P to perennial pastures after an irrigation to allow the moist soil surface to increase the possibility of P adsorption. Fertiliser should be applied during spring or autumn when the irrigation frequency is lower and there is greater opportunity for P adsorption.

- Ensure effective management of dairy shed effluent through appropriate storage and disposal methods.

- Install buffer strips at the end of the irrigation bays (further research is required to confirm any potential benefits).

- Fence channels and drains to keep animals from the water. This serves many purposes, but principally it prevents damage to the channel or drain itself through pugging of banks, eliminates additional nutrients entering the water via manure, assists in the prevention of weed growth and minimises the build up of liver fluke snails and pathogenic bacteria and viruses. In the case of drains, which could harbour potentially toxic blue-green algae, this measure will also prevent stock losses.

Potential Nutrient Reduction Practices - Horticulture and Vegetables

- Utilise trickle irrigation in conjunction with black plastic sheeting to minimise water losses, nutrient accession to drainage, and growth of weeds. Under correct management trickle irrigated crops contribute little to surface drainage as there is no significant run-off. Water is placed under the plant in direct contact with the root system and quantities are metered out to ensure adequate, but not excessive water is supplied.

- Correctly time fertiliser applications to plant nutritional requirements.

- Undertake plant and soil testing in conjunction with sound agronomic advice to accurately determine overall fertiliser requirements.

- Utilise data from experimental trials to maximise yield and reduce accession of nutrients to the environment.

- Use neutron probes to determine soil water saturation levels and schedule irrigations. Information is also currently available from government agencies on daily crop water usage and this data should be used.

- Follow existing recommendations for the application of urea to reduce sub-surface losses.

- Apply N fertiliser dissolved into irrigation water (trickle), or broadcast and water immediately to minimise losses through volatilisation. Do not apply fertiliser until after the first irrigation has closed the cracks in the soil surface. Cracks increase the likelihood of fertiliser leaching beyond the root zone of the crop and reaching the water-table.

- Keep informed of research initiatives. Work underway at ISIA Tatura has found that sub-surface drainage is likely to reduce the volume of surface runoff and the phosphorus load exported to the drainage system. However, sub-surface drainage tends to have a very high concentration of nitrogen due to its mobility in the soil profile (and in salinity) and disposal of this water may present a problem. Research has determined a winter-spring peak in nutrient concentration within sub-surface drainage, and ties this event to the high rainfall period. As a consequence of this initial work, further research into the area of efficient fertiliser application will be initiated to minimise the nitrate accumulation and leaching through the soil profile just prior to this annual high rainfall event.

- Preparation of fine seed beds for vegetable production will increase the likelihood of soil erosion and consequent nutrient loading to drains. Further research should be undertaken to examine cultivation methods designed to minimise soil disturbance under vegetable cropping.

Likely Effect of Management Practices on Nutrient Levels in Drains

The basis of the information presented in the following tables is a mixture of local knowledge integrated with a study performed by the CSIRO using the Catchment Management Support System (CMSS) for the Onkaparinga catchment of South Australia, (Davis and Farley, 1991). This area has a degree of similarity with the SIR, being predominantly dairy and grazing with areas of perennial horticulture, potatoes and some market gardening.

Due to the lack of significant amounts of definitive data, Tables 5.9 and 5.10 give a rating to various management practices in terms of their likely effect on reduction to nutrient levels in the drainage system. The greater the number of - symbols, the more benefit the practice is likely to have in terms of reducing irrigation water volumes reaching drains, or concentration of nutrients in run-off, while a + symbol denotes that the management practice is likely to increase nutrient concentration or volume, while 0 denotes an action expected to have no effect.

Management practices most likely to reduce the volume of run-off water include: the installation of water re-use systems, minimisation of tail water and changing to alternative forms of irrigation technology, notably trickle irrigation. Management practices with potential to reduce the concentration of nutrients in irrigation drains include: optimal timing of fertiliser application, minimising tail-water and installation of buffer strips at the end of bays.

Table 5.9: Farming Practices likely to affect run-off volumes and nutrient concentrations in drains - Pasture and Dairying

MANAGEMENT PRACTICE	LIKELY EFFECT ON LOAD REDUCTION	
	VOLUME	CONCENTRATION
WHOLE FARM PLANNING:-		
a. Water re-use systems	- - - -	0
b. Laser grading and other land	+	0
FERTILISER USE:-		
c. Optimal timing of fertiliser application (relative to approaching fronts)	0	-
d. Application of fertiliser to cracked soils	0	++
e. Application of N fertiliser to boost DM production in drought conditions	0	+
f. Substitution of dairy shed effluent for fertiliser	0	-
g. Judicious spreading of fertilisers and/or dairy shed effluent in proximity of drainage channels	0	-
WATER USE:-		
h. Weed free drains (to encourage good drainage)	0	+
i. Minimisation of tail water, especially after fertiliser application in terms of water and fertiliser losses	- - -	- -
j. Irrigation immediately following fertiliser broadcasting (minimisation of N volatilisation)	0	+
k. Use of riparian buffer zones at base of bays to filter out sediment and absorb nutrients from tail water	0	-
OTHER ISSUES:-		
l. Fencing drains to exclude stock	0	-
m. Planting of 10 m buffer strips at base of bays to intercept nutrients	0	- -
n. Establishment of on-farm wetland systems to remove nutrients	0	-

Table 5.10: Farming Practices likely to affect run-off volumes and nutrient concentrations in drains - Horticulture

MANAGEMENT PRACTICE	LIKELY EFFECT ON LOAD REDUCTION	
	VOLUME	CONCENTRATION
FERTILISER USE:-		
a. Use of leguminous cover crops between rows (orchards and vineyards)	0	-
b. Application of appropriate amounts and forms of fertiliser	0	-
c. Optimal timing of fertiliser inputs	0	- - -
WATER USE:-		
d. Move to different irrigation techniques:		
- over-tree sprinklers	-	0
- under-tree sprinklers	- -	0
- trickle irrigation	- - -	0
e. Use of automated watering systems	-	0
f. Tile drainage	+	++

DRAINAGE DIVERTERS

Existing Drainage Diversion Policy

The policy on drain diversion has been the subject of review for some time based on the need for improved management of drainage water. As a means of minimising the quantity of salt and nutrients leaving the SIR, drainage diversion has been promoted within the development and implementation of the SIRLWSMP. Drainage water can for the most part be seen as being of reasonable salinity and rich in nutrients for re-use on pasture, rather than being viewed as a disposal problem.

HydroTechnology (1994e) has prepared a draft discussion paper outlining issues that may need to be addressed in relation to the existing policy and the above broad objective. The paper summarises the existing policy, highlighting:

- 15 year agreements between GMW and the consumer.
- water to be taken for irrigation by pumping, up to a specified annual total unless otherwise agreed to by the supplier.
- the supplier has the ability to restrict supply.
- no liability on supplier with respect to supply volume or quality.
- an annual charge is fixed for the specified volume (administration charge plus a licensed volume fee at 25% of cost of wheel water).
- consumer to be responsible for the installation of pumping equipment, for keeping a record of the water used, and where directed to fit and maintain a meter.

The draft paper also highlights issues that may need to be addressed as part of any review targeting improved management. These issues include:

- a lack of security exists for this resource, and may be adversely affected by future impacts of expanding on-farm water re-use systems.
- a clear understanding of the Water Act is required with respect to consumers rights and suppliers responsibilities.
- SPAC policy on re-use throughout the whole catchment needs to be clear with respect to the means of reducing salt and nutrient loads to the Murray (eg on-farm versus drain re-use).
- the suppliers role in managing times of low drain flows needs to be defined.
- not all diversions currently conform to policy in that gravity diversion exists.
- potential exists for diversion of high flows into storages, although the effects this may have on the environment of the downstream rivers needs to be considered.
- the commercial interests of the supplier may not be in line with SPAC policy.

- costs to landholders of meeting policy requirements are of concern. Secondary re-lift from a re-use dam introduces further costs.

- conflict exists between the requirements of all interested parties - irrigation supply, salinity and nutrient control, the environment, water suppliers.

- conflict in levels of service, and hence potentially price, exists between drainage within GMW arterial drains versus community drains.

- what are the legal rights to water following construction of new drains?

The above reflects the complexity in development of policies to increase diversion along drain systems for salt and nutrient management.

Extent and Status of Existing Licenses

Information on drainage diverters in the SIR has been collated and analysed to determine their level of impact on nutrient loads in the irrigation drainage system. A list of drainage diverters in the SIR was obtained from the GMW Customer Information and Billing (CIB) database in which the diverter's name and address, SPG number, drainage diversion agreement number, licensed diversion volume (ML) and area irrigated (ha) are stored. Unfortunately, the CIB database does not include information about diverters located on community based drainage schemes.

Each diverter was assigned to their respective irrigation area (ie, Rochester, Central Goulburn, Shepparton and Murray Valley) and the area managers asked to provide details on their locations. Figure 6.1 is a map showing the locations of the approximate 620 diversion licences in the SIR. Drainage diverters are located along the Lockington, Bamawm, Warrigul Creek, Deakin, Undera, Rodney, Ardmona, Shepparton Central, Shepparton East, Shepparton North and Murray Valley Drains 3, 5 and 6 drainage systems. Table 6.1 lists the areas, number of diverters and the licensed diversion volume for each drainage catchment. For those catchments that are monitored, the table lists the licenses upstream of the monitoring point (> 98% of all licenses). Also included in the table is a summation of licenses outside of the monitored catchments (eg. downstream of monitoring site). At present, 610 (98%) of the diverters have been identified and annotated within their appropriate sub-catchments. Table 6.1 also includes a summation of the 10 licenses yet to be identified.

Figure 6.1: The locations of the drain diverter licences in the SIR.

Table 6.1: Sub-catchment area, number of diverters and the licensed diversion volume.

Catchment	Area (ha)	Number of diverters	Licensed Volume (ML)
Lockington Main Drain	20,467	5	572
Bamawm Drainage System	26,800	62	8,947
Deakin Main Drain	56,114	164	24,070
Rodney and Ardmona	26,780	36	4,409
Shepparton North Drainage System	N/A	45	2,849
Murray Valley Drain 3	8,928	2	222
Murray Valley Drain 6	18,343	34	2,314
Shepparton East Drainage System	n/a	126	9,999
Warrigul Creek	37,740	124	14,186
Murray Valley Drain 5	n/a	1	30
Outside of monitored catchments	n/a	11	3,597
Not yet located	n/a	10	6,354
TOTALS		**620**	**77,549**

n/a = Not Applicable.

Drainage Diverter Statistics

For each drain catchment, statistics and frequency distributions have been calculated on the licensed diversion volumes. The statistics reported are the minimum, maximum, median, the 10, 25, 50, 75 & 90 percentiles, and the total. For ease of interpretation, licensed volume has been categorised in ranges of 50 ML (eg., 0 to 50 ML, 50 to 100 ML etc.). Two plots are provided for each of the catchments:

- licensed volume (category) versus number of diverters and,
- licensed volume (category) versus total licensed volume.

These plots, together with the drain diverters statistics are shown in Figures 6.2 to 6.10, respectively. The percentiles in the following figures represent the distribution of diverters with respect to licensed volume eg., Bamawn, 25% of diverters have a license of 62 ML or less. With respect to the following figures, note:

- percentiles were not produced for the Lockington Main Drain and Murray Valley Drain 3 because of the low total number of diverters in these systems (5 and 3, respectively).
- no graph for the one diverter for Murray Valley Drain 5.

Figure 6.2: Frequency plots and drain diverter statistics for the Lockington Main Drain.

Figure 6.3: Frequency plots and drain diverter statistics for the Bamawm Drainage System.

Figure 6.4: Frequency plots and drain diverter statistics for the Deakin Drainage System

Figure 6.5: Frequency plots and drain diverter statistics for the Rodney Drainage System.

Figure 6.6: Frequency plots and drain diverter statistics for the Shepparton North Drainage System.

Figure 6.7: Frequency plots and drain diverter statistics for Murray Valley Drain 3.

Figure 6.8: Frequency plots and drain diverter statistics for Murray Valley Drain 6.

Figure 6.9: Frequency plots and drain diverter statistics for the Shepparton East Drainage System

Figure 6.10: Frequency plots and drain diverter statistics for the Warrigul Creek Drainage System.

Key features of the above statistics are:

- approximately 30% of all diverters have licenses less than 50 ML.
- at least 50% of all diverters have licenses less than 100 ML.
- the larger licenses (approximate value) are:
  - Bamawn - 2 @ 600 ML
  - Deakin - 1@ 1,200 ML, 1@ 1,000, 2 @ 750 ML
  - Rodney and Ardmona - 1 @ 400 ML
  - Warrigul Creek - 1 @ 700 ML
  - Shepparton East - 1 @ 1200 ML

The greatest proportion of potential volume diverted is held by diverters with licenses less than 200 ML. However, single high volume licenses do have the potential to divert significant volumes within any one area eg, Bamawn, 1 license close to 10% of the total licence volume.

The distribution of licenses and license volumes towards the low end of volume categories suggests that under current arrangements, significant effort and increased complexity in system management would be involved in dealing with many diverters to achieve substantial increases in the volumes diverted, and hence reduced nutrient, and salt loads, to the River Murray.

A Study of Bamawn Drainage Diverters

Within the SIRLWSMP, GMW is investigating drainage diversion practices within the Bamawn Main Drain to assist development of a management strategy to minimise salt and nutrient flows from irrigation areas reaching the River Murray. Management of the Bamawn diversion system is assisted by the Bamawn Drainage Advisory Council (BDAC) which was formed in 1983.

The current investigation is based around a program of monitoring of drain flows, channel outfalls, diversion volumes, water salinity and nutrient levels. The landholders are involved in the project, with a survey of diverters carried out by Schroen (1993). Key outcomes of the landholder attitudinal survey reported by Schroen (1993) were:

- availability of water "when it was wanted" appeared to be the major constraint on the system.
- landholders considered the system to be committed and adding new diverters would compound the problem of availability of drainage water.
- automation to take advantage of night time flows was not favoured. Diverters already pump at night time, and night time irrigation may not match overall farm management.
- installation of storage systems may be beneficial towards the bottom of the system where water was available and suitable soils exist.
- drainage diversion was limited by license volume, lack of security and water quality.
- weeds in drains is a significant problem, blocking diversion pumps.

The monitoring program in the Bamawm drainage system commenced in July, 1993. Flows passing Dargan's Bridge and the volume diverted upstream of this site for the 1993/94 season are presented in Table 6.2. Dargan's Bridge is the most reliable downstream flow monitoring site for this study, although several large diverters exist below this site.

Table 6.2: Monthly flow at Dargan's Bridge and the upstream drainage diversion in 1993/94.

	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Flow at Dargan's Bridge (ML)	405	2675	4734	2285	2905	2430	3083	2870	1782	989	**24157**
Volume Diverted upstream (ML)	0	0	119	587	1012	815	749	952	1004	428	**5666**
Total Licensed Volume (ML)											**8947**

The zero diversion volumes in August and September, and the low volumes in October, resulted from significant rainfall during this period. In most years there would be significant volumes of diversion in this period. On a regional basis, the above figures show diversion being 63% of licensed volume. Given very little diversion early in the season, this effectively represents close to full diversion utilisation.

The actual versus potential diversion with respect to licensed volumes has been further explored by analysing individual licenses. For the 1993/94 and 1994/95 (to end of April, 1995) irrigation seasons, a percentage usage has been calculated for each license and these were ranked to give the 10, 25, 50, 75 and 90 th percentiles. Note that for the 1994/95 season, data analysis to date limits the licenses considered to only 55 (out of 62) due to some missing data. The distribution of the percentages for each season is given in Table 6.3.

Table 6.3: Distribution of Volume Diverted versus Licensed Volume on Individual Licenses

Percentiles	Percentage of license volume diverted - 1993/94	Percentage of license volume diverted - 1994/95 (to end April, 1995)
10 th	0%	23%
25 th	9%	52%
50 th	57%	89%
75 th	99%	125%
90 th	121%	162%

For 1993/94, it can be seen that a high proportion of diverters used significantly less water than their licensed volume - eg 10% of diverters used no water, 25% used less than 9% of the licensed volume and 50% of all diverters used less than 57% of their licensed volume. However, in this generally wet year a significant number of diverters still used much more than their licensed volume - eg. 25% of diverters used more than 99% of their licensed volume and 10% of diverters used greater than 121% of their licensed volume.

While the pattern of significant numbers of both relatively low usage and very high usage is similar for the much drier conditions of 1994/95, a general shift towards greater usage exists. Even allowing for some further usage during May 1995 (not included in the analysis), a significant number of diverters have not used their licensed volume - eg 25% of diverters used less than 52% of their licensed volume. At the same time, the number of diverters using water in excess of their license, and the magnitude of the excess, increased, with 10% of diverters using greater than 162% of their licensed volume.

While these statistics are not volume based, they do highlight several common features during both a wet year and a dry year:

- a significant number of diverters did not use their licensed allocation in both the wet (1993/94) and dry (1995/96) years

- equally, there are a number of diverters who use significantly more than their licensed volume, even in “wet” years.

Without consideration of other factors, the existence of both regular low volume users and extremely high volume users suggests that elimination or reduction in the licensed volume tied up but not **regularly** used would be a first step in increasing the amount of actual diversion within a drainage system.

The data in the earlier Table 6.2 also indicates that significant flows still pass through the system, even with the overall high level of diversion. For the months November through to May of 1993/94, the total volume passing Dargan’s Bridge was approximately 16,300 ML, some 10,700 ML greater than the volume diverted, and approximately 74% of the water accounted for in the system (ie. the sum of flow at Dargan’s Bridge, 16,300 ML, and the volume diverted, 5,700 ML). Simplistically, this water represents a very significant resource currently not being used (Note: Downstream of Dargan’s Bridge there are a number of large volume diverters - licence volume > 2,000 ML in total, and other significant features such as Murphy Swamp, Richardson’s Lagoon and the Lockington Main Drain and these have a significant impact on the volume of water reaching the River Murray).

A preliminary analysis has been carried out on the distribution of the flows passing Dargan’s Bridge with time, as an indicator to the characteristics of the flows considered potentially available for diversion. Table 6.4 summarises the distribution.

Table 6.4: Distribution of Flow Passing Dargan's Bridge, 1993/94 Irrigation Season

Percentile (time)	Daily Flow at Dargan's Bridge - ML/day	Total Flow at Dargan's Bridge - ML
10 th	16	350
25 th	41	1,630
50 th	62	5,740
75 th	81	11,200
90 th	106	15,400
TOTAL		24,157

Table 6.4 shows the following:

- The median flow for the 1993/94 season was 62 ML/day.
- Of the total flow of 24,157 ML passing Dargan's Bridge during the 1993/94 irrigation season, only 5,740 ML, or 24%, passed during 50% of the time.
- 25% of the daily flows were greater than 81 ML/day, and in total carried 12,957 ML (24,157 - 11,200), or 54% of the total.
- 10% percent of the daily flows were greater than 106 ML/day, and in total carried 8,757 ML (24,157 - 15,400), or 36% of the total.

The data indicates that significant increases in the volume diverted, and hence nutrients diverted, would only be achieved by targeting the higher flow periods. This would most likely be best achieved with a strategy of high volume diverters, rather than many low volume diverters that would lead to increased complexities with respect to security and management.

The potential to use the resource currently passing through to the River Murray is based on many factors, which are the focus of the ongoing Bamawn study. Significant development of the study, incorporating recommended management strategies for re-use, is expected throughout the 1995/96 financial year, following collection and analysis of data from the two previous irrigation seasons. It is expected that such data and analyses will significantly improve the understanding of implementation issues in maximising drain diversion. At the broad scale, integration of nutrient, salinity and environmental issues will be required.

Given the differences in irrigation sub-catchments (eg. spatial distribution of flows and diverters) across the Goulburn and Broken catchments, detailed studies and action plans for other catchments will most likely be required.

The elements of such studies and plans are further developed later in this section and in later sections of this issues paper.

The Potential Impact of Drain Diverters on Nutrient Loads Exported from the SIR

The potential impact of introducing more drain diverters on nutrient loads has been explored by using licensed volumes, flows and nutrient loads leaving the drainage systems for the irrigation and non-irrigation seasons over the period July 1991 to June 1992.

Table 6.5 presents the licensed diversion volumes and the loads leaving the system.

Table 6.5: Flow, phosphorus and nitrogen loads for the irrigation and non-irrigation periods of the 1991/92 financial year.

Catchment	Area (ha)	No. of diverters	Licensed Volume (ML)	Catchment Flows 91/92 (ML/yr)		Phosphorus Load (kg) exported from catchment		Nitrogen Load(kg) exported from catchment	
				Irrigation Season	Non-Irrigation	Irrigation Season	Non-Irrigation	Irrigation Season	Non-Irrigation
Lockington Main Drain	20,467	5	572	9,671	3,328	3,564	1,515	16,979	8,082
Bamawm Drainage System	26,800	62	8,947	25,838	691	-	-	-	-
Mullers Creek	775	0	0	505	791	48	89	641	1,095
Deakin Main Drain	56,114	164	24,070	30,142	14,264	20,809	9,925	77,039	46,340
Warrigal Creek	37,740	124	14,186	10,266	2,923	-	-	-	-
Rodney and Ardmona	26,780	36	4,409	24,710	15,326	4,846	4,397	35,467	29,064
Murray Valley Drain 3	8,928	2	222	4,570	796	-	-	-	-
Murray Valley Drain 6	18,343	34	2,314	22,596	4,452	15,651	1,981	41,038	7,689
Toolamba Depression	2,200	0	0	262	129	36	1	221	7
Totals	**198,417**	**427**	**54,720**	**128,560**	**42,700**	**44,954**	**17,908**	**171,384**	**92,276**

The above table shows that catchment outflows over the 1991/92 irrigation season were greater than double the licensed diversion volume, highlighting the potential for nutrient load reduction through increased drain diversion. The 1991/92 season could be considered close to average with respect to flows over recent times.

The feasibility of nutrient reduction via increased diversion has been explored by assessing the number of diverters required to achieve a 50% reduction in nutrient loads for two scales of diversion - 100 ML and 500 ML per license. The lower range represents a common license volume throughout the study area, with the higher figure reflecting a strategy to target steady to high flow periods in the drains, diverting into storages (eg 100 ML storages filled 5 times throughout the season). Use of 500 ML of drainage water from a storage would not be possible for a typical farm having 40 ha of irrigated land. However sharing of storages between neighbouring properties may be an effective strategy to increase flexibility and reduce costs of drainage re-use. Table 6.6 summarises the results.

It can be seen that if increases in drain diversion targets the “average” diverter (100 ML/licence), significant reductions in nutrient loads in the order of 50% would only be achieved through the introduction of some 640 new diverters, or a doubling of the licensed volume for each of the existing diverters, or some combination of existing and new diverters. Either way, existing difficulties with security of supply and system management would escalate, presenting an effective barrier to implementation.

Table 6.6: The number of diverters required to decrease the flow during the 1991/92 irrigation season by 50%.

Catchment	No. of diverters	Licensed Volume (ML)	Flows (ML) during the 91/92 Irrigation Season	50% Flow reduction (ML)	50% Phosphorus Load Reduction (kg)	50% Nitrogen Load Reduction (kg)	No. of Diverters @ 100 ML/licence to achieve 50% reductions	No. of Diverters @ 500 ML/licence to achieve 50% reductions
Lockington Main Drain**	5	572	9,671	4,836	1,782	8,490	48	10
Bamawm Drainage System**	62	8,947	25,838	12,919	-	-	129	26
Mullers Creek	0	0	505	253	24	321	3	1
Deakin Main Drain	164	24,070	30,142	15,071	10,405	38,520	151	30
Warrigal Creek	124	14,186	10,266	5,133	-	-	51	5
Rodney and Ardmona	36	4,409	24,710	12,355	2,423	17,734	124	23
Murray Valley Drain 3	2	222	4,570	2,285	-	-	23	2
Murray Valley Drain 6	34	2,314	22,596	11,298	7,826	20,519	113	23
Toolamba Depression	0	0	262	131	18	111	1	1
Totals	**427**	**54,720**	**128,560**	**64,280**	**22,477**	**85,692**	**643**	**65**

**Note, Table 6.6: For these two sites there is a need to consider several important features further downstream that effect the volume of water reaching the River Murray.

The alternative approach is to develop drain diversion primarily as a nutrient control option. This need not necessarily lose sight of the fact that diversion will only be developed through identification of benefits to the landholders. The encouragement of higher volume licenses based on storages will introduce greater diversion throughout the season and for each season, rather than reliance on diverters that target dry years only, and at the same time simplify system management. In the introduction of such a system, issues to be addressed include:

- security of supply for existing diverters.
- security of supply for the new diverters. This will involve an understanding of seasonal variations in drain flows, long term distribution of flows (ie. occurrence of low flow years), distribution of flows along a drain system, long term water salinity, and fundamentally costs and benefits. Issues of policy and pricing would need to be linked to security, and be addressed by GMW. Storages introduce significant capital and annual costs, and issues of security and benefits to the farmers will need close attention for successful implementation.

Table 6.6 shows that even at 500 ML/licence a significant number of diversion systems would be required within the bigger drain catchments to achieve significant reductions in nutrient export. Simplistically, siting of these large licences and their storages at the bottom of the catchment would make sense, however, practical implementation suggests these diversion systems would be distributed more evenly throughout the catchment. This highlights the issue of security in terms of the distribution of flows throughout a system.

The Deakin system has been used as a case study to further explore these issues. This system has a reasonable number of flow monitoring sites along the drainage network. Four sites have records of flow available for the period July 1989 to June 1994. From the bottom of the catchment up to the top, the sites are:

- site 406704, the Main Drain Outfall, is at the bottom of the system, with a catchment area (drained catchment) of 56,100 ha (100 % of area served by drains)
- site 40673, at Gray Road, is the next site up the catchment, with a catchment area up to the next gauging site (406749) of 9,900 ha (18 % of area)
- site 406749, at Mason Road, is the next site up the catchment, with a catchment area up to next gauging site (406747) of 4,700 ha (8 % of area)
- site 406747, at Midland Highway, is the next site up the catchment, with an area of 2,100 ha (4 % of area)

This data allows assessment of both total flows passing each site, and the flow generated within each specific sub-catchment area. The annual passing flows and mean, minimum and maximum mean monthly flow for each site for the 5 year period to June 1994 are given in Table 6.7. The table also includes average unit area flows for the irrigation season, generated within each identified sub-catchment defined by the areas above.

Table 6.7: Estimated Drainage Flows in the Deakin Drainage System

Gauging Station	**406704 Main Drain Outfall**	**406731 Gray Road**	**406749 Mason Road**	**406747 Midland Highway**
Annual Flows	ML/year:	ML/year:	ML/year:	ML/year:
1989/90	40,820	19,140	22,940	6,210
1990/91	40,140	21,630	17,970	5,930
1991/92	44,410	21,610	16,420	6,730
1992/93	73,080	32,650	20,200	8,090
1993/94	75,980	33,920	21,470	8,940
Average	54,900	25,800	19,800	7,200
Irrigation Season	ML/season	ML/season	ML/season	ML/season
Passing flow - average	47,110	22,190	17,500	6,170
Individual catchment flow - average	n/a	4,690	11,330	6,170
Individual catchment flow - average, ML/ha	n/a	0.5	2.4	3.0
Monthly Flow during irrigation season: 7/89 to 6/94 - passing flow	ML/month	ML/month	ML/month	ML/month
Mean monthly flow	4,950	2,320	1,820	640
Minimum monthly flow	1,329	332	289	148
Maximum monthly flow	18,539	9,154	5,149	1,933

Note: unit catchment area flows have not been calculated for 406704 due to the difficulties in estimating the contributing area.

The above figures suggest that throughout the Deakin system, water in the drainage network is generated at a rate of between approximately 0.5 to 3 ML/ha of irrigated land over the irrigation season. These flows result from some combination of tailwater runoff, groundwater pumping, drain diversion, channel outfalls and contributions from undrained areas which have not been quantified for this analysis. Quantification of these water sources and sinks will be essential for the development of a meaningful strategy. The fact that the higher unit area flows are generated in the smaller, upper sub-catchments has not been explored at this stage, given the lack of detailed quantification of the above sources or sinks. However, this general ratio of drain flow to area is a starting point for siting and sizing of drain diversion storage dams given the lack of detailed monitoring throughout the study area.

A further factor in assessing drain diversion, in particular security of supply, is variability in flow over a season. Table 6.7 shows that the minimum monthly flows for the monitored period were in the order of 15% to 20% of the mean monthly flows. For each site, the minimum flows were all recorded in August 1992, and were significantly less than any other month in the period of record. The mean minimum monthly flows were generally 50% of the mean monthly flow. This suggests some form of rostering storage dam filling over several months in most years would not present significant management or resource problems.

In introducing large scale drain diverter storage systems, long term security also needs to be considered. However, lengthy time series data sets for drain flows are not available for such an assessment. The approach adopted here has been to link drain flows to the seasonal allocation for the Goulburn component of the GMID. This allocation is dominated by the contents held in Lake Eildon on the Goulburn River. Linke (1992) reported on computer simulation modelling of the Goulburn system for a study of off stream storages in Boort. The modelled allocations for the period 1896 to 1988, based on existing catchment conditions, in terms of allocation as a percentage of water right were:

- = 220%, 61% of time
- < 180%, 34% of time
- < 140%, 26% of time
- < 100%, 2% of time

Greater than 200% allocation generally represents unlimited supplies. Less than 140% represents significant restrictions. Hence, it could be assumed that with existing conditions of supply and demand, 1 year in 4 would have significant restrictions on supply, resulting in significantly lower drain flows. The future supply policy of GMW may also alter the allocation frequency, towards lower levels of supply.

Given this potential for relatively frequent low seasonal flow in the drains, a policy of targeting large drain diversion storages and licences towards farmers who have access to wheel water may be required. When available, drainage water could be used instead of the sales water (or a proportion of the sales water) normally used, and in dry years access to wheel water would provide a level of security. This would encourage diverters to make the long term strategic investment decisions required, based on an increased security of supply over most years.

As stated earlier, long term changes to the salinity of drainage water is also a factor to be considered. The SIRLWSMP, by way of increasing salt export to the River Murray, will result in increases in drain water salinity, which could reduce the viability of using drain water. Potential changes in drain water salinity are discussed under other catchment water quality issues in this issues paper in Section 8. Primarily, these changes arise from the sub-surface drainage strategy. Continued construction of farm re-use systems could also result in drain salinity increases by reducing the amount of "fresher" irrigation tailwater runoff.

Similarly, any strategies by GMW to increase supply system efficiency and reduce channel outfalls to drains would also result in increased drain salinities. However, while increasing salinity, such actions would also increase nutrient concentrations, effectively increasing the effectiveness of drain diversion in reducing nutrient loads to the River Murray.

The use of storages for diversion of drainage water will increase the flexibility in the system, giving opportunity to target the lower salinity water. While drain salinity will need to be considered in implementation, the relatively small magnitude changes predicted across the full range of flows during an irrigation season indicates water salinity will not be a barrier to drain diversion being a valid nutrient reduction option. However, it will be important to transfer the understanding of the long term salinity changes, within the context of any revised diversion policy and management, to potential diverters to maximise their confidence in the sustainability of drainage diversion.

Elements of Implementation of Re-use/Drain Diversion Systems

The discussion on drain diversion in this section has highlighted a number of features:

- Drainage water is a valuable source of water and nutrients suitable for re-use.
- Existing diversion policy is the subject of review, addressing security, high flow diversion, costs, pricing and compatibility with irrigation supply, salinity and environmental plans, amongst other issues.
- Existing licenses are weighted in number and volume towards relatively low volume diverters.
- Drain flows leaving the study area are significantly greater than licensed diversion volumes.
- In the Bamawn system, while total diversion may be close to licensed volume (eg. 1993/94), there are many diverters using much less water compared to their licensed volume over a full season. At the same time, many diverters use much more than their licensed volume. To significantly increase diversion in this system, the short duration high flows need to be targeted, and the volume tied up with unused or low usage licenses reduced.
- To limit the problems already existing with security and management of diversion, a few high volume diverters would be preferable to many low volume diverters.
- The spatial and temporal distribution of flows, over a full season, and over a longer time period of many years, needs to be quantified to assess security of supply.
- The benefits of high volume diverters and the issue of risk to security of supply point to the use of storages. However, as significant costs are introduced with the use of storages, the level of security issue remains, moving from being driven by the short term variations in drain flow to longer term seasonal flows. On this basis, it is recommended diversion storages be linked to irrigators with access to wheel water that can be used to maintain some level of service during low drain flow seasons.

Clearly, resolution of a number of complex issues such as security of water supply, water quality (eg. salinity), equity issues, and investment confidence is required for successful implementation of this option for nutrient load reduction.

The following systematic approach will need to be adopted on a sub-catchment basis:

A. Drainage Water Volumes, Reliability and Distribution.

A survey is required of the full sub-catchment area that is subject to potential diversion. This survey would have to locate:

- existing drain diverters with license volume (completed), and the diversion structure,
- existing drain network and projected drain construction (with drain type),
- channel outfall sites,
- any other sites of sources or sinks for drainage water,
- other catchment characteristics with respect to influence on drainage - eg. location and volumes pumped for groundwater pumps, farm re-use schemes (recognising issues of variability in performance of scheme).

Following this survey, a data collection program should be developed and implemented. Fundamentally, this should include monitoring of drain flows throughout the system, and monitoring of drain inputs and outflows. However, extensive monitoring may not be timely or cost effective, and relationships between catchment characteristics and flow generation should be explored as required. For example, installation of meters on all existing diverters is not practical given the likely cost involved (possibly at least $1,000 per site for meter and installation). Consideration to monitoring “type cases”, or parts of systems that can be used to generate useful data for unmonitored areas may be required.

The expected outcome of the monitoring and/or analysis would be an increased understanding of:

- the distribution (time and spatial) of water within the system (this requires monitoring),
- the volumes available, tied to a definition of frequency and,
- the water quality (nutrients, salinity, other pollutants).

Where possible, continuous monitoring is recommended to provide an understanding of flow variability over short time periods, and hence optimise diversion potential. Computer simulation models of the drain systems, for drain flow, diversion volumes, and water quality over both short and long time frames may prove beneficial in the development of diversion strategies. Segmentation of catchments may also be beneficial, allowing diversion targets (or nutrient load targets) to be set for sub-systems.

B. Landholder attitudes. The likelihood of landholders taking action will be based on benefits related to:

- Economics - the economics of any scheme must significantly benefit the farmer if they are to be adopted. Groups of farmers should consider sharing dams/storages to reduce the costs for a given supply volume. This will require site specific design of both drain structures and storages.
- Confidence - security of supply in terms of both quantity and quality is essential to achieve significant increases in drain diversion. Confidence in the investment required (eg. pumps, storages, meters) will need to be based on hard data from monitoring, meaningful

investigations, appropriate pricing policy and cost sharing, and an effective communication strategy.

C. Feasibility of Options. Further testing of the feasibility of individual licenses and any development of segments of drains for diversion targets will be required based on:

- Environmental Issues - the diversion policy must take account of environmental values. Changes in flow regimes should not impact on areas with significant conservation value.

- Engineering feasibility - individual sites will require feasibility assessment. This would include pumping considerations, the potential for gravity diversion, and the design of diversion structures.

- Soil type definition for storage dams. Minimal leakage from storage dams and hence any potential adverse effects from recharge to the groundwater table would be required. This may severely limit potential locations as alternate means of leakage control (eg. lining) are generally very costly.

D. Water Supply Pricing and Policy. Policy and operational instruments need to be established by the water supplier to account for legal rights, security for existing diverters, pricing policy and cost sharing to encourage adoption given the requirement for significant capital and ongoing costs. Pricing and policy development will need to target maximising drain diversion in typical years and removal of under-utilised commitments. This may include:

- installation of meters for all new licenses to provide the operational data for policy management.

- reduction of the length of license agreements to increase system management flexibility. Security of license to be linked to usage.

- cost sharing and rating bases to make allowance for variations in security. Such variations could be based on geographical location (eg. catchment, or location within a drain system), the license volume, and the use of a storage, and incorporate both flow and quality.

- cost penalties for under-utilisation. Given metering, charging to be based on usage, and structured to encourage full utilisation.

- a review of all existing agreements, and possible survey of landholders and targeted data collection, to lead to eventual removal of all “dry year only” users.

The process will also require a review of all system management costs (eg. metering, monitoring, analysis, administration), to feed into the required review of pricing. The review will need to include an assessment of the ability of the irrigators to pay for the full costs.

Resolution of the above issues should allow a detailed assessment of the potential for drain diversion as a nutrient control strategy within the various catchments in the study area. However, such programs must be considered with other nutrient control options to provide the coordination required for effective implementation.

It needs to be recognised that considerable time is likely to be involved in working through all of the above processes in any one catchment. In the short term, system managers should consider all new license applications within the framework outlined above, placing priority on specific issues as appropriate on the basis of the overall risk to the long term strategy. This may be facilitated by using the above to develop a checklist and decision chain, incorporating weighting factors derived from existing system information (eg. license distribution, environmental features, nutrient loads, flow distribution (or land use distribution), long term salinity plan initiatives). Consideration of issuing only short term licenses is recommended to maintain operational flexibility during the period required for development of the longer term plan.

3. DRAIN MAINTENANCE AND MANAGEMENT

Generally, the cycling of nutrients in drains is poorly understood, making it difficult to confidently relate drain maintenance and management practices to nutrient management.

The maintenance of drains in their best possible condition conflicts with the use of drains for nutrient management. Weed control in drains is necessary because excessive vegetation decreases hydraulic efficiency through increased friction, and reduces the available head for farm drainage to outfall into the drainage system. However, increasing the hydraulic efficiency will decrease the retention time in drains and is likely to reduce any nutrient stripping ability they afford. Deliberate use of weeds in drains as a nutrient control strategy is generally not promoted because of the level of service issues.

- **Control of Weeds in Drains**

In the past, control of weeds in irrigation drains was achieved through mechanical harvesting. This caused damage to the drains themselves, through the passage of heavy machinery, and re-mobilised nutrients in sediments deposited on the drain floor. It was also expensive in terms of fuel and time and had to be performed frequently.

Today, mechanical clearing has been replaced with herbicide applications using “acrolein” which significantly reduce the labour input. This selectively eliminates all weed growth and degrades rapidly to cause minimal environmental impact beyond the area of application. Initially, when acrolein was added to drains, a large dose of around 13 to 15 mg/L was applied to the drain and allowed to stand for up to 48 hours. Farmers were notified, and had to restrict stock access and drainage diversions. Today however, it is known that low concentrations of 0.25mg/L are effective and at these levels it will not affect pasture if water is diverted and used for irrigation. The cost of acrolein treatment of drains is in the range $75 to $150/km. The frequency of treatment varies with time of year, and at the height of the growth season may have to be undertaken approximately every six weeks. It is unclear what happens to the nutrients that are in the plant material once the herbicide has been applied.

- **Buffer strips**

The buffer strip concept could also be logically extended to the use of grass swathes placed either on the drain verge or within the drain itself. The growth could be harvested for animal feed or removed at intervals, along with the nutrient rich sediments for application as a mulch. These strategies would have to be researched extensively to more accurately determine potential benefits.

- **Other Issues**

Other issues that need to be considered in terms of drain management and maintenance are:

- the removal of phosphorus and potassium rich sediments from the drain system during desilting and the long term fate of the sediment and nutrients. For example, stock piling of sediment on drain banks is potentially a source of nutrients that may be remobilised through erosion or a leaching process.

- The role of carp in resuspending sediment and hence nutrients back into the water column.

otHER CATCHMENT WATER QUALITY ISSUES

Salinity

The primary aim of the SIRLWSMP is to reduce the amount of water entering the watertable and to remove water from it to achieve salinity control. Within this broad objective, the plan has four components:

- an environmental program
- a farm program
- a sub-surface drainage program
- a surface drainage program

These programs will increase the volume of water and salt leaving the region. Regulation of salt disposal to the River Murray are considered in the SIRLWSMP and the MDBC Salinity and Drainage Strategy, but increases in nutrient disposal are not directly addressed. However, recent initiatives by the MDBC to develop an algal management strategy for the River Murray will ensure that the “salinity only” export strategy will be modified to account for nutrient impacts. Hence there are significant overlaps between these two programs which cannot be treated in isolation and a “do-nothing” nutrient option is difficult to determine.

The environmental program in the SIRLWSMP contains a combination of:

- protection of floodplain wetlands and existing wetlands (some of high conservation value) along drainage courses, in terms of reducing nutrient loads that may adversely affect native and indigenous species and/or waterlogging (wetlands for protection have been specified within the plan).
- creation of new wetlands along drainage courses as compensation for wetlands lost through drainage construction.

In the development of any strategy involving existing or new wetlands for nutrient control, integration with the guidelines for the environmental program will be required. This may either support or conflict with the nutrient control strategies depending on the individual site characteristics.

The farm program includes landforming and re-layout, within farm restructuring, farm drainage and drainage re-use, private groundwater pumps (and/or tile drainage), water pricing and tree planting. The farm re-use systems, together with improved irrigation efficiency (eg. landforming), have the potential to significantly reduce drainage volumes, and hence nutrient loads to drains. However, the farm program relies on integration with the drainage strategies to provide a mechanism to remove sufficient salt for long term salinity control. Similarly, landforming without a farm re-use dam may in fact increase drainage if close attention is not paid to watering times by the farmer.

In the short term, it is likely farm re-use systems will target areas without drainage, giving individual landholders the opportunity to assist in salinity control.

It could be assumed that the farm program would continue independent of any nutrient strategy, given the farm productivity benefits and cost sharing arrangements outlined within the salinity plan. However, further benefits through nutrient re-use would add to the attractiveness of this program. The salinity benefits of this program point to a likely high adoption rate independent of the relative benefits ($ per kg nutrient reduction) within a nutrient management strategy.

A concern with the farm program, in particular the installation of re-use systems, is the reduction of the fresher drainage flows that dilute the more saline sub-surface drainage and direct groundwater flows to drains. Increasing salinity in the drains may lead to a long term reduction in the volumes of drainage water, and hence nutrients, removed for re-use. Given this salinity-nutrient conflict, an integrated sub-catchment approach to salinity and nutrient management would need to be based on an understanding of long term flow and salinity assessments within reaches of a system (ie. sub-surface disposal strategy, surface drainage program, adoption of farm and drain re-use systems), seasonal variations, and the potential for storage of better quality drainage water. As nutrient concentration, unlike salinity, is largely independent of flow, targeting diversion of the lower salinity drain water would not reduce potential nutrient diversion.

The sub-surface drainage strategy can be considered in two broad categories:

- Private Pumps - targets fresher ground-water in the irrigation season for farm re-use. Out of season the private pumping program is based on managed discharge to the River Murray. Generally discharge to river is allowed when flow in the Murray at Torrumbarry exceeds 10,000 ML/day, and is likely to be sustained above this level for at least 60 days. The net effect is to achieve a nominal salt balance for the area through winter export.

- Public Pumps (salinity control pumps) - generally operate for two 60 day periods, one in season, discharging to channels or drains, and one out of season, to the River Murray, again subject to flows as outlined above. Channel discharge is based on trying to target large capacity channels for effective dilution to limit salinity increases. However, salt export from channels to drains will occur as a result of emergency system shutdowns and other outfalls. Re-use of up to 95% of channel discharge may be possible. Disposal of poor quality ground-water (generally greater than 11,500 EC), would be to evaporation basins to limit salt disposal to the River Murray.

The salinity plan states that 62% of the salt generated by the sub-surface drainage program will remain in the region. For the water discharged to the Murray, levels of nitrate in the ground-water are likely to be more of a concern than levels of phosphorus. Harrison (1994) reports nitrogen levels for ground-water in irrigated areas throughout the Goulburn region ranging from 0.3 mg/L-N to 10 mg/L-N. Corresponding levels of phosphorus were all less than 0.066 mg/L-P. Total loads of nitrogen and phosphorus generated under this strategy are included in Section 4. In comparison to other sources, phosphorus loads are insignificant, while nitrogen loads are significant.

It can be assumed the private pump system will have little effect on drain salinities during the irrigation season. For the public pump program, simulation of drain salinities in the development of the salinity plan suggested drain salinities could increase by up to 100%, although on an average basis increases would be in the order of 50% or less (RWC, 1989). However these results could be considered “averages”, and over short time periods (hourly or daily), impacts could be much greater. Such increases in drain salinities adds to the competing issues of the salinity program and drain diversion for nutrient control as discussed above.

The elements of the surface drainage program are outlined in Section 2.6 of this report. The surface drainage program of the SIRLWSMP, in mobilising more water and salt for export to the River Murray, will also mobilise nutrients. It is this element of the plan that needs to be integrated with the development of a nutrient management strategy. While the extra drainage generated will increase nutrient loads out of the irrigation area (particularly phosphorus), a further increase in nutrient export may result from increases in efficiency of existing drainage systems, in effect reducing retention time of water in drain systems and hence nutrient losses along the drain. A compensating process may result from increased drain lengths associated with construction of new systems (Harrison, 1994). The nutrient balance along drain systems is not well understood, making it difficult to in quantify the overall net effect of the above processes in a meaningful manner. There is a need for specific monitoring programs along various drain systems to provide information for such assessments. Harrison (1994) also highlights the potential for some irrigators to become less careful with irrigation applications once surface drainage facilities are provided, generating an increase in water leaving the farm.

A discussion and broad estimate of the changes in nutrient export resulting from increasing surface drainage is presented in Section 3 of this report.

Environmental considerations within the surface drainage program may present conflicts between salinity and nutrient management. Proposed drainage systems may pass through environmental features eg. natural or artificial wetlands, native vegetation. This can present a conflict within the SIRLWSMP where landowners may view wetlands as occupying valuable productive land or causing farm management problems, and the option of diverting drains around wetlands is also not favoured as it also may not maximise use of productive land (SPPAC, 1989). General guidelines addressing this conflict are outlined in SPPAC (1989), and are based on maintenance and enhancement of environmental values where possible, particularly through co-operation between landholders and government.

Pathogens

Irrigation drainage may carry disease organisms such as Salmonella, Mycobacterium (Johnès Disease), Campylobacter (enteritis), Leptospira (Leptospirosis), Brucella (Bucellosis), and Shigella. There has been almost no investigation on the pathogens carried by irrigation drainage and how long they persist. Literature suggests that many pathogenic organisms may survive for up to 1 year in faecal material (Stevenson and Hughs, 1988; Mitscherlich and Marth, 1984). For example, *Mycobacterium paratuberculosis*, the organisms responsible for Johnès Disease (a form of enteritis that affects ruminants, including cattle) is capable of surviving in river water for up to 163 days, in pond water for up to 270 days, and in cattle faeces for up to 11 months (Chiodini et al., 1984). All the above pathogens are known to occur in cattle faeces (as do many other pathogenic bacteria and viruses).

The current and possible future occurrence of pathogens carried by irrigation drainage is an area that should be investigated further.

The use of piggery and dairy effluent to fertilise dairy pastures, along with the failure to restrict stock access to channels, waterways and drains raises the possibility of spread of diseases through ingestion of bacteria, viruses and internal parasites. There have been no studies performed linking proximity to drains, or access to drains with a higher incidence of the following diseases, however the spread of Johnès disease is very clearly via ingestion of feed, water or milk contaminated with the manure of infected animals, and thus it is possible that drains, with elevated temperatures and an abundance of nutrients could form a reservoir of infection for disease. It is suggested that further research be initiated to examine this issue.

Johnès Disease

Johnès Disease is caused by the bacterium *Mycobacterium paratuberculosis*. It cannot be cured and by the time the disease has been diagnosed, the wall of the intestine has become thickened and incapable of nutrient absorption. Initially the animal suffers diarrhoea and loss of condition, followed by death due to malnutrition.

Unfortunately this disease is common within the study area. It is passed from animal to animal via ingestion of the organism on grass or in water or milk contaminated by faeces, or to an unborn calf through the placenta. The disease usually affects calves, but due to its long incubation period, the clinical disease is not observed until maturity, if at all. The non-symptomatic carriers are capable at all times of spreading the infection, and for this reason calves should, as far as possible, be excluded from cows, effluent and paddocks fertilised with dairy shed effluent. *Mycobacterium paratuberculosis* is capable of surviving for three to four months on pasture and has been known, under favourable conditions, to survive for up to 12 months under moist conditions. The management guidelines to reduce the risk of stock contracting Johnès disease are well understood and these should be followed.

Leptospirosis

Leptospirosis is also a bacterial disease common to humans and animals. Again this disease is prevalent in the SIR and most herds show a positive reaction to blood tests for exposure to the disease. Leptospirosis causes influenza like symptoms in humans and can cause abortion and atypical mastitis in cattle and pigs. It is spread through exposure to urine droplets and is thus commonly acquired by dairy shed workers (Macalister Research Farm Co-operative, 1992).

Unlike Johnès disease, cattle (and also humans) can be vaccinated against Leptospirosis, which will prevent the clinical disease, and some vaccines will also reduce shedding of Lepto organisms in urine. Waste-water may also contain Leptospirosis organisms. If waste-water is disposed of onto paddocks, a rest period of two to five weeks is recommended before mature animals are grazed in order to allow time for disease carrying organisms to die out and for pasture palatability to improve. As with Johnès disease, the management principles for Leptospirosis are well understood and these should also be adopted by farmers.

Biocides

A number of biocides (pesticides, herbicides and fungicides) are used to control weed and pest infestations in the irrigation areas. For example, pesticides are sprayed in horticultural areas to protect crops against attack by insect pests, while herbicides are used to prevent excessive weed growth and thus maintain the design capacity of irrigation drains.
Organochlorine biocides such as DDT and dieldrin have a low solubility, degrade slowly and persist in the environment, often attached to soil organic matter. Organophosphate biocides generally have high solubility and degrade quickly (McKenzie-Smith et al., 1994; McKenzie-Smith, 1990). Transportation of biocide residues will therefore be affected by factors such as timing of application before irrigation or rainfall, the rates of application, rates of adsorption to and desorption from sediments, transportation of sediments and biocide degradation rates.

The toxicity of biocides on flora and flora may be either chronic or acute. Chronic toxicity results from prolonged exposure to biocides which leads to impairment of growth, behaviour and/or reproduction, and may possibly cause death. Biocides such as organochlorines have the potential to accumulate in the tissues of biota. Acute toxicity generally results in the death of biota in a relatively short period of time.

The transport of biocides therefore has the potential to affect plant and animal populations in receiving waters by acute toxicity, reduced growth or growth abnormalities, reduced species diversity and dominance, and reduction in available habitat. While there have been a number of studies of biocides in waters and sediments of the adjacent Ovens River basin (McKenzie-Smith et al., 1994; McKenzie-Smith, 1990), little information exists on these issues in the irrigation areas of the Goulburn\Broken Basin. The studies available suggest that biocide levels in irrigation drainage are low and usually below the level of detection of the analytical methods used (Tozer, 1994; State Water Laboratory, 1994).

In a study of pesticides at twenty four locations in the Shepparton Region (State Water Laboratory, 1994), organochlorine levels were all below the levels of detection. At one site (Murray Valley Drain 6) atrazine concentrations were found to be above recommended levels for drinking water on the first two of the eight sampling events conducted on a monthly basis. 2,4 D was recorded in measurable quantities at two sites (Murray Valley Drain 6 and the Deakin Main Drain) although still well below the recommended guidelines for pesticide levels in drinking water.

Overall, the levels of pesticides recorded in irrigation drainage in the Shepparton region are unlikely to represent a threat to water supplies, although more data needs to be gathered to confirm the results gathered to date.

Heavy Metals

Metals such as cadmium, lead, arsenic and mercury reach agricultural land via fertiliser and pesticide applications, disposal of sewage effluent and sludge by irrigation and aerial fallout from industrial and automotive transport sources (OCE, 1992). Similarly to biocides, the presence of high concentrations of heavy metals in irrigation drainage may result in chronic or acute toxicity effects on the biota in receiving waters.

As was the case with pesticides, little information is available on heavy metal levels in irrigation drains. Preliminary, "one off" tests in some irrigation drains by the EPA (Rooney, 1991, in prep.) found that metal concentrations were generally low and unlikely to lead to adverse biological effects. The only possible exception based on the EPA results was the aluminium levels in the Deakin Main Drain which was recorded as 23 mg/L (although this record was from a single water sample from one site on one occasion only). Although heavy metal concentrations in irrigation drainage is likely to be low (personal communication, W. Trewhella) some supplementary testing should be considered to confirm this.

Environmental Flows in Rivers

In the rivers, which are the receiving waters for irrigation drainage, the flow rate has a major impact on the change in nutrient concentration and the algal growth patterns. In general, the concentration of phosphorus and nitrogen in the river is much lower than irrigation drainage water. Therefore, as the flow rate in the river increases, the net increase in nutrient concentration from inflows of irrigation drainage is reduced. Flows are also known to be an important factor in the development of algal blooms and increasing the flow rate will interfere with algal growth patterns. In river systems, four major types of Environmental Flows have been identified and these are:

1. Sustaining Flows

These are generally low level flows provided to maintain aquatic biotic diversity. Compensation flows from storages or regulating structures were developed for maintaining water access for downstream riparian users. Sustaining flows are different from compensation flows in that they have been set with consideration of the ecological integrity of the river. Sustaining flows can be useful in establishing balanced ecological conditions which inhibit the development algal blooms.

2. Spring Flushing Flows

Spring Flushing Flows are specific flows released from storages which have characteristics that mimic elements of natural flow regimes (timing, hydrograph shape, etc.). These form cues for the breeding of fish and invertebrates and stimulate migration in certain fish species. These flows are developed to suit the individual conditions of a particular river system and its biota. However, these flows are most likely to occur prior to the peak algal season and are therefore unlikely to be useful in flushing algal blooms. If additional flows were to be released in late summer in an effort to flush algal blooms, the likely result would be ecological problems due to disturbances arising from aseasonal pulses of water.

3. Channel Forming Flows

These flows are usually high (bankfull) flows which are released to imitate the bankfull flows which naturally occurred yearly or every second year prior to regulation. They are important in maintaining bed and bank morphology of rivers, which are vital for aquatic habitat development and prevention of sand and/or silt build up, both of which degrade instream values. Well formed channels prevent catastrophic damage of riparian vegetation during floods.

4. Flooding Flows

Flooding flows are overbank flows which flood billabongs and wetlands along the river floodplain. These flows are often difficult to supply in highly regulated systems because of their large water volumes and legal problems (for water authorities) due to flooding of farmland and other private property. Opportunities exist to release flooding flows in "topping-up" natural downstream tributary flows which overcome both of the major problems with releasing flooding flows. Flooding flows are important in ecosystem and biotic diversity maintenance. These are key factors in natural controls of algal blooms and nutrient reduction via an established floodplain ecosystem.

Organic Pollution

Biological decomposition of the organic matter carried by irrigation drainage may lead to the depletion of oxygen in the sediments of irrigation drains, in irrigation drainage water and in receiving waters. Reduced oxygen conditions can result in the death of aquatic organisms such as fish and invertebrates. Lowered redox conditions also favours the mobilisation of sediment bound phosphorus into the water column, where it is available for uptake by aquatic plants and algae.

The likely change in Biological Oxygen Demand (BOD) resulting from extension of the drainage system in the study area and its effects on the biota in receiving waters should be considered. Potential hazards may then be identified and measures taken to protect sensitive receiving waters.

4. NUTRIENT management OPTIONS

• Framework For Nutrient Management

It has been clearly established that perennial pasture is the major source of nutrients that reach the River Murray from the irrigation areas within the Goulburn-Broken catchment, and fundamentally therefore must be a primary focus for nutrient management.

However, in determining management options, the farms themselves must not be considered in isolation. Integration of farm strategies with strategies focussed on the drains, extending to regional and catchment based management plans is essential. The major barrier to be overcome is the need for communication and information exchange across levels of government and between the agencies responsible for agriculture, environment, water allocation and pollution control. In addition, education and transfer of new technology to the farming community is vital to the success, and continued adoption of strategies for nutrient control. Such education needs to be based on issues at the local scale, as well as the catchment and Murray Darling Basin scale.

As the number of issues and activities that lead to nutrient export from farms, farm drains and the main drains of an irrigation catchment are complex and often difficult to define, there will be no easy way to establish the best mix of management options to reduce nutrient export from the irrigation areas. Finding the best mix of nutrient reduction options will therefore depend on a systems approach to defining the factors that result in nutrient export from an irrigated catchment, and not necessarily confined to nutrient generation. This will mean the evaluation of issues and practices from a farm to whole catchment scale.

• Available Nutrient Management Options

There are many ways in which nutrient export in irrigation drainage might be reduced, ranging from activities at the farm scale to a large scale catchment approach. A number of these options are listed in Table 9.1 (in no particular order). It should be remembered that this is by no means an exhaustive list and that many of the options will be dismissed out of hand as too costly or impossible to implement. It is quite likely that those charged with developing a nutrient reduction strategy for the various irrigation catchments will identify other opportunities that are specific to individual catchments and take advantage of local features and activities as those opportunities arise (eg. if an urban centre was to be sewered, would there be an opportunity to have some irrigation drainage diverted to a local sewage treatment plant). A brief description of the listed options is given below in Table 9.1.

Table 9.1: Generalised Available Nutrient Management Options

OPTION	DESCRIPTION
Change Irrigation Methods	Change current irrigation techniques from predominantly flood irrigation to another more directed method. The aim is to reduce flow, and hence nutrient load, leaving the farm and entering the drain. Improve irrigation scheduling with on farm storages to better match crop water requirements and hence reduce runoff, and therefore nutrient loads.
Constructed Wetlands and Vegetated Drains	Install wetlands (either on farm or adjacent to irrigation drains) and vegetated drains to serve as nutrient sinks
Containment of Dairy Shed waste on farms	Utilise storages for dairy shed wastewater for a source of nutrients to be used on the farm.
Dilution/Flushing Flows	Flush rivers with good quality water to increase flow and reduce nutrient concentrations and hence reduce the potential for algal growth. Flushes would be based on monitoring of critical indicators and risk assessment of an algal bloom.
Drain Design	On a site specific basis, utilise drain design features to reduce concentration of nutrients or increase diversion for re-use - eg drain dimensions to allow easier diversion for re-use, a series of swales along a drain to act as nutrient sinks, drain dimensions to increase retention time (hence related to level of service offered by drain).
Drain Diversion	Install storage dams on farms to divert drainage water for irrigation. Increase drain diversion without dams.
Drain Maintenance	Protect and manage existing drains to stop livestock access and prevent erosion. Hence reduce nutrient load to drains carried in sediment.
Economic Policies	Change water supply and pricing policies to conserve and re-use water and nutrients.
Fertiliser application Techniques	Look at the timing, type and method of application to maximise crop uptake of fertilisers, reducing concentration and load leaving the farm.
Installation of Riparian or Buffer Strips	Place vegetation as a barrier between tail water and farm drains, reducing the concentration and load in the tail water
Irrigated Woodlots	Use irrigation drainage to irrigate commercial tree plots, reducing flow and nutrient load in the drainage system.
Minimise Tail Water	Install fully automated irrigation systems, laser grade and improve pasture to ensure full utilisation of irrigation water. Hence reduce load leaving the farm.
Reduce Channel outfalls	Reduce channel outfalls to increase effectiveness of drain diversion. Reduction in nutrient load associated with reduced outfalls likely to be minor.
Re-use Systems	Installation of farm re-use systems to collect and re-use irrigation tailwater, thus minimising the nutrient enriched water discharged to irrigation drains
Sediment Management	Remove sediment from drains, re-use dams, and apply to farms as a source of nutrients. Remove sediment stockpiles from drain banks
Storage of Drainage Water, Changed Discharge Timing	Install large storage facilities to hold irrigation drainage to protect receiving waters during times of low flow - discharge at times of high flow. Hence reduce concentration in receiving waters at critical times.
Sub-surface drainage	Install sub-surface drainage to encourage greater recharge, and hence less runoff. Hence reduce flow and load entering drain (disposal of sub-surface drainage water, possibly at a lower concentration of TP and higher concentrations of TN and salinity, is required - eg evaporation, to drain)
Tile Drainage and re-use	Install tile drainage to reduce groundwater flow to drain and re-use for irrigation. Hence reduce concentration in drains (particularly for TN)
Transfer Drainage Water back to supply system	Transfer irrigation drainage to local irrigation supply systems, and possibly to other catchments or irrigation regions. Hence reduce flow, and therefore load in the drainage system.

Each of these options was given a subjective evaluation against their likely cost of implementation, likelihood of implementation, potential for nutrient reduction and feasibility. This subjective analysis helps to identify those options deserving of further, more detailed examination and other options that might be dismissed as fanciful or of doubtful use.

Table 9.2 includes a rating system for each option with respect to cost, nutrient reduction, likelihood of implementation, and feasibility. The rating system is as follows:

Nutrient Reduction , Likelihood of Implementation, Feasibility	********	**High (good),**	**to**	*** Low (bad)**
Cost	**$$$$**	**High (bad),**	**to**	**$ Low (good)**

The key focus of nutrient reduction is a reduction in loads that enter the River Murray. As highlighted earlier in Chapter 4, a significant level of uncertainty remains with respect to nutrient processing between the farm and the entry point to the River Murray. Hence there will be a degree of variability between nutrient reduction ability for each option depending on the benchmark conditions used eg. high nutrient load reduction leaving a farm will not necessarily result in a similar magnitude load reduction to the River Murray. A critical factor in this relationship is location, in particular distance from the River Murray. The closer to the river, the more likely a direct correlation would exist between local impact and Murray impact. A further issue in ranking options on the basis of total impact on the River Murray, is assessing the potential level of adoption. While an individual option may produce a significant nutrient load reduction, if it is not likely, or not possible, to be widely adopted, it will not be as effective with respect to loads to the river.

Hence, while the rankings in Table 9.2 are primarily related to River Murray impacts, the table also includes a nutrient reduction ranking with respect to the more local effects of the option.

Table 9.2 also includes issues for each option in support of the rankings in each category, and that may need to be addressed prior to implementation (eg. issues to be solved, costed, researched before the option can be accepted or implemented).

Table 9.2: Possible Options for Reducing Nutrients Carried by Irrigation Drainage

OPTION	ISSUES	COST	NUTRIENT REDUCTION Murray	local	LIKELIHOOD OF IMPLEMENTATION	FEASIBILITY
Change Irrigation methods	Cost of change very high - needs long term view Requires high value added crops Markets for products	$$$$	***	***	*	****
Changed Irrigation Scheduling	Timing of water supply On farm storages	$$$$	*	**	*	****
Constructed Wetlands	Land availability and cost Pumping effort Variable nutrient removal efficiency Maintenance Modify existing sites	$$$	**	**	**	***
Containment of Dairy Shed waste on farms	Water Quality (as per reuse systems) Shed/pond location Odour Disposal to drains Code of Practice Education/Management Areas of Concentrated Waste - Feed Pads, Night Sheds, Laneways	$$$	**	***	****	****
Dilution - Flushing flows in River Murray	Volume of good quality water required Potential waste of valuable resource	$$$$	*	n/a	*	**
Drain Design	Trade off with level of service Land availability Uncertainty with benefits associated with nutrient sinks	$$$	*	***	****	**
Drain diverters	Security of supply Equity Level of Adoption Financial incentives Water quality Location of diverters Management Required Education Programs required on benefits	$$	****	****	***	****
Drain Maintenance	Fencing from stock Erosion control	$$$	*	*	**	****
Economic Policies (pricing policies etc)	Equity Ability to absorb costs - cost share between landholders, region and State. Institutional arrangements	$$$	**	**	****	***
Fertiliser Application Techniques	Storing of Fertilisers (costs, facilities) Timing of applications Incorporation into soil or not? Equipment requirements Types of Fertilisers - Increased use of DAP means an increase in N. Fertigation vs Broadcasting (limited to N) Side dressing P application to Pastures	$	**	**	***	***

Table 9.2 Continued

OPTION	ISSUES	COST	NUTRIENT REDUCTION Murray	local	LIKELIHOOD OF IMPLEMENTATION	FEASIBILITY
Installation of Buffer Zones	Species to be established Weed/Pest Management Land Availability Effectiveness Management of strip Other Benefits - Windbreaks Education required on wider benefits Integration into WFP	$	*	**	**	**
Irrigated Woodlots	Land availability Nutrient loading rates Economic return Groundwater pollution	$$$	**	**	**	***
Minimising Tailwater	Automation Laser grading Whole farm planning Pasture improvement (Cost benefits need to be highlighted)	$	***	****	**	****
Reduce Channel outfalls	nutrients in irrigation water (minor) increase effect of drain diversion -reduce dilution	$	**	**	**	**
Re-Use Systems	Level of Adoption Water quality - Salinity, Nutrients, Algae, Biocides, Heavy Metals and pathogens Maintenance - Fouling Accessions to Groundwater Usage if installed Management Required Education Programs required on benefits Standards Established - Water Quality - Management/Use - Conditions for release to drains	$$	***	****	****	****
Sediment management	Cost Effectiveness	$$	**	**	**	****
Storage of drainage water	Discharge drainage water in winter Availability of land Water quality Likelihood of success	$$$$	*	*	*	**
Sub-surface drainage	Cost water quality - disposal high nitrates in horticulture	$$$$	*	*	*	**
Tile drainage and reuse	Drainage disposal Cost	$$$$	*	*	*	****
Transfer drainage water	Cost Suitable buyers Maintenance Water quality	$$$	***	***	**	****

- **Costs and Nutrient Load Reductions of Options**

For a number of options an assessment of the costs and the associated nutrient load reductions has been carried out. The evaluation is based on an estimation of cost per kg reduction in TP and TN.

The financial analysis is based on a farm perspective, rather than regional or Statewide. Where applicable, cost is estimated as net cost, taking account of benefits from re-use of nutrients back on the farm (ie. saving in fertiliser application), and re-use of water (from farm re-use systems or from the drains). Benefits from reduced nutrient loads to the River Murray, and hence potential algal blooms, have not been assessed.

The options in this analysis are restricted to those where meaningful estimates of both cost and nutrient load reductions could be obtained.

The costs of options have been estimated based on a 8% interest rate and a project life of 30 years. The costs include capital and ongoing annual maintenance and operational costs.

Appendix F outlines the unit rates and method of estimation of these costs. In summary, the key features of the basis of the quantification of costs and benefits are as follows:

- For **drain diversion with storages**, costs for 20 ML, 50 ML, and 100 ML storage capacities have been estimated to provide a means of comparative analysis across a likely range.

- Capital cost items for **drain diversion** include earthworks for the dam, farm channel construction, pump and pump structure, and diversion structure. Annual cost items include fuel, general repairs and pump replacement.

- For **wetlands**, a 20 ML/day inflow was assumed, with a requirement of 10 days retention time for 60% removal of nutrients. Hence a 200 ML storage was required. Capital costs include pumped diversion to an off-line wetland, land acquisition, earthworks, and return drain. The feasibility of on-line wetlands appears limited due to the low natural grades of the region. Annual costs include pump power, equipment maintenance, drain maintenance, and harvesting of vegetation. The option of not harvesting, with a reduction in nutrient removal from 60% to 40%, is included. Given the likely variation in site conditions, and hence costs, to achieve the above benefits, a scenario with 50% reduction in capital costs has also been included in the analysis.

- **Whole farm planning** with re-use has been based on a major development cost for a typical dairying property, including laser grading, pasture establishment, channels and drains, a re-use system, laneways and fences, and stocktroughs. Two scenarios for re-use have been adopted - 100% re-use and 50% re-use (regionally, some figure between these two is most likely).

- **Tailwater Management** incurs a loss of production of 80% for a 30 day period (2 irrigations) over 10% of the farm area. There is an associated saving of water and nutrients that remain on the farm.

- **Benefits** for the options include the value of water and fertiliser saved within the various options:

- water was valued at $18/ML (an approximate average across the Goulburn Murray Irrigation District). For re-use from the drain, water has been valued at 25% of normal irrigation water.
- Nitrogen has been valued at $0.40/kg
- Phosphorous has been valued at $2.00/kg

The benefits with respect to water saved have been restricted to the local scale, being the saving in costs of water delivered to the farm. However, it should be recognised that at a regional or State scale, it may be more appropriate to value the water saved in terms of the Gross Margin from potential alternate use of that water. For example, the water may be held in storage for use the following year, or used for new irrigation areas. As an indication of this benefit, Gross Margins for dairying would most likely be at least $100/ML. On this basis, the cost analyses for those options involving reuse of water are conservative, potentially underestimating benefits.

The further complexity of potential increased benefits to farmers for increased supply regularity has not been assessed. Greater security of supply generally has a greater value on a seasonal basis, potentially allowing more intensive irrigation development over a given area. This would be relevant to all options involving savings in use of normal irrigation water.

A further benefit associated with those options that reduce the volume of water reaching the River Murray is the river salinity benefit derived from the salt load in the water that does not reach the river. This benefit has also not been quantified.

The costs identified are for the full options, independent of the beneficiary. For example, in whole farm planning, no allowance has been made for the fact that plans are proceeding within the salinity plan, largely independent of any identified nutrient benefits.

Table 9.3 below shows the cost analysis. In deriving the cost/kg reductions, the net cost has been expressed as an equivalent annual cost for comparison with annual load reductions.

Table 9.3: Cost of nutrient reduction strategies (interest 8%, for drain diversion - storages filled 20 times/year)

Strategy	Costs			Benefits	Net cost	P Removal	Net Cost/P removed	N removal	Net Cost/N removed
	Capital Cost	O&M	EAV		$/yr	(kg/yr)	($/kg)	(kg/yr)	($/kg)
Wa: Wetlands - harvesting (40ha)	360,000	11,859	43,837	0	43,837	2,628	17	6,570	7
Wa: Wetlands - no harvesting	360,000	3,859	35,837	0	35,837	1,752	20	4,380	8
Wb: Wetlands - harvesting (40ha)	180,000	10,188	26,177	0	26,177	2,628	10	6,570	4
Wb: Wetlands - no harvesting	180,000	2,188	18,177	0	18,177	1,752	10	4,380	4
Dairy shed pondage systems (40 ha, 120 cows)	5,000	167	611	552	59	108	0	840	0
Whole farm planning including 100% reuse	92,000	3,320	11,492	2,035	9,457	218	43	400	24
Whole farm planning including 50% reuse	92,000	3,000	11,172	1,018	10,155	109	93	200	51
Reuse only (100%)	18,000	790	2,389	2,035	354	218	2	400	1
Reuse only (50%)	18,000	558	2,157	1,018	1,139	109	10	200	6
Tailwater Management	0	560	560	480	80	144	1	48	2
Drain diverter (20ML storage = 400ML)	34,000	2,296	5,316	6,120	-804	240	-3	600	-1
Drain diverter (50 ML storage =1000ML)	68,000	5,562	11,602	15,300	-3,698	600	-6	1,500	-2
Drain diverter (100 ML storage = 2000ML)	126,000	10,677	21,869	30,600	-8,731	1,200	-7	3,000	-3
Drain diveter no storage , 400 ML licence	13,000	2,296	3,451	6,120	-2,669	240	-11	600	-4

Wa: Wetland assuming “high” capital costs, **Wb**: equivalent wetland with respect to benefits, with “low” capital costs if site suitable
EAV: refers to equivalent annual value of capital and annual costs
O@M: refers to annual operation and maintenance costs

The estimated costs per unit P or N reduction in Table 9.3 show both positive and negative numbers. Positive indicates costs are greater than the identified benefits, and negatives indicate identified benefits are greater than costs. However, in itself, the sign is not important, as total benefits are not represented in the analysis - eg. reduction in potential algal blooms. Hence, positive numbers do not necessarily mean the option should not be adopted.

With respect to the net costs per unit nutrient reduction outlined in Table 9.3, options of drainage diversion using storages are the most favourable. These options attract significant benefits in terms of normal irrigation water saved, as well as reduced fertiliser costs through the re-use of nutrient rich water.

Water re-use dams are also ranked high, with relatively low capital and ongoing costs, and benefits from both water and fertiliser retained on the farm. The table highlights the importance of the performance of the reuse system, where a drop to only 50% capture of water leaving the farm, instead of 100%, results in a significant shift from a net benefit to a net cost.

Dairy Shed pondage systems shows low costs. However, the total impact of this option on the River Murray is thought to be small given that it is not a significant source in comparison to nutrients in tailwater from agricultural sources.

Tailwater management also shows relatively low net costs, given that the only costs incurred is an annual loss in production.

Table 9.3 also shows whole farm plans to be very costly with respect to nutrient benefits. However, as stated previously, this is not a complete cost benefit analysis, and it can be assumed whole farm plans will proceed without recognition of nutrient benefits due to the high salinity benefits. The table does highlight the increased benefits of whole farm plans that incorporate re-use systems over and above those already identified within the salinity plan (ie. water table control and productivity benefits).

Table 9.3 also shows relatively high net costs for wetlands. Hence, as a single solution to nutrient control, such wetlands may not be attractive. However, this does not preclude looking for site specific opportunities to incorporate wetlands at possibly lower costs into an overall systems approach that includes other options to reduce the dependency of the wetland for nutrient management. The net cost per unit nutrient reduction for wetlands that are harvested are lower than for those without harvesting. However, there is less certainty with respect to the increased nutrient reductions from harvesting of vegetation, giving less reliability to this result. This uncertainty is partly driven by the fact that a large proportion of the biomass in the plant is underground, making it difficult to quantify the long term nutrient removal through harvesting.

The nutrient reductions identified in Table 9.3 (and following tables) reflect the localised benefits - eg. Phosphorous (P) removal for a whole farm plan is that volume of phosphorous that would no longer enter the drain, and for a drain diversion system, it is the volume removed from the drain. This is an important point in undertaking any comparison of benefits to the River Murray. As discussed earlier, issues of distance up the drainage system, the type of drain construction, the existence of diverters, and other catchment features such as wetlands and depressions will all affect the final benefits with respect to the load reductions to the river. A simplistic example is a farm reuse system located in the upper reaches of a catchment that would generate less benefit to the river than one located much closer to the outlet to the receiving waters, based on an assumption of nutrient losses along a drain.

This highlights the need for a systems approach for catchments that integrates nutrient management solutions, as well as incorporating other catchment issues, particularly salinity.

The figures in Table 9.2 must also be assessed in the context of overall level of adoption, and hence total load reduction, that could be achieved within any one option. For example, while dairy shed pondage systems may be more favourable than wetlands, the total load reduction across a catchment may not be significant. Such considerations do not preclude implementation of any option, but do need to be understood within the broader catchment framework and goals.

There are many assumptions within the analyses used to derive the figures in Table 9.3, and a sensitivity analysis has been used to test these assumptions. The sensitivity analysis is based on a number of approaches:

- vary the interest rate

- for drain diversion, vary the configurations of storage size and volume diverted

- vary key inputs of capital cost, annual cost, P removal, N removal, and the value of water each by 20%. These variations lump a number of processes eg. a 20% reduction in P removed may result from a concentration change, or a irrigation runoff change.

Table 9.4 shows the sensitivity of the analysis to interest rates of 4% and 10%. In general, there are no major shifts in the results arising from the different interest rates. As the rate increases, the cost of capital increases, increasing the net costs. Options with low capital costs are less affected by this parameter (eg. diverters without storages).

The benefits of drain diversion using storages still outweigh the costs under the various interest rates, with a reduction in net benefit for higher rates reflecting the higher annual cost of capital.

Table 9.4: Sensitivity of Net Cost of nutrient reduction strategies to interest rates of 8%, 4% and 10%

Strategy	8%		4%		%10	
	Net Cost/P removed ($/kg)	Net Cost/N removed ($/kg)	Net Cost/P removed ($/kg)	Net Cost/N removed ($/kg)	Net Cost/P removed ($/kg)	Net Cost/N removed ($/kg)
Wa: Wetlands - harvesting (40ha)	17	7	13	5	19	8
Wa: Wetlands - no harvesting	20	8	15	6	24	10
Wb: Wetlands - harvesting (40ha)	10	4	8	3	11	4
Wb: Wetlands - no harvesting	10	4	7	3	12	5
Dairy shed pondage systems (40 ha, 120 cows)	0	0	0	0	0	0
Whole farm planning including 100% reuse	43	24	30	17	38	27
Whole farm planning including 50% reuse	93	51	67	37	84	60
Reuse only (100%)	2	1	-1	0	2	1
Reuse only (50%)	10	6	6	3	9	7
Tailwater Management	1	2	-1	-0.1	1	0
Drain diverter (20ML storage = 400ML)	-3	-1	-8	-3	-1	0
Drain diverter (50 ML storage =1000ML)	-6	-2	-9	-4	-4	-2
Drain diverter (100 ML storage = 2000ML)	-7	-3	-10	-4	-6	-2
Drain diveter no storage , 400 ML licence	-11	-4	-13	-5	-10	-4

Wa: Wetland assuming “high” capital costs,
Wb: equivalent wetland with respect to benefits, with “low” capital costs if site conditions are suitable

For the option of drain diversion, with farm storages, the assumptions of the size and number of times a storage would be filled obviously affect costs and benefits. These assumptions have been tested further, and the results are shown in Tables 9.5 and 9.6, and Figure 9.1.

Table 9.5 includes 20 ML, 50 ML, and 100 ML storages filled 20 times per year. Table 9.6 includes the same size storages, but filled only 5 times per year.

Figure 9.1 plots the cost/kg of nutrient load reduction for various combinations of storage size and filling multiple eg 20, 50 and 100 ML storages filled either 5, 10, or 20 times each year. The variations shown within the tables and Figure 9.1 demonstrate the following:

- as the size of the storage increases for a given number of fills per year, effectively increasing the volume diverted, the net costs per load reduction reduce.

- as more water is diverted for a given size storage, the net costs per load reduction reduce eg. for a 20 ML storages, Figure 9.1 indicates benefits would exceed costs for close to 300 ML/year diverted (half way between the 10 multiple (200 ML) and the 20 multiple (400 ML)).

- big storages filled infrequently are significantly disadvantaged by reduced benefits for high capital costs - ie. capital costs outweigh running costs.

In further assessing the option of drain diversion, consideration needs to be given to practical limitations on the size of the storage, and hence the potential for any one site to use a given volume within any one year. The concept of adjacent farms sharing the costs and benefits of a storage has been mentioned earlier in this section of the report. On the basis of a typical dairy farm with 40 ha of perennial pasture, using 400 ML/year, the water right would be approximately 50% of the total used, indicating 200 ML of drainage water could be used. Hence a 400 ML storage could be suitable for adjoining farms.

Opportunities may exist for very large diverters, say 2,000 ML/year, using a 100 ML storage. However, the analysis shows that for a typical situation, diversion into a 20 ML storage 20 times per year may be the most practical and economically viable solution. If sharing a storage is not an option, the analysis shows a smaller 10 ML storage filled 20 times is a more economically favourable solution than a 20 ML storage filled 10 times.

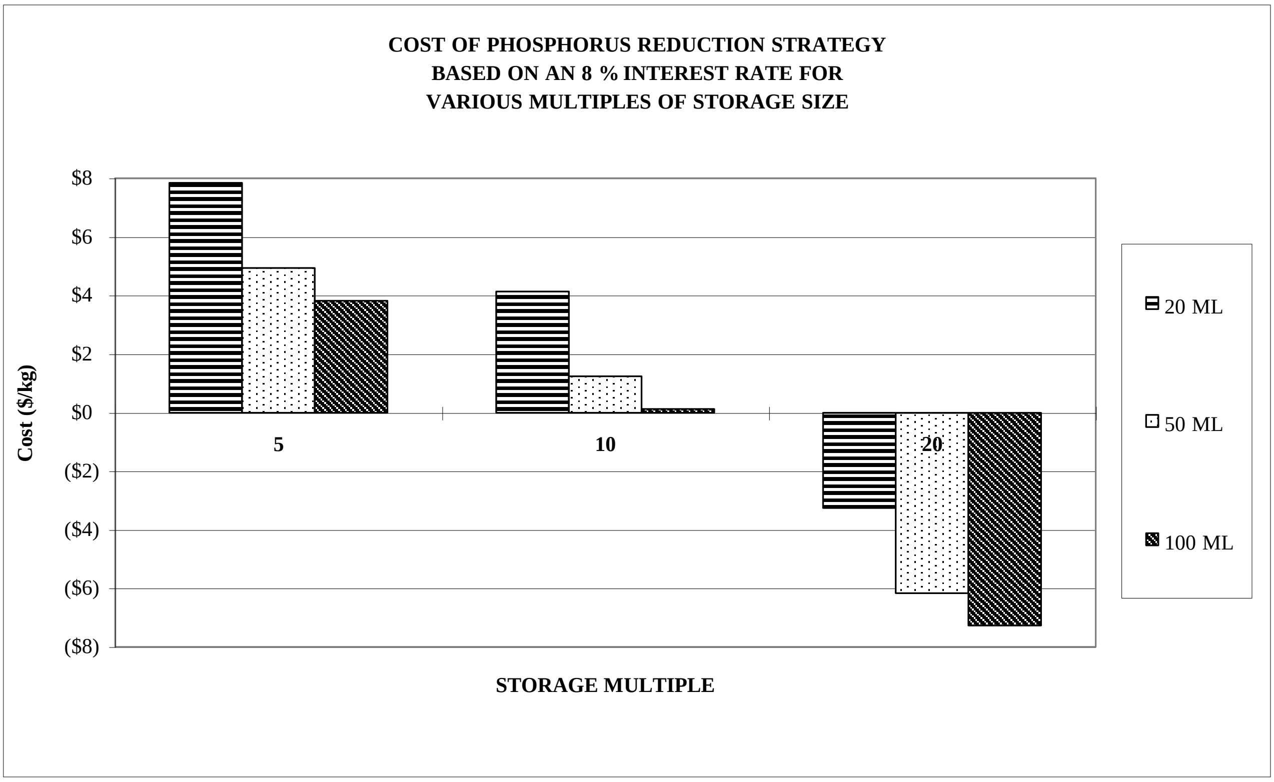
Table 9.5: Cost of nutrient reduction strategies (interest 8%, storage filled 10 times).

Strategy	Costs			Benefits	Net cost	P removal	Unit P Cost	N removal	Unit N Cost
	Capital Cost	O&M	EAV			(kg/yr)	($/kg)	(kg/yr)	($/kg)
Drain diverter (20ML storage= 200ML)	34,000	1,393	4,413	3,420	993	240	4	600	2
Drain diverter (50 ML storage= 500ML)	68,000	3,252	9,292	8,550	742	600	1	1,500	0
Drain diverter (100 ML storage= 1000ML)	126,000	6,057	17,249	17,100	149	1,200	0	3,000	0

Table 9.6: Cost of nutrient reduction strategies (interest 8%, storages filled 5 times)

Strategy	Costs			Benefits	Net cost	P removal	Unit P Cost	N removal	Unit N Cost
	Capital Cost	O&M	EAV			(kg/yr)	($/kg)	(kg/yr)	($/kg)
Drain diverter (20ML storage = 100ML)	34,000	930	3,951	2,070	1,881	240	8	600	3
Drain diverter (50 ML storage =250ML)	68,000	2,097	8,137	5,175	2,962	600	5	1,500	2
Drain diverter (100 ML storage = 500ML)	126,000	3,747	14,939	10,350	4,589	1,200	4	3,000	2

Figure 9.1: Sensitivity of Net Cost of Drain Diversion to Size of Storage and Volume Diverted - Phosphorous and Nitrogen



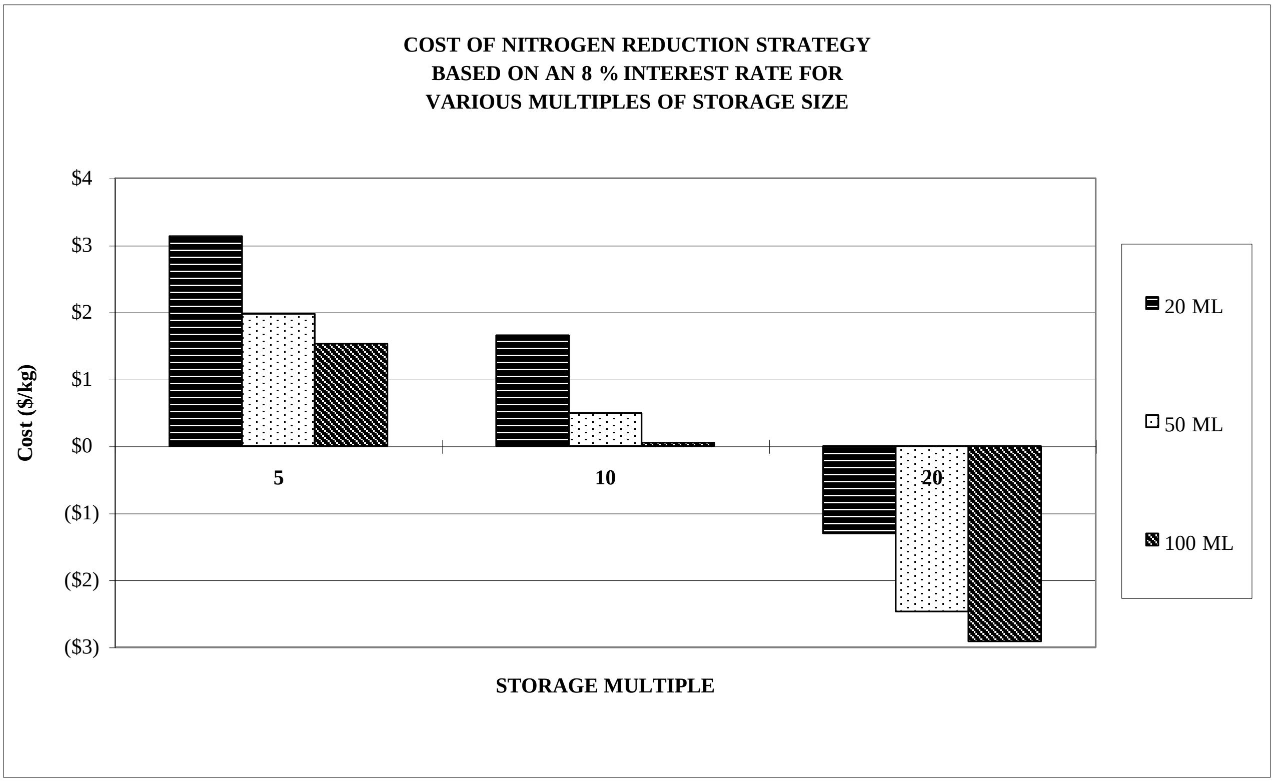


Table 9.7 summarises the results from the sensitivity testing of the results to a general 20% change in various inputs. Generally, cost per unit P reduction has been used to demonstrate the sensitivity, given the similarities in P and N shown in Table 9.3. However, the cost per unit N reduction has been calculated for the two cases involving the volume of N.

Drain Diversion remains a favourable option, although it is very sensitive to the value of water. Tailwater Management shows particular sensitivity to the annual operating costs, being the lost agricultural productivity. Restricting the lost productivity to an area less than 10% of the irrigated area shifts a net cost to a net benefit. However, even with automated watering shut off systems, it could be assumed that greater farmer input is required to control the watering in a way to minimise the lost productivity.

Table 9.7: Option Sensitivity analysis

Strategy	Net Cost/P removed ($/kg)									Net Cost/N removed ($/kg)		
	Baseline	Capital Cost		O&M Cost		P removal	N removal	P&N removal	water value	Baseline	N removal	P&N removal
		20% red'n	20% inc	20% red'n	20% inc	20% red	20% red	20% red'n	20% red		20% red	20% red'n
Wetlands - harvesting (40ha)	17	14	19	16	18	21	17	21	17	7	8	8
Wetlands - no harvesting	20	17	24	20	21	26	20	26	20	8	10	10
Wetlands - harvesting (40ha)	10	9	11	9	11	12	10	12	10	4	5	5
Wetlands - no harvesting	10	9	12	10	11	13	10	13	10	4	5	5
Dairy shed pondage systems (40 ha, 120 cows)	0.5	-0.3	1.3	0.2	0.8	1.2	1.2	2.0	0.5	0.1	0.2	0.3
Whole farm planning including 100% reuse	43	36	51	40	46	55	44	55	45	24	30	30
Whole farm planning including 50% reuse	93	78	108	88	99	117	93	117	95	51	64	64
Reuse only (100%)	2	0.2	3.1	0.9	2.4	2.5	1.2	2.7	2.9	1	1.2	1.5
Reuse only (50%)	10	8	13	9	12	14	7	14	12	6	7.2	7.5
Tailwater Management after fertiliser applications	0.6	0.6	0.6	0.2	1.3	1.2	0.6	1.2	0.8	1.7	2.2	4
Drain diverter (20ML storage = 400ML)	-3	-6	-0.7	-5	-1.3	-4	-4	-3	-1.2	-1.3	-1.5	-1.3
Drain diverter (50 ML storage =1000ML)	-6	-8	-4	-8	-4	-7	-6	-7	-2	-2	-3	-3
Drain diverter (100 ML storage = 2000ML)	-7	-9	-5	-9	-5	-9	-7	-8	-3	-3	-4	-3
Drain diverter no storage , 400 ML licence	-11	-12	-10	-13	-9	-13	-11	-13	-7	-4	-5	-5

- **Preferred Package of Nutrient Reduction Options**

The nutrient reduction options can be considered in two categories:

- **Reduce the concentration of nutrients** in the drains, and hence the loads to the River Murray.

- **Reduce the flow** in the drains, and hence the loads to the River Murray.

A range of the above options have been considered for further evaluation of their usefulness and suitability to conditions in the study area.

The preferred options described here represent opportunities for the control of nutrient discharge in irrigation drainage at the farm, irrigation drain and drainage catchment scale. Again it must be emphasised that this set of options is not exhaustive, nor meant to preclude other options as they arise.

In the short term, a preferred package of options should be directed towards reducing the summer concentration in the River Murray and consequently the loads in the drainage system during the irrigation season. This strategy will target the local algal blooms that coincide with the low summer flows in the River Murray.

In the longer term, these preferred options must also reduce the total annual loads being exported to the River Murray, in effect encompassing nutrient issues for the lower reaches of the Murray. While the nutrient dynamics and transport along the river are not well understood, a process of storage of nutrients within the river system is highly likely, linking nutrient loads generated in times of high flows to the more critical low flow periods.

In the preferred package, a number of BMP's have been recommended despite the fact they their ability to reduce nutrient levels have not been quantified. Given the balance of probabilities it is felt that these BMP's are worth implementing particularly given their additional benefits to salinity, productivity, profitability and the farmers management lifestyle. These benefits may also overcome barriers to adoption.

(i) Farm Scale Options

In general, farm scale options should be focussed on:

- perennial pasture, identified as the major source of nutrient loads reaching the River Murray

- farms with high concentrations of animals

- the lower catchment areas, where a more direct relationship is likely between reduced nutrient load from the farm and reduced nutrient load to the River.

Within the above framework, the options that are considered to have particular merit in reducing nutrient export in irrigation drainage are generally related to developing best management practices. These options include:

- automation of irrigation to minimise the water leaving irrigation bays,

- tailwater management after fertiliser applications,
- installation of re-use dams to reduce tail water leaving the farm,
- adoption of improved irrigation scheduling to increase water use efficiency,
- adoption of appropriate timing of fertiliser applications to minimise concentration of water leaving the farm,
- installation of buffer strips between the bay and the drain.

It is unlikely that these measures will be implemented for the sake of nutrient reduction only. It is essential therefore that education programs are developed to explain that options for reducing nutrients leaving farms may also have the benefit of better control of farm activities. For example, the installation of automation for irrigation will free the farmer to pursue other activities as well as reducing the potential for water to reach the drains. However, these benefits will only emerge if systems such as automation and re-use dams are properly utilised and managed.

In particular, automation of watering will require both a high level of reliability, and a commitment to maintenance by the users. If this is not the case, the potential for tailwater flows to drains could increase significantly, and at the same time widespread adoption would most likely be inhibited through lack of community confidence.

It will also be necessary to indicate that one measure on its own is unlikely to achieve either the farm management or nutrient reduction benefits that might be achieved when all factors are considered together. For example, laser grading of paddocks without installing automation or re-use systems may lead to increased runoff from irrigation bays due to increased velocity of water. Wetlands, buffer strips or vegetated drains are only likely to work efficiently if they are part of an overall management package. Relying on such systems in isolation runs the risk of the wetlands quickly becoming overloaded and serving as nutrient sources rather than nutrient sinks. Wetlands and buffer strips are likely to be most effective when nutrients are attached to particulate matter. Unfortunately, significant portions of the nutrients present in irrigation drainage is in a soluble form that is less readily retained by wetlands or buffer strips.

(ii) Irrigation Drain Scale Options

The nutrient reduction options most likely to succeed at this scale include:

- drainage diversion, with particular emphasis on high volume diverters possibly utilising storages,
- drain design where local conditions are favourable,
- the possible installation of constructed wetlands after careful consideration of their location and inclusion only as part of a drain management strategy.

Pumping of water from the irrigation drains to large storage dams strategically located along drainage lines has the potential to significantly reduce the volume of water, salt and nutrients discharged to rivers and streams. The costs of siting the large storage dams required for such an option could be offset if two or more farms shared the construction costs and the water. Linking large diversion licenses to landholders with access to wheel water is one means of increasing regularity of supply through the low flow seasons. The potential success of this option will require resolution of issues of security of water supply, long term water quality, equity, and community confidence.

Even given the limited application of wetlands for treating irrigation drainage, strategically placed constructed wetlands may be of use as part of a drain management strategy. For example, if a wastewater containing nutrients is used for irrigation as part of a wastewater treatment process prior to discharge to irrigation drain, then the installation of a constructed wetland may serve as a polishing process for the wastewater prior to discharge.

(iii) Drainage Catchment Scale Options

The main options to consider at the drainage catchment scale are most likely to focus on:

- economic instruments,
- institutional arrangements and,
- education.

Economic factors might include the following:

- decreasing the costs of drainage water for large scale diversions,
- decreasing the length of drain diversion license agreements to increase drain management flexibility,
- linking the price of irrigation water to water quality in the drains,
- financial penalties to eliminate inappropriate farm and drainage practices, including removal of low utilisation licenses.
- establishing nutrient targets for individual catchments and methods for ensuring these targets are met within established time frames. Consider penalties if targets are not met.
- appropriate cost sharing between the landholders, region and State to encourage adoption and utilisation of works and measures.

Institutional arrangements should be investigated to ensure that a systems approach is used to evaluate the opportunities for nutrient reductions at all scales and identifying who is responsible for ensuring that any water quality targets are met. In particular, coordination is required across different catchment management disciplines, in particular incorporation of salinity, drainage and environmental management.

Ensuring that all key stakeholders are educated about the necessity for nutrient reductions in irrigation drainage and that the methods to achieve this have economic and farm management benefits will be a vital part of any strategy. Methods of transferring information between resource mangers and water users will also require further evaluation.

The management associated with the above catchment scale issues may reside with:

- the Goulburn Catchment and Land Protection Board
- SPAC
- Goulburn-Murray Water

Within all of the above options there can be considered to exist three tiers of options based on a level of certainty to offer the most cost effective benefit to the River Murray (Tier 1 - greatest level of certainty).

Tier 1

drain diversion
education programs
economic policies: financial and cost sharing
water re-use
tailwater minimisation : automated watering, water use efficiency, targeting fertiliser applications
dairy shed waste containment
control of point sources
transfer of drainage water into the supply system

Tier 2

wetlands: constructed or modified
local drain design
buffer strips

Tier 3

reduce channel outfalls
irrigated woodlots
sediment management from drains

While this broad division is based on level of confidence in the benefits, and hence contributes to prioritisation of options, actual selection of options will require consideration of other factors, including:

- trade off between cost, benefit and risk,
- level of adoption,
- local and regional integration with other catchment issues.

Examples of elements of a successful strategy can be found in the Bamawn system, downstream of Dargan's Bridge:

- There are several large diverters with licenses of the order of 2,000 ML in total, and a co-operative system of 5 landholders exists, increasing the regularity of demand.

- A weir exists in the drain to store water, and one property has two water harvesting dams of 240 ML and 80 ML capacity.

- A number of wetland systems exist - Murphy's Swamp and Richardson's Lagoon.

- **Implementation of Preferred Package of Options**

It is recognised that this package of options is not site or catchment specific, but a broad overview to a systems approach. Implementation of the package will require a prescription to assist those charged with catchment and resource management. The key features of such a prescription are outlined below.

Education Program

Information Packs

This Irrigation Drainage Issues Paper should be used to develop information packs at a sub-catchment (irrigation drainage catchment) scale.

Local groups will require: land use information, nutrient sources, salinity plan implementation actions, and an idea of how their sub-catchment fits into the broader Goulburn Broken Catchment regarding nutrients. In addition they will have to develop an understanding of the importance of local actions, and how they, as landowners, can implement and affect strategies.

Workshops & Meetings

The information packs would be a central part of a series of drainage catchment scale meetings or workshops which aim to educate and share information amongst local practitioners and agency staff.

Initiate the Implementation Process

The implementation process involving information pack development and workshops should be initiated as a test of its effectiveness. The success would be gauged via the ability to educate and demonstrate the effectiveness of these actions to local and other drainage catchment groups (eg. Landcare groups or Collectives of Landcare Groups). This process would allow the assessment of time and resources needed to develop information packs and the degree of detail required in order to educate landholders in adopting BMP’s and nutrient reduction initiatives.

Two sub-catchments in which the WQWG group should initiate this model are: the Deakin Main Drain and the Murray Valley Drain 6 catchments. The selection of these sub-catchments is based on both load and concentration of nutrients. Information derived will serve as an important model to demonstrate the benefits which can be achieved in areas where a nutrient reduction strategy would have greatest impact.

At the same time, the adoption of options should be encouraged across the whole study area, using both this issues paper and the any outcomes from the initial sub-catchments as a general framework.

Priority List

Develop a list of catchments in terms of: their loads and concentration of nutrients, impact of projected reductions as a percentage of the total Goulburn and Broken load, and likelihood of local groups/landholders to take action. For example, catchments could be ranked according to criteria developed for a decision support system used to assess nutrient export from the Goulburn/Broken catchment (O'Shanassy, 1995). As stated above, the Deakin Main Drain and the Murray Valley Drain 6 catchments are considered high priority based on the monitored data.

Develop a strong link between Whole Farm Plans and nutrient reduction options

Re-use dams are an essential part of whole farm plans and should be encouraged for several reasons:

- Nutrient management
- Water and Drain Management
- Other Initiatives (eg. Salinity Program)
- Effluent Management (dairy shed)

Other BMP's should be incorporated into the Farm plan process. While the nutrient benefits of some BMP's are not well defined, timely research in conjunction with an extensive eduction program will help to increase the adoption rate of Farm Plans.

Implementation of Reuse/Drain Diversion Systems

The diversion of water from irrigation drains will clearly reduce the nutrient load discharged to rivers and streams. However, there are complexities involved in the implementation of this option which have been outlined earlier in Section 6.6. These are centred around issues of security of water supply, water quality (eg. salinity), equity, and landholder confidence.

The approach outlined in Section 6.6 involved the following processes:

Quantify drainage water volumes and the reliability and distribution of flows. Use a combination of mapping of sources and sinks of water, monitoring, and system analysis possibly including modelling.

Develop an understanding of landholder attitudes. Consider the need for clear economic benefits to farmers, and the link between security of supply and potential for adoption.

Evaluate feasibility of options. Consider environmental impacts, pumping and gravity options, and soil types for re-use dams.

Review water supply pricing and policy. Target maximising drain diversion in typical years and removal of underutilised commitments. Consider use of meters, shorter license agreements, cost sharing linked to security of supply, and cost penalties for underutilisation.

Implementation of other elements of the Package of Options

Identify and take opportunities for site specific solutions/nutrient reduction activities (eg. Engineering options, BMP's, Wetland Construction, Installation of buffer strips). These would be largely driven by local issues, cost, local interest, community and environmental benefits.

The rationale for each action would be local nutrient reduction, demonstration of wider applicability and effectiveness. This would generate local community confidence in the role of these actions in a nutrient reduction strategy.

Initiate Monitoring and Investigations to fill significant knowledge gaps.

The primary knowledge gaps which will impede the implementation of a nutrient reduction strategy are defined in Section 11. Appropriate monitoring and investigations need to be initiated to provide the required data, quantify processes, provide input to analyses, and develop confidence in strategies.

However, it needs to be recognised that definitive resolution of a number of issues may not be possible in the immediate future, and some trade off between the quality of information and the confidence in option effectiveness will most likely be required for satisfactory implementation progress.

Develop an accounting system to support effectiveness monitoring and potential Victorian or Murray Darling Basin compliance requirements.

This will include:

- Development of a network of sites for monitoring nutrients. A significant level of compliance monitoring of outfalls to the River Murray exists. However, the monitoring network needs to be based on local, regional as well as Basin wide scales. Further discussion on monitoring requirements is included in Section 10.

- Measurement of the level of adoption of options needs to be recorded. Data is required on the location, the type of action, the process involved (eg. change in loads, concentrations, scale of works). An effective information storage and retrieval system is required.

- Performance of trend analyses on the data on a routine basis, based on the requirements for meaningful statistical inference.

Community Feedback

Regular Reporting of achievements is essential. Reports need to be centred around implementation actions, monitoring, and related research and investigation. Reports should take the form of:

- Newsletters of actions in the Goulburn-Broken catchments.

- Reports - scientific, technical and summary reports for distribution.
- Media reporting - electronic and print media releases.
- Videos - showing demonstration projects and field days.
- Education programs - link with education and community monitoring programs.

5. MONITORING AND RELATED RESEARCH PROGRAMS

Given the large land area, diversity of land uses and activities, widespread population and number of water bodies, monitoring of water quality in the Goulburn and Broken catchments is widespread and conducted for various reasons. For example, there are many monitoring sites that have been established for determining long term trends in water quality (eg. as part of the Victorian Water Quality Monitoring program), while other sites and locations undergo shorter more intense investigations for specific purposes. Monitoring in the catchments includes measuring physico-chemical parameters (eg. pH, turbidity, nutrients, salinity), and biological indices (eg. macroinvertebrates or algae in water bodies). The existing monitoring programs with sites in the Goulburn-Broken Basin include:

Victorian Water Quality Monitoring Network: Rivers and Streams
Victorian Water Quality Monitoring Network: Wetlands
Murray Darling Basin Commission Water Quality Monitoring Program
Environment Protection Authority Fixed Sites Network
Major Storages Operational Monitoring Program
Biological Monitoring
Lake Mokoan Restoration Project
Lake Nagambie Water Quality Study
Nutrients in Irrigation Drains.

A summary of these monitoring programs was prepared for by Water Ecoscience for Goulburn Murray Water (O'Shanassy, 1994, draft unpublished). Readers should refer to this draft report for information on what is monitored at these sites and at what frequency.

As the above programs were mostly established for reasons other than directly monitoring the water quality in irrigation drains, some additional monitoring (or expansion of existing programs) will be necessary if the factors affecting nutrient levels in drains and the effectiveness of future nutrient reduction strategies are to be assessed.

Examination of the location of monitoring sites (Figure 10.1) indicates that a large section of the Goulburn River (the mid Goulburn between Eildon to Nagambie) where little water quality information is now collected. Given that there are many factors (eg. discharges from intensive animal industries, groundwater inputs, urban runoff) that will contribute nutrients to the Goulburn River and ultimately to irrigation water, additional long term monitoring along the mid Goulburn River will help to identify how changes in upstream land use or catchment management practices are likely to affect the quality of irrigation supply water. It is suggested that the feasibility of monitoring the Goulburn River between Seymour and the township of Nagambie be investigated for this purpose.

While there is a program of monitoring nutrients leaving the major irrigation drainage catchments, monitoring of drainage leaving catchments such as that of Murray Valley Drain Number 3 (Figure 10.2) and the irrigation areas near Shepparton and along the Broken Creek would yield valuable information on the nutrient contributions from these catchments. While the monitoring of water quality at McCoy's Bridge on the Goulburn River is well established, there is no monitoring of the contribution of nutrients discharged from the Wyuna Main Drain and Warrigul Creek, which discharge to the Goulburn River downstream of McCoy's Bridge. It is recommended that short to medium term monitoring programs (1 to 3 years) be established to investigate the nutrient loads and concentrations leaving Murray Valley Drain 3 and the Wyuna Main Drain and Warrigul Creek.

Similar short to medium term studies of the nutrient contributions from the irrigation areas surrounding Shepparton would help to delimit the significance of drainage from horticultural areas as opposed to the dairying areas.

Given that the Deakin drainage system is to be extended through the Mosquito Depression towards Tatura over the next decade, it is recommended that a monitoring site be established to assess the changes to water quality that might result. A stream gauging station exists on the Mosquito Main Drain (Mosquito Depression Main Drain at Currs Rd) that could easily be upgraded for this purpose. Similar extension of the existing drainage system through the Timmering Woolwash Depression would also warrant long term monitoring. The establishment of such monitoring sites will be valuable in assessing the success of both the Salinity Management Plan and future nutrient management strategies.

Figure 10.1: Location of existing water quality monitoring sites in the Goulburn River catchment

Figure 10.2: Location of existing water quality monitoring sites in the Broken River catchment.

6. Knowledge Gaps and Impediments to Implementation

There are a number of significant knowledge gaps in our understanding of how nutrients behave in the irrigation drainage system in the study area. These include:

- Nutrient cycling on farms. For example, research has or is in the process of quantifying nutrient levels in tailwater runoff from individual irrigation bays for a range of different land uses. At this stage however, no research has been undertaken on the fate of nutrients in the farm drainage system before the tailwater leaves the farm.

- The benefits of BMP's on farms. Based on the balance of probability many BMP's are worth doing at any rate. However, without quantification it is often difficult to rank different options and educate farmers about their merits.

- Farmers attitudes to the different BMP's.

- Nutrient cycling in the drainage system. Nutrient levels in the drainage system show a decrease in concentration downstream along the drainage system. At present, it is not clear whether nutrient levels are falling because of dilution effects and/or nutrients are being removed from the drainage water. If nutrients are being lost it is not clear how much is being taken up, what the relationships might be and the longer term fate or these nutrients ie. remobilisation or permanently removed from the system.

- An accurate description of Landuse for the irrigation areas in the SIR that is easily manipulated to suit the purpose and boundaries of the study.

- Pathogens, pesticides and heavy metal levels in irrigation drainage.

- Quantification of impacts on ecological processes.

- The methodology for setting N and/or P targets (annual, monthly, daily) for irrigated land.

- The impacts of nutrients on re-use dams and drains and the nutrient and algal management options for these systems.

- The cost sharing, funding and institutional arrangements for nutrient reduction options.

- The short and long term ability of engineered systems and biological options eg. swales, wetlands and weedy drains for nutrient stripping.

- The interrelationships of the chemical dynamics eg. nutrients, heavy metals etc.

7. RECOMMENDATIONS FOR FURTHER WORK

The first priority for further work is to address the knowledge gaps identified in Section 10. The approach will be to adopt a combination of field work, monitoring and assessment which in a broad sense will need to include:

- Integrate the findings from this study with parallel studies on nutrients from dryland areas, sewage treatment plants, urban areas and intensive animal industries.
- Undertake true economic analysis of options at a regional scale, incorporating other beneficiaries and costs (eg. salinity, cost of algal blooms, value of water saved)
- nutrient cycling and dynamics both on farms and in the irrigation drainage system
- establish additional monitoring sites to measure the impact of extending the drainage system and effectiveness monitoring of future nutrient strategies
- site specific monitoring along drainage, especially from the end of the farm and along the first several hundred metres of drain
- co-ordination of research, allowing for the role of the newly established Catchment and Land Protection Board and local committees
- legislative approaches within preferred packages of options
- Research into quantifying the effects of Management Practices on farms on the nutrient concentration and volume of run-off requires investigation. Economic and social ramifications of BMP’s also require study
- Investigate the effects of sedimentation in the drains and the impact of sediment mobilisation in high flow situations
- Examine the potential of en-route wetlands as potential treatment options for reducing nutrient concentration in drainage water
- Land use information for the area is also unreliable and further development of GIS or a similar system would improve invaluable for studies utilising land use information

Information generated through the research and development of any of the various strategies and studies both current and future, should be broadly circulated to enhance co-ordination of future research and educate the target audience, namely the farming community.

8. REFERENCES

Agriculture Victoria, (1994). Environmentally sustainable fertiliser use through improved flood irrigation management techniques. First Milestone Report. Institute for Sustainable Irrigated Agriculture, Tatura. p. 6.

Austin, N.R., Prendergast, J.B. and Collins, M.D. (1994). Reducing fertiliser nutrient losses through improving flood irrigation management. Water Down Under '94. Proc. Int. Conf. IEAust, Adelaide Nov. 1994 Vol 1, pp. 543-546.

ANZECC, (1992). Australian Water Quality Guidelines for Fresh and Marine Waters. Australian and New Zealand Environment and Conservation Council, Draft 7 October 1992.

AWRC, (1974). An Assessment of Eutrophication in Australian Inland Waters. AWRC Technical Paper No 15.

Barling, R.D. and Moore, I.D. (1992). The role of buffer strips in the management of waterway pollution. Workshop on the Role of Buffer Strips in the Management of Waterway Pollution from Diffuse Urban and Rural Sources. Woodful et al. eds).

Barling, R.D. (1993). Analysis of Nutrients in Irrigation Drains in the Goulburn Irrigation Area May 1990 to June 1993. HydroTechnology Report CW/2220A/1.

Connor, D.J. and Smith, D.F. (1987). Agriculture in Victoria.

Cottingham, P., 1994. Development of a Nutrient Management Strategy for the Goulburn and Broken Catchment. Inception Report. State Water Laboratory of Victoria, Report No. 113.

CMPS&F, (1995). Investigation of Urban Stormwater and Local Water Quality Issues in the Goulburn-Broken Catchment, January 1995.

Crocos, A. and Wrigley, R., (1993). Dairy Waste Management.

Davis, J.R. and Farley, T.F.N., (1991). Development and application of a catchment management support system for the Onkaparinga catchment of South Australia. CSIRO, Division of Water Resource, Consultancy Report 91/21, September 1991.

Department of Agriculture Victoria, (1962). Soils and Land Use in Part of the Goulburn Valley, Victoria. Technical Bulletin No.14 Melbourne, 1962.

Department of Agriculture Victoria, (1979). Agnote No. 192/79.

Department of Agriculture Victoria, (1983). Agnote No. 2145/83.

Department of the Environment, Department of Health. (1990). Cryptosporidium in Water Supplies. Report of the Group of Experts. Chairman - Sir John Badenoch. London: HMSO.

Edwards, C.A., Norton, L.D. and Redmond, C.E., (1988). Characterising macropores that affect infiltration into non-tilled soil. Soil Society of America Journal (522).

EPA, (1983). Recommended Water Quality Criteria. First Edition, Environment Protection Authority of Victoria, Publication 165, May 1983.

Finlayson, C.C., von Oertzen, I., and Chick, A.J., (1990). Treating poultry abattoir and piggery effluents in gravel trenches. In 'Constructed Wetlands Pollution Control' eds P.F. Cooper, and B.C. Findlater,. Proc. Int. Conference on the Use of Constructed Wetland in Water Pollution Control, Cambridge, UK, pp. 559-62. Pergamon Press: (Oxford).

Finlayson, C.M., Chick, A.J., von Oertzen, I., and Mitchell, D.S., (1987). Treatment of piggery effluent by an aquatic plant filter. Biological Wastes 19, 179-96.

Gill, W.R., (1971). Economic assessment of soil compaction. In Barnes, K.K., Carleton, W.M., Taylor, H.M., Throckmorton, R.I. and Vanden Bergs, G.E. (eds) Compaction of Agricultural Soils. Monograph No. 1. American Society of Agricultural Engineers, St. Joseph, Michigan.

Grevis-James, A. and Kamel, J., (1977). Technical Bulletin No. 32. Queensland Department of Primary Industries.

GHD, (1995). Nutrient Loads form Intensive Animal Industries.

Hall, A.G., Rendell R.J. and Fowler, C.A., (1983). Rural Water Commission of Victoria. Laser Grading in the Goulburn Murray Irrigation District. Part 1: The Extent of Laser Grading in Northern Victoria.

Hamilton, S.D., Chalk, P.M., Smith, C.J. and Hopmans, P., (1990). The Use of A-Values to Estimate N_2 Fixation by ^{15}N Isotope Dilution.

Harrison J., (1994). Review of Nutrients in Irrigation Drainage in the Murray-Darling Basin. Water Resources Series No. 11, CSIRO Division of Water Resources, Canberra, ACT.

Harrison, J. and Schalken, T., (1990). Nutrient Monitoring of Sunraysia Irrigation Drains October 1989 to May 1990. Water, Materials and Environmental Science Branch, Rural Water Commission of Victoria, Report No. WQ-43.

Hatfield, J.L., (1993). Sustainable Agriculture: Impacts on Non-point Pollution. Wat. Sci. Tech. Vol 28.

Humphrey, T.J. and Beckett, P., (1986). *Campylobacter jejuni* in dairy cows and raw milk. Epidem. Inf. (1987) 98, 263-269.

HydroTechnology, (1993). Analysis of Nutrient Monitoring in Sunraysia Irrigation Drains. CW/2152A/1.

HydroTechnology, (1993). Salt and Nutrients in Pumped Bores.

HydroTechnology, (1993). Evaluation of Surface Runoff Volumes and Quality from Irrigated Pastures in a High Watertable Areas.

HydroTechnology, (1994a). Shepparton Region Surface Drainage Strategy, HydroTechnology Draft Report, January 1994, pp 30.

HydroTechnology, (1994b). Drainage Diversion Policy Review, HydroTechnology Draft Discussion Paper, February 1994, pp 12

HydroTechnology, (1995). Nutrients in Irrigation Drains in the Shepparton Irrigation Region July 1993 to July 1994. MC/44010.000/1.

Ian Drummond and Associates Pty Ltd., (1992a,b): Feasibility Study for Surface Drainage of Timmering-Woolwash Depression. 2 Vols.

Jones, L.D., (1992). Review of Trends in Irrigated Culture and On Farm Water Management Practices. MDBC irrigation Management Strategy Regional Case Studies, Goulburn Valley Study. Irrigation Technology Branch, RWC.

Lal, R. and Pierce, F.J. (eds), (1991). Soil Management for Sustainability. Soil and Water Conservation Society. Ankeny. IA.

Leamon, K., (1979). Agnote No. 928/79. Guides to efficient irrigation. Department of Agriculture and Rural Affairs.

Linke G.K., (1992). Boort Off Stream Storage Pre Feasibility Study. Investigations Branch Report No. 1992/43, Rural Water Corporation, 28 pp.

Logan, T.J., Davidson, J.M., Baker, J.L. and Overcash, M.R. (eds)., (1987). Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis publishers, Chelsea. M1.

Long, G., (1992). A Regression Model for Blue Green Algae Density in the River Murray Downstream of Hume Dam. Murray Darling Basin Commission Technical report 92/6. MDBC Canberra, ACT.

Macalister Research Farm Co-operative, (1992). Dairy farming in the Macalister Irrigation District. Department of Agriculture

McKenzie-Smith, F. (1990). Biocide Contamination in the Aquatic Environment: A study of the Ovens and King Rivers Region. Environment Protection Authority of Victoria, Report SRS 90/004.

McKenzie-Smith, F., Tiller, D. and Allen, D., (1994). Organochlorine Pesticide Residues in Water and Sediments from the Ovens and King Rivers, North-East Victoria, Australia. Arch. Environ. Contam. Toxicol., 26, pp. 483-490.

McNab, S., Jerie, P., O'Connor, R. and MacDonald, P., (1995). Efficient Fertiliser Application Techniques and Nutrient Losses in Irrigated Horticulture. ISIA, Tatura, in prep.

Mitscherlich, E. And Marth, E.H., (1984). Microbial Survival in the Environment. Springer-Verlong Publishers, Berlin

Mulcahey, S. and Schroen, J. eds. (1993). Target 10 Irrigation and Drainage Reference Manual.

Mundy, G.N. (1993). Guidelines for the Economic Use of Nitrogen Fertiliser on Irrigated Dairy Farms. Victorian Department of Agriculture.

Murphy, J.P., Cornish, J.B., Jones, L.D. and Norman, I. W. eds), (1983). Irrigation - Its Relevance to the National Economy in a Modern Environment, Seminar Proceedings. Sponsored by the Victorian Irrigation Research and Promotion Organisation.

MDBC, (1990). Report to the Murray-Darling Basin Ministerial Council on a Drainage Program for the Murray-Darling Basin.

MDBC (1992): Goulburn Valley Regional Study, Murray Darling Basin Commission Irrigation Management Strategy, December 1992, pp 67.

MDBC, (1993). Draft Algal Management Strategy for the Murray Darling Basin. Murray Darling Basin Commission, Canberra, ACT.

MDBC, (1994). The Algal Management Strategy for the Murray Darling Basin. MDBC, Canberra, ACT.

Neher, D. (1992). Ecological Sustainability in Agricultural Systems: Definitions and Measurements. J. Sustainable Agric. 2.

Newman, A.R. (1991). User-friendly computer programs for agriculture. Environ. Sci. Technol. 25 7).

OCE (1988). State of the Environment Report 1988 - Victoria’s Inland Waters. Office of the Commissioner for the Environment. Government of Victoria.

O’Shanassy, K., 1995. Water Quality Monitoring in the Goulburn-Broken River Basin (draft). Water Ecoscience Report to Goulburn Murray Water.

O’Shanassy, K., Cottingham, P. and Dunn R., (1994). The Use of Decision Support Systems to Assess Nutrient Export from the Goulburn-Broken Basin. Water Ecoscience Report No. 2/94.

Rendell, R.J. and Fowler, C.A. (1984). Rural Water Commission of Victoria. Laser Grading in the Goulburn Murray Irrigation District. Part 8: The Slope of Irrigation Bays.

Rendell, R.J. (1983). Farm Channels for Border Check Irrigation. Water Talk No. 50,

Rendell, R.J. State Rivers and Water Supply Commission. Designing Paddocks on an Irrigated Dairy Farm.

Reynolds, A. (1994). Culture Sheet data.
Robinson, A.R. (1971). Sediment: Our Greatest Pollutant? Ag. Engineering 52.

Rooney, G., 1991. Pilot Survey of Trace Elements in Northern Victorian Saline Waters (Draft). Environmental Studies Branch, Environment Protection Authority of Victoria.

RWC (1989). Shepparton Irrigation Region Land and Water Salinity Management Plan. Background Papers. Volume 1.

RWC (1992a). Goulburn Valley Study-Review of Trends in Irrigated Culture and on Farm Water Management Practices, Rural Water Corporation, Irrigation Technology Branch, October 1992, pp 16.

RWC (1992b). Annual Report 1991-92, Rural Water Commission of Victoria, July 1992, pp 120.

RWC (1994). Annual Report 1993-94, Rural Water Corporation, July 1994, pp 61.

Segerson, K. (1990). Incentive policies for control of agricultural water pollution. In ' Agriculture and Water Quality International Perspective', eds J.B. Braden and S.B. Lovejoy. Lynne Rienner Publishers: Boulder and London). pp 39-62.

Shepparton land and Water Salinity Management Plan (Draft) August 1989.

Small, D.R. (1985). Effect of Irrigation Land Use on Nutrients in Runoff. Department of Agriculture. Animal and Irrigated Pastures Research Institute. AWRC Research Project 78/99.

Smith, C. (1993). Pasture Management for Dairy Farmers. Department of Agriculture, Victoria.

South Australian Dairy Farmers Association, (1993). Dairy Farm Waste Management in the Mount Lofty Ranges.

SPPAC (1989): Shepparton Land and Water Salinity Management Plan- Draft Report, Goulburn Broken Region Salinity Pilot Program Advisory Council, August 1989, pp 151.

State Water Laboratory of Victoria, 1994. Pesticides in Drainage Water. State Water Laboratory of Victoria report to Goulburn Murray Water.

Stevenson W.J. and Hughes, K.L., 1988. Synopsis of Zoonoses in Australia, 2nd Ed. Commonwealth Department of Community Services and Health, Canberra, ACT.

Sullivan C., R. Croome and D. Welsh, 1989. Nutrient and Algal monitoring of the Deakin Main Drain. Water, Materials and Environmental Science Branch, Rural Water Commission of Victoria., Report No. WQ-20, p 68.

Till, M.R. (1973b). Re-Use of Drainage Water as a Means of Disposal - Vol. II Appendices. Department of Agriculture, South Australia. Soil Conservation Branch S12/73.

Tozer, R., 1994. Evaluation of Surface Runoff Volumes and Quality from Irrigated Pastures in a High Water Table Area. HydroTechnology Tatura.

TPRB (1992). Commercial Tree-Growing for Land and Water Care A Proposal for Research and Development Funding to Support Commercial Tree-Growing for Land and Water Care in Key Irrigation Areas in the Murray-Darling Basin. Trees for Profit Research Board, Research Centre; University of Melbourne; Department of Conservation and Environment; Rural Water Corporation of Victoria; CSIRO Division of Forest Products; CSIRO Division of Forestry; Treecorp Pty Ltd.

Weston, B.A., Cummings, D.J. and Shaw, H.A. (1986). Soil, water and nutrient movement through pastured filter strips. Hydrology and Water Resources Symposium, Nov. 1986, Griffith University, Brisbane.

Wrigley, R. and Monks, L. (1993). Managing Dairy Shed Wastes, Volume 1. Dairy Research and Development Corporation.

Wrigley, R. (1994). Managing Dairy Shed Wastes, Volume 2. Dairy Research and Development Corporation.

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