USE OF RECLAIMED WATER BY THE AUSTRALIAN HORTICULTURAL INDUSTRY—THE STATE OF PLAY AND CHALLENGES FOR THE FUTURE

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1 Introduction

Due to environmental and economic pressures, the volume of reclaimed water being used in Australia is increasing (Dillon 2000, Radcliffe 2003). One of the major potential, and current, uses of this water is for irrigation of horticultural crops. In recognition of this, Land and Water Australia funded the present project—*Use of reclaimed water in Australian horticulture*—, which is intended to position the horticultural industry to both assess and develop reuse schemes. There are two main stages. Stage One is a reconnaissance study aimed at identifying the major knowledge gaps related to the use of reclaimed water for horticultural irrigation. Research aimed at filling the gaps will comprise Stage Two. The review presented here is one of the major components of Stage One. The other two main components are the construction of a systems framework and an inventory of reclaimed water resources and horticultural water usage. This is a preliminary version of the review; the final version will be completed by December 31 2003, after experts have been contracted to add to certain sections.

A major initiative, the Australian Water Conservation and Reuse Program (AWCRP), was recently established to improve continuity and coordination of research into reuse issues in Australia (Dillon nd). The AWCRP program includes a variety of projects covering various aspects of water reuse research. The reclaimed water use in horticulture project is closely linked to the AWCRP program.

1.1 References

Dillon (nd). Prospectus for an Australian water conservation and reuse research program. CSIRO Land and Water, Adelaide.

Dillon, P.J. (2000). Water reuse in Australia: current status, projections and research. *In* Water Recycling Australia, P.J. Dillon (Ed.), CSIRO and AWA, Canberra ACT.

Radcliffe, J. (2003). An overview of water recycling in Australia—results of a recent ATSE study. Water recycling Australia: second national conference, Brisbane, 2003.

2 Guidelines

2.1 State guidelines

Several states have developed guidelines for the use of reclaimed water. The South Australian guidelines were the first to be drafted, and the other states have generally used these as a model for constructing their own guidelines. The following discussion of the various state guidelines attempts to summarise their major characteristics, particularly with respect to horticulture, and to make comparisons between states. To do this, some simplification of the guidelines was necessary. There are detailed and specific caveats associated with all the state guidelines. Thus, the information presented here should only be considered in terms of making general conclusions about the guidelines as they apply to horticulture, and managers and practitioners should always consult the guidelines themselves (Section 2.3).

All the state guidelines share common elements. With the exception of the draft NSW guidelines, they all adopt a water class system, where three or four classes are defined by various physical, chemical and microbiological parameters (Table 2.1). In contrast, the national guidelines are not based on a class system (Section 2.2). Turbidity is considered for all classes in Victoria, but it is only used for Class A in South Australia, and it is not used at all in Tasmania. Similarly, suspended solids are used in defining all water classes in Victoria, yet they are only considered in Classes A and B in South Australia, and they are not used in the definition of any of the Tasmanian classes. However, while the Tasmanian guidelines do not account for the concentration of suspended solids in the definition of the water classes, they do recommend that they be monitored for all classes (Dettrick and Gallagher 2002). The NSW draft guidelines define three categories of effluent quality, based on physical and chemical properties (Table 2.2). A mathematical model that takes into account the effluent quality category, land area to be irrigated, storage, and other factors is presented so that appropriate irrigation strategies can be developed (Annex A of EPA NSW 1995, or see Shannon 1992 for a more detailed description of the model).

Table 2.1. Comparison of the major characteristics of the state and national guidelines for use of reclaimed water for irrigation. TC = thermotolerant coliform bacteria (note that some guidelines specify *Escherichia coli*), BOD_5 = five day biochemical oxygen demand, SS = suspended solids. The NSW draft guidelines do not use water quality classes; rather, A, B and C refer to "disinfection levels" in this case.

	Class	NSW (draft)	SA	Tas.	Vic
Median TC/100 mL (refer to guidelines for measure of central tendency used)	A	< 300 (max < 2,000)	< 10	< 10	< 10
	B	< 750 (max < 5,000)	< 100	< 1,000	< 100
	C	< 3,000 (max < 14,000)	< 1,000	< 10,000	< 1,000
	D	NA	< 10,000	No Class D	< 10,000
Turbidity (NTU)	A	NA	≤ 2	NA	< 2
	B	NA	NA	NA	< 20
	C	NA	NA	NA	< 20
	D	NA	NA	No Class D	< 20
BOD_5 (mgL^{-1})	A	NA	< 20	< 10	< 10
	B	NA	< 20	< 50	< 20
	C	NA	< 20	< 80	< 20
	D	NA	NA	No Class D	< 20
SS (mgL^{-1})	A	NA	NA	NA	< 5
	B	NA	< 30	NA	< 30
	C	NA	< 30	NA	< 30
	D	NA	NA	No Class D	< 30

Table 2.2. Effluent classification used in the NSW Draft guidelines. TDS = total dissolved solids.

	low	**intermediate**	**high**
Total nitrogen (mgL^{-1})	< 50	50–100	> 100
Total phosphorus (mgL^{-1})	< 10	10–20	> 20
BOD_5 (mgL^{-1})	< 40	40–1500	> 1,500
TDS (mgL^{-1})	< 500	500–1,000	> 1,000–2,500

In addition to defining the various water classes in accordance with particular physical, chemical and microbiological criteria, the state guidelines describe treatment practices to achieve these criteria. These are very similar across all states (Table 2.1). Most guidelines also contain specific guidance for pathogen reduction, but this is primarily in relation to helminth contamination of grazing pasture.

Table 2.3. Best practice treatment protocols for achieving water of a particular quality (class). The NSW draft guidelines do not use water quality classes; rather, A, B and C refer to "disinfection levels" in this case.

Class	NSW (draft)	SA	Tas.	Vic
A	• 30 days ponding or other means acceptable to the EPA and Dept of Health	• 1º + 2º + 3º + disinf’ • Treat to reduce risk of infection from all type of potential human pathogens.	• Treatment: coagulation, flocculation, advanced filtration and other best practice treatment processes to remove nutrients, sediments and other contaminants. • Disinfection: microfiltration, U.V., ozonation and chlorination. • Chlorination may be best practice if a residual is required to prevent the bacterial regrowth.	• 1º+ 2º +3º + disinf’ with sufficient log reductions to achieve: < 10 *E. coli*/100mL; < 1 helminth/L; < 1 protozoan/50 L; and < 1 virus/50 L
B	• 20 days ponding or other means acceptable to the EPA and Dept of Health	• 1º + 2º + disinf’ + assurance that SS below threshold	• Treatment: high rate processes such as activated sludge or trickling filters. • Lagoon treatment with separate polishing lagoons is acceptable for < 1,000 TC / 100 mL. • Disinfection: chlorination, U.V. and ozonation. Detention lagoons will not be sufficient if a concentration of < 100 TC / 100 mL is required.	• 1º + 2º + disinf’
C	• 10 days ponding or other means acceptable to the EPA and Dept of Health	• 1º + (full 2º or lagooning). Disinf’ required only to meet micro standards.	• Lagoon based systems. • No additional disinfection required.	• 1º + 2º + disinf’
D	• NA	• 1º + (full 2º or lagooning)	• No Class D	• 1º + 2º

The various state guidelines stipulate the type of crops that can be irrigated with reclaimed water of differing quality, and the best practice irrigation methods (Table 2.4). In general, for all states the applicability of reclaimed water for irrigation, with respect to food safety, is a function of three factors: water quality, degree of contact with the crop, and typical processing status (e.g. raw or cooked) of the product upon consumption.

Table 2.4. Best-practice irrigation methods outlined by the state guidelines. The NSW draft guidelines do not use water quality classes; rather, A, B and C refer to "disinfection levels" in this case (see Tables 2.1 and 2.2).

Class	NSW	SA	Tas.	Vic
A	• Crops for human consumption which will be commercially processed = furrow or trickle • Crops for human consumption which will be cooked before being eaten = furrow or trickle	• Plants with large surface area on or near ground = spray or flood • Root crops consumed raw = spray, drip, flood or furrow • Crops without ground contact = spray	• No spray drift beyond boundaries of irrigation area	• Crops grown close to ground and consumed raw = unrestricted • Root crops consumed raw = unrestricted • Crops grown over 1 m above ground and eaten raw = unrestricted • Crops which are skinned, peeled or shelled before consumption = unrestricted
B		• Plants with large surface area on or near ground = drip or furrow • Root crops consumed raw = sub-surface • Crops without ground contact = flood • Crops without ground contact and skin that is removed before consumption = spray • Crops with contact with ground and skin that is removed before consumption = spray	• No spray drift beyond boundaries of irrigation area • Dropped crops not to be harvested from the ground • Crops contacted by effluent must be cooked, commercially processed or peeled before consumption • Restricted public access • Withholding period = 4 hours or until crop dry	
C	• Orchards and vineyard crops for human consumption = furrow or trickle	• Plants with large surface area on or near ground = drip or furrow • Crops without ground contact = drip or furrow • Crops without ground contact and skin that is removed before consumption = flood • Crops with contact with ground and skin that is removed before consumption = drip, flood or furrow • Root crops processed before harvesting = spray, drip, furrow or sub-surface • Surface crops processed before harvest = spray, drip, flood or furrow	• No spray drift beyond boundaries of irrigation area • Restricted public access • Withholding period = 4 hours or until crop dry	• Crops grown over 1 m above ground and eaten raw = flood, furrow, drip, sub-surface • Crops which are skinned, peeled or shelled before consumption = flood, furrow, drip or sub-surface. • Crops to be cooked (> 70ºC for 2 min.) or processed before sale to consumers = unrestricted
D	• No Disinfection Level D	• Crops without ground contact = sub-surface • Crops without ground contact and skin that is removed before consumption = drip, furrow or sub-surface • Crops with contact with ground and skin that is removed before consumption = sub-surface • Surface crops processed before harvest = sub-surface • Crops not for human consumption = unrestricted	• No Class D	• Crops not for consumption

2.2 National guidelines

As part of the National Water Quality Management Strategy, the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), the Australian and New Zealand Environment Conservation Council (ANZECC), and the National Health and Medical Research Council (NHMRC) devised national *Guidelines for Sewerage Systems*. A sub-set of these guidelines, namely, *Guidelines for Sewerage Systems: Reclaimed Water* (ARMCANZ, ANZECC and NHMRC 2000 a), is concerned with the use of reclaimed water, including its application to irrigated crops. It is these guidelines that will be discussed below. It should be noted, however, that another sub-set of the guidelines, the *Guidelines for Sewerage Systems: Effluent Management* (ARMCANZ, ANZECC and NHMRC 2000 b), is also appropriate to horticultural use of reclaimed water, as they deal with the broader issue of community consultation in relation to reuse projects.

A working group is currently in the process of developing revised national guidelines for reclaimed water use. These guidelines should be completed towards the end of 2004. In the meantime, however, the ARMCANZ, ANZECC and NHMRC (2000 a) guidelines apply. The main features of these guidelines, as they relate to irrigation of horticultural crops, are outlined in Table 2.5. In essence, the national guidelines are similar to those of the states. High microbiological standards and thorough treatment methods are required for crops that are in direct contact with the irrigation water and consumed raw. The target water quality and treatment level are then relaxed as the contact of the water with the crop decreases, and/or if the produce is cooked, peeled or processed before consumption.

Table 2.5. Summary of the national guidelines for the use of reclaimed water with respect to irrigated horticulture. TC = thermotolerant coliforms, cfu = colony forming units. Adapted from Table 3 of *Guidelines for sewerage systems: reclaimed water* (ARMCANZ, ANZECC and NHMRC 2000 a).

Type of reuse	**Level of treatment**	**Reclaimed water quality**	**Reclaimed water monitoring**	**Controls**
Food production Raw human food crops in direct contact with reclaimed water, e.g. via sprays, irrigation of salad vegetables	Tertiary ***and*** pathogen reduction	• pH = 6.5 – 8.5 • turbidity <= 2 NTU • 1 mgL^{-1} Cl_2 residual or equivalent level of disinfection • < 10 TC cfu 100 ml^{-1}	• pH weekly • turbidity continuous • disinfection systems daily • TCs weekly	• Application rates limited to protect groundwater quality. Salinity should be considered. • A minimum of 25 days ponding or equivalent treatment (e.g. sand filtration) for helminth controls.
Food production Raw human food crops not in direct contact with reclaimed water (edible product separated from contact with effluent, e.g. by peel, use of trickle irrigation) ***or*** crops sold to consumers cooked or processed	Secondary ***and*** pathogen reduction	• pH = 6.5 – 8.5 • < 1,000 TC cfu 100 ml^{-1}	• pH weekly • TCs weekly • BOD weekly • SS weekly	• Application rates limited to protect groundwater quality. Salinity should be considered. • Dropped crops not to be harvested from the ground • Crops must be cooked (>70ºC for 2 minutes), commercially processed or peeled before consumption
Non food crops Silviculture, turf and cotton etc.	Secondary ***and*** pathogen reduction	• pH = 6.5 – 8.5 • < 10,000 TC cfu 100 ml^{-1}	• pH weekly • TCs weekly • SS weekly • BOD weekly	• Application rates limited to protect groundwater quality • Restricted public access • Withholding period of nominally 4 hours or until irrigated area is dry

2.3 References

ANZECC and ARMCANZ (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ARMCANZ, ANZECC and NHMRC (2000 a). *Guidelines for sewerage systems: reclaimed water*. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ARMCANZ, ANZECC and NHMRC (2000 b). *Guidelines for sewerage systems: effluent management*. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

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EPA Victoria (2002a). Guidelines for environmental management—disinfection of treated wastewater. Publication 730. EPA Victoria, Southbank, Victoria.

EPA Victoria (2002b). Guidelines for environmental management—use of reclaimed water. Publication 730. EPA Victoria, Southbank, Victoria.

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Shannon, I. (1992). Guidelines for utilisation of wastewaters for irrigation. Environmental biometrics conference, Sydney, Australia, December 1992.

Dettrick, D. and Gallagher, S. (2002). Environmental guidelines for the use of recycled water in Tasmania. Environment Division, Department of Primary Industries, Water and Environment. Tasmania.

3 Policy and Economics

3.1 *Australia's water policy reform*

Significant reforms in water policy have occurred in the last decade, and these have been summarised in a number of works (Radcliffe 2003, Tisdell *et al.* 2002, Rendell McGuckian 2002). The defining points in the rethinking of the management of Australia's water resources include:

- The Ecological Sustainable Development Report (ESD 1991), which recognised the growing demand for water for conservation, recreation, irrigation, industry and domestic uses, and the need for an integrated catchment-wide approach to water and land resource management.
- Adoption of a strategic framework for the reform of the Australian water industry by the Council of Australian Governments (COAG) in 1994. The COAG framework of initiatives covered water-pricing reform based on the principals of consumption-based pricing and full cost recovery, elimination of cross subsidies, and making subsidies transparent. It also addressed issues on water allocation and entitlement, reform of irrigation systems, allocating water for environmental purposes, and institutional reform (Tisdell *et al.* 2002).
- The Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) developed the National Framework for the Implementation of Property Rights in Water in 1995.
- The National Competition Council (NCC) was charged with assessing the States' and Territories' implementation of COAG water reforms. The NCC set up a list of reform commitments regarding water allocations and trading.

3.2 *Current policy position for reclaimed water*

The opportunity to supplement diminishing water supplies with alternatives has been gaining momentum. The use of reclaimed water presents a potential water resource for agricultural and urban purposes. Significant outcomes in the past decade have been summarised by Radcliffe (2003), and they include:

- A State of Environment report that noted that sewage disposal was inadequate (DoEH 1996).
- The emphasis by State regulatory bodies on the reduction of nutrients to coastal environments.
- The publication of a series of guidelines under the National Water Quality Management Strategy including *Guidelines for sewerage systems—reclaimed water* and *Guidelines for sewerage systems—effluent management* (ARMCANZ, ANZECC and NHMRC 2000 a and b respectively).
- The National Land and Water Resources Audit, which showed that 26 percent of Australia's surface water management areas were overused, or close to overused, compared with their sustainable flow regimes. Furthermore, water from 168 of Australia's 538 groundwater management units was either fully or over-allocated (NLWRA 2002).
- A senate inquiry into Australia's management of urban water recommended the establishment of a National Water Policy including state and local targets, with

timeframes for effluent use, stormwater retention and pollution removal, decentralised, small scale sewage treatment, and reduced effluent to ocean outfalls (Allison *et al.* 2002).

- The Australian Research Council sponsored the Australian Academy of Technological Sciences and Engineering to undertake a review of water reuse in Australia in 2003 (Radcliffe 2003).

3.3 Environmental drivers

The most significant driver for the use of reclaimed water has been the requirement for compliance with EPA standards for outfall discharge (*e.g.* Melbourne Water 1999, Melbourne Water and CSIRO nd, Reynolds 2000). There are numerous examples of the adverse impacts of sewage discharge to the environment. For example, the sewage outfall from the Bolivar treatment plant in South Australia is believed to be the primary cause for the loss of about 5,000 ha of seagrass since 1935 (DoEH 2001, NP&W 2002). Seagrass beds are important breeding sites for many marine animals. Furthermore, the Bolivar outfall is considered to be responsible for the loss of about 250 ha of mangroves (DoEH 2001). Sewage disposal into Port Phillip Bay in Victoria has had detrimental impacts on intertidal macroalgae (Bellgrove *et al.* 1997, Kevekordes and Clayton 2000) and macroinvertebrates (Hindell and Quinn 2000).

While the potentially negative impact of nutrients and other possible contaminants has driven much of the activity, the recognition of limited water supplies is becoming an equally important issue. There is no doubt that many of our rivers, streams and groundwater resources are in crisis. The issue of allocation of water for the environment is paramount, as evidenced in the State of the Environment Report (DoEH 1996) and the recent green paper released in Victoria, “Securing our Water Future” (DSE 2003). Ensuring good environmental condition for stressed water supplies can be achieved by appropriate allocation of water to the environment. The substitution of potable water used in agriculture and urban irrigation with reclaimed water is one such method to achieve this outcome.

These drivers are associated with minimising environmental impact. However, the implementation of reclaimed water schemes for agricultural use does carry with it potential environmental risk. Application of reclaimed water to land can result in rising water tables, salinity and/or waterlogging. The environmental costs may also be too great when all indicators are considered, such as the potential impact on the environment through the emission of greenhouse gases (South East Qld Recycled Water—Task Force Report 2003).

3.4 Economic drivers

The economic drivers for the use of reclaimed water in horticulture are currently unclear. This arises from the fact that costing and pricing mechanisms are not transparent, with the true cost of neither potable nor recycled water reflected in current prices (Radcliffe 2003). The review by Radcliffe (2003) demonstrated considerable disparity in pricing of water in a number of schemes ranging from 7–83 c/kL. This is compared with estimates of the true cost of reclaimed water that ranged from \$1.45–\$3.00 /kL.

Radcliffe (2003) attributed these significant differences to the consideration of four key issues:

- the cost and source of capital;
- the cost of environmental externalities;
- the need for profitability; and
- pricing and marketing of reuse *vis-à-vis* potable water.

3.4.1 Capital

The cost of capital is often not accounted for in determining recycled water costs or prices (Radcliffe 2003).

3.4.2 Externalities

Externalities such as impacts on the environment are frequently not costed, although the cost of compliance with EPA requirements for discharge can readily be determined using a cost avoidance methodology. The traditional financial analysis approach often demonstrates a significant gap between the cost of the water and the price offered. For example, studies of the proposed Lockyer Valley scheme determined negative financial outcomes with expected recovery between 16 and 21% of commercial requirements (South East Qld Recycled Water—Task Force Report 2003).

Robinson (2003) argues that economic cost-benefit analysis (CBA) has the capacity to appraise the benefits associated with the use of reclaimed effluent water. These quantifiable benefits include the achievement of environmental health and preservation, the benefit of being able to delay investment in irreversible water storage infrastructure, and using an under-used scarce resource. CBA facilitates consideration of impacts that may be difficult to value in monetary terms, explicitly addressing financial, environmental and social criteria (Robinson 2003). An economic cost benefit analysis was undertaken for the Lockyer scheme, including environmental benefits/costs. This analysis quantified positive environmental outcomes for Moreton Bay and aquifers in the irrigated region, but these were out-weighed by significant negative impacts on greenhouse gas emissions. Thus, the environmental cost-benefit analysis was negative (South East Qld Recycled Water—Task Force Report 2003).

Where environmental and social issues are involved, there is growing recognition that multiple criteria analysis (MCA) is a useful tool for providing information to decision-makers. Robinson (2003) proposes that it is a useful adjunct to economic CBA in the consideration of reclaimed water schemes.

3.4.3 Profitability

Often there is an assumption that the use of reclaimed water in horticulture will provide opportunity for economic development. However, this is usually considered in isolation from the market realities for the product. The horticultural industry has identified this as a key challenge in the Strategic Initiative—the potential for overproduction as water is switched to horticultural crops from lower value uses (without appropriate market development strategies in place) (HAL Water Initiative—HAL 2003). Alternatively, the economic benefits for the industry may be considerable as they are “squeezed out” of the potable water market as urban development occurs. This assumes that reclaimed water is provided at a lower cost than potable water. Increasingly, horticultural producers are seeing security of water as a significant threat to their business viability. Therefore, the potential for a secure water source is an important issue for economic profitability.

3.4.4 Pricing of reclaimed and potable water

There is a lack of integration in the management of potable water, sewage, stormwater and groundwater resources (Radcliffe 2003). This can result in irrational use of resources and failure of market forces. Hatton-MacDonald (2003) stated that as reclaimed water and potable water are substitutes in production processes, changes in the price of one will have implications for the other. A holistic approach to these inter-connected markets is required if unintended impacts are to be avoided (Hatton-McDonald 2003). Movements towards an integrated whole-of-water cycle approach to water management have been initiated with the National Resource Management Ministerial Council in April 2003 asking its standing committee to report back on water recycling and water-sensitive urban design.

The Natural Resources Management Ministerial Council agreed at its Perth Meeting in October 2003 to the following:

(a) To endorse the proposal for the updating of National Guidelines on Water Recycling and stormwater management and reuse under the National Water Quality and Management Strategy;

(b) Agrees to participate with the Environment Protection and Heritage Council and other relevant Councils in the development of these guidelines (consistent with the priority analysis at Annex A) for:

(i) large scale-treated sewage and grey-water to be used for:

- residential garden watering, car washing, toilet flushing and clothes washing;
- irrigation for urban recreational and open space; agriculture and horticulture;
- fire protection and fire fighting systems;
- industrial uses, including cooling water;

(ii) grey water treated on-site for use for residential garden watering, car washing, toilet flushing and clothes washing;

(b) To endorse the draft terms of reference for a joint Steering Committee, including representatives of standing committees of the Environment Protection and Heritage Council (EPHC), Natural Resource Management Ministerial Council (NRMMC), National Health and Medical Research Council (NHMRC) and Australian Health Ministers Council (AHMC), to oversee the development of the Guidelines;

(c) To endorse the process and timeline for development of the guidelines noting the priority for the redevelopment of the Guidelines for Sewerage Systems – Use of Reclaimed Water (NWQMS 10);

(e) To endorse the proposal for the EPHC Service Corporation to provide project management and support to the Steering Committee and associated technical working committees, on a cost-recovery basis; and

(f) To endorse that project management and publication costs be met by EPHC and NRMMC agencies using the standard formula for cost-sharing amongst jurisdictions within Australia (50% Commonwealth and 50% States/Territories by population), noting that any further proposals for expenditure in relation to consultancies or other research will be brought before the relevant Standing Committees.

These resolutions were strongly supported by an independent working group for the Prime Minister's Science, Engineering and Innovation Council. Governments were encouraged to accelerate this process so that appropriate Guidelines become available as soon as possible (PMSEIC, 2003).

3.5 Social drivers

The key social drivers are associated with economic development in horticultural regions. The Lockyer Valley proposal identified social advantages in employment and populations for the regions receiving reclaimed water. There was also a significant financial benefit identified for individual property owners ($0.8 Million per property) (South East Qld Recycled Water—Task Force Report 2003). The report also identified the possibility for significant distribution costs and benefits between and within communities, and the potential for this to provoke appreciable community concern.

3.6 Implications for horticulture

The extensive reform to water policy has significantly affected the horticultural industry. A strategic initiative was launched in 2003 by Horticulture Australia Limited entitled "Water—to ensure ongoing access to water for horticulture". The key challenges to be addressed in this initiative include:

- the diversity of irrigated production in the industry, from annual to perennial crops through to amenity and urban horticulture;
- the spread of horticulture across most major catchments, and the wide variation in irrigation infrastructure and competing uses between and within these catchments;
- the different regulatory and management regimes between states and catchments;
- the changing definition of water security as policy continues to evolve;
- a significant industry presence on the urban fringe with both the resultant competition with urban users and the potential for recycling;
- the lack of water facing some horticultural users;
- the potential for over production as water is switched to horticultural crops from lower value uses; and
- management of water quality impacts on production.

The overall strategy for horticulture is to make a case for ongoing access to water through its high economic and social contribution, and the sustainable nature of horticultural production.

The initiative also recognises that the increased opportunities for re-use and access to urban wastewater raise questions of opportunities for further irrigated horticulture development.

3.7 Implications for growers

Horticulture can be defined as the production of perishable food and amenity products that, with the exception of a requirement for some products to be cooked, can be consumed in their 'raw state'. With few exceptions, notably viticulture, these industries are dependent on the use of irrigation.

The majority of horticultural growers are concerned about sustainability and the environment, and this was confirmed in a rapid rural appraisal of concerns amongst a range of horticultural growers in the peri-urban region around Perth in Western Australia (Paulin *et al.* 1994). As with the general community, the level of 'real or financial' commitment to these issues is based on the ability to satisfy some of more basic needs as generally described in the 'Maslov' hierarchy of needs. The environmental concern is therefore unlikely to be met before financial responsibilities and associated needs to satisfy requirements of family health, education and security, have been largely satisfied. It is also likely that the level of expectation at which these requirements are met will be below those of the overall community and in particular, the urban community (R. Paulin, personal view).

Land use planning processes generally consider peri-urban land, where significant areas of horticulture occur, to be a resource for future urban development. Consequently growers are unlikely to invest capital in upgrading infrastructure such as irrigation systems to meet emerging environmental concerns associated with their activities. This resistance is largely based on their inability to recover this investment when they sell their land to an alternate use, such as urban development.

In addition to the production of fresh food and amenity products, horticultural industries also make important contributions to:

- employment in both urban and rural areas;
- secondary processing industry development;
- tourism and other peri-urban/rural small business activity; and
- the social framework and fabric of the urban community.

3.7.1 Risk

For most horticultural growers, water availability is a primary concern. In situations where water supply is limited, they are likely to use reclaimed water providing that:

- their ability to compete in terms of production costs is not adversely affected;
- its use will be acceptable within various quality management programs and associated certification schemes;
- they will not be disadvantaged in the market place; and
- they understand how potential risks are being managed and how these processes are implemented.

While cost is the major concern, issues relating to management and regulatory requirements, together with the above concerns such as potential impacts on market access, will need to be effectively addressed. Linkages with the concurrent communication project managed by Jim Kelly and based on the South Australian experience will contribute significantly to minimising these concerns.

3.7.2 Cost

With few transitory exceptions, horticulture is a highly competitive industry whose cost structure is under continual upward pressure. Any change particularly to water resources will be viewed with the greatest concern because it will be assumed to result in cost increases and inevitably to reduced returns.

Ideally, water costs need to be maintained within current ranges and cost increases should be managed within the overall water market. On the Swan Coastal Plain in Western Australia, where the potential to use reclaimed water is greatest, growers currently have self supply water costs in the range of 7–10 c/kL.

Costs associated with managing the reuse of treated water will be viewed as a whole of community responsibility that needs to be equitably shared across all sectors. Growers will view increased water costs with great hostility if they are associated with delivering reclaimed water. This equability argument has successfully stopped previous attempts to introduce ground water management fees in Western Australia.

Accepting the sensitivity of horticultural industries to continuing cycles of increased costs and reduced returns, costs associated with the reuse of processed water need to be recovered within the overall water market. In this way the cost can be born equitably across the wider community and not within a sector, such as growers. It could be argued that given the potential disadvantages associated with reclaimed water use, that at least in the short term, its price could be set below that of fresh water.

3.7.3 Security

As already indicated, most horticultural growers have a requirement for secure access to water and as indicated, they will view any change to its potential availability and cost with strong concern and political action. Both water quality and quantity are elements of this dependence.

Their claim to use water is based on their economic dependence on its availability, and is defended on the basis of historic right and the importance of their industry to the community and the economy.

Growers view their role as suppliers of fresh food and other perishable amenity products as being extremely important. This has been supported by studies involving both urban and rural communities that have identified the availability of fresh locally produced food as being only slightly less important than the availability of fresh ‘potable’ drinking water (McCreddin *et al.* 1997)

Despite the development of global trade and management process that enable horticultural products to be successfully transported over large distances, there is continuing and if anything, increasing demand for access to locally produced product. This is because of:

- growing awareness of the benefit of consuming food that is minimally processed and that can be consumed with minimal delay from harvest;

- concerns about food safety and for their reduced ability to influence the cause of these concerns in other locations;
- beliefs that local produce taste better—this has been repeatedly confirmed by consumer surveys; and
- impacts on availability that arise from global uncertainty/politics and result in rapid change to trade relations.

To support the infra-structure associated with horticultural use of reclaimed water, planning processes need to ensure that areas can remain in horticultural production. Achieving this will be aided by:

- effective implementation of the planning policy that protects indiscriminate and non-strategic conversion of productive agricultural/horticultural land (*e.g.* Statement of Planning Policy—SPP11 in Western Australia) to other land uses; and
- growers adopting 'best management practice' that embrace 'environmental management system' principles.

In providing land use security for horticulture, the provision of agricultural zoning that has significant importance in the overall strategic planning process is also needed to ensure that land prices are determined by agricultural uses and not by alternative land use markets such as urban/industrial use. The need for this strategic land use planning approach can be strengthened by the ability of these areas to provide a market for recycled organic wastes from urban development in addition to a market for reclaimed water. Economic/sustainable reuse of reclaimed water and organic waste will ultimately be determined by transport costs, acknowledging that moving both water and bulky organic waste is expensive.

The reuse of organic waste in horticulture can improve soil organic matter development, and therefore improve the potential for these industries to manage the range of environmental issues associated with their activity. Environmental issues associated with nutrient and pesticide contamination of the ground, will tend to increase over time. They are exacerbated by declining soil organic matter levels that inevitably result in increasing use of irrigation, fertilisers and pesticides. Improving soil organic matter levels through the reuse of organic wastes will also improve irrigation efficiency.

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4 Market Requirements

4.1 Understanding the markets

Horticultural products are either sold on the local markets or through an exporter to overseas retailers. Growing for these markets requires compliance with different standards as determined by the purchaser.

4.1.1 Domestic market

The producer is regularly required to comply with supermarket requests as described in standards. These standards can refer to the quality of the product, food safety, environmental integrity and/or worker heath and safety. The standards are generally prescriptive. Business management tools can be used to achieve these standards and include Quality Assurance (QA) and Environmental Management Systems. These tools rely on the principles of continuous improvement through the plan-do-check-review process. Typically, the schemes that are used in Australian horticulture include a blend of process-based systems and more prescriptive production based standards. There is a multitude of schemes currently in use. These are predominantly focused on food safety and quality (incorporating QA and HACCP, see Sections 4.2 and 4.3) and include SQF2000, Fresh Care and preferred supplier schemes of individual supermarkets.

4.1.2 Export markets

Production for overseas markets requires compliance with standards that are determined by the individual supermarket or a conglomerate. While food safety and quality assurance are paramount, these markets are increasingly requiring demonstration of compliance with worker health and safety and positive environmental impacts. The implementation of these schemes has a significant impact for Australian exporters. Non-compliance will in effect restrict access to these critical markets. These schemes can therefore represent a trade barrier to those suppliers who cannot demonstrate compliance.

A plethora of schemes and standards have been introduced in Europe and USA, including Integrated Fruit Production (IFP) and individual supermarket requirements (*e.g.* Walmart). More recently, there has been a move towards a common scheme across European retailers which aims to harmonise approaches to quality, food safety, worker health and safety and environmental issues. This scheme is referred to as EUREPGAP and stands for the Euro-Retailers (*i.e.* European retailers) Produce Working Group on Good Agricultural Practice (see section 4.5).

4.2 Quality assurance

QA programs are used in the horticultural industry to ensure that produce is acceptable with respect to both food-safety and quality. QA programs involve regular auditing of growers' practices. Enrolment with a QA program is essential for the grower intending to supply one of the major retail chains (*i.e.* supermarkets), but those purely involved with smaller purchasers do not necessarily need official QA certification (Ulloa 2000). There are many QA programs for growers to chose from. Ulloa (2000) listed the following as some of the major QA programs that have been adopted within the Victorian vegetable industry.

- SQF 2000
- WVQMS (for Woolworth suppliers)
- Fresh Care
- ISO 9000

Most QA programs in Australia incorporate HACCP (Section 4.3) into their structure. The use of reclaimed water for irrigated horticulture is likely to make QA certification even more important, particularly from a food safety perspective. A challenge for the QA providers will be to develop protocols that are based on sound science.

4.3 HACCP

The Hazard Analysis Critical Control Point (HACCP) system has been adopted by food industries in many developed nations to ensure food safety. The premise of HACCP is that through the establishment of an effective hazard detection system, infringements and failures are detected early and the fault corrected before the product reaches the consumer. HACCP is incorporated into quality assurance programs, and has been adopted by Codex Alimentarius. HACCP has been successfully used by the drinking water industry in Australia, and it has been suggested that this would be a useful model for developing a HACCP system for the water reuse industry (Cunliffe and Stevens 2003). Incorporation of HACCP into growers' management protocols could lead to market advantages.

4.4 EMS

4.4.1 Principles of EMS

Taken from Baker and Boland (2003) and Boland and Baker (2003)

An Environmental Management System (EMS) is a formal management plan for conducting all business activities in a manner that aims to minimise negative impacts upon environmental quality, and where feasible, attempts to maximise any positive impacts. The EMS is a management tool for incorporating specific performance/productions standards (Carruthers 2000). It is a process based management tool for building environmental considerations into the day-to-day conduct of business, and it is applied at the enterprise level. Most of the following discussion is drawn from Baker and Boland (2003) and Boland and Baker (2003).

An EMS is a cyclical process of Plan, Do, Check and Review based upon the key principle of continuous improvement (Figure 5.1). This process is similar to, and compatible with, that used in other management systems including those for quality assurance, occupational health and safety, and food safety.

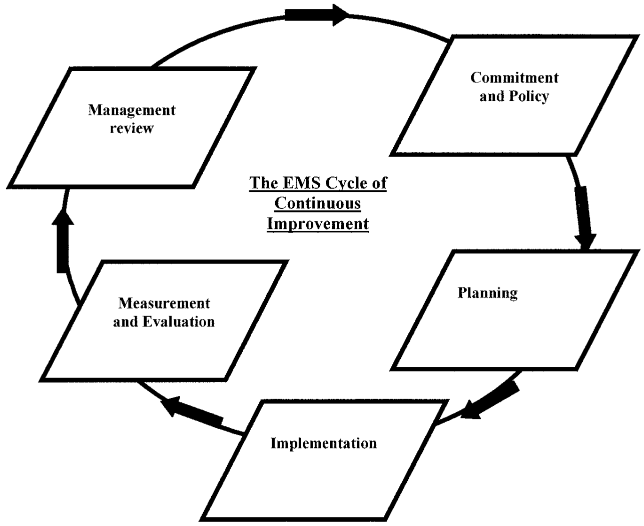

Figure 5.1. The Environmental Management System process *(adapted from AS NZS ISO 14004)*

Any formal process standards for EMS, including *ISO 14001*, are management standards, which focus upon managing the environmental impacts of enterprises. The specific performance/production standards that an enterprise would build into their environmental management system include the following:

- legislation;
- market requirements;
- catchment / regional guidelines;
- industry guidelines;
- community expectations; and
- business goals and aspirations

An EMS enables the business to “process” the external requirements of the various stakeholders (Figure 5.2). As such, the EMS does not itself set standards.

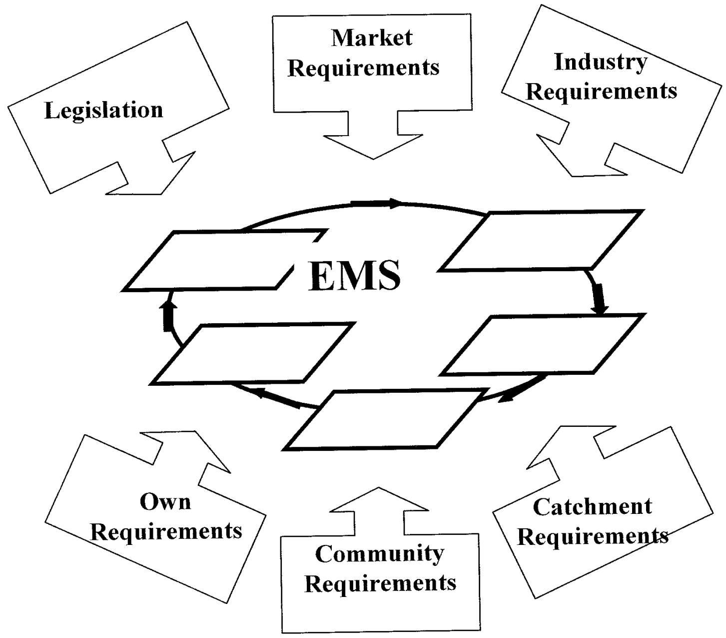

Figure 5.2. The role of EMS in addressing requirements.

The role of EMS is to ensure that an enterprise:

- identifies all its environmental management requirements;
- addresses them in an effective and efficient manner;
- can demonstrate that it is addressing environmental management in a manner that is acceptable to, and satisfies, requirements of relevant stakeholders; and
- regularly reviews the application of the management process to ensure it remains up-to-date and relevant.

From an industry perspective, adoption of effective EMS will enable the industry to substantiate claims of appropriate environmental management practices and performance by demonstrating these to various stakeholders (e.g. supermarkets). In addition, the adoption of EMS will allow the industry to rapidly anticipate and respond to changes in stakeholder requirements.

From an individual business perspective, there are three broad key areas of potential benefit that can be identified:

- production/business efficiency (*e.g.* good business management, efficient use of resources with potential financial savings, improved understanding of and compliance with external requirements);
- market advantage (*e.g.* continued and/or increased market access, potential for a price premium); and
- natural resource benefits (*e.g.* minimise negative environmental impacts, improved management of rural/urban fringe conflict).

4.4.2 Environmental schemes

There are several environmental management schemes and tools that have been developed overseas to address environmental management needs in agriculture and/or horticulture (see Carruthers and Tinning 2000, Fisher *et al.* 2000). These schemes include Low Input Viticulture and Enology (LIVE) http://www.liveinc.org/ ; Linking Environment and Farming (LEAF) (England); Farm*A*Syst (USA); Vitiswiss http://www.vitiswiss.ch/ and the Lodi-Woodbidge Winegrape Commission Integrated Pest Management Program (USA). Many of these schemes are portrayed as and/or perceived to be Environmental Management Systems. In most cases this is inaccurate, as they are in fact environmental management tools that can assist in the implementation and/or maintenance of an Environmental Management System at the enterprise level. There are aspects of such schemes that could be adapted and incorporated into an approach for Australian horticulture, and a review is provided in Baker and Boland (2001).

4.4.3 Relevance to horticultural use of reclaimed water

An EMS enables a business to identify and act upon any external requirements. In the case of reclaimed water the business would identify EPA legislation as the minimum standard which must be met. In addition, the EMS would identify any additional requirements from industry standards (e.g. codes of practice), market requirements (e.g. domestic or export regulations) and/or catchment management targets.

4.5 Export requirements

EUREPGAP is an initiative of the major European supermarket chains and their suppliers. It is an on-farm management system that covers Good Agricultural Practices (GAP), including food safety, environmental protection, production and worker welfare considerations. McBride (pers. comm. 2003) referred to some significant features of EUREPGAP:

- It is a private sector initiative that will affect commercial contractual relationships between (European) supermarkets, their suppliers and in particular the farms that supply these supermarkets with fresh produce from all parts of the world including Australia.
- It involves harmonisation of on-farm production standards, as it brings together a single standard that covers food safety, quality, environmental issues, and worker health, safety and welfare.
- The current priority is fresh fruit and vegetables, but working groups have been established for cut flowers and ornamentals, coffee, livestock, feed and combinable crops. A draft all-farm protocol is also under development.
- The standard for fruit and vegetables was published in a protocol in September 2001 after about five years of development. It is now being revised for release in 2004.

4.5.1 Relevance to reclaimed water use

The EUREPGAP standards are fairly prescriptive in their requirements. New protocols are currently in development for release in 2004. However, the current protocols (2001) refer to the use of reclaimed water in Section 7c (Quality of Irrigation Water) and section 10b (Post-harvest washing). The protocols refer to a series of issues (Control Point) and the action that is required (Compliance Criteria). These issues are grouped into those that need to be addressed (Major and Minor "Musts") and those that should be addressed

("Shoulds"). The Major and Minor Musts are listed below (taken from EUREPGAP, 2001).

Control Point	**Compliance Criteria**
7.c.1 Is or has untreated sewage water been used for irrigation?	Untreated sewage water must never be used for irrigation.
10.b.1.1 Is the source of water used for product washing compliant with microbiological aspects of EU regulations on water potability?	Within the last 12 months there has been carried out a bacteriological water analysis at the point of entry into the washing machinery which indicate that the water is compliant.
10.b.1.2 If recycled water is used for product washing, has this water been filtered?	Where washing water is recycled, there is an effective filter system for solids and suspensions that have a documented routine cleaning schedule according to the usage and water volume.

Additional analysis of the implications for the use of reclaimed water for other domestic and export schemes is required by December 31.

4.6 Consumer perceptions

Consumer acceptance of the use of reclaimed water in horticulture has been poorly studied in Australia. In a pilot survey of key Australian researchers, it was identified as the most important research priority (Dillon 2000). To date, most Australian research has focussed on residential potable reuse (Marks 2003 a and b, Marks *et al.* 2003). There have however, been some preliminary investigations of community perceptions to horticultural reuse (Wilkins 1992, Michels Warren 1999, Syme and Nancarrow 1999, Marks 2003 a). A common finding of these studies was that the level of acceptance generally decreases as the level of contact or proximity to the reclaimed water increases. Marks (2003 a) also found that with respect to potable reuse, the level of acceptance was influenced by personal experience with using reclaimed water and trust in the water supply institutions.

SKM (2002) identified three main areas that will need to be considered with respect to the public's perception of reclaimed water use. These were:

- risk perception in relation to differing uses of recycled water;
- trust in the authorities to ensure quality control; and
- "disgust", especially in regard to human contact.

They also acknowledged, however, the added complexity arising from Shepard's (1999) finding that individuals make decisions about food intake after balancing a suite of positive and negative aspects. For example, if we simplify the situation to just two opposing influences, the positive environmental effect associated with reclaimed water use would need to be balanced against the negative possibility of becoming sick from it.

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5 Environmental and Agronomic Issues

5.1 Salinity and sodicity

There is an enormous amount of information regarding plant responses to salinity, its affects on soils, and its management (*e.g.* Maas and Hoffman 1977, Rengasamy and Bourne 1998, Sumner and Naidu 1998, Shaw 1988; ANZECC and ARMCANZ 2000). In the development of a reclaimed water scheme this should be one of the first criteria to be checked, and the scheme should not be developed if the salinity of the water will be detrimental to plant growth, soil properties, or the environment. If the salinity is too high, another approach is dilution, with a better quality water, or desalination. Both of these alternatives come at an additional cost.

5.1.1 Sustainable management of soils

Like any water source, reclaimed water must be matched to the end uses to be sustainable. Quality of reclaimed water varies considerably between sewage treatment plants (STPs) and consequently different schemes will have different restrictions depending on water quality, soil type, site hydrology, crops to be grown and climatic conditions. The quality of the reclaimed water used for irrigation will eventually lead to changes in soil chemical and physical properties (Stevens *et al.* 2003). The challenge is to ensure that these changes do not lead to decreases in soil productivity and affect the sustainability of the reclaimed water irrigation scheme. Two key soil and water related constraints are salinity and sodicity (Pettygrove and Asano 1985, Asano 1998, Bond 1998, Surapaneni *et al.* 1998, Surapaneni and Olsson 2002, Tillman and Surapaneni 2002). Heavy metals also have the potential to limit plant growth, but as the primary concern associated with heavy metal accumulation relates to human health issues, they will be discussed later (Section 8.3)

The interaction and affects of water salinity and related sodicity have also been extensively researched over the last decades (Rengasamy and Olsson 1993, Sumner and Naidu 1998). There are good data available to estimate if water salinity and sodicity will lead to the development of sodic soils and the related chemical and structural problems (e.g. soil dispersion and slaking leading to decreases in permeability). This knowledge allows prevention and management of sodic soils within certain boundaries. There is a delicate balance when irrigating with relatively sodic water—sodium absorption ratio (SAR) > 3—on heavy soils. Obtaining this balance is crucial to the long-term sustainability of a reclaimed water scheme (Aljaloud *et al.* 1993, Balks *et al.* 1998, Bond 1998, Stevens *et al.* 2003). In some cases, sodicity can be managed through the use of calcium amendments. Other schemes, like FILTER that receive much higher hydraulic loading (1-1.5ML per ha per fortnight) of saline-sodic sewage effluent (SAR = 7.4-8.7) than traditional irrigation schemes, have maintained hydraulic flows while draining the profile to a sub-surface drain that collects salty leachate for further use or disposal (Jayawardane *et al.* 2001).

Salinity of irrigation water, soil type and crops grown determine the leaching requirement, and ultimately the water requirement, of an irrigation scheme. The salinity of water (reclaimed, ground, or surface) can lead to the application of tons of salt/ha/year to the soil. For example, to grow a crop with a 0.6 m application of reclaimed water (6 ML/ha) containing 1000 mgL^{-1} of total dissolved salts (TDS), adds 6 t/ha of salts per a crop. This example could be considered within the range of what is generally found in Australian reclaimed water schemes. If you assume 3% salts in the harvestable portion of a plant (Hillel 2000) and a yield of 10 t/ha, this equates to 0.3 t/ha of salts removed via the plant, any balance of salts, including those applied through fertiliser and soil amendments, need to be leached past the rooting depth of the crop and will ultimately accumulate in the soil or groundwater somewhere. Improved water efficiencies (*i.e.* more plant growth with less water), decreases the rate of salt accumulation and in rare cases a balances of salt inputs and outputs is possible, although for normal irrigation scheme this is usually associated with high yield forage crops and reclaimed water of low salinity. In the above example, if fertiliser input is discounted, the salinity of the irrigation water needs to be 50 mgL^{-1} TDS to achieve a salt balance. An example, at the higher extreme of crop salt removal might be if the harvestable yield (*i.e.* removed from the paddock) was assumed to be 30 t/ha and it had a salt content of 6 %, not considering rainfall and fertilisers application, the TDS of the irrigation water would need to be 300 mgL^{-1} to be in equilibrium with the salt removed from the site in the harvestable portion of the crop.

Obviously, the requirement for leaching of salts and the contribution to groundwater or increased soil salinity down the soil profile can be one of the most difficult balances to achieve. Ultimately, if this whole-of-scheme water balance is not achieved on- and off-site impact will be experienced. On-site, increases in soil salinity or rising water tables will degrade soil fertility and plant health. Off-site, sustainability may also be impacted from excessive leaching of nutrients, other mobile pollutants and salts into groundwater or surface waters causing undesirable impacts on the environment (e.g eutrophication; salinisation and contamination from pesticides).

So pervasive and inherent are the problems with irrigation, in general, that some critics doubt whether irrigation in general can be sustained in any one area for very long (Hillel 2000). However, if drainage of salt and nutrients is directly to the sea and nutrient release is diffuse with low loading rates (*i.e.* fresh water aquifer intrusions into seawater) the impacts may be low enough not to impact on marine life significantly and therefore sustainable. Another possible method for overcoming these impacts is offered by serial biological concentrations techniques (Blackwell *et al.* 2000). If these methodologies are adopted then full mass balance for water and salt could be achieved.

When establishing a reclaimed water scheme for horticulture, if the sodicity levels of the reclaimed water are matched within the boundaries of an appropriate soil type, soil sodicity will be manageable. The biggest challenge that faces the sustainability of a reclaimed water irrigation scheme is the management of salinity. Sustainable systems, which allow the leaching of salts as required to environmentally acceptable locations must be developed. Given the complexity of developing reuse schemes, some buffers should be allowed when estimating salinity and sodicity ratings that are acceptable for a particular soil and environment. Allowing some error margin ensures that poor estimates will not ultimately result in unsustainable reclaimed water schemes being developed.

5.1.2 Impact on plants

The salinity of reclaimed water must be matched with the plants to be grown to ensure crop production is not impaired.

Plant function

An increase in the concentration of salts in the root zone causes a decline in the osmotic potential of the soil-water solution and reduces the availability of water to the plant. The decline in soil osmotic potential is referred to as the osmotic effect of salinity. The yield response of plants relates well to the osmotic solution. This reduction in yield is frequently attributed to water deficiency, but the principal cause of reduced plant growth from salinity is now generally considered to be an energy limitation (Maas and Nieman 1978). Much energy is required for water uptake and expended to accumulate ions for osmotic adjustment.

In contrast to the osmotic effect, the toxic effect only occurs after the salt ions enter the plant, and this may occur through the leaves (when they are wet by irrigation water as with over-canopy irrigation) or roots. Ion toxicity is primarily of concern to perennial horticultural crops.

Yield

Salt tolerance is crop dependent, with crop yield being adversely affected by salinity when the salinity threshold of the particular crop species is exceeded. Most plants respond to the salinity of the soil solution which bathes their roots (EC_e) rather than the salinity of the applied water (EC_w), except where the foliage is irrigated directly (as occurs with overhead sprinkler irrigation) when the crop is affected by EC_w. EC_e refers to the average salinity of the soil water in the root zone of the particular crop under consideration.

The salinity-yield response model developed by Maas and Hoffman (1977) is generally adopted (see Equation 1). This provides the most comprehensive coverage available, and addresses the salt tolerance of over 200 crops and pastures.

For most crops the relationship between relative yield and soil salinity (EC_e) is sigmoidal in shape (Maas, 1990). However, some crops die before yield decline approaches zero, and in these situations the bottom half of the sigmoidal curve is absent. Maas and Hoffman (1977) proposed that the response curve could be represented as two straight lines, one a tolerance plateau with a slope of zero and the other a concentration dependent line in which the slope indicates the yield reduction per unit increase in soil salinity. The point at which the two lines intersect is the threshold salinity below which no yield loss occurs. At soil salinities greater than the threshold the relative yield is estimated by the following equation:

$$Yr = 100 - b(EC_e - a) \qquad \textit{Equation 5.1}$$

where a is the threshold salinity expressed in dS/m, b is the slope expressed as the relative yield decline (%) per dS/m, and EC_e is the electrical conductivity of a saturated soil paste extract averaged over the depth of the root zone.

The compilation of salt tolerance data by Maas and Hoffman (1977) was frequently based on immature crops grown in sand tanks and were generally short-term. More recent studies on horticultural crops have been conducted which have improved the salt tolerance relationship data.

Grapevines: numerous studies have been conducted on grapes—Prior *et al.* (1992a and b), Walker *et al.* (1996), Walker *et al.* (pers. comm.).
Citrus: Maas (1993) reviewed the response of citrus to salinity, considering results from experiments on lemon, grapefruit and orange on a variety of root-stocks.
Stone and pome fruit: long term field experiments on the response of mature plum trees to salinity were conducted in the San Joaquin Valley of California (Hoffman *et al.* 1989, Ziska *et al.* 1991, Catlin *et al.* 1993). In Australia, experiments have been conducted on peaches (Boland *et al.* 1993) and Williams Bon Cretien pear trees (Myers *et al.* 1995). These studies generally confirm the relationships of Maas (1990) and Bernstein (1980) as a reasonable basis for soil salinity/yield assessments.
Vegetables: most vegetables are considered sensitive to moderately sensitive to salinity stress, with the exception of asparagus, which is rated as tolerant. Maas (1990) provides guidelines for salinity thresholds and rates of yield decline with increasing salinity for most vegetables. Two more recent reviews (Shannon and Grieve 1999, Cuartero and Fernandez-Munoz 1999) provide a comprehensive assessment of tolerance of vegetable crops to salinity.

Importance of crop development stage

Salt sensitivity changes considerably during the development of a plant. Most crops are relatively tolerant of saline irrigation during germination. However, considerable evidence indicates that they are salt sensitive in the early seedling period (Lauchli and Epstein 1990, Shalhavet 1994) but generally become increasingly tolerant again as growth proceeds through the vegetative and reproductive stages (Francois and Maas 1994). With fruit crops there may be a difference in sensitivity from the juvenile to mature stages of growth, or differences within a season at varying stages of development—e.g. between the flowering phase and the rapid fruit growth phase. However, there has been little work on the effect of salinity on fruit trees at different stages of growth, either between or within seasons. Boland *et al.* (1997a and b) irrigated stone fruit trees with saline water (EC_w to 1.2 dS/m) at different stages of fruit growth, but found no effect of the treatment on fruit growth or final production.

Foliar injury

The entry of sodium and chloride into many horticultural crops is much easier through the leaves than the roots. Sprinkler irrigated crops can therefore suffer additional damage as the directly applied salts accumulate in the leaves. The degree of injury relates to the concentration of salt in the leaves, but the weather and water stress can influence the onset of injury. The leaves of many plants readily absorb sodium and chloride (Maas 1985) and crop sensitivity to chloride and sodium-induced foliar injury varies between species (Maas 1990).

Long-term toxic effects
Fruit trees are among the most sensitive crops to soil salinity (Maas 1990). Fruit yields are affected at relatively low threshold soil salinity levels and decrease more rapidly than most crops as salt concentrations increase above the threshold. The reduction in growth and yield is related in part to the total concentration of soluble salts or osmotic potential of the soil solution. However, tree crops are also susceptible to specific ion toxicities resulting from the excessive uptake of Cl and Na. Evidence of toxicity includes 'burning' or necrosis of tissue around the tips and margins of leaves. Research shows that salt builds up in the wood from one year to the next, until eventually Na levels suddenly begin increasing in the leaves. A yield decline may therefore not occur for 5–6 years. This observation has been reported for a number of fruit trees (Boland *et al.* 1997a).

Importance of root-stocks
The ability of different root-stocks to tolerate soil salinity is an important factor in rating the salinity tolerance of fruit tree and vine crops. Their tolerance appears to be related to the ability of different root-stocks to regulate the uptake of Na and Cl or both (Maas 1990). For grapes, Downton (1977) demonstrated the greater chloride-excluding capacity of Salt Creek, Harmony and Schwarzmann root-stocks over vines on own roots and Walker *et al.* (pers. comm.) have incorporated scion and rootstock tolerance into the model Vine LOGIC based on Australian data.

Effect of irrigation technology
The range of irrigation technologies used to irrigate horticultural crops in the Murray Valley/Riverland regions includes flood and furrow irrigation, overhead and under-canopy sprinklers, and micro-jet and drip irrigation. Irrigation method and volume of water applied have a pronounced influence on salt accumulation and distribution.

Impact of management on irrigation efficiency and leaching rates
It is difficult to compare the performance of irrigation systems, because cultural or management practices have such a profound influence. It is assumed that initially irrigation management will be based on a water conservation mentality and that minimal leaching will be applied in situations where management, not soil type, determines leaching potential (sprinkler and micro-irrigation systems). However, leaching fractions are likely to be increased as soil salinity levels rise. This is the action that an average farmer would adopt (GH&D 1999).

5.1.3 Management models

When considering the use of reclaimed water for crop irrigation, the ANZECC and ARMCANZ (2000) guidelines for marine and freshwaters should be consulted. These guidelines also recommend the use of a computer program, SALF (DNR 2000), to determine appropriate irrigation methods for saline water. Another useful computer program is MEDLI (Gardner and Davis 2000). This is a model designed for irrigation scheduling using reclaimed water. It takes into account a variety of factors including salinity, sodicity, nutrients and microbiological risks associated with spray drift. For grapevines, VineLOGIC (CRCV 2003) is a user-friendly program that uses expert systems and models to assist vignerons with making decisions about most production issues, including salinity management.

5.2 Ground-water contamination

The leaching of salt and nitrate were considered by Bond (1998) to be the most significant risks to groundwater health arising from irrigation with reclaimed water. He suggests that "monitoring of groundwater beneath effluent irrigation is an essential indicator of environmental performance." He also argues that changes in the "quality" of the groundwater may occur, but the impact will be minimal. For example, elevated nitrate levels might not be considered problematic if the groundwater does not discharge to surface waters and is not a potable resource.

Snow *et al.* (1998, 1999) have shown that the risk of contaminating groundwater with nitrate can be significantly reduced by appropriately matching plant production systems to climate and effluent characteristics. It is argued, for example, that in dry climates, high-yielding crops with large amounts of nitrogen in their biomass would be more effective than tree plantations at reducing nitrate leaching.

5.3 Surface-water contamination

High concentrations of nutrients, particularly nitrogen and phosphorus, in reclaimed water have the potential to cause eutrophication of surface waters. Of particular concern is the development of toxic cyanobacterial blooms. Other contaminants in reclaimed water, such as industrial hydrocarbons, detergents and heavy metals also have the potential to pollute waterways. Appropriate irrigation practices, that ensure no run-off, should prevent such contamination of surface-waters. Trigger concentrations for contaminants in surface waters throughout Australia are provided in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ (2000), and monitoring and management options are also covered in detail.

5.4 Plant nutrition

The use of reclaimed water for the irrigation of horticultural crops adds a further complexity in the management of crop nutrition. Nutrients contained in the reclaimed water may need to be accounted for and variation in water application rates may lead to over supply of the nutrients found in reclaimed water. The aim of any nutrient management program is to provide adequate and balanced nutrition to:

- optimise yield and quality; and
- minimise potential environmental risks from over fertilisation.

The above aims form the basis of Best Management Practice (BMP) for nutrition management in the production of crops. BMPs are management practices that combine information from scientific and practical knowledge to optimise crop yield and quality, whist ensuring the protection of the environment. Crop production should not be limited by under-supply of nutrients (deficiency) or over supply (toxicity) of essential nutrients, while environmental risks (*i.e.* nutrification) must be minimised while providing an adequate supply of nutrient to the plant (Figure 5.1).

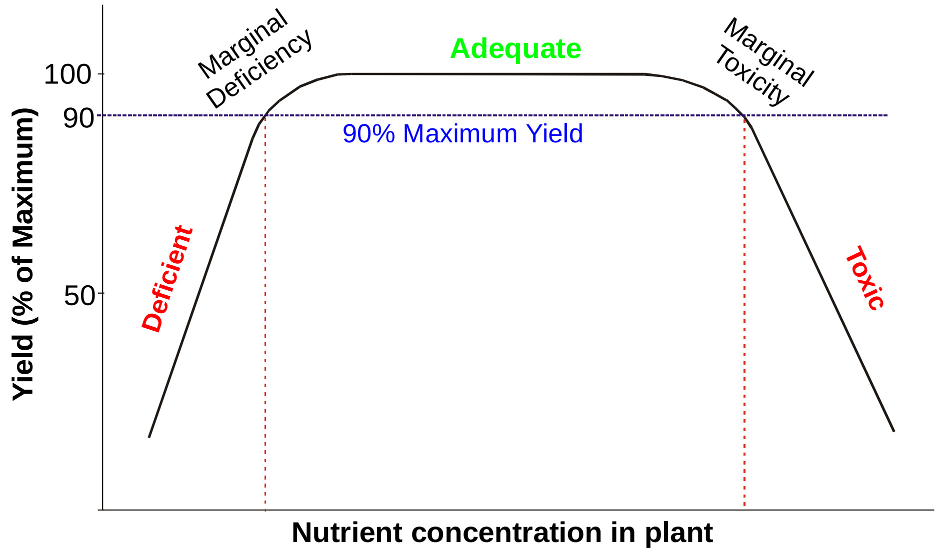

Figure 5.1. The relationship between plant nutrient concentration and crop yield.

The difficulties in providing an adequate and balanced nutritional program increase as the intensity of the horticultural production increases (Grundon). Growers and farm advisors need to establish crop requirements and the availability of nutrients from the soil (Creswell and Huett 1998). Realistic crop yields need to be established, and soil and crop tissue analysis used to identify nutrient deficiencies, verifying fertiliser programs. The potential problem in the management of crops irrigated with reclaimed water is to identify the amount of nutrient being applied to the crop during the growing period and to match nutrient requirement with nutrient application and soil nutrients. As your would expect, the rate and total amount of nutrient applied with reclaimed water depends on irrigation frequency and total depth of irrigation applied (Table 5.1).

Table 5.1. Nutrients applied per hectare (kg/ha) from the Virginia pipeline scheme at different irrigation depths (Kelly *et al.* 2002).

	Irrigation Applied (mm)								
Nutrient	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	
Nitrogen$_{(total)}$	25	33	41	49	58	66	74	82	**Nutrient applied kg/ha[A]**
Phosphorus	3.5	4.6	5.8	6.9	8.1	9.2	10.4	11.5	
Potassium	141	187	234	281	328	375	422	468	
Calcium	120	160	200	240	280	319	359	399	
Magnesium	93	123	154	185	216	247	278	308	
Sodium	825	1100	1375	1650	1925	2200	2475	2750	
Chloride	1146	1528	1910	2292	2674	3056	3438	3820	
Boron	1.1	1.5	1.8	2.2	2.5	2.9	3.3	3.6	

[A] Note that the nutrients applied depends on the nutrient concentration in the irrigation water

Many studies have reported yield increases, especially in nutrient deficient environments, from irrigation crops (lettuce, celery, sorghum and maize) with reclaimed water (Kaddous and Stubbs 1983, Sheikh *et al.* 1998, Marecos Do Monte 1998). Further to yield responses, evaluation of produce quality and shelf life have demonstrated that produce grown with reclaimed water was, as good as, and in some cases superior to, produce grown with well water (Sheikh *et al.* 1998). Use of some reclaimed waters has led to 30-60% reduction in supplementary fertilisers in vegetable crops, but this will be depend on the nutrient concentrations in the reclaimed water used. An important role to be undertaken by advisors and consultants will be to educate growers on the nutrition value in reclaimed water and include it in the development of a fertiliser management program.

If nutrient concentrations in the reclaimed water are high, the crops ability to make use of the nutrients applied with the water must be considered (Vazquezmontiel *et al.* 1996, Myers *et al.* 1995). Growers and managers may need to rotate crops (Table 2) to enable the removal of any excess nutrients applied through reclaimed water irrigation, or mix the reclaimed water with a water source with low nutrients to avoid over fertilisation. Over fertilisation can lead to environmental issues or excessive growth in some crops (discussed below).

Another potential area of concern with irrigation of reclaimed water is the timing of nutrient application. Traditionally a large proportion of crop's fertiliser is applied pre plant or at planting due to the problems associated with side dressing as the crop matures (Creswell and Huett 1998). Plants generally grow best when there is a constant nutrient concentration at the root (Creswell and Huett 1998). Therefore, theoretically, the constant supply of nutrient through irrigation with reclaimed water may provide some production benefits. However, some concerns have also been raised over the timing of nutrient and plant development. For example, nutrition late in a crop's development can have and impact on yield and quality.

Over fertilisation through irrigation with reclaimed water has been shown to affect the yield and maturation of perennial crops, or reduce fruit size and quality, through the excessive application of nitrogen (Baier and Fryer 1973). Others have found that irrigation with high nitrogen effluent (30.2 mgL^{-1}) caused late maturation of sunflowers (Marecos Do Monte 1998). Whether delays in maturation lead to decreases in yields, will be factor of site specific conditions.

Table 5.2. Estimated nutrient removed by vegetable crops.

Crop	Yield	Plant Part	Uptake kg/ha N	P	K	Ca	Mg
Cabbage	50 t/ha	Total	147	24	147	36	13
Capsicum	20 t/ha	Total	41	4	69	52	7
Carrots	44 t/ha	Root	100	14	90	15	6
		Leaf	110	5	180	160	12
		Total	210	19	270	175	10
Cauliflower	50 t/ha	Curd	119	23	134	55	10
		Leaf	62	5	91	72	8
		Total	181	28	225	127	18
Celery	190 t/ha	Total	308	97	700	290	38
Cucumber	18 t/ha	Fruit	28	5	45	4	2
		Leaf & Stem	38	7	75	30	6
		Total	66	12	120	34	8
Lettuce	50 t/ha	Total	100	18	180	10	3
Potato	40 t/ha	Tuber	132	15	180	10	3
		Leaf & Stem	132	8	130	56	18
		Total	264	23	310	66	21
Tomato	57 t/ha	Leaf & Stem	32	13	45	68	14
		Fruit	79	33	147	6	8
		Total	111	46	192	74	22
	194 t/ha	Leaf & Stem	211	49	241	315	58
		Fruit	361	84	615	33	29
		Total	572	133	856	348	87

Source: modified from the Australian Vegetable Growing Handbook (Creswell and Huett 1998)

In summary, from a nutritional prospective, most data available suggests improvement in crop yield and quality from use of reclaimed water. However, there are some concerns with respect to the timing and rate of nutrient application, which are usually linked to nutrient concentration of reclaimed water, irrigation requirement and specific crop requirements. To-date, these concerns appear to be manageable over a range of crop types and water qualities, but nutrient budgets need to consider the nutrients applied with reclaimed water.

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6 Public health

There are at present no federal legal requirements for substitution of fresh water with reclaimed water. However, wastewater treatment plant owners may be liable under common law, and in accordance with the Trade Practices Act, for the use of reclaimed water that results in harm to persons (ARMCANZ, ANZECC and NHMRC 2000). Thus, it is in the interests of all parties to follow guidelines and best practice management strategies. As the discussion below will reveal, however, simply complying with the existing guidelines cannot be treated as guaranteed mechanisms for ensuring production of safe produce now and into the future. Much effort needs to be made to ensure that the Australian horticultural industry keeps abreast of the latest hazard detection technologies and adopts appropriate practices.

6.1 Microorganisms

Risks arising from microbiological contamination of reclaimed water are generally considered to be greater than those associated with chemical compounds (Mara and Cairncross 1989). The literature on microbiological risks associated with use of reclaimed water for irrigating horticultural crops is expansive. However, while lessons can be learnt from particular experiences, each study is concerned with a specific circumstance, and making generalisations about microbiological hazards across studies is imprudent. Soil type, crop type, irrigation method, climate and cultural practices can all influence the levels of pathogenic microorganisms found on a crop. Furthermore, as with other potential hazards (see below), the quality of the reclaimed water being used needs to be considered. Water derived from a sewerage system with a high industrial input could be expected to pose different hazards than effluent from a predominantly domestic source. A comprehensive literature review of microbiological hazards associated with the use of reclaimed water for irrigation was conducted by Toze (1997), and much of Section 6.1.1 is derived from this review. Another major literature review is that of Fegen *et al.* (1998). Both of these reviews are particularly relevant, as they put the issues into an Australian perspective.

Guidelines developed for reclaimed water use—such as the state and national guidelines outlined in 2.1 and 2.2, and the WHO (1989)—attempt to account for some of the variables outlined above, so that some form of standard practice can be implemented across industry in order to minimise the risk of contaminated produce. It is worth noting that the WHO guidelines are primarily based upon reuse scenarios for third-world countries, and thus are based on the assumption that little or no treatment can be implemented. The susceptibility of third-world populations to various diseases also differs substantially from that of developed countries, and this needs to be accounted for when developing reuse strategies. Third-world populations experience high exposure to viruses, and consequently immunity to many viruses (e.g. hepatitis A and polio viruses) typically develops early in life (Shuval 1991, Toze 1997). In contrast, people in developed countries are not subjected to such high exposure levels, and thus do not build up immunity at a young age, which results in a greater vulnerability to viral diseases. Pathogens such as helminths, however, do not induce an immune response, and are likely to be a greater risk in third-world countries, where treatment technologies are not as advanced. The WHO (1989) thus listed helminths as the greatest health risk associated with the use of reclaimed water. Thus, consideration of technological and demographic characteristics must be considered in the development of reuse strategies by the Australian horticultural industry: we cannot simply afford to mimic other approaches.

6.1.1 Detecting contamination

One of the major challenges facing the reuse industry in Australia is the need to develop new faecal contamination detection methodologies. Thermotolerant coliform bacteria have traditionally been used, and are the basis of most microbiological safety guidelines. As indicators of faecal contamination, however, they have several disadvantages (Toze 1997). They are more sensitive to environmental change than some pathogenic bacteria, protozoan cysts, helminth eggs, and most viruses. Furthermore, the presence of thermotolerant coliforms is not necessarily indicative of faecal contamination from a human source: it could reflect the presence of faecal matter of any homoiothermic mammal.

Several other bacteria have been propounded as faecal indicators, including sorbitol-fermenting bifidobacteria, *Bacteroides*, faecal streptococci, *Clostridium perfringens* spores, but all have their advantages and disadvantages: none can be considered a “silver bullet” (Jagals *et al.* 1995, Baker and Bovard 1996, Ferguson *et al.* 1996, Hill *et al.* 1996, Leclerc *et al.* 1996, Toze 1997).

Viruses, while potentially being significant pathogens in reclaimed water, are poor indicators of faecal contamination themselves, as the laboratory techniques required to culture them are extremely time-consuming and expensive. However, viruses that attack bacteria, bacteriophages, do have potential to be used as indicators of the presence of particular viruses in sewage (Havelaar *et al.* 1993, Jofre *et al.* 1995). Like viruses, the laboratory techniques associated with detection and enumeration of pathogens, such as *Giardia*, *Cryptosporidium* and helminths, are laborious and highly specialised, and thus preclude their use in regular monitoring for most schemes.

Perhaps one of the greatest limitations associated with any microbial faecal indicator, however, is the time-lag associated with the processing of samples. Standard incubation times for thermotolerant coliform bacteria and *E. coli* are 48 and 24 hrs respectively. Thus, it will usually take at least a day or two before results of a water quality test can be reported. In many cases this will be too long: a crop could have been irrigated with contaminated water and harvested within this time-frame.

Thus, while thermotolerant coliforms are used as indicator species in all Australian guidelines at present, they do have their limitations, and it is important that the horticultural industry bears this in mind and remains vigilant. Rapid molecular detection methods, such as polymersae chain reaction (PCR), are showing promise, and will hopefully circumvent many of the problems associated with the various microobiological indicators (Toze 1997). The development of automated, and quantitative, PCR methodologies is under way. Such tools may even supplant reliance on indicator species, since many PCR probes could be developed for the large array of potential pathogens.

6.1.2 Risk assessment modelling

Another major challenge facing the successful implementation of reuse projects is development of risk assessment models. Such models would not only be used to assess the validity of proposed irrigation schemes, but they could also be coupled with monitoring programs. Risk assessment modelling for the drinking water industry is an advanced field, owing primarily to extensive work of Charles Haas and his colleagues (e.g. Gibson *et al.* 1998, Haas 1983, 1995, Haas *et al.* 1993, 1996). In contrast, few risk assessment models have been constructed for reclaimed water crop irrigation scenarios. Shuval *et al.* (1997) extended the risk assessment model of Haas *et al.* (1993) to determine risk associated with consuming cucumber and lettuce irrigated with reclaimed water. Firstly, the probability risk of infection by ingesting pathogens (P_I) was estimated as follows:

$$P_I = 1-[1+N/N_{50}(2^{1/a}-1]^{-a} \qquad \textit{equation 6.1.}$$

where N is the number of pathogens ingested, N_{50} is the number of pathogens that will infect 50% of the exposed population, and a is the ratio N/N_{50}.

The next step involved calculating the risk of an infected person becoming diseased or ill (P_D). This was calculated as:

$$P_D = P_{D:I} \text{ x } P_I \qquad \textit{equation 6.2.}$$

where $P_{D:I}$ is the probability of an infected person developing clinical disease.

Shuval *et al.* (1997) then conducted experiments to determine the level of contamination attained for cucumbers and long lettuces irrigated with reclaimed water. Thus, knowing the amount of food consumed, parameter N in *equation 6.1* could be found, and ultimately the risk of persons falling ill could be estimated using *equations 6.1* and *6.2*. The model was then validated using a data set from a cholera epidemic in Jerusalem. This validation tended to support the model, although several assumptions had to be made.

Asano and Sakaji (1990) used a similar approach to that just outlined, *i.e.* based on Haas *et al.*'s (1993) model, to model risk of virus related illnesses associated with the use of reclaimed water for irrigating market gardens and golf courses, groundwater recharge, and recreational use.

Such risk assessment models need to be constructed for other scenarios, such as different crops, climatic conditions, irrigation methods and populations, if we are to seriously evaluate the safety of reclaimed water irrigation schemes. Furthermore, existing models, such as those outlined above, need to be refined and improved. For example, the level of contamination was arrived at in the model of Shuval *et al.* (1997) by estimating the amount of irrigation water that would cling to the plant, and assuming all the pathogens present in this volume of water adhered to surface and survived upon drying. Moreover, the inoculation procedure they used, whereby the entire plant was submersed in the irrigation water, represented a worst case scenario. Physical models that describe the dispersion of irrigation water—such as that of Camann (1980) for spray irrigation—need to be developed.

6.2 Endocrine disruptors

An endocrine disruptor is any chemical that interferes with the functioning of an animal's endocrine system. They can be either naturally occurring or synthetic compounds. In Australia, there has been considerable research effort devoted to the study of endocrine disruptors, and in recognition of this, the Australasian Society for Ecotoxicology recently formed an endocrine disruptor special interest group. Short reviews/updates of the endocrine disruptor issue in Australia were conducted by Ying and Kookana (2002) and Moore and Chapman (2003). A worldwide review on the current state-of-knowledge with respect to endocrine disruptors and their environmental and health impacts has recently been conducted (WHO/IPCS 2002). A review specifically dealing with endocrine disruptors in the context of Australian drinking water has also just been published (Falconer *et al.* 2003).

Recently, there has been considerable debate about the effects of exposure to low concentrations to a group of endocrine disruptors known as xenoestrogens. These are synthetic chemicals with hormonal activity. Their biological effects are exploited in some pesticides and pharmaceuticals, and thus it is reasonable to expect that they could affect non-target organisms. In humans, the developing embryo or foetus is probably the most vulnerable stage to harmful effects of endocrine disruptors. Exposure to much higher concentrations would most likely be necessary to cause harm to adults (e.g. to the reproductive system or body homeostasis). Based on the epidemiological data available, "low-level environmental exposure to EDCs [endocrine disrupting compounds] has not yet been demonstrated to cause harm" (Moore and Chapman 2003).

6.3 Heavy metals

The loading of heavy metals applied to the soil through irrigation with reclaimed water is directly related to the concentration of heavy metals in the reclaimed water. The concentration of heavy metals in reclaimed water is dependent on the inflow into the sewage treatment plant and the treatment processes at the wastewater treatment plant. Simple loading calculations can be used to calculate the potential for accumulation of metals in soils (e.g. metal concentration x water volume / ha x years of irrigation x weight of top soil/ha).

Heavy metals are predominantly adsorbed to the solid phase (biosolid) of the treatment process (Pettygrove *et al.* 1985, Bunel *et al.* 1995). Concentrations for metal and metalloids in reclaimed water are generally within or below ANZECC long-term trigger values and are usually below ANZECC short-term trigger values (ANZECC and ARMCANZ 2000, Smith *et al.* 1996, Stevens *et al.* 2000). Even though heavy metals are generally not found in high enough concentration in reclaimed waters to be a direct threat to human health, they do have potentially harmful effects and should be monitored (Bahri 1998, Chang *et al.* 1996). Similarly, effects from long-term accumulation of heavy metals on plant growth should not be ignored as this could affect the long-term sustainability of a reclaimed water irrigation scheme (Smith *et al.* 1996).

Metal mobility and bioavailability in soil varies significantly with soil properties for similar total soil metal concentrations. Some metals pose little hazard through food chain contamination due to their strong phytotoxic effects (*i.e.* increasing metal concentrations cause mortality before transfer to the next trophic level has an opportunity to occur). This has been termed the "soil-plant barrier" and metals can fall into four groups based on their retention in soil and translocation within the plant (Table 6.1). Cadmium has been identified as the major heavy metal of concern in sewage as it is, relative to most other metals, more available to plants and is found at concentrations in harvestable portions of the crops that could be harmful to humans, but show no toxic signs to the plant.

Table 6.1. Metal bioavailability grouping.

Group	Metal	Soil adsorption	Phytotoxicity	Food chain risk
1	Ag, Cr, Sn, Ti, Y and Zr	Low solubility and strong retention in soil	Low	Little risk because they are not taken up to any extent by plants
2	As, Hg and Pb	Strongly sorbed by soil colloids	Plant roots may adsorb them but not translocate to shoots or generally not phytotoxic except at very high concentrations	Pose minimal risks to the human food chain
3	B, Cu, Mn, Mo, Ni and Zn,	Less strongly sorbed by soil than group 1& 2.	Readily taken up by plants, and are phytotoxic at concentrations that pose little risk to human health.	Conceptually, the "soil-plant barrier" protects the food chain from these elements
4	Cd, Co, Mo and Se,	Least of all metals	Pose human or animal health risks at plant tissue concentrations which are not generally phytotoxic.	Bioaccumulation through the soil-plant-animal food chain.

Source Chaney (1980)

Appropriate thresholds for inorganic contaminants in agricultural soils have not yet been derived in Australia (McLaughlin *et al.* 2000). The National Environmental Protection Council (NEPC) in 2000 released the National Environmental Protection Measure (NEPM), which included suggested health-based investigation levels (HBILs) for contaminants in soils. These were developed principally for urban or residential areas and are not appropriate for application to agricultural areas (unless these are being developed for residential use). A second series of investigation levels, Interim Urban Environmental Investigation Levels (EILs), were developed based on environmental thresholds, with plant phytotoxicity being used as the critical risk pathway. There are several shortcomings in using these EILs to assess contaminant risks in agricultural soils (McLaughlin *et al.* 2000), including lack of consideration of soil microbial risk pathways (*i.e.* risk of contaminants to soil health), poor inclusion of soil background concentrations and the drawbacks associated with using total contaminant concentrations to assess risk (*i.e.* a lack of appreciation of contaminant bioavailability). Nevertheless, the NEPM EILs are forming the basis for the draft National Guidelines for Sewerage Systems—Biosolids Management, which are used for agricultural soils. In Victoria, the Draft Environmental Guidelines for Biosolids Management are still under review by the Victorian EPA, but the last draft of the guidelines (February 2000) proposed Receiving Soil Contamination Ceiling Levels (RSCCLs) very similar to the NEPM EILs, except that Cd has a RSCCL of 1 mg/kg instead of 3 mg/kg in the NEPM EIL (Table 6.2). Note also that the NEPM specifies EILs for phosphorus of 2000 mg/kg, sulfur 600 mg/kg and sulfate 2000 mg/kg). Other states have defined similar soil limit values for sludge application to agricultural soils (McLaughlin *et al.* 2000). Queensland have adopted NSW guidelines as an interim measure until they can finalise their guidelines.

Table 6.2. Soil contaminant investigation levels (mg/kg), for the Draft Victorian Environmental Guidelines for Biosolids Management.

SUBSTANCES	Health Investigation Levels (HILs)[1]				EILs[10]	Background
	A	D	E	F	Interim [5]	Ranges[6]
METALS/METALLOIDS					Urban	
Arsenic(total)	100	400	200	500	20	1 to 50
Barium				300	300	100 - 300
Beryllium	20	80	40	100		
Cadmium	20	80	40	100	3	1
Chromium(III)	12%	48%	24%	60%	400	
Chromium(IV)	100	400	200	500	1	
Chromium(Total)[*7]						5-1000
Cobalt	100	400	200	500		1 to 40
Copper	1000	4000	2000	5000	100	2-100
Lead	300	1200	600	1500	600	2-200
Manganese	1500	6000	3000	7500	500	850
Methyl mercury		10	40	20		
Mercury (inorganic)		15	60	30	1	0.03
Nickel	600	2400	600	3000	60	5-500
Vanadium	50	20	-	500	50	20-500
Zinc	7000	28000	14000	35000	200	10-300
OTHER						
Boron	3000	12000	6000	15000		
Cyanides(Complexed)	500	2000	1000	2500		
Cyanides(free)	250	1000	500	1250		
Phosphorus					2000	
Sulfur					600	
Sulfate[9]					2000	

Source EPA Victoria(2000)

[1]Human exposure settings based on land use have been established for HILs (see Taylor and Langley 1998). These are:

A. 'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children's day-care centres, kindergartens, preschools and primary schools.

D. Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high-rise apartments and flats.

E. Parks, recreational open space and playing fields: includes secondary schools.

F. Commercial/Industrial: includes premises such as shops and offices as well as factories and industrial sites.

(For details on derivation of HILs for human exposure settings based on land use see Schedule B(7A).

[2] Site and contaminant specific: on site sampling is the preferred approach for estimating poultry and plant uptake. Exposure estimates may then be compared to the relevant ADIs, PTWIs and GDs.

[3] Site and contaminant specific: on site sampling is the preferred approach for estimating plant uptake. . Exposure estimates may then be compared to the relevant ADIs, PTWIs and GDs.

[4] These will be developed for regional areas by jurisdictions as required.

[5] Interim EILs for the urban setting are based on considerations of phytotoxicity, ANZECC B levels, and soil survey data from urban residential properties in four Australian capital cities.

[6] Background ranges, where HILs or EILs are set, are taken from the Field Geologist's Manual, compiled by D A Berkman, Third Edition 1989. Publisher – The Australasian Institute of Mining & Metallurgy. This publication contains information on a more extensive list of soil elements than is included in this Table. Another source of information is Contaminated Sites Monograph No. 4: Trace Element Concentrations in Soils from Rural & Urban Areas of Australia, 1995. South Australian Health Commission.

[7] Valence state not distinguished – expected as Cr (III).

[8] The carbon number is an 'equivalent carbon number' based on a method that standardises according to boiling point. It is a method used by some analytical laboratories to report carbon numbers for chemicals evaluated on a boiling point GC column.

[9] For protection of built structures.

[10]Ecological Investigation Levels (EILs)

Heavy metal uptake by plants varies greatly between plant species and part. For example, the fruiting organ generally contains the least Cd and the leaves higher concentrations. These concentrations can vary from <0.5 to 15 mg Cd/kg dry matter, depending on the species (Davis 1984). Therefore, any crop that has a leaf as the edible part has a much greater risk of containing high levels of Cd in a given situation. The potential risk of cadmium uptake is higher for root and tuber vegetables, leafy vegetables and peanuts (AFFA 2001). However, many factors influence the phytoavailability of metals in soil. Some of the major factors are soil pH, clay content, organic matter, salinity of irrigation water, and plant species and cultivars.

Arsenic, cadmium, mercury and lead are the main inorganic contaminants likely to be scrutinised in relation to food quality (Table 6.3). Lead is rarely an issue in terms of crop uptake, as the metal is strongly absorbed by soil and if taken up by roots, is rarely translocated to edible plant parts. Where lead contamination has been identified, this is usually due to aerial contamination of the produce, either through dust contamination, or uptake of atmospheric lead derived from automobile or industrial sources. Similarly, arsenic is strongly retained by soil and is generally not regarded as a high risk for food chain contamination.

It is unlikely that either chromium or nickel pose great risks as these elements are often strongly adsorbed or precipitated in soils. For chromium, elemental speciation is critical in assessing risks, as the Cr (III) form is non-toxic and precipitated in soil, while Cr (IV) is highly toxic and mobile. Lead is also strongly retained in soils and not readily taken up by plants or microorganisms.

It has been known for some time that after addition of soluble metals to soil, availability of the metal decreases with time. Initially this decrease is associated with adsorption of metals to soil surfaces, but longer-term, slower “fixation” reactions appear to proceed, following adsorption, which continue to reduce metal bio- and phytoavailability. Metal adsorption needs to be distinguished from metal fixation—the former leads to a reversible binding of metal to the soil solid phase, while the latter leads to an irreversible (or less reversible) binding of metal to soil. The heavy metals added with reclaimed water are usually added slowly over time, which may allow slower fixation of these metals and plant availability may be lower in the long-term.

Table 6.3. Maximum permitted concentrations of metal contaminants in food.

Contaminant and food	Contaminant mg/kg as consumed
Arsenic (total)	
Cereals	1
Arsenic (inorganic)	
Crustacea	2
Fish	2
Molluscs	1
Seaweed (edible kelp)	1
Cadmium	
Chocolate and cocoa products	0.5
Kidney of cattle, sheep and pig	2.5
Leafy vegetables (as specified in Schedule 4 to Standard 1.4.2)	0.1
Liver of cattle, sheep and pig	1.25
Meat of cattle, sheep and pig (excluding offal)	0.05
Molluscs (excluding dredge/bluff oysters and queen scallops)	2
Peanuts	0.1
Rice	0.1
Root and tuber vegetables (as specified in Schedule 4 to Standard 1.4.2)	0.1
Wheat	0.1
Lead	
Brassicas	0.3
Cereals, Pulses and Legumes	0.2
Edible offal of cattle, sheep, pig and poultry	0.5
Fish	0.5
Fruit	0.1
Infant formulae	0.02
Meat of cattle, sheep, pig and poultry (excluding offal)	0.1
Molluscs	2
Vegetables (except brassicas)	0. 1
Mercury	
Crustacea mean level of	0.5*
Fish (as specified in Schedule 4 to Standard 1.4.2) and fish products, excluding gemfish, billfish (including marlin), southern bluefin tuna, barramundi, ling, orange roughy, rays and all species of shark	0.5*
Gemfish, billfish (including marlin), southern bluefin tuna, barramundi, ling, orange roughy, rays and all species of shark	1*
Fish for which insufficient samples	1
Molluscs	0.5*
Tin	
All canned foods	250

Source ANZFA (2001).

- mean level as prescribed by ANZFA (2001).

Even though the concentration of cadmium in reclaimed water could be negligible, an insignificant amount of Cd would be added to the soil through irrigation with reclaimed water. Changes in soil salinity and chloride concentrations due to use of reclaimed water has the potential to increase plant availability of Cd (McLaughlin *et al.* 1994).

Heavy metals in reclaimed water are generally insignificant, however, issues could potentially arise and concentrations should be monitored. Loading rates of heavy metals in irrigation water can be easily calculated and potential issues identified with readily available guidelines. Heavy metal accumulation in soils is best managed by prevention, as once applied to the soil they are difficult to remove.

6.4 Unknown hazards

Despite the best efforts of science, there is always the possibility that some potential hazards have simply not been discovered. Such 'fear of the unknown' is difficult to deal with, as risks cannot be estimated easily, if at all, and arguments can generally only be conducted at a philosophical level. Nonetheless, it is a legitimate concern, and it is one often put forward in debate on genetically modified organisms. Furthermore, it is supported by history, most notably with the environmental impacts of DDT (dichloro-diphenyl-trichloroethane). At the very least, Australian scientists need to be vigilant and aware of the latest international research on potential hazards. Recording health incidents in a centralised database could be a useful means of studying long-term trends, and thus could help researchers detect subtle or previously unknown health effects (SKM 2002).

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7 Australian horticultural production: field trials and reuse schemes

7.1 Field trials on the use of reclaimed water for horticultural production

There have been surprisingly few field trials in Australia aimed at investigating the impact of irrigating with reclaimed water on production and food-safety parameters of horticultural crops. This is perhaps somewhat surprising considering the large number of horticultural reuse schemes currently operating in Australia (Section 7.2). The most comprehensive studies were one at the Bolivar STP in SA in early 1970s and another conducted in the late 1970s–early 1980s at the Vegetable Research Station at Frankston, Victoria.

The South Australian study involved irrigating lucerne, glass-house tomatoes and cucumbers, almonds, potatoes, onions, root crops, cabbages, cauliflowers and wine grapes with effluent from the Bolivar STP, and assessing the viability of each scenario from an agronomic perspective (Matheson and Lobban 1974, Read *et al.* 1974). Food safety studies were not conducted. With the exceptions of almonds and wine grapes, there were no significant problems identified with using the reclaimed water to irrigate any of these crops. However, it was acknowledged that adjusted fertiliser requirements of the crops irrigated with reclaimed water were not studied. High concentrations of sodium and chloride were found in the leaves of almond trees, and thus the success of a long term reclaimed water irrigation scheme for this crop was questioned. Similarly, salinity was identified as a potential issue when irrigating wine grapes, but it was suggested that this may be able to be circumvented with appropriate management practices.

This Victorian project at Frankston involved irrigating vegetable crops with reclaimed water from the South-eastern Purification Plant at Carrum. This study was divided into two main streams, one dealing with agronomy (Kaddous and Stubbs 1983) and the other with human health issues (Smith 1982).

In the agronomic study, five different irrigation/fertiliser treatments were applied to cabbage, carrot, celery, lettuce, spinach and tomato crops. Four of the treatments involved the use of reclaimed water, and one, bore water. The general finding of the study was that there was no significant difference in the marketable yield, for any of the crops, resulting from the application of the various irrigation/fertiliser treatments. Furthermore, depending on crop type and season, irrigation with reclaimed water lead to a mean saving of 60%, 33% and 40% of the crop requirements for nitrogen, phosphorus and potassium respectively. The accumulation of heavy metals in the soil and plant tissues did not differ significantly between treatments. However, the concentrations of heavy metals in the reclaimed water used were generally very low, reflecting the almost exclusively domestic origin of the sewage. The effluent from many large sewage treatment plants originates from high industrial inputs (e.g 40% of the sewage at the Western Treatment Plant, Victoria, is of industrial origin). Heavy metals would generally be expected to be substantially higher in industrial waste than domestic waste.

The study of the human health risks involved investigations into the retention and accumulation of bacteria, viruses and heavy metals in crops that had been spray irrigated with reclaimed or control (bore) water. Parasites and organic chemicals were not sampled. The bacteriological study of cabbage, carrot, celery and tomato crops revealed that the levels of *E. coli*, while being significantly higher in the reclaimed water than the control water, were not significantly different between plants irrigated with reclaimed or bore water. However, the possibility of contamination of the control crops from spray drift, could not be discounted. *Salmonella typhimurium* was only detected on one occasion, in the reclaimed water, and was never found on the vegetables. The virological study identified significantly higher levels of viruses in the reclaimed water compared to the control water, but this did not translate into significant differences in levels found in the vegetables (cabbage, carrot, celery, lettuce, tomato and spinach). However, before application, the reclaimed water in this study was stored in a retention lagoon for varying periods, and this was considered to be an important step for reducing viral loads in the irrigation water. Concentrations of up to 1,825 infectious viral units per litre were detected in reclaimed water prior to entering the storage pond, but concentrations never exceeded 8 infectious viral per litre in the water leaving the storage pond. As described above, heavy metal concentrations were relatively low in the reclaimed water, most likely owing to the domestic origin of the water, and the concentrations found in plants irrigated with reclaimed and control water were not significantly different.

A few smaller field studies on horticultural reuse in Australia have been conducted, primarily to confirm the validity and safety of proposed reclaimed irrigation schemes for particular enterprises. For example, the agronomic and human health issues associated with the use of reclaimed water for irrigating potato crops were studied by Premier *et al.* (2000). Yields and quality were similar between crops irrigated with reclaimed and potable water. Similarly, irrigating with reclaimed water did not lead to elevated heavy metal (*e.g.* cadmium) concentrations in the crop, although the fact that the water was derived from a predominantly domestic sewerage system, unlikely to have high heavy metal concentrations, was acknowledged. Bacteriological studies suggested that disease risk to consumers was the same for potatoes irrigated with reclaimed and potable water. The results of this small study, however, need to be treated with caution, as logistical constraints prevented a replicated trial design.

7.2 Existing and proposed horticultural reuse schemes

Despite the controversy surrounding the use of reclaimed water, it is currently being used in many parts of Australia to irrigate horticultural crops, and several major schemes are in development. There are too many small horticultural enterprises using reclaimed irrigation water to be described here. However, a brief description of the major horticultural reuse schemes in each state and territory will be presented. An inventory of reuse schemes was recently produced by Radcliffe (2003), and unless otherwise indicated, the information below has been sourced from this work. Radcliffe (2003) identified many public open space schemes (e.g. golf courses and parks), industrial uses and residential “third-pipe” projects. Here, however, we are solely concerned with major horticultural reuse projects (summarised in Table 7.1).

At present, there is only one horticultural reuse project in the Australian Capital Territory. Tertiary treated effluent from the Lower Molongo Sewage Treatment Plant (STP) is being used to irrigate vineyards. The largest reuse initiative in NSW is the Shoalhaven Reclaimed Water Management Scheme on the south coast of NSW (Moore and Gould 2003). The reclaimed water is sourced from six interconnected STPs in the Shoalhaven region. Operation of the scheme started in December 2001. All of the reclaimed water undergoes tertiary treatment, including filtration and chlorination. The scheme will supply 9 GL of reclaimed water to 1,200 hectares of irrigated farmland. At present there are 16 properties using the effluent, but these are mostly dairy enterprises.

The only horticultural reuse scheme in the Northern Territory is at Alice Spings (Ireland 2003). Effluent from waste stabilisation ponds (WSPs) at the Alice Springs STP undergoes further treatment including either aquifer storage and recovery (ASR) or soil aquifer treatment (SAT). The project is currently in its infancy, but it is intended that reclaimed water will be used to irrigate commercial horticultural crops.

In 1996 a proposal to supply irrigated crops in the Lockyer Valley was put forward. This was later extended to include Darling Downs, Bremer Valley and Warrill Valley, and became known as the South East Queensland Recycled Water Project (Lehmann and Evans 2003). The scheme is currently under consideration (South East Qld Recycled Water—Task Force Report 2003). Another proposed reuse scheme in Queensland is at Toowoomba, where reclaimed water from a new 16 ML/day STP will be used for agriculture, including horticulture, and coal washing.

The Virginia Pipeline Scheme in South Australia is Australia's largest reuse scheme for horticulture (Krackman *et al.* 2001, Kelly *et al.* 2003). The Virginia region accounts for about 35% of South Australia's horticultural production, which equates to about AU$120 million (Krackman *et al.* 2001). The reuse scheme involves providing Class A reclaimed water from the Bolivar STP to about 250 vegetable growers. The water undergoes standard primary sedimentation, secondary treatment via biological trickling filters, and tertiary treatment with a dissolved air flotation/filtration plant followed by retention in a disinfection and storage contact reservoir. Currently, about 8 GL/annum of this reclaimed water is being used by horticulturalists, but the system can potentially deliver 23 GL/annum (Kelly *et al.* 2003, Radcliffe 2003. Another major South Australian reuse scheme involves the provision of Class C reclaimed water to viticulturists in the Southern Vales. ASR is also being tested at both Virginia and the Southern Vales (Dillon *et al.* 1999, Dillon *et al.* 2001).

In Tasmania, the only large reclaimed water irrigation scheme is that of the Coal River Irrigation District in the south, where over 500 farms, including horticulture, viticulture and turf growing, are supplied with secondary treated effluent from the Rosny Park STP. Possibly the largest demand for reclaimed irrigation water will be in the Midlands, where the climate is generally much drier. This area is, however, greatly affected by salinity, and this may prove to be a significant impediment to adoption of reclaimed water irrigation schemes.

There are several horticultural enterprises in Victoria currently using reclaimed water for irrigation, and a few large-scale reuse schemes are being planned. Barwon Water is providing Class C reclaimed water from its Black Rock STP to irrigate grape vines, flowers, potatoes, tomatoes and turf. Western Water is supplying Class B reclaimed water to farmers via its Sunbury-Melton pipeline, and South-East Water also supplies agricultural producers with reclaimed water from its Pakenham STP. Relatively small volumes of reclaimed water from the Eastern Purification Plant (EPP) are supplied by Melbourne Water to horticultural producers.

A target of 20% reuse of Melbourne's water by 2010 has been fixed by the Victorian Water Recycling Action Plan (Anon. 2002a). In addition to those outlined above, other recycling schemes need to be implemented if this goal is to be reached. To this end, a scoping study identifying potential zones for reuse schemes in the greater Melbourne region was conducted (Bluml *et al.* 2002). There are two major schemes being developed: the Werribee Plains Vision (DSE 2002) and the Eastern Irrigation Scheme (Arbon and Ireland 2003).

Highly treated reclaimed water for the Werribee Vision would be sourced from the Western Treatment Plant (WTP). The Werribee Vision scheme aims to use reclaimed water from the WTP to irrigate crops in the region. One possibility is to direct some water to the existing vegetable market gardens in Werribee South. This plan has been received with circumspection by some growers, who demand more proof of the safety of irrigating with reclaimed water (Fisher 2003). A much larger project is the development of a new horticultural district near Balliang (KBR 2003). It has been proposed that approximately 10,000 hectares 45 km north of the WTP, currently being used for dryland grazing, be converted to irrigated horticulture (Anon. 2002b). Likely crops would be vines, stone fruits, vegetables and olives. Another component of the Werribee Vision is the commissioning of a 400 hectare demonstration site at the WTP. The purpose of this site will be to promote horticultural irrigation with reclaimed water (Anon. 2003).

The Eastern Irrigation Scheme will draw on reclaimed water from the ETP, which will be upgraded with the addition of tertiary treatment facilities. The reclaimed water will mainly be used to irrigate horticulture in the Cranbourne-Koo Wee Rup region (Arbon and Ireland 2003). Allied with the scheme is a plan to use treated effluent from the existing discharge pipeline from the ETP. This pipeline runs the length of the Mornington Peninsula, and could be used to irrigate the horticultural irrigation area at Boneo as well as orchards and vineyards at Moorooduc.

There were 67 reuse schemes in Western Australia in 2002, and a further eight are soon to be commissioned (Radcliffe 2003). Most of these are small agricultural schemes. To date, there has been little demand for reclaimed water in the Perth district, owing to the ready availability of good quality groundwater. Radcliffe's (2003) review did not identify any specific horticultural reuse schemes. There are, however, major horticultural/agricultural reuse schemes currently being considered (CSIRO *et al.* 2002). Opportunities for large horticultural/agricultural reuse schemes have been identified for the Swan Valley, Carabooda, Guilerton, and possibly Harvey. In the Swan Valley current horticultural and viticultural production is limited by the availability of suitable groundwater. The proposed reuse scheme would be expensive and difficult owing to the need for local treatment, seasonal demand issues and the potential for contamination of waterways with nutrients. At Carabooda the proposal is to substitute the 10 GLpa of superficial groundwater currently used for horticultural irrigation with reclaimed water from the Beenyup STP. The proposal at Guilderton is to establish a new horticultural area that will be supplied with reclaimed water from the Beenyup STP, and possibly in the future from the planned Alkimos STP. At Harvey, the proposal is to use reclaimed water from the Woodman Point STP or the planned East Rockingham STP to irrigate the existing horticultural area.

Table 7.1. Major horticultural reuse schemes in Australia

scheme	state/territory	crops	status
Molongo	ACT	vineyards	operational
Shoalhaven	NSW	agriculture/horticulture	operational/expanding
Alice Springs	NT	horticulture	under construction
SE QLD (Lockyer)	QLD	agriculture/horticulture	proposed
Toowoomba	QLD	agriculture/horticulture	proposed
Virginia Pipeline	SA	horticulture	operational
Southern Vales	SA	viticulture	operational
Coal River	Tasmania	horticulture/viticulture	operational
Black Rock	Victoria	grape vines, flowers, potatoes, tomatoes and turf	operational
Sunbury-Melton Pipeline	Victoria	agriculture	operational
Pakenham	Victoria	agriculture	operational
Werribee Vision	Victoria	horticulture	proposed
Eastern Irrigation Scheme	Victoria	horticulture	proposed
Carabooda	WA	horticulture	proposed
Guilerton	WA	horticulture	proposed
Harvey	WA	horticulture	proposed
Swan Valley	WA	horticulture/viticulture	proposed

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