# Australasian experiences with land treatment schemes and irrigated forestry

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## 1. ABSTRACT

Governments are being forced by societal demands to counter any deterioration in living standards caused by climate change, air and water pollution from industry and society. This often generates conflicting requirements for low cost solutions that also meet stringent health and environmental standards. Research since the early 1960's indicates that waste water irrigation of forests and plantations is potentially an effective low cost treatment option and a productive re-use of waste water, while contributing to economic development and environmental protection.

Some excellent scientific research has been generated in the past 40 years to improve our understanding of crop physiological responses and environmental sustainability of Effluent Irrigated Forests (EIF), yet larger scale uptake in both Australia and New Zealand appears stalled because of a lack of industrial end uses for the biomass produced. Some recent research results present sobering prospects for the potential of EIF, particularly with regard to long term growth and sustainability issues.

Maintenance of tree growth rates and site productivity is crucial to the achievement of desired social, economic and environmental outcomes, the development of markets or local industry to use forest products, for the continuation of this method of waste disposal. Nutrient and contaminant loading rates have major implications for effluent application rates, total land area requirements, and species choice. Salinity and sodicity issues will continue to challenge the long term environmental sustainability of effluent-irrigated plantations, particularly in Australia. Additional multidisciplinary research is required on the effects of salt and nutrient loading on soils, and management of the effluent – soil – crop system. Critical species choice and sustainability issues cannot be adequately addressed without long term funding.

Regulatory pressure to renovate effluents to potable water standards by removal of nutrients, other chemicals and micro-organisms constitutes a threat to potential revenue producing disposal options. There are biological solutions to biological problems such as effluent disposal. Effluent irrigated forestry presents a disposal option that provide environmental benefits and co-products which avoid the human food chain, while reducing the requirement for expensive secondary treatment and disinfection. Wastes will remain a perpetual and increasing problem to society, and economic and environmentally friendly options such as energy production from biomass need greater publicity and investment support.

## 2. INTRODUCTION

Explosive population growth has increased the generation of both solid and liquid wastes from society, however many communities still rely on the removal and dilution of their treated effluent by discharging into nearby rivers or oceans. Degradation of those waters and associated ecosystems has greatly increased with population expansion and industrial development, however environmental and regulatory pressures have now forced many local authorities responsible for effluent treatment to consider alternative land application options, or use expensive tertiary treatment processes.

Research since the early 1960's indicates that waste water irrigation of forests and plantations is potentially an effective low cost treatment option and a productive re-use of waste water if sufficient land is available close to sewerage treatment plants.

Effluent irrigated forestry (EIF) plantations operate under similar constraints as other land disposal schemes, but also have additional benefits including non-food products and greater water use per unit area of land. It is also feasible for EIF to renovate secondary or even primary effluent outside the human food chain by absorbing nutrients and destroying microbial contamination within the soil system, without the need for expensive pre-treatment and disinfection. There is now nearly 40 years experience from trials established in Pennsylvania that demonstrate forestry disposal options may recharge potable quality groundwater at minimal net cost (Sopper, 1971).

Much of the pioneering knowledge on species performance and silviculture in irrigated plantations in southern Australia was gained from trials established in Victoria during 1972–1980, including those at Kyabram (McKimm, 1974), Werribee, Mildura, Robinvale, Merbein, Horsham, Wangaratta, Wodonga (Stewart *et al*., 1979, 1982, 1988), and Dutson Downs (Cromer *et al*., 1983). These trials screened a wide range of eucalypt species, but willows, poplars and radiata pine were also trialled. The excellent growth responses in these trials prompted larger irrigation projects along the Murray River in South Australia, and Alice Springs for firewood (Stewart *et al*., 1986). Both Australia and New Zealand have produced excellent land treatment guidelines (Myers *et al*., 1999; NZLTC, 2000).

In New Zealand, research has focussed on irrigation of radiata pine plantations, although a number of other hardwood genera including eucalypts have been evaluated. The New Zealand Land Treatment Collective was established in 1989 to provide information on treatment technology and research developments, and improve communication among researchers and industry partners in the land treatment sector.

Growth of tree plantations over most of the Australian continent is often constrained more by lack of water than low soil nutrient levels. Stewart and Boardman (1991) reported there were 20 effluent projects in southern Australia with a total area of 350 ha in operation at that time, and even greater potential to develop eucalypt plantations irrigated with agricultural drainage water or moderately saline groundwater. Large volumes of water and an estimated 200,000 ha of land were available in South Australia alone.

Several major EIF studies in Australia initiated in the early nineties have investigated biomass production potential, tree water use and nutrient dynamics of several promising species under a range of soil types, climate and effluent composition. These studies include trials at Werribee, Bolivar, Loxton, Wagga Wagga (Wagga) and Shepparton. Some studies included variations in effluent application rates and stocking, and investigated silvicultural regimes for specified products including bioenergy production. Larger scale projects were established during this period at Albany, Koorlong (Mildura) and Albury with a range of species and effluents.

Considerable information on many of the recent Australian and New Zealand trials are presented in the proceedings and field notes for the N.Z. Land Treatment Collective meeting in Australia in 1996 (Polglase and Tunningley, 1996). Nicholas (2000) provided a more recent overview of effluent irrigation results pertinent to short rotation crops (SRC) at the International Energy Agency (IEA) Task 30 conference in Albany. Readers are referred to these papers for more detailed trial information and summaries of results.

Many of the results reported to date present early growth data to age four or six, which indicate high survival and rapid growth rates, but give little evidence of the longer term growth potential. Maintenance of tree growth rates and site productivity is crucial to the achievement of desired social, economic and environmental outcomes, the development of markets or local industry to use forest products, for the continuation of this method of waste disposal. Some excellent scientific research has been generated in the past 40 years to improve our understanding of crop physiological responses and the environmental sustainability of EIF, yet larger scale industrial uptake in both Australia and New Zealand appears stalled because of a lack of end uses for the biomass produced (Nicholas, 2000).

Some recent research results present sobering prospects for the potential of EIF, particularly with regard to long term growth and sustainability issues (Duncan *et al*., 2002; Polglase *et al*., 2002). It is pertinent to review these implications, their relevance to natural resource management and future research directions.

## 3. SUSTAINABILITY ISSUES

Long term sustainability of effluent irrigation is inextricably linked to two key issues – the total volume and the quality of the effluent. Both have significant impacts on the methods of disposal adopted, along with implications for silvicultural management of the crop. Their combined impact determines the overall load of nutrients and contaminants applied to each site, and defines the primary objective of effluent management (water disposal, nutrient stripping or pollution prevention).

The volume of effluent available has major effects on the required tree water use rates, and the total area to be established. The latter may vary depending on soil type (storage volume and porosity) and climate, particularly rainfall and evaporation. Tree transpiration rates in southern Australia are strongly cyclic, typically reaching a maximum over summer, and falling sharply during winter. High vapour pressure deficits over summer may cause stomatal closure and reduced transpiration, while low water use over winter may necessitate development of effluent storage structures. Major differences in rainfall between sites in New Zealand and Australia may increase the requirement to store effluent during periods of heavy rain, and increase the risk of surface runoff to pollute streamflow. Where limited land area is available, options such as flood or sprinkler irrigation which increase evaporation losses may assist effluent disposal.

Results from a three-year study of growth and water use in young, flood-irrigated eucalypt plantations near Deniliquin have been recently reported by Polglase *et al*. (2002). On shallow clayey soils, or where sub-soil properties impeded root penetration, the authors recommended irrigation every 10-14 days in relatively small volumes (0.5 ML/ha) to maximise growth per megalitre of water applied and minimise application losses during flood irrigation. On sandy loam soils conducive to deeper root development, less frequent irrigation (4 times/season) in larger volumes (1.5 ML/ha) was considered more efficient. The sandy loam texture of the soil holds water less tightly and a greater volume is stored due to the large rooting depth, making more of the water applied available to trees, with higher crop productivity.

Careful selection of sites, soil types and species, followed by appropriate irrigation strategies, are required if plantation projects are to achieve reasonable growth rates and control rising watertables. Broad scale flood irrigation was found to be highly inefficient since about 50-70% of applied effluent was lost through direct evaporation, deep drainage or run-off. Irrigation systems that increase the efficiency (and cost) of application could apply less water more frequently, or alternatively enable irrigation of larger areas of plantation. More efficient agricultural irrigation practices would reduce the initial sustainability problem. A combination of flood irrigation of pasture and trickle irrigation of approximately 300 ha of *E. globulus* for wood chip has been established at Albany, Western Australia as a land treatment option (Sillifant, 1996).

The use of sub-surface irrigation with specially designed systems appears to hold considerable promise. This is under evaluation with a eucalypt crop in New Zealand (Gearing *et al*., 2002).

The composition of the effluent is usually the critical determinant of irrigation practice, species choice and long term project viability. Effluents are essentially a cocktail of water plus contaminants from a wide range of sources (municipal, industrial, cannery, dairy, irrigation drainage). While some contaminants are potentially valuable plant nutrients, and others toxic to plant growth, excessive amounts of any single constituent are often detrimental to plant growth. Monitoring of application rates and the environmental effects on groundwater and soil parameters are critical to the successful operation of EIF schemes.

### 3.1. Nutrients

One of the major limitations for sustainable effluent disposal using trees or crops is the uptake and storage of large quantities of nutrients within the soil – plant system.

Irrigation alone is likely to increase mineralisation of native soil nutrient reserves, regardless of the additional quantities supplied in effluents. Under rainfed conditions, young trees obtain their nutrient requirements from the soil, however most forests have relatively closed nutrient budgets at older ages that rely extensively on internal nutrient cycling to meet their annual growth needs. Most nutrients are stored in greatest quantities in foliage, and uptake and storage in harvestable biomass such as wood and bark is significantly slower.

The two nutrients of greatest concern in EIF projects are usually N and P since movement into waterways may cause eutrophication and toxic algal blooms. Nitrification, the conversion of ammonium to nitrate, is potentially one of the major factors limiting the total amount of effluent that can be applied, as nitrate is poorly sorbed by soil particles and is readily leached to pollute groundwater. Nitrate is a recognised health risk, but the use of short rotation crop to maximise accumulation of nutrients in vegetation can mitigate leaching and may reduce groundwater contamination. Many eucalypt species are able to use this form of nitrogen better than conifers without developing severe stem malformation.

The phosphate ion is strongly sorbed on clay soils by iron and aluminium, and many forests systems efficiently retain additional supplies of P. Leaching of P through the soil profile at Wagga was not as rapid as predicted from conventional soil P transport models (Falkiner and Polglase, 1997).

Maintenance of stand health and vigor requires comprehensive monitoring of inputs/outputs in soils and vegetation, and knowledge of differences in nutrient balance and accumulation between species. Full nutrient analysis of biomass components is rarely undertaken, particularly for older trees, due to cost and sampling problems.

Foliar analysis is often used to monitor the health of plantations since foliage is the site of important physiological growth processes such as photosynthesis and transpiration, and generally contains the greatest store of nutrients. Past studies have focussed on the macronutrients N P K Ca Mg, with significantly less emphasis on other elements. Trace element analyses are less frequently undertaken, and are even rarer for biomass and soil studies. Reliable data on soil movement, tree uptake and storage of heavy metals from industrial effluent sources in Australasia is surprisingly uncommon.

### 3.2. Salinity and Sodicity

Sodium and chloride may be significant components of effluent, particularly in coastal situations and drier environments due to annual accessions in rainfall and naturally higher levels in drinking water. These problems can be exacerbated by location of sewerage works on saline wasteland and evaporative losses during secondary treatment. The presence of bicarbonate/carbonate ions in effluent may add further management complications through alteration of soil alkalinity, with related impacts on the soil mobility and plant availability of trace elements.

Salinity and sodicity are inter-related issues of critical importance to the management of effluent-irrigated plantations. Sodicity results from displacement of Ca and Mg by Na in soil cation exchange capacity, leading to dispersion of clay and reductions in soil permeability. Reduced rates of water infiltration have implications for leaching of salt through the rootzone. Soils with an exchangeable sodium percentage (ESP) > 15 are usually considered sodic, however use of deep soils (preferably sands or pumice) with low clay content may cause little reduction in surface permeability or tree growth as salts can be rapidly leached below the major rootzone in the upper 40 cm of soil.

Large increases in ESP from application of saline effluent are frequently observed, particularly just below the major tree root zone. Falkiner and Smith (1997) observed a very large increase in ESP from around 2% to over 25 % at around 35 cm depth after 4 years of effluent irrigation at Wagga, although there was no measurable decrease in infiltration rate (Balks *et al*., 1998).

Analyses of groundwater, irrigation water, foliage, surface soil and tree growth to age 6 for flood irrigated eucalypt trials ("Trees for Profit"series) in northern Victoria were recently reported by Duncan *et al*. (2002). A range of water sources and qualities available in northern Victoria (low salinity channel water to high salinity groundwater to nutrient-rich municipal effluent) were applied to four eucalypt species at each site (*E. camaldulensis, E. globulus, E. grandis* and *E. saligna*). Strong correlations between the salinity of the irrigation water and the development of salinity and soil sodicity were observed. At Tatura and Timmering, where the irrigation water was highly saline groundwater (4.0 to 6.9 dS/m), salt accumulation has occurred throughout the soil profile, and growth of all species was significantly reduced. Salt accumulation was not a serious problem at sites irrigated with low salinity water, but unfortunately there are inadequate records of frequency and amounts of irrigation applied at some sites.

Six years of irrigation with saline groundwater at the Timmering site resulted in the soil becoming highly sodic, significant chloride accumulation in tree foliage, and poor growth rates. Only a slight increase in soil sodicity and much higher growth rates by all species were observed on the same site by irrigation with channel water. Irrigation with high sodium municipal effluent at Shepparton also increased soil salinity and sodicity, and foliar Cl. Any potential negative impacts on tree growth appear masked by the beneficial effects of the additional nutrients in the effluent as growth rates to age 6 years are amongst the highest recorded in southern Australia.

The trend of increasing soil salinity and sodicity at a number of TFP sites under saline irrigation, associated with higher foliar Cl levels and reduced tree productivity, represents a serious sustainability issue. Irrigation with channel water appeared an effective method to leach salts below the root zone at some sites, however the authors (Duncan *et al*., 2002). questioned the environmental sustainability of eucalypt plantations irrigated with low quality water.

## 3.3 Salinity

The negative effects of salinity are manifested through reductions in tree productivity, principally through affects on leaf production (leaf chlorosis and premature leaf shed). Reduced leaf area reduces rainfall interception and transpiration, and constrains the volume of effluent that can be applied. Tolerance to salinity is highly species dependent. Foliar analysis often reveals very low levels of chloride in *E. camaldulensis* compared to *E. globulus, E. grandis* or *E. saligna* (Duncan *et al*., 2002), but faster growth rates of the latter species suggest alternative storage of chloride in non vital tissues and biomass. Short term growth of *E. grandis* at Wagga was decreased by up to 75% with experimental increases in effluent salinity, whereas growth of *P. radiata* was unaffected (Myers *et al*., 1998). Re-examination of the water use data suggest that water use of *E. grandis* was reduced by around 9% over the period if pre-treatment differences in leaf area are accounted for.

Salinity can be managed by the imposition of leaching fractions (flushing with extra water), but large amounts of over-watering are required for relatively intolerant tree species such as *E. grandis*. Constraints such as lack of water supplies, inadequate soil depth or the presence of highly saline groundwater may preclude use of this option. Alternative species may be required in many situations, but this may reduce plantation productivity. Adding N+P fertiliser via dripper irrigation to promote growth of *E. camaldulensis* successfully reduced the impact of saline irrigation treatments at Loxton (Sweeny and Stevens, 1997).

### 3.4 Land requirement and loading rates

Sustainable wood supplies to industry may be achieved using intensive silviculture to attain high growth rates on limited areas, or by using less intensive inputs and practices to obtain lower growth rates over larger areas. The scale of EIF plantations is ultimately limited by the volume of wastewater available.

In trials where irrigation rates or sources were included as treatments, the fastest initial growth rates have been achieved with the highest rates of application. Growth to around age 4 are greatest with municipal effluents, even though nutrient and salt loadings are higher, and growth rates are slowest with freshwater treatments low in nutrients. However the freshwater and low effluent rate treatments may achieve similar productivity at later ages, as evidenced by results at Bolivar (Shaw *et al*., 1996) and unpublished data for Wagga (L. Stewart, CSIRO pers comm). Productivity of *P. radiata* treatments at Wagga equaled or surpassed the initially faster *E. grandis* by age six, with better long term increment potential due to greater crown mass, water use and nutrient uptake.

The Wagga and Bolivar results are particularly interesting as they provide a key to maintaining long term production and environmental sustainability. Rates of effluent application at Wagga were nominally 0.5x, 1.0x and 1.7x tree demand as determined by monitoring soil moisture changes. Broadly similar growth rates across irrigation treatments suggest lower rates of effluent application over a larger land base will achieve higher overall project productivity than application of greater quantities of irrigant to a reduced land base. Although land costs or availability may preclude this option in some circumstances, salt and nutrient loadings are reduced per unit area by this option. Long term site sustainability and project viability would be enhanced, and the greater resource availability may encourage development of markets or utilization industries. This lack of resource size has limited utilisation options for one of New Zealand's EIF sites (G. Newnham pers comm.).

Extensive clearance of deep-rooted perennials for agricultural crops over the last 100 years has changed the hydrologic equilibrium in low rainfall (300-600 mm) areas of Australia. Increased infiltration of rainfall has raised water tables and mobilised otherwise harmless stored salts to discharge to the surface in the most productive lower parts of the landscape. It is estimated that over 5 million ha of land has been damaged so far, and this area will rapidly increase unless urgent action is taken to ameliorate the problem. Current estimates predict over 17 Mha will be affected by 2050 (NLWR Audit, 2001). Increased salinity in river systems is a major problem in water catchments and is also causing loss of biodiversity, amenity and damage to infrastructure. Tree crops may be required on over 14 million ha (20%) of the wheatbelt to redress the salinity problem (Bartle and Shea, 2002), and there is potential for co-operative research among EIF and salinity researchers and translation of results on issues of mutual concern.

In New Zealand one of the main concerns with land requirement and loading rates has been the result of scheme operators treating the system as a disposal system, rather than one of environmental sustainability, resulting in inappropriate loading rates. At times these have lead to system breakdown.

## 4. CHOICE OF SPECIES

EIF research in Australia has mainly focussed on native eucalypts, although a range of species and genera were evaluated in early trials. The research emphasis in New Zealand has been on trials involving radiata pine, largely because existing pine forests (and markets) have been adjacent to effluent sources, however hardwood tree species have been preferred in some treatment schemes (Nicholas, 2000).

Interest in hardwood species stems from their fast initial growth rate, higher wood density, and higher biomass production at young age than most conifers. (Nicholas, 1986). This attribute is advantageous in EIF systems as fast early growth usually translates to greater water use and nutrient uptake. The high wood density is also suited to the production of fuelwood or bioenergy, an attractive market for products derived from land treatment schemes. Waste to energy options for projects based on nutrient stripping assist sustainability since site nutrient exports may be maximised using whole tree harvesting.

Although a range of species have been tested in research projects, it is difficult to identify the most preferred hardwood species for EIF schemes due to the variety of effluents, soil types and climate at treatment sites in New Zealand and Australia. *E. camaldulensis, E. grandis*, *E. globulus* and *E. saligna* have been extensively tested in Australian trials, but *E. globulus* is the main plantation eucalypt species. *E. ovata* and *E. botryoides* have performed well in various EIF trials in New Zealand, but have no recognized commercial importance in Australia. While *E. saligna* and *E. nitens* have also shown promise, they are prone to insect attack and *E. nitens* has shown variable success. *E. maidenii* has performed well on one site, but is still under evaluation. *E. camaldulensis* has often performed poorly against other species in both countries.

*E. occidentalis* and *Casuarina glauca* have shown consistently good performance in several Australian trials, particularly at older ages when significant salinity has built up within the root zone. Both species displayed higher wood density at age 6 than *E. globulus, E. grandis* and *E. camaldulensis* provenances tested at Bolivar (Clark, 2001). Various provenances of *E. occidentalis* exhibit poor stem form, but tree breeding initiatives are already underway as this species is of considerable interest for farm forestry in low rainfall areas.

Most trial results have been achieved using seedlots from natural provenances, with no tree breeding inputs. Significant genetic variation in commercially important characteristics, both between and within provenances, has been demonstrated in trials in many different countries. Further tree breeding work would improve the stem form and growth of many species. Tolerance of frost, waterlogging, salinity and drought are useful attributes for species grown under EIF in arid environments, particularly if water supply is limited or irregular. Some initial species screening trials were not very comprehensive or employed poor silvicultural practices by current standards. Further testing of species and provenances of known performance against current operational seedlots is warranted on any new EIF sites. The effects of enhanced growth rates on wood quality and suitability for different forest products also requires further investigation. An improved understanding of the eco-physiology of each species would be useful in the selection of sites for establishment, and tailoring silvicultural inputs to optimise plantation growth and economic returns.

Many eucalypt species occur in highly specialized ecological niche situations, and attempts to grow a subtropical species like *E. grandis* on sawlog regimes in more saline or arid microclimates requires careful consideration. Increased growth and adaptability to a wider range of sites may be achieved through exploitation of hybrid vigor from inter-specific eucalypt crosses. Dale (2003) reported improved volume growth of *E. grandis* and *E. globulus* hybrids with *E. camaldulensis* compared with either of the pure species parents in Australian trials. *E. grandis* has shown great potential in hybrid combinations with hardier species such as *E. camaldulensis* and *E. tereticornis* (redgums) on more demanding sites. Highly productive hybrids with *E. urophylla* are reproduced vegetatively for commercial plantation establishment at Aracruz in Brazil. Hybrids with redgums or *E. robusta* appeared to have greater resistance to freeze damage than pure *E. grandis* in Florida (Franklin and Meskimen, 1983). The potential to obtain genetically improved seed from advanced breeding programs in other countries should be pursued where appropriate.

### 4.1 Use of exotic species

Eucalypts are an exotic species in New Zealand, but in Australia a number of species evaluation projects are seeking alternative species for salinity management, revegetation and low rainfall farm forestry, however the principal focus is exploring the potential of native species. This largely ignores the fact that exotic species have greater growth potential than native species in any country, mostly due to the lack of significant insect and fungal pests that destroy leaf production. Growth of *Pinus radiata* in Australasia is an excellent example, while eucalypt productivity in South America, Africa, and Asia frequently exceeds growth rates obtained in Australian plantations.

Willows and poplars are extensively used in Europe as bioenergy crops because of their rapid growth rates, and offer potential as an exotic species in Australasia. Tree breeding work has been undertaken in Europe and New Zealand (van Krayenoord *et al*., 1995; Wilkinson, 2000), and clones are easily reproduced by vegetative cuttings. Non-deciduous varieties are required however since the annual climates are very different, and growth can be maintained for longer periods in the southern hemisphere with appropriate selections. Higher levels of annual radiation should allow year round growth potential in many parts of Australia and New Zealand (particularly around the major population centres where effluent is generated).

The impact of irrigation on growth rates of *P. radiata* has been explored in a number of Australian trials, mostly as an adjunct to better understanding of wood quality and growth responses under rainfed (and droughted) conditions (Nicholls and Waring, 1977; Snowdon and Waring, 1991). Cromer (1980) reviewed the potential for utilising municipal waste water on *P. radiata* in Australia. Growth and biomass of *P. radiata* under effluent irrigation has also been examined in research trials at Albury and Dutson Downs in Victoria (Stewart *et al*., 1988; Cromer *et al*., 1983) and Wagga Wagga (Myers *et al*., 1996), while larger scale operational plantings of over 300 hectares have been established using improved clones to utilise relatively high quality TMP pulp mill effluent at Albury (Coghill and Dahl, 1996).

Use of exotic species may provide the higher productivity required to stimulate establishment of new rural industries in the short term, however the choice of native versus exotic may become less relevant in the longer term. Increased international trade and travel means that the world is getting smaller, with a corresponding breakdown of quarantine barriers evident in recent years. In New Zealand insect incursions that have eucalypts as a host have been occurring every 18 months (T. Withers pers comm). Pine pitch canker in radiata pine in California is a major threat to plantations in Australia and New Zealand and Guava rust presents a serious threat to eucalypts in Australia, not only for current plantation ventures, but also the extensive areas of native forest comprising the bulk of Australian ecosystems.

## 5. IMPLICATIONS FOR BIOENERGY

The relatively low cost of fossil-fuel energy in Australasia is likely to limit the development of biomass energy unless consumer awareness and demand for Green Power significantly increases, government subsidies are reduced or fossil fuel reserves are totally exhausted (e.g., post Maui gas field in New Zealand). Crops solely grown for energy purposes are expected to be a more expensive biomass source than residues from higher value crops directly available at utilization plants. However, SRC may provide supplementary resources in niche situations such as EIF to establish additional generation capacity or sustain demand when cropping residues are exhausted.

Research trials in many countries using wastewater from municipal and industrial sources have consistently indicated substantial short and medium term tree growth responses under carefully monitored conditions, but these results have rarely been translated into broadscale application to treat the quantities of effluent generated by large population centres. Unfortunately there are only limited opportunities to access these substantial effluent sources, as many of the sewage plants servicing major coastal cities are landlocked by urban expansion as traditional waste disposal methods have relied on discharge to ocean outfalls, and land availability and cost may preclude alternative land disposal options.

The greatest SRC prospects in Australia are for crops that yield other commercial products (eucalypt oil, activated carbon) or provide environmental benefits as well as bioenergy. Some forestry agencies are exploring biomass options for cofiring and charcoal with electricity generators and steelmakers. The development of Carbon trading and market values for environmental services including EIF (public health issues/eutrophication reduction/beneficial re-use of wastewaters) are currently being investigated, and could generate significant investment for development of new “green” rural industries.

The main opportunity for EIF and bioenergy in New Zealand has been the use of small town/community effluent schemes, but to date these have not demonstrated viable utilisation of the product.

## 5. CONCLUSION

Governments are being forced by societal demands to counter any deterioration in living standards caused by climate change, air and water pollution from industrial and municipal sources. This often generates conflicting requirements for low cost solutions that also meet stringent health and environmental standards.

Fresh water resources are finite, and demand exceeds supply in many countries, therefore both current and future generations need to be far more efficient in their use of water and other natural resources. Agricultural, industrial and domestic strategies must be developed to minimise total water use and avoid waste. The reclamation and productive reuse of wastewater could potentially provide a significant method of reducing total water requirements of society, while contributing to economic development and environmental protection.

Forestry is traditionally viewed as a long-term venture, with recognized higher risks associated with the longer rotation lengths before commercial returns are achieved. Many EIF trials conducted by government forestry research organisations have placed too much emphasis on the production of typical forest products such as pulp, sawlog and veneer, rather than investigate alternative product options such as bioenergy or environmental credits.

Many research projects in drier environments have placed significant emphasis on maximising growth rates with irrigation applications up to rates of potential evapotranspiration, rather than applying smaller volumes of effluent across larger areas. More research is required on lower irrigation rates since it is possible to grow productive plantations in lower rainfall environments if trees are not severely stressed and tree water use demands are met by appropriate initial stocking, thinning and rotation length adjustments.

Integration of deep rooted perennial vegetation into Australian farming systems is currently considered an essential component of halting land degradation from rising saline watertables, and interest in commercial prospects for farm forestry in low rainfall areas is increasing. Some research results from EIF trials have broader implications for management of tree growth in these situations. Increased supply of wood from sustainably-managed plantation forest has the potential to significantly reduce pressures on natural forest resources, as well as contributing to economic development and environmental care.

Sustainability issues associated with salinity and sodicity will continue to challenge the environmental sustainability of effluent-irrigated plantations, particularly in Australia. Additional multidisciplinary research is required on the effects of salt and nutrient loading on soils, and management of the effluent – soil – crop system. Critical species choice and sustainability issues cannot be adequately addressed without long term funding.

Regulatory pressure to renovate effluents to potable water standards by removal of nutrients, other chemicals and micro-organisms can limit potential revenue producing disposal options. There are biological solutions to biological problems such as effluent disposal. Contaminants do not disappear from the environment, but must be converted or moved into multiple long term stores such as wood products or soils. Effluent irrigated forestry presents a disposal option that provide environmental benefits and co-products which avoid the human food chain, while reducing the requirement for expensive secondary treatment and disinfection, using Sopper's "Living Filter" concept, (Sopper, 1971). Wastes will remain a perpetual and increasing problem to society, and economic and environmentally friendly options such as energy production from biomass need greater publicity and investment support.

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