Bio-physical options

to

prevent, minimise

or

manage salinity issues

in the Lockyer catchment

Roger Shaw

April 2008

Prepared for Lockyer Valley Regional Council

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Sources

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The report covers a number of technical issues associated with the expression and management of salinity in the Lockyer Valley. It does not cover all the aspects concerned with salinity.

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Background

Salinity has been an issue of concern in the Lockyer Valley for many years with small saline areas investigated in the 1940s. Variable groundwater salinity in the major alluvial aquifers was well known in the 1940s. Land use changes result in a change in the hydrologic balance of a catchment through clearing of native vegetation, the addition of water through irrigation or urban and peri-urban developments and infrastructure such as roads and dams. Since salts move with water, a change in hydrology will mean a change in the salt balance of hydrologically sensitive landscapes which may result in land and water degradation and deterioration of infrastructure assets. Most commonly, salinity issues are the result of increased groundwater recharge and the movement of historic salts in the unsaturated soil zone above the watertable which have accumulated over centuries to millennia in sensitive landscapes.

Generally there has been limited success of salinity mitigation efforts in Australia over the last 50 years. Profitable options for reversing the increasing trend in salinity are lacking. People are motivated to address salinity at the local and paddock scale which often leads to only short term improvements because the catchment scale issues and factors determining salinity are not adequately addressed. Proactive salinity management in the Lockyer Valley is likely to be more successful than for Western Australia, South Australia or Victoria which have considerably worse salinity problems than Queensland for a wide range of reasons.

However, to achieve a vision of sustainably reducing the impacts of salinity degradation in the Lockyer catchment and proactively dealing with the impacts of emerging pressures affecting salinity, a shift in emphasis is required to optimise and share the benefits and costs of intervention to reclaim salinity. This can be achieved by "turning the salinity problem into an available resource" wherever feasible, rather than seeing salinity only as a cancerous problem requiring major changes at considerable cost. Thus the emphasis is to look for opportunities to use excess water in the landscape and to develop policy and codes of practice that will have positive and long lasting impacts.

Uncertainty in responses to any initiatives is expected. Thus implementation within an adaptive management approach with a formal process to evaluate the progress towards the desired goals at significant periods after implementation isessential.

The objectives of this study as outlined in the full report are:

- to provide a sound foundation for action on salinity based on the principles of salinity processes and effective remediation directly applicable to the Lockyer Valley through:
    - determining the salinity processes operating in the Lockyer Valley
    - outlining the current and possible future salinity issues in the Lockyer catchment
    - identifying preferred bio-physical options to prevent, minimise or manage salinity
    - estimating future salinity risk for the natural environment and human assets and infrastructure from current and emerging pressures, the likelihood of worsening salinity, the severity of the consequences and the benefit from recommended management options
    - the spatial applicability of salinity management options to high risk areas based on local situations, and

- proposing actions as a basis to develop planning guidelines and codes of preferred practice to achieve sustainability with minimal salinity degradation.

Salinity processes

There are two main causes of land and water degradation in the Lockyer catchment:

- Development of *shallow watertables* that move subsoil salts and concentrate salts at or near the soil surface due to evaporation of water, leaving the salts behind. This cause of salinity can occur in dryland or irrigated areas (particularly where surface water is used for irrigation), and

- *Irrigation water salinity* where the use of water of moderate to high salt content results in direct effects on plant growth. High proportional concentrations of sodium in irrigation water can cause sodicity which degrades soil structure. This is discussed in a later section of this summary.

The salt concentration of soils and waters increases in four ways:

1. when *water evaporates*, the salts are left behind and if there is limited seasonal flushing of salts out of the system, the salts accumulate. (Lake Eyre is a classic example.)
2. when *plants transpire water* from the soil and leave salts behind in the root zone. This is normal. Whether the salt level is an issue depends on whether there is a shallow watertable present (as a source of water and salt), or whether accumulated salts in the soil can be slowly moved downwards by rainfall.
3. when *groundwater moves* through aquifers or soils and weathering of rocks or dissolution of salts occurs in the moving water. The Great Artesian Basin waters are a classic example, and
4. when *periodic shallow watertables* occur where evaporation and transpiration result in salt accumulation at or near the soil surface which is then flushed downwards to the watertable in periods where the watertable is below the rooting depth of vegetation. The salt concentration of the subsoil and groundwater increases.

Bare salted areas are transitions for catchments, not final states when considered over the long term. Bare salted areas are not stable due to death of vegetation making them vulnerable to increased erosion subject to local geology. The catchment will try to come to a new equilibrium wherever possible by the excess groundwater leaching out the accumulated salts, eroding and draining the affected areas resulting in lowering the watertable. Then, once soil conditions become more favourable, revegetation with more salt and water tolerant species can occur. The timeline for these changes to happen will generally be very long from 100s to 1000s of years, reducing productive livelihoods in the meantime. There are good warning signs and it is possible to predict where salinity may occur and steps to minimise the extent of degradation can be taken.

A number of forms of salting have been identified for Queensland which indicate hydrologically sensitive landscapes where there is some natural or human made restriction to flow of groundwater which makes the area sensitive to salinity. The most common forms of salting in the Lockyer Valley in decreasing order of frequency, are:

- Catchment restriction - by weathering resistant Winwill conglomerate
- Confluence of streams – usually smaller creeks meeting major alluvial areas
- Dams
- Roads, and
- Stratigraphic form of seepage.

The reason salinity reclamation has not been very successful in the past is that once watertable salinity develops, a catchment flips into a different state with different processes operating. A return to stable non saline state requires a much greater reversal than when salinity first appeared as illustrated in Figure 1.

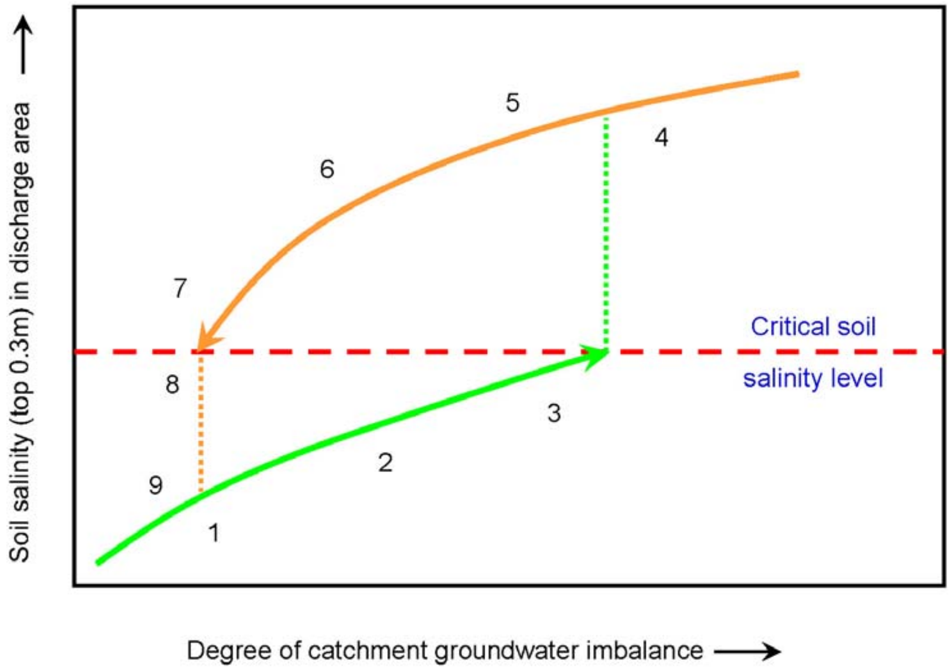

Figure 1. Change of state from a normal catchment (stages 1 & 2) to a degraded and saline catchment (stages 4, 5 & 6) once a critical soil salinity level is exceeded and the degree of reversal required to restore the area to a non saline state (stages 8 & 9) requiring a return below a critical soil salinity level.

Three changes are required concurrently to restore a saline catchment based on Figure 1:

- *reduce soil salinity* levels in the root zone to less than the critical soil salinity value so vegetation can survive
- *reduce the degree of groundwater imbalance* to lower the watertable levels since water and evaporation drive the system, and
- *increase the resilience of the catchment* to be able to withstand some variation in hydrology without changing to a saline state. This often means reducing the groundwater inflow/outflow imbalance to achieve a greater watertable depth buffer than would be required for an average rainfall situation. The depth to the watertable in an affected area should be > 3 metres below ground and preferably > 5 metres where possible.

There are over 30 areas in the Lockyer that show bare saline areas. Also extensive areas of the northern alluvium of Woolshed and Plain Creek catchments near the junction with Lockyer Creek are very close to the critical soil salinity threshold tipping point. These areas have very high groundwater salinity levels (half seawater salt concentration) at only 3 to 4 m below ground in 2006-2007 in a very dry period. Large salted areas are expected to develop if watertable levels rise as expected due to increased pressures in these catchments that would be virtually impossible to reclaim given the quantities of water and salt involved.

There is a distinct and repeating pattern of landscape features associated with salinity in the Lockyer Valley both in small dryland catchments and in the major southern tributaries that shows that Winwill conglomerate geological formation is strongly associated with the occurrence of salinity. Winwill conglomerate is acting as a weathering resistant formation restricting the rate of groundwater movement out of the catchments and not as a source of saline groundwater leaking into the alluvial areas. This means that salinity is due to local and relatively shallow groundwaters. It is unlikely that deeper aquifers are contributing water and salt to the system although some additional investigations may be required to confirm this in situations where water composition may indicate a strong sandstone influence. Thus salinity and watertable management can be targeted to local and shallow systems that respond more quickly and have a greater chance of success from reclamation strategies.

Current and emerging pressures on watertable salinity

There are five current and emerging pressures that are expected to make watertable salinity issues worse in the Lockyer Valley in the short and longer term.

1. Rainfall expected to increase. Areas of significant salting and shallow watertables are currently present following a period of 10 to 15 years of decreasing rainfall. This indicates that in a wetter rainfall period, salting will increase. Given the dry conditions and that salted areas are still present, any strategy that reduces recharge as a management strategy (such as replanting recharge areas or discharge areas with trees) will be inadequate to manage salinity in the catchments in wetter periods.

2. Non sewered residential subdivisions. Since these areas receive reticulated water supply and residents collect and store rainwater, which is then used and disposed of on-site, there is a large additional hydraulic loading from the developments. Assuming 160 L/person/day and given four people per house on 0.5 hectare blocks, and that only about 1/3 of the water is evapotranspired due to over wetting of local areas by the disposal systems and very poor soil permeability in most areas used for rural residential development, then this will amount to an equivalent additional rainfall of 300 mm/yr/hectare of residential area. Waterlogging, wet areas and salinity issues have already occurred and will only get considerably worse in wet periods.

   Since the disposal areas are only a small part of the residential area, then the actual loading on the disposal area is much higher than the measured irrigation water use in the Lockyer at around about 370 mm/ha on average depending on rainfall. Thus not only is the loading too high but also in wet years, it will be considerably greater than can be reasonably used by vegetation, thus recharge of groundwaters and overland flow into stream lines is inevitable.

3. Dams and storages on surrounding Winwill formation appear to leak and contribute to salinity. Because of recent periods of lower rainfall, the number of dams is expected to increase. These storages reduce peak flows in the main streams, reducing flushing of salt out of the catchment and maintenance of creek beds and banks.

4. Degree of sedimentation in creeks and degradation of riparian vegetation. The degree of sedimentation in creeks, particularly Woolshed and Plain Creeks, is expected to restrict drainage of groundwater from the shallow watertable areas by the creeks and the confinement by the sedimentation is pressurising the saline groundwater so that it now covers a larger area of the catchments. It is quite probable that this will cause shallower watertables further and further upstream because of groundwater confinement.

5. Vegetation management. Since wholesale clearing is now largely completed areas, any further changes to hydrology are expected to be small although, because of the very long lag times for hydrologic change following clearing, there could be some additional changes in more recently cleared areas. Over grazing of pastures also causes additional recharge to the groundwaters and once the site has reached a critical salinity threshold, salinity will occur. Grasses are an effective means of managing intermittently affected saline areas in that a good grass cover minimises evaporative concentration of salts on the soil surface, slows overland flow and

enhances surface flushing of salts. There is a common practice of grazing on salt affected lands without any controls which makes the salinity problems worse in a very short period of time and thus controlled grazing is required.

Options to manage watertable salinity

There are eight options to manage watertable salinity areas. Often a single option is not sufficient of itself and combinations of options are required. Table 10 in the report lists, in detail, options appropriate for the salinity sites in the Lockyer. In summary the options and their potential for the Lockyer Valley are:

1. Do nothing – only for small and relatively stable areas, fencing is required
2. Stabilise the affected area – only if small and limited chance of expansion of salinity
3. Reduce groundwater inputs (recharge area) – not viable by itself
4. Intercept groundwater (transmission zone) – considerable potential
5. Increase groundwater outputs (discharge area) – limited unless groundwater irrigation of salt tolerant vegetation established on mounds
6. Store the salt – in the soil above the watertable is where it occurred naturally and has considerable potential
7. Remove the salt including desalination – possible with enhancement of evaporation in evaporation basins, and
8. Recycled water reuse – considerable potential with non sewered subdivisions.

Summary of watertable salinity risk

A salinity assessment has been made for 29 sites by estimating the likelihood (or probability) of salinity getting worse, and consequences (or magnitude) of the effects of salinity on human or natural assets and ecological services. The details are given in Tables 10 and 11 of the report and existing salinity and potential salinity sites shown in Figure 30 of the report. In summary:

- Over 95% of the sites assessed are associated with Winwill geology and many have confluence of streams as an associated form of salinity
- Dams have contributed to salinity in 31% of the salinity sites
- 50% of the sites are classed as having high or very high risk of salinity based on the emerging pressures
- The 5 sites shown on Figure 2 as ellipses with transparent fill are sites that have a very high risk of developing salinity in response to the identified pressures. These sites currently do not show salinity
- Most sites surveyed are either in an expanding or an equilibrium stage of salinity and range from small to moderate severity of salinity
- Even though very dry conditions have existed over the past few years, most sites still show significant salinity indicating that interventionist and proactive action is required if reduction in salinity effects or reclamation is to be achieved
- Salinity areas under the most severe pressure are associated with non sewered subdivisions either as already salted areas adjacent to the subdivisions or are showing early signs of significant salinity development
- Infrastructure such as roads, bridges and other built infrastructure is generally not presently affected by salinity. Fifteen of the 29 sites under emerging pressures would show salinity effects on infrastructure if salinity was allowed to develop as expected without remedial action or control of the pressures
- The only road currently affected by salinity in the sites investigated is at site S2, Woodlands Road in Sandy Creek, where seepage caused by a stratigraphic form of salinity has affected the road surface in the past to a small extent. Houses near Grantham in the unnamed gully site U1 and Soda Spring Creek site S3 are on salt affected areas, and
- Use of excess water in the landscape upslope of the salinity areas is a viable option to manage salinity, where water quality is acceptable. In 13 of the 29 sites

opportunities are available to use this water and thus reduce watertables in affected areas provided incentives are available.

Priority watertable salinity sites for prevention and reclamation

The salinity sites of highest risk and priority that need to be addressed at the earliest opportunity based on the evaluation of salinity are as follows:

1. Woolshed Creek because of the severe impacts should salinity develop on the lower alluvium. A whole of catchment strategy has been developed.
2. Regency Downs, Lorikeet Ave and the broad drainage line as a preventative measure to prevent salinity developing.
3. Fairways estate development bordering Woolshed creek with salinity in the tributary draining through the estate.
4. Plain Creek lower alluvium for similar reasons to Woolshed Creek, and
5. Unnamed creek near Grantham with severe existing salinity but potential for interception and irrigation.

Irrigation water salinity

The Lockyer Valley has one of the best combinations of soils and groundwater for irrigated agriculture in Australia. In the major alluvial valleys the soils are fertile, resilient to soil chemical and physical degradation under best practice management due to their ability to swell and shrink and restructure. Because the basaltic parent materials continue to weather in situ releasing calcium and magnesium they can counter the effects of sodium in the irrigation water as well as releasing other nutrients.

The alluvial soils are relatively permeable because of their good structure and high calcium and magnesium. This aids leaching of accumulated salts below the soil root zone. The composition of the groundwater used for irrigation is good being relatively low in sodium and although the salt content is relatively high, the high proportion of calcium in the groundwaters precipitates as calcium carbonate in the upper soil root zone raising soil pH to around 8.4 – the equilibrium pH expected and slightly lowering the effective soil salinity.

Both the salinity and sodicity of irrigation water together with soil properties are critical parameters in determining the suitability of a water for irrigation. Clay minerals are sensitive to sodium and sodium can have direct effects on soil behaviour. Under various situations the relationship between salt concentration of irrigation water and relative sodium content (sodicity) is a good indicator of the likely soil response to irrigation.

There is generally an equilibrium reached between the soil root zone salt accumulation and the crop being grown such that there are natural limits and feedbacks that prevent excess salt accumulation for productive agriculture.

There is a perception of increasing alluvial groundwater bore salinity by some irrigators, more so during dry periods. The likely causes are:

- In dry periods, irrigators use greater quantities of groundwater for irrigation and in areas using irrigation waters of moderate salinity, there is an increase in root zone salinity because there is less flushing of accumulated salt by rainfall. Irrigation is supplemental to rainfall and in general rainfall plus irrigation water used is approximately 1 240 mm/year based on measured water use, and
- There will be changes in some bores within the areas of the major southern tributaries in the region of exposed Winwill formation which may show fluctuating groundwater salinity and sodicity due to the mobilisation of salt in the unsaturated pockets of salty water in these historic salt accumulation zones. Thus there may be periods of several years of elevated salinity. Further work is underway to clarify the

processes operating. The increase in off stream storages in this catchment will provide a greater flushing of salts out of the aquifers over the long term.

A concern with irrigation is soil sodicity. If waters of marginal sodicity are used for irrigation, soil exchangeable sodium percentage will increase and result in soil stability issues. Because of the high cation exchange capacity of these soils, this generally takes greater than 5 years for surface soils to come to a new equilibrium.

High soil sodicity results in soil particle dispersion, surface crusting erosion, poor permeability and limited soil water holding capacity. Dispersibility of soils has been well studied and for most soils, dispersion due to sodicity of a water can be managed by salt content of irrigation water within limits. However, there is an issue under heavy rainfall where the salts in the surface soil layers are leached resulting in increased soil dispersion. Ensuring waters are used with appropriate sodicity levels is most important for the long term sustainability of irrigation. Small variations during dry periods will not make large differences.

Policy and planning issues

To prevent salinity degradation and reclaim affected areas and consider the opportunities salinity issues can present we need to consider:

- Granting rights equally to the ecosystem. In the same way rights need to be granted to future generations and downstream users. Then some system of allocation of resource use and trading needs to be worked out. This issue is discussed in detail by Young and McColl (2002)
- Adopting the principle that any reuse of land or natural resources for an alternative purpose means that it has to be restored to a level of sustainability as a minimum condition of development. This is to preclude declining values because of degradation and to ensure no resource continues to decline to a state where massive investment is required to achieve sustainability
- Move towards paying the full cost of ecosystem services by implementing some early salinity management processes at a basic level. These could include:
    - All residents within a catchment pay a basic charge to go part way to maintaining ecological services on which life and quality of life depends as an access charge and to provide incentives to carry out required actions
    - Where a particular resident or user can benefit from the restoration of the ecological services without harming the service, then the beneficiary also pays. For example if the excess water in a catchment that is to be used to restore it to sustainability is available for use, a charge needs to be paid by the person who, because of position in the catchment, has the capability to use the water
    - If no one wants to beneficially use the asset or service, and the water has to be used to maintain sustainability, then the community pays through incentives for joint investment. Incentives may be necessary to allow the level of ecological services required to be provided. Market forces may be the best mechanism, such as auctioning off the rights of access etc. Separation of land and water rights is an important aspect
    - If anyone wants to do something that is not aligned to maintaining or enhancing basic ecological services, then an additional charge is paid for using that practice or resource. Trade-offs, tradeable development rights or alternative management options that may compensate and do not significantly compromise the ecological services may be used to overcome any degradation. An example of major impact is dams and their impact on stream flow and riparian vegetation and stability
    - Best practice options be adopted to reclaim degraded areas and if landholders are not able to comply within say a 5 year period, then additional foreshadowed levies are paid to rectify the issues being caused. If agreed practices are not followed, and there is sometimes good reasons for this in that innovative solutions

do not follow from everyone using conventional thinking, then if a deterioration becomes evident after 5 years, trade-offs need to be made or the liability to the ecosystem covered through insurance or bonds etc

- Reticulated water and effluent disposal in non sewered subdivisions are vexed issues and most likely to result in serious salinity problems and probably health issues in sensitive landscapes. Residents who use reticulated water and dispose of effluent may have to pay for the overload to ecological services by a levy to be used to restore the hydrologic balance through effluent disposal schemes, and
- If people wish to conduct business or construct or locate infrastructure in areas of higher risk or which poses a higher risk of degradation, or there is a risk it will deteriorate under a proposed development, then environmental insurance needs to be taken out to cover the possibility of degradation within a specified time period of say 10 years and which will ultimately be the responsibility of someone else to fix. Examples are dams in salted drainage lines, roads across salted areas and fallow cropping in salinity sensitive areas.

Conclusions

There is a distinct and repeating pattern of watertable salinity in the Lockyer Valley both in small dryland catchments and also in the major southern tributaries that shows that Winwill conglomerate geological formation is strongly associated with the occurrence of salinity. Winwill formation is acting as a weathering resistant formation restricting the rate of ground water movement out of the catchments. It would appear that many of the areas expected to show salinity in the Lockyer already have salinity or can be relatively well predicted using the pattern with Winwill conglomerate. The few catchments draining out of Winwill that are not already salt affected are sensitive to hydrologic change and will be influenced by the emerging pressures on salinity. It is most unlikely that serious expansion of salinity in the Lockyer will occur but some of the identified areas will expand.

The Lockyer has an excellent combination of soil and groundwater resources, although in limited quantity. Water salinity for irrigation has built in feedback processes and salinity is unlikely to cause degradation to irrigated soils. Salinity problems in some locations will always be present. It is expected that salinity of alluvial aquifers in the southern tributaries to Lockyer Creek will very slowly reduce. Sodicity of irrigation water however is a risk if more marginal quality waters are used for irrigation. Guidelines are available to minimise any degradation from sodicity. A sodium adsorption ratio of the irrigation water of 5 to 6 should not be exceeded except under special circumstances where compensating management is undertaken.

There are existing and emerging pressures from an increased number of dams, non sewered residential subdivisions and the high level of siltation and degradation of the major creeks that are influencing the incidence of salinity. Together with a return to normal rainfall patterns, there will be increases in salinity problems in existing and sensitive areas since existing salinity areas are still showing signs of salinity even after a considerable period of dry years.

The concept of reducing recharge in recharge areas by replanting vegetation and deep rooted perennial pastures will never be effective alone in reducing the area of salt affected land. It is a ’systematised illusion’ whose veracity comes from constant repetition. Areas showing significant salinity in an extended dry period (such as the current period) when there has been little or no recharge indicates that more than revegetation alone will be required if salt affected lands are to be reclaimed.

Salinity risk areas have been identified and mapped and management actions recommended for each area that should minimise or reclaim areas and prevent further degradation in the catchments. Further investigations are required if expensive reclamation is to be undertaken followed by adaptive management.

Woolshed and Plain creeks are the worst salinity risk followed by areas in or adjacent to non sewered subdivisions. The option of proceeding with an evaporation basin with enhanced evaporative technology and salt harvesting in Woolshed and Plain creeks as well as the options recommended in Shaw (2007) should be considered. Areas in or adjacent to developing non sewered subdivisions are already showing salinity which can only get worse if no preventative strategies are implemented.

The large number of dams in the Lockyer upstream of salted areas as well as the relatively high proportion of dams that leak and cause salinity problems directly are a major concern. Policy is required for water management on a catchment basis to manage dams, flows and stream health.

Since voluntary methods are unlikely to be effective in achieving sustainability and particularly for salinity reclamation, incentives and policy changes have been identified as possible options. More interventionist and structural changes will probably be required.

Priority areas for salinity reclamation and prevention have been identified and action while the rainfall pattern is still in the dry period will offer considerable advantages in managing salinity before wetter periods return. Some experimental salinity areas are identified to begin the process and demonstrate the potential and opportunities that can come with proactive salinity management.

Recommendations

1. A salinity strategy is needed for the whole Lockyer Valley that targets prevention and reclamation options to achieve agreed results. Proactive intervention is required beyond commonly recommended recharge area control measures if salinity is to be effectively managed before further areas are affected.
2. Policy options, codes of practice, bonds and/or insurance for developments that pose a salinity threat would improve prevention of future salinity issues.
3. Future non sewered subdivisions need to be carefully evaluated for their cost benefit of incorporation of wastewater treatment systems and recycled water use over time periods up to 30 years. Non sewered subdivisions pose significant salinity threats in hydrologically sensitive Winwill geology areas because of the particular landscape features of these areas that cause salinity, the development on generally lower quality lands which may already have salinity and the wastewater disposal systems which are inadequate to deal with the quantity of effluent produced.
4. A catchment scale water management strategy is required with emphasis on approvals for all dams including intended use, construction, maintenance and procedures when leakage and salinity arise. Dams pose a major issue in the Lockyer because of leakage and salinity. In non sewered subdivisions the numbers of dams are amazingly frequent and of large storage capacity which is predicted to cause considerable issues into the future.
5. An education and awareness campaign on the effects of resource use on salinity in sensitive landscapes is required to minimise the number of practices that are adversely affecting salinity because people are not aware of the implications. An emphasis on rights and responsibilities and duty of care to maintain and enhance the sustainability of the region is not well known, and
6. Agreement to a proactive salinity management strategy for the high risk Woolshed and Plain Creeks is required to prevent the expected large saline areas developing at the northern ends of the catchments and possible compensation claims that may result.

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1 Introduction

Salinity has been an issue of concern in the Lockyer Valley for many years with small saline seepages identified in the 1940s (Bureau of Investigation, undated). Groundwater salinity in alluvial aquifers was discussed in the Bureau of Investigation (1949) technical report. There have been many studies on salinity aspects in the Lockyer Valley with summaries in White (1980), QDPI (1985), Salcon (1997) and others.

Land use generally changes the hydrologic balance of a catchment through clearing of native vegetation or the addition of water through irrigation or by urban and peri-urban developments. Changed flow regimes due to infrastructure development can lead to localised hydrologic change. Since salts move with water, a change in hydrology will mean a change in the salt balance which may result in land and water degradation and deterioration of infrastructure assets in hydrologically sensitive landscapes. Most commonly, salinity issues are the result of increased groundwater recharge under land use change and the mobilisation of salts in the unsaturated soil zone above the watertable.

Generally there has been limited success of salinity mitigation efforts in Australia over the last 50 years. Robins (2004) summarised the results of 10 years of research as part of the National Dryland Salinity Program for Australia and concluded that profitable options for reversing the increasing trend in salinity are lacking. People are motivated to address salinity at the local and paddock scale which often leads to only short term improvements because the catchment scale issues and factors determining salinity are not adequately addressed.

Probable reasons for the poor success rate for salinity reclamation include:

- reclamation from a saline degraded state is very difficult because different processes operate in the degraded state compared to the native state
- the complexity and scale of the salinity issues means only the simple aspects are tackled
- most methods of management are expensive and often compete with current resource use and livelihoods
- salinity issues are the result of long term processes, and
- overly optimistic expectations of interventions and the occurrence of unintended consequences lead to disillusionment.

Solutions to salinity issues at the ecosystem and catchment scales offer the only viable and long term sustainable approach to dealing with salinity. These solutions need to be based on an understanding of processes and functional relationships within the particular environment being considered. Ecosystem is used to refer to specific holistic and integrative systems embodying a dynamic equilibrium maintained among organisms and the physical environment (Alario & Brün 2001). It recognises that humans are an integral part of many ecosystems.

This report provides an overview of salinity processes in the Lockyer Valley based on the basic principles of water and salt mass balance and movement. It identifies preferred bio-physical management options for the larger salted sites and some emerging salt affected sites based on regional and catchment scale processes. Irrigation salinity issues are evaluated. This work follows an earlier report by Shaw (2007) on salinity mitigation investment for Woolshed and Plain Creek catchments for SEQ Catchments Ltd. but takes a broader view for the whole Lockyer catchment and focuses on bio-physical options to prevent, minimise or manage salinity issues arising from current and emerging pressures.

A risk assessment of existing and predicted salinity areas in response to the current and emerging pressures is made from which policies and actions can be developed to address salinity.

A proposed vision for the long term outcomes of proactive salinity management in the Lockyer Valley is:

> *Investment in appropriate catchment management strategies and implementation of policies and codes of practice based on process understanding can sustainably reverse or reduce the impacts of salinity degradation and proactively reduce the impacts of emerging pressures affecting salinity in the Lockyer catchment.*

To achieve this vision, a shift in emphasis is required to optimise and share the benefits and costs of intervention to reclaim salinity. This can be achieved by "turning the salinity problem into an available resource" rather than seeing salinity only as a cancerous problem requiring major changes at considerable cost. Thus looking for opportunities is the emphasis to develop policy and codes of practice that will have positive and long lasting impacts. Uncertainty in responses to any initiatives is expected. Thus implementation within an adaptive management approach with a formal process to evaluate the progress towards the desired goals at periods after implementation is important (Leach et al. 2006).

1.1 Objectives for this report

The objectives of this study as outlined in this report are:

- to provide a sound foundation for action on salinity based on the principles of salinity processes and effective remediation directly applicable to the Lockyer Valley through:
    - determining the salinity processes operating in the Lockyer Valley
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    - identifying preferred bio-physical options to prevent, minimise or manage salinity
    - estimating future salinity risk for the natural environment and human assets and infrastructure from current and emerging pressures, the likelihood of worsening salinity, the severity of the consequences and the benefit from recommended management options
    - the spatial applicability of salinity management options to high risk areas based on local situations, and
- proposing actions as a basis to develop planning guidelines and codes of preferred practice to achieve sustainability with minimal salinity degradation.

2 Salinity overview

Salinity is often the trade-off resulting from land and resource development and thus is an integral part of landscape management. Salinity is an issue in natural resource management and for human assets and infrastructure when it reduces the potential diversity, productivity and use of natural resources and it shortens the lifespan, reduces the reliability and increases the maintenance for human assets and infrastructure.

2.1 Concepts and definitions

Salts move with water or are exposed by erosion of the land surface thus water movement and changed water regimes need to be considered concurrently. **Hydrology** is taken to mean the interrelationships between water occurrence, distribution, movement and balances in ecosystems. The **watertable** is defined as the upper surface of a zone of saturation in a soil or unconfined aquifer. Below the watertable, the aquifer is permanently saturated with water. **Salinity** can be defined as the presence of soluble salts in soils or waters (Salcon 1997). Salinity processes are natural processes of landscape and soil formation. However, human activities can contribute to salinity and long-term land and water degradation. Salinity usually becomes an issue when:

- the concentration of salt or sodium adversely affects water quality, plant growth or ecosystem diversity
- the value of property or natural resources is reduced

- the ability of the ecosystem to supply essential goods and services is compromised
- soil structure is degraded or soil erosion results
- vegetation and fauna are affected
- the useful life of assets and built infrastructure is reduced. and
- the potential use of a water is limited by its salt content or its salt composition.

Commonly, salinity is measured by the salt concentration using electrical conductivity of a water since conductance is linearly related to salt content. Figure 1 shows the scale of values for salinity and the potential use of waters of varying salinity based on the measure of electrical conductivity (EC) in units of deciSiemens/metre (dS/m). Table 1 gives common conversions to other units. EC is adopted in this report as the measure of salt concentration.

Salts are the dissolved material from the weathering of the earth's crust. These dissolved materials also include dissolved silica, iron, manganese and other heavy metals which rarely remain in solution as the concentration increases. The more soluble the salts the more they contribute to landscape salinity. Because the less soluble calcium and magnesium salts precipitate out of solution first as the concentration increases, there is a change in salt composition with increasing salt concentration. As the salt solution becomes more and more concentrated, the salt composition for many waters approximates the composition of seawater dominated by sodium chloride. However, for waters sourced from basalt geology, magnesium and sometimes calcium are of higher relative concentration than sodium and may remain in solution at higher salt concentrations. This is the case for the southern tributaries of Lockyer Creek.

Table 1. Conversions between common units of salinity.

From	To		
	EC mS/cm ≡ EC dS/m	**EC µS/cm**	**Total dissolved ions mg/L or ppm**
EC dS/m	1	1 000	2/3 multiply by 1 000
mg/L (ppm)	Divide by 1 000, multiply by 1.5	1.5	1

Figure 1 illustrates the wide range of potential uses for waters with up to moderate salt concentration. The relative composition of salts is as important in the use of particular waters as the total salt content. Generally waters high in sodium will cause problems in soils leading to erosion, soil dispersion and instability, surface crusting, limited soil wetting, low water holding capacity as well as soil structural degradation, erosion, poor plant growth and productivity. Waters higher in calcium and magnesium concentrations are more useable at higher salt concentrations.

Sodicity in a soil or water is defined as the presence of a high proportion of sodium ions to other cations (in soluble and/or exchangeable form) and leads to the problems described above. Different measures of sodicity are used for soils and waters (or solutions) as follows:

- **ESP** (exchangeable sodium percentage) represents the amount of sodium adsorbed onto the clay mineral surface as a percentage of the total cation exchange capacity of the soil.

- **SAR** (sodium adsorption ratio) the relative content of sodium to calcium plus magnesium in a water or solution. It is based on ion exchange relationships and closely approximates the ESP of a soil in equilibrium with a water or solution with the given SAR. The actual relationship between ESP and SAR is given in Salcon (1997).

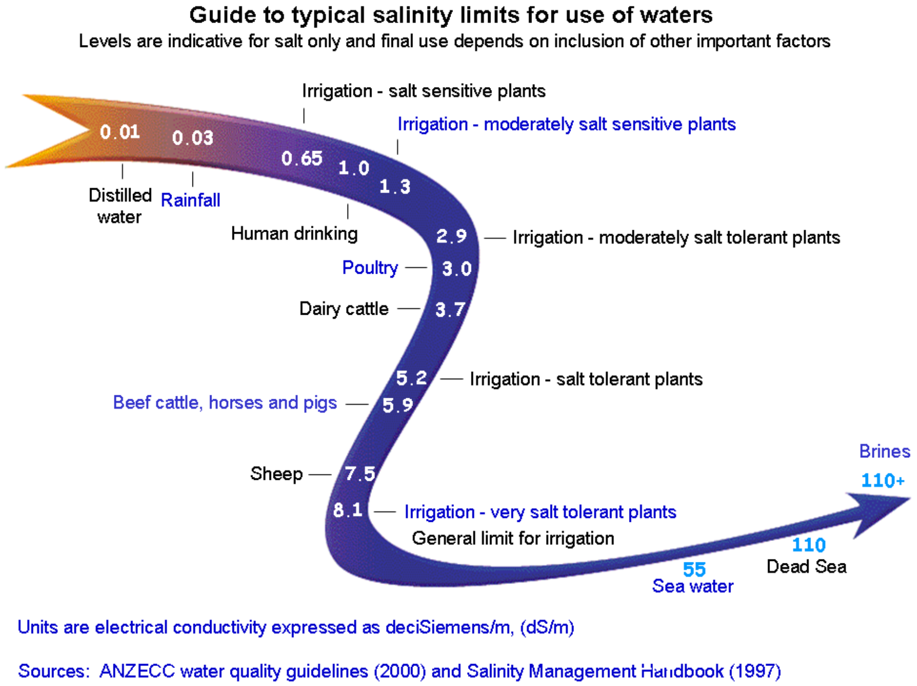

Figure 1. Guide to salt concentration and agricultural use of waters with increasing salt content. The composition of the salts needs to be considered for many of the applications. For human and domestic use, additional analyses are required for assessment of the suitability of a water for an intended use.

Land and water degradation due to salinity in the Lockyer catchment has two main causes:

- Development of *shallow watertables* that concentrate salts at or near the soil surface due to evaporation of water leaving the salts behind and/or movement of subsoil salts to the soil surface resulting in the death of vegetation and probable erosion. This cause of salinity can occur in dryland or irrigated areas (particularly where surface water is used for irrigation rather than groundwater since the hydrologic balance of the catchment changes), and

- *Irrigation water salinity* where the use of water of moderate to high salt content results in direct effects on vegetation and/or increase in the soil root zone salinity to levels that affect plant growth. High proportional concentrations of sodium in a water can cause additional sodicity issues as discussed above.

While a range of terms have been used to describe salinity occurrences, such as salt scald, salt seepage, salt pan etc the two types mentioned above will be used in this report. This is consistent with Salcon (1997) which describes salinity development and reclamation in detail for Queensland. These two terms are used since they clearly indicate the mechanism of salinity occurrence and each require different management approaches.

2.2 Salinity processes

Salinity is visible at the soil surface when water containing salts is evaporated, or in a stream bank where seepage from groundwater occurs. Under natural situations before European settlement, catchments were generally in some equilibrium with rainfall, groundwater recharge, and the groundwater outputs by evaporation, transpiration by plants, stream flow and groundwater flow out of a catchment. Vegetation was the buffer in the system and largely accommodated the varying rainfall patterns and groundwater level fluctuations. In areas that were more continuously wet, increased vegetation density occurred with species that could withstand wetness and/or higher salt content. Where salting occurred and vegetation died, erosion of the bare surface resulted in gullies, increased the depth to the watertable by drainage and reduced the salt concentration in the soil at the same time. Plants could then regrow and stabilise the area.

The salt concentration of soils and waters increases in four ways:

1. when *water evaporates*, the salts are left behind and if there is limited seasonal flushing of salts out of the system, the salts accumulate. Lake Eyre is a classic example.
2. when *plants transpire water* from the soil and leave salts behind in the root zone. This is normal. Whether the salt level is an issue depends on whether there is a shallow watertable present (as a source of water and salt), or whether accumulated salts in the soil can be slowly moved downwards by rainfall.
3. when *groundwater moves* through aquifers or soils and weathering of rocks or dissolution of salts occurs in the moving water. The Great Artesian Basin waters are a classic example, and
4. when *periodic shallow watertables* occur where evaporation and transpiration result in salt accumulation at or near the soil surface which is then flushed downwards to the watertable in periods where the watertable is below the rooting depth of vegetation, the salt concentration of the subsoil and groundwater increases.

2.2.1 Watertable salinity

Since groundwater is the major driving influence on the expression of watertable salinity we can consider the processes in a catchment as shown in Figure 2. Where there is some natural or human made restriction to groundwater flow out of a catchment, and the inflow of water through recharge below the root zone or through stream beds is greater than the ability of groundwater and/or stream water to flow out of the catchment, salinity or waterlogging will occur.

A ***recharge area*** occurs where there is a net movement of water downwards into the groundwater. A ***discharge area*** occurs where there is a net movement of groundwater out of the catchment. Waterlogging and salinity will occur if the groundwater discharges to the soil or creek bank surface.

The extent of the groundwater imbalance is approximately indicated by the area that is salt affected or waterlogged since this is the way that a catchment returns to a hydrologic equilibrium. The restriction to groundwater flow may be any of the following, singly or in combination:

- low aquifer transmission
- a physical barrier such as resistant rock formation or hydraulic barrier such as a dam, and
- a very low hydraulic gradient, resulting in reduced lateral flow of groundwater.

The distance between a recharge area and discharge area can be short, tens of metres to thousands of kilometres as for the Great Artesian Basin.

Salts are deposited on the soil surface by evaporation through capillary rise through the soil (like a wick) from a shallow watertable, or where plants transpire the water and leave the salts behind and then a gradually rising watertable level moves those salts to the soil surface. Generally if groundwater moves upwards through the soil at a rate greater than the evaporation rate, it will flush away the accumulated salts at the soil surface giving a wet area or seep with little to moderate salt content unless the groundwater is saline.

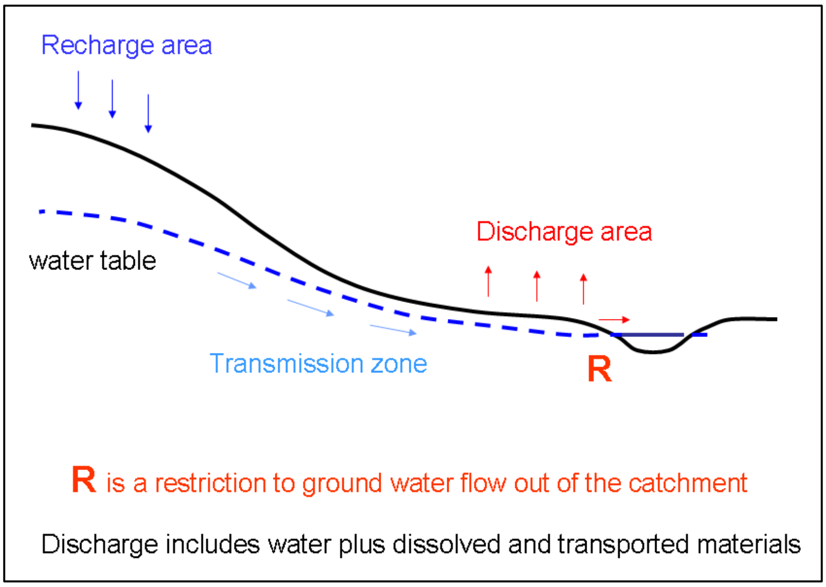

Figure 2. A simple model of groundwater processes resulting in watertable salinity in a catchment illustrating recharge, transmission and discharge zones. Evaporation occurs in the discharge area from a shallow watertable. Figure based on Salcon (1997).

There is a continuum between the balance of groundwater recharge, groundwater outflow and use, and salinity as follows:

- if groundwater *recharge is less than water outflow and water use* and if the depth to the watertable is greater than around 5 metres, then watertables are generally too deep for accumulation of salts by evaporation. This is a normal situation.
- If groundwater *recharge exceeds groundwater outflow and use*, shallow watertables will often occur with associated salinity. This is typical of hydrologically sensitive landscapes, and
- if groundwater *recharge is substantially greater than groundwater outflow and use*, flushing of accumulated salt occurs and waterlogged or wetland areas of generally low salinity develop. An example of this last situation is given in Photo 1.

Photo 1. Example of a catchment where groundwater seepage flushes accumulated salts resulting in a non saline and waterlogged area (from the eastern Darling Downs).

2.2.1.1 Mass balance of water and salt

Watertable salinity processes can be analysed using the concept of salt and water mass balance. This is important because dealing with salt concentration by itself does not improve a salinity issue unless the quantity of water involved is considered as well. Salt and water mass balance means that for an undisturbed landscape at equilibrium (sometimes called steady state), the mass of salt and water entering the catchment will be in approximate equilibrium with the mass of salt and water leaving the catchment. Thus the input of a large volume of low salinity rainfall can be in equilibrium with a small quantity of saline stream water or groundwater leaving a catchment. This can be expressed as

$$Q_i c_i = Q_o c_o$$

where

Q_i is the quantity of water entering a system
c_i is the salt concentration of the water entering the system
Q_o is the quantity of water leaving a system, and
c_o is the salt concentration of the water leaving the system

This means for a very small sub-catchment as an example receiving 750 mm rainfall over say a 10 hectare area (7.5 ML), under equilibrium the figures on an annual basis could approximate: 7.5ML rainfall x EC 0.03 dS/m rainfall = 0.5ML groundwater outflow x EC 0.45 dS/m groundwater salinity

Thus with the EC of rainfall = 0.03 dS/m and most of the water used for transpiration by plants, then the groundwater flowing out of the catchment may be only 0.5 ML and it would have an EC of 0.45 dS/m and be in equilibrium with the inputs from rainfall alone since some of the water has been used by plants leaving the salt behind. Thus higher salt concentrations in out-flowing water do not necessarily indicate a salt problem.

Under equilibrium conditions where there is no salt problem, there is often a salt storage in the landscape in the unsaturated soil below the active root zone depth. Salt may also be contributed from weathering processes and/or saline or non saline inputs from aquifers in the catchment. Thus the mass balance equation needs to include a term for change in salt storage when there are changes in hydrology that will affect the salt storage. The equation becomes:

$$Q_i c_i + \Delta S = Q_o c_o$$

where ΔS is the change in salt storage by the changed hydrology. This is illustrated in section 2.2.2 for soil salinity under irrigation where the salt and water balance in the soil root zone is of greater concern than the catchment scale.

When the landscape is disturbed by clearing or addition of water from outside of the catchment, then any salt stored in the landscape in the unsaturated soil profile will be mobilised and extra salt can be exported from the catchment. Managing a small quantity of moderately saline water is obviously much easier than managing a large quantity of very saline water.

The depth to the watertable and the salt content of the groundwater determine the concentration of salts accumulating at the soil surface with evaporation. A typical example is given for the lower Burdekin region in Figure 3. The maximum groundwater salt concentration occurs in a watertable depth range where capillary rise from the watertable to the soil surface is most efficient. As the depth increases, the rate of capillary rise is reduced which reduces the salt concentration at the soil surface. Where the watertable depth is at or very close to the soil surface, flushing of the salts occurs and the salinity more closely reflects that of the groundwater or even less than groundwater salinity depending on rainfall. The high salt content of the groundwater in the lower Burdekin occurs between 1 and 4 metres depth to the watertable. The range in depth reflects the fluctuating watertable levels and the periodic movement of salts on the soil surface and upper root zone down to the watertable under rainfall. The implications are that soils above a very saline watertable will not be affected to any significant degree provided the depth to the watertable is greater than about 4 to 5 metres for most of the time. Generally a depth of 2 metres to the watertable is considered very marginal in salinity risk areas and likely to cause surface salting depending on soil texture. It also does not allow any buffer for high rainfall periods when watertable levels are likely to rise.

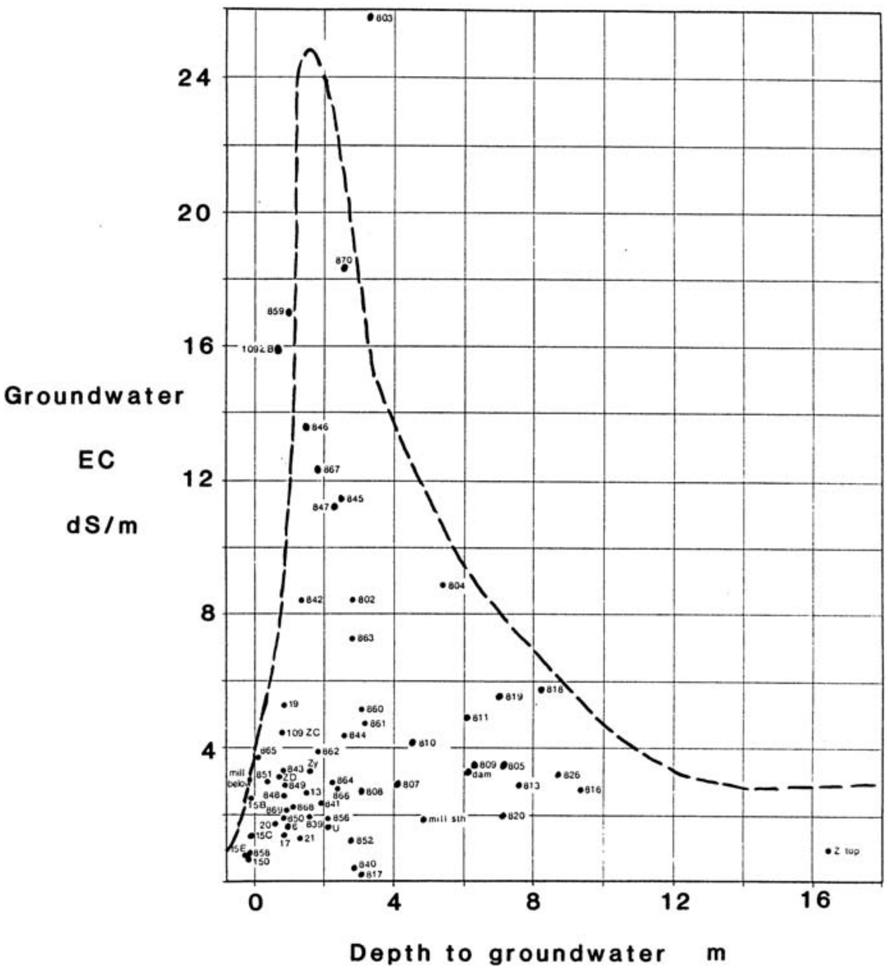

Figure 3. Relationship between depth to the watertable and the salinity of the watertable for the lower Burdekin region from Shaw et al. (1987). The flushing of evaporated salts is evident when the depth to the watertable is very shallow or at the soil surface.

When there is limited ability of vegetation to buffer watertable level changes, evaporation of groundwater from bare salted areas is the way the catchment tries to come to groundwater equilibrium with any additional water inputs. It is not as efficient a process as evaporation from exposed free water because salt accumulates and affects soil structure and evaporation rate. As a guide to the Lockyer Valley region, normal evaporation is around 1 500 mm/year and a bare soil with seepage at the soil surface may be expected to evaporate around 600 up to 1 000 mm per year. As a general principle, significant salinity will be evident on the soil surface when the depth to the watertable is less than 1 m below ground level and certainly at a depth around 0.5 m (depending on soil properties).

Bare salted areas are transitions not final states for catchments when considered over the long term unless it has a non-draining lake or similar. Because a bare salted area is not stable, due to death of vegetation making it vulnerable to increased erosion, the catchment will try to come to a new equilibrium wherever possible by the excess groundwater leaching out the accumulated salts, eroding and draining the affected areas resulting in lowering the watertable. Then revegetation with more salt and water tolerant species can occur once soil conditions become more favourable. The timeline for these changes to happen will generally be very long from 100s to 1 000s of years, reducing productive livelihoods in the meantime. In some situations, there are good warning signs and we can predict where salinity may occur and can minimise the extent of degradation.

2.2.1.2 Forms of salinity

From the range of occurrences of salinity in Queensland, it is possible to list readily identifiable landforms associated with the occurrence of salinity that align with the simple recharge, transmission, discharge model of Figure 2 and the restrictions to groundwater flow that lead to salinity. The presence of these forms of salinity indicates hydrologically sensitive areas where salinity could be expected. Factors which modify the likelihood of watertable salinity are discussed in section 3.6.

These forms were developed for Queensland by Shaw et al. (1987) and reported in Salcon (1997). They are generally consistent with those used in the national classification of catchments for salinity (Coram 1998). Figure 4 shows the common forms and readily observable features to identify catchments sensitive to salinity from likely restrictions to groundwater flow. Often more than one form of salting will occur together. For example, construction of dams can enhance recharge, and roads can compact the alluvium and restrict the limited groundwater flow rates even further in sensitive landscapes.

The most common forms of salting in the Lockyer Valley, based on Figure 4, in decreasing order of frequency, are:

- Catchment restriction - by weathering resistant Winwill conglomerate
- Confluence of streams – usually basaltic alluvium
- Dams
- Roads, and
- Stratigraphic form.

The recognition of these forms can readily identify sensitive areas for further evaluation.

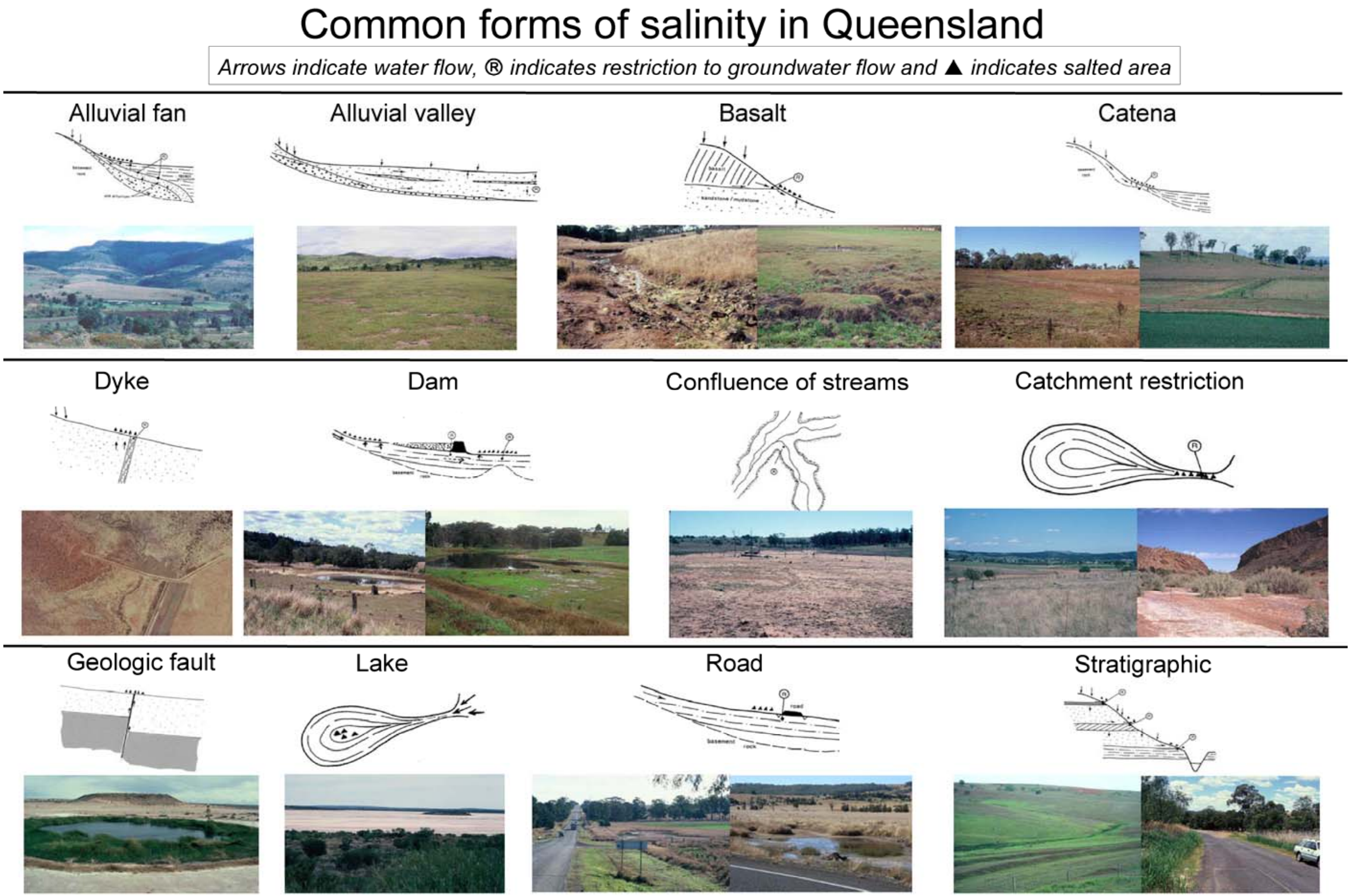

Figure 4. Common forms of salinity in Queensland identifying restrictions to groundwater flow and processes operating based on Shaw et al. (1987).

2.2.1.3 *Equilibrium and resilience*

The two concepts of equilibrium and resilience are important in evaluating the stages of salinity development and reclamation and in determining the most appropriate intervention for control or mitigation to achieve a sustainable outcome. **Equilibrium** can be defined as 'a dynamic state of balance between the forces that counteract each other'. Once land clearing and use of land and water resources occurred, the forces acting on the landscape also altered because of increased recharge, increased surface runoff and associated erosion and reduced buffering by vegetation of the periods of above average rainfall and shallow watertables. Thus there has been a shift to a new equilibrium state that is quite different from the original native state.

Resilience can be defined as 'the capacity of an ecosystem to tolerate disturbance without collapsing into a different state that is controlled by a different set of processes'. Resilience is a reflection of the sensitivity of a catchment to groundwater hydrological change. There are five factors that have a major influence in determining the resilience of a catchment to development of watertable salinity as given in Table 2.

Table 2. Key factors that strongly influence the resilience of a landscape to salinity and their relevance to the Lockyer Valley.

Factor	Role	Situation for Lockyer catchment
rainfall	groundwater recharge, surface flow & erosion	high probability of salinity at 800 mm/yr. The approximate range for salinity to occur in sensitive landscapes is between 400 and 1 300 mm/yr
rate of ground-water outflow	drainage and flushing of groundwater	very low for smaller catchments to large for main southern tributaries with a high proportion of basalt in the catchment
vegetation type and density	buffering capacity by variable vegetation density accommodating wet periods	very low in most agricultural areas due to extensive clearing
quantity of salt storage at shallow depths	indicates sensitive landscape and potential for expression of salinity	moderate to high in areas of hydrologic restriction. Salt affected soils usually occur in conjunction with salted areas indicating historic accumulation of salt probably by evaporation. Very high salinity in Woolshed and Plain creeks
relative sodium concentration	poor soil structure, poor soil permeability and high erodibility	very high in sandstone formations to very low in major areas of alluvium

Factors such as hydraulic gradient, stream incision depth etc, as discussed in section 3.6 also determine the resilience of a catchment to a change in groundwater hydrology. Areas with higher hydraulic gradient and deeper stream incision tend towards a lower incidence of salinity because groundwater flow out of the area is higher. Beyond a certain point, where watertables rise and surface soil salinity from capillary rise and evaporation causes the death of vegetation, the situation becomes unstable and the system will collapse to a less desirable state.

The changes that occur in an area degrading to a less desirable state of watertable salinity are illustrated in Figure 5. As the degree of groundwater imbalance increases, salinity in the shallow watertable areas increases until a critical soil salinity is reached when the catchment changes into a different state. The critical soil salinity level is the salt concentration at which most vegetation can no longer grow productively in an area. Figure 5 also shows the approximate stages of salinity development and reclamation (as numbers) as outlined in the next section and shown in Figure 6 and Table 3.

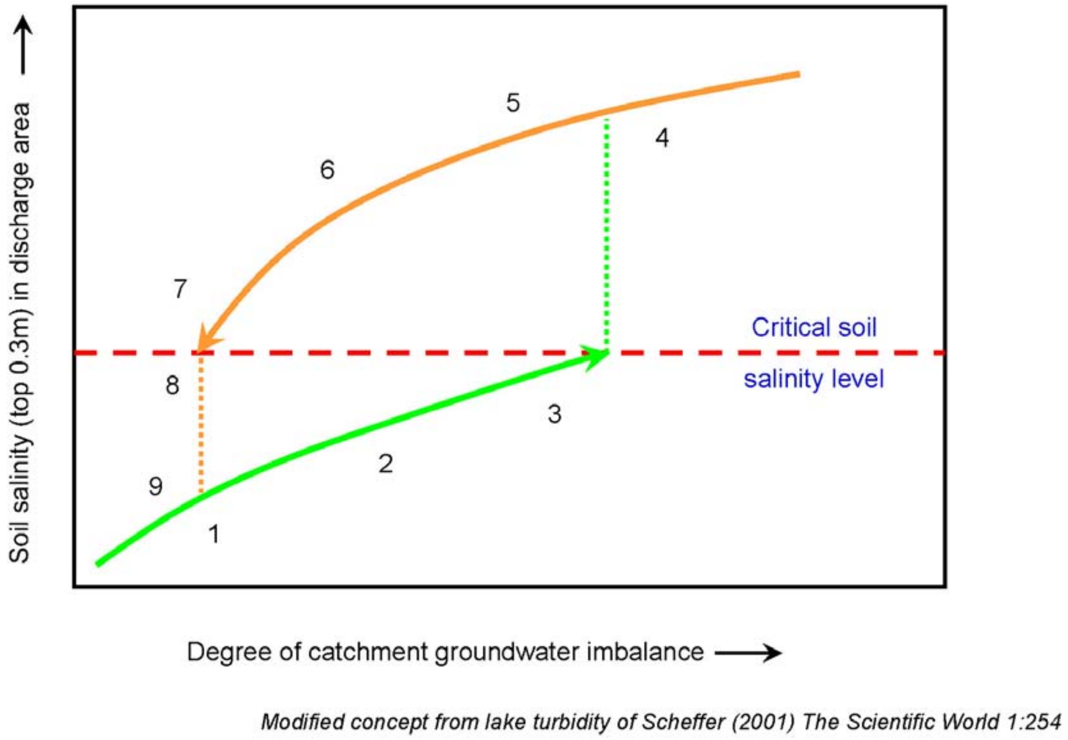

Figure 5. Change of state from a normal catchment to a degraded and saline catchment and the degree of reversal required to restore the situation given the need to return below a critical soil salinity level. The numbers correspond approximately to the stages of salinity development and reclamation of Figure 6 and Table 3.

Three changes are required concurrently to restore a saline catchment based on Figure 5:

- *reduce soil salinity* levels in the root zone to less than the critical soil salinity value so vegetation can survive
- *reduce the degree of groundwater imbalance* to lower the watertable levels since water and evaporation drive the system, and
- *increase the resilience of the catchment* to be able to withstand some variation in hydrology without changing to a saline state. This often means reducing the groundwater inflow/outflow imbalance to achieve a greater watertable depth buffer than would be required for an average rainfall situation.

In general, a salted catchment will move down the upper curve of Figure 5 during active reclamation to the critical soil salinity level. This point will always be a much smaller value for the groundwater imbalance than when the catchments began to show salinity and flipped into the degraded state. Thus a considerable change in water and salt is required before vegetation can re-establish successfully. Planting salt tolerant vegetation into salted areas is not a viable option for the long term. Also Figure 5 indicates that just reducing groundwater recharge will not result in reclamation unless soil salt levels are also reduced. Because salted and bare areas often have changed soil structure due to the high sodium concentrations, leaching of salts is slow and soil dispersion makes plant establishment difficult. Once a catchment has become salted it will be much more difficult to treat effectively.

Thus it is important to maintain a buffer depth to groundwater in catchments that are sensitive to salinity, that is, in catchments that have low resilience to be able to cope with rainfall and groundwater level fluctuations before the critical soil salinity value is reached. Monitoring is vital to achieving successful and sustainable management options.

Extensive areas of the alluvium of Woolshed and Plain Creek catchments near the junction with Lockyer Creek are very close to the critical soil salinity threshold. Some areas have already exceeded the critical salinity threshold. Also the very high groundwater salinity levels over much of the two catchments (EC around 25 dS/m) at only 3 to 4 m below ground in 2006-2007, in a very dry period, indicate these catchments are very close to the tipping point where large salted areas are expected to develop. There are increased land development pressures on these catchments that could well tip the catchments into a degraded state that would be virtually impossible to reclaim given the quantities of water and salt involved.

The concept of non-reversibility of changes to ecosystems or the necessity to change several factors at once before a change to a more sustainable condition is not a new idea. Rapport and Whitford (1999) stated that “human induced stresses on ecosystems are often not a vitalising agent, but a debilitating one and these stressed ecosystems do not recover, rather, further degradation may follow” even when the initial stresses have been removed.

2.2.1.4 Stages of watertable salinity development and reclamation

The area of salinity in a salt affected catchment will increase until a new groundwater equilibrium is established where the quantity of water entering the groundwater through recharge is balanced by the quantity of water that:

- flows out of the catchment through the stream from groundwater or seepage, and
- is evaporated from the bare salted surface or any ponded area or wetland, and
- is transpired through the vegetation in the area where vegetation can use the groundwater. Areas where vegetation is effective usually have shallow watertables of less than 3 metres below ground and are largely non-saline (Hatton 2002).

The time period for a catchment to come to a new equilibrium varies from a few years after clearing to 100 years or more depending on the catchment size, gradient of groundwater flow, rainfall, soils and sensitivity of the catchment to change in the groundwater balance. Many of the areas in Queensland that now show salinity have strong evidence of being at least temporally affected by salt in the past.

Salinity development and reclamation can be considered as stages in a process with recognisable features and management options for reclamation. Figure 6 illustrates the nine stages of salinity development and reclamation. Figure 7 shows some examples and photographs of what these stages might look like. Table 3 gives a description of the stages and outlines some broad management options to be considered. Site characteristics will determine the actual suitability of any one management approach and its long term viability. Some investigation and rough calculations of catchment groundwater and salt mass balances are usually required to make sure any investment in reclamation is effective for the longer term.

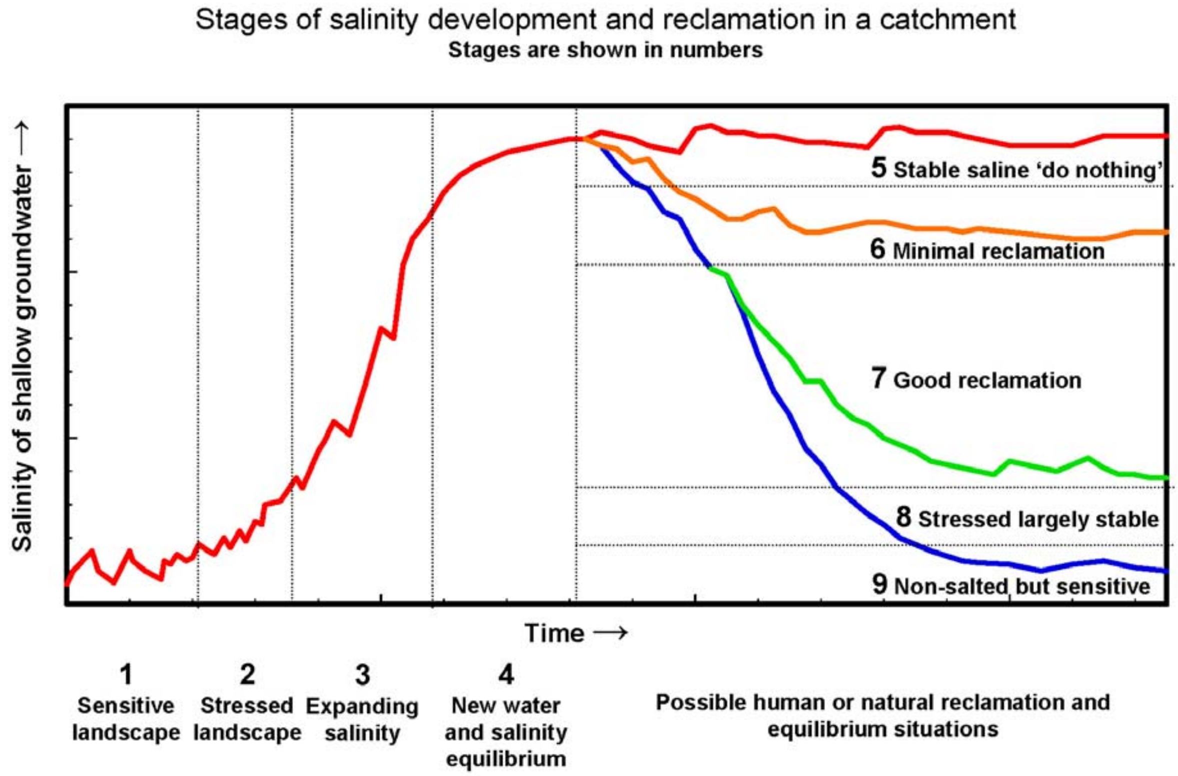

Figure 6. Stages of salinity development and reclamation from Shaw (unpublished).

Stages 1 to 4 are stages of salinity development and stages 5 to 9 are stages of progressive reclamation where it is possible. Some salted areas can reclaim themselves naturally and others can be reclaimed by human intervention, but the majority are difficult to very difficult to reclaim depending on the geology of the area and the quantity of water that needs to be managed. The salinity of the groundwater at a depth of between 2 and 5 metres in, or very close to the salt affected area is a relatively good indicator of the stage of salinity and together with the area affected by salinity can indicate how difficult it might be to manage or reclaim.

Based on personal observations of salted areas in the Lockyer Valley over the last 25 years and the trends for Darbalara farm as discussed in section 3.6, many of the visible occurrences of watertable salinity have reached some semi-equilibrium, that is stages 4 or 5 of Figure 6. Some areas have reached stages 6 and 7 although they have been assisted by the recent series of very dry years and thus it is unlikely it is a sustainable change for the better. Because there are often many indicators for stages 2 and 3, proactive and early management can make a major difference rather than waiting until the catchment is degraded and then attempting to reclaim it as discussed in section 4.

Stage of salinity development and reclamation together with resilience of the area affected are used in the salinity risk assessment in section 7.1.

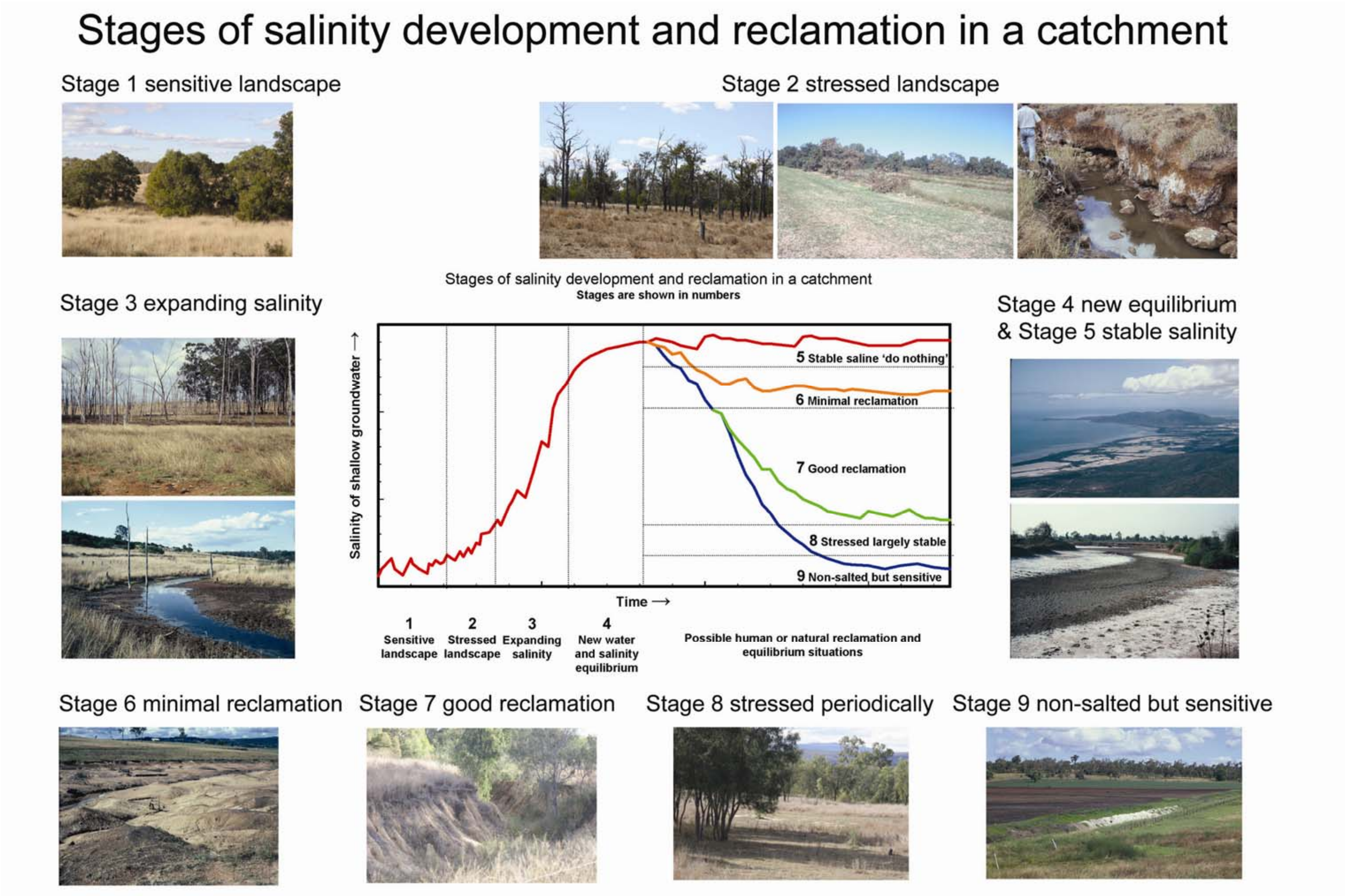

Figure 7. The nine stages of salinity development and reclamation with examples of each stage. Stages graph from Shaw (unpublished).

Table 3. Description of stage of salinity development and reclamation and possible management options.

Stage	Name	Description	Management options
1	Sensitive landscape	Episodic seepage or saline bare areas of short time duration (< 5 years) but largely controlled by native vegetation which may be water and/or salt tolerant.	Proactive management and control measures are essential. Identify extent of episodically affected area, maintain native vegetation at all costs, minimise up stream catchment disturbance or preferably increase groundwater outputs in upstream areas to maintain the salt affected and adjacent areas intact.
2	Stressed landscape	Episodic bare, waterlogged and/or seepage area that lasts for longer than about 10 years. The extent of the affected area is responsive to varying rainfall. Affected area shows signs of tree death and change in grass species.	Proactive management and control measures are essential. Controlled grazing of the affected and adjacent areas to maintain substantial cover at all times. A previously cultivated area with invasive grasses or periodic waterlogging should not be cultivated. Sow deeper rooted plants and/or lucerne or equivalent into the grass depending on the groundwater salinity and depth. Reduce groundwater inputs and increase groundwater use above affected area wherever possible to maintain the watertable level in the affected area to > 3.5 metres below ground wherever possible.
3	Expanding salinity	A rapid change over a 10 year or longer period with increasing seepage and/or bare areas as the catchment comes to a new hydrologic equilibrium.	The lag time from a significant hydrologic change in the catchment can be short or in the order of several decades so that any management may be very slow to have an impact. Site investigations are needed to assess the salt and water balances to allow appropriate management options to be devised. Suitable options will depend on the quantity of excess water, the salinity of the groundwater and the soil salt content.
4	New water and salinity equilibrium	The area has reached a new equilibrium where the extent of the bare area plus any seepage reflects the quantity of water that has to be evaporated or removed to be in an approximate equilibrium. The size of the salt affected area will vary with rainfall patterns	Because the area has reached some stability, the quantity of water to be controlled can be roughly estimated. Given the associated salt loads, strategies can be devised ranging from 'do nothing' through site stabilisation to site reclamation. A priority is to stabilise the area as much as possible by removing stock and cultivation from adjacent areas and ensuring vegetative cover at all times. The next steps will depend on site characteristics but strategies will need to increase groundwater use above the salted area.
5	Stable saline 'do nothing'	The geomorphology of the area will be the major determinant in what eventuates over the long term or what can be achieved. The extent of bare area and/or quantity of seepage will vary with rainfall patterns.	The aim should be to stabilise the area as much as possible to minimise erosion and subsoil exposure. This will probably be a default option in situations where the quantity of water to be managed, the salinity and/or the geomorphology provide major limitations to what reclamation strategies can be implemented.
6	Minimal reclamation	Bare saline areas are transitory (maybe over centuries depending on climate). Natural processes try to reclaim the area by erosion and drainage to enable vegetation to re-establish resulting in some stability. Minimal reclamation would be expected where the geomorphology prevents erosion and gully formation.	As above for stage 5 but more options are available to reduce the salted area with time. There may be a continuum between stage 5 and stage 6 with some sites fluctuating over time. Reducing groundwater inputs and in particular using excess groundwater upslope of the affected area wherever possible are preferred options. Groundwater use is subject to salinity, chemical composition and accessibility of the water.
7	Good reclamation	Some sites will reclaim significantly if they were not affected in the historic past and the geomorphology is favourable, or they can be readily reclaimed by human intervention.	This is a desirable state and can happen naturally where the geomorphology is favourable to lowering the watertable. It is important to create a buffer by lowering the watertable below any critical level to minimise evaporation at the soil surface to cope with natural variability in water inputs.
8	Stressed but largely stable	A site that shows only intermittent bare and salted areas or seepage similar to stage 2 above.	As for stage 7 above except that it may not be possible to lower the watertable sufficiently for most of the time and thus some small areas will remain affected in most years.
9	Non-salted but sensitive	A site that has returned close to the original water balance through natural or human intervention but remains hydrologically sensitive.	This is an ideal state but is not often achieved due to land use change upstream of the affected area. With careful monitoring, such sites may be maintained in this state by ensuring watertable levels in the affected and adjacent areas are below any critical depth to minimise evaporation at the soil surface.

2.2.2 *Irrigation water salinity*

Irrigation water salinity affects plants directly, or through salt accumulation in the soil root zone, or through addition of salts that are leached into the groundwater used for irrigation. Figure 8 shows the typical salt content of soil profiles in the top 2 metres for recharge, normal, discharge and intermittent discharge areas. The shape of the profiles is a reflection of the direction of movement of the dominant source of water and soil properties. Rainfall or rainfall plus irrigation is dominantly downwards while a shallow watertable is upwards movement. Recharge areas are permeable or fractured rock areas with limited salt accumulation because the water moves through the soil quickly. Normal profiles reflect the result of plant transpiration where the source of water is rainfall. Salt accumulates most at the bottom of the active root zone depth. On clearing or irrigation with surface water, the salt in the soil is leached downwards to a new equilibrium salt profile with less salt. The red dotted line for discharge areas is typical of regions of shallow watertables where the dominant source of water is from the watertable with evaporation at the soil surface.

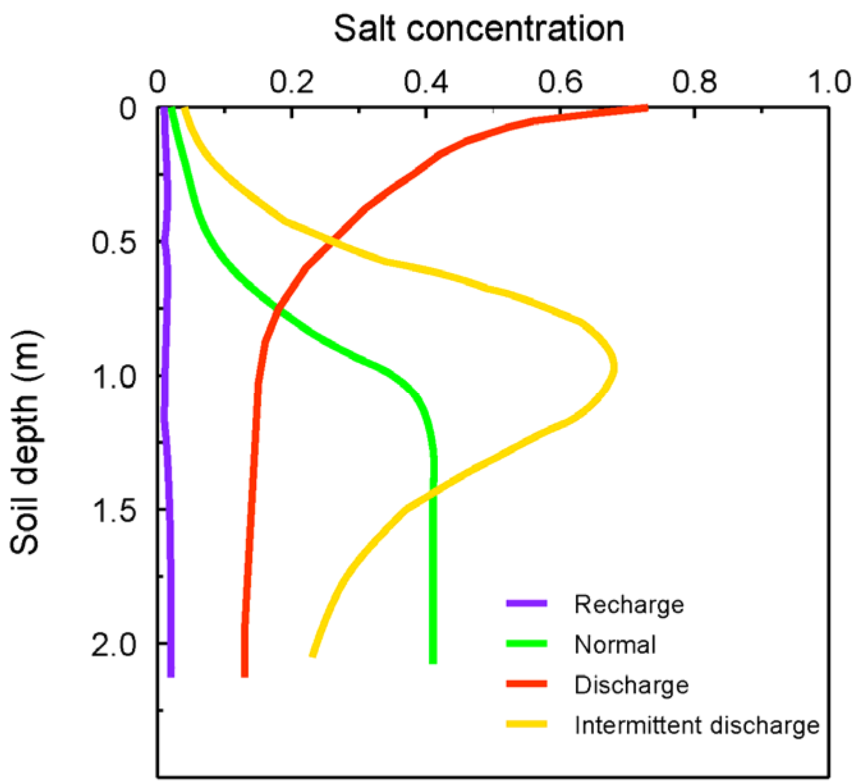

Figure 8. Idealised shapes of salt concentration with soil depth for recharge, normal, discharge and intermittent discharge areas. Figure based on Salcon (1997).

The intermittent discharge profile is typical of situations with alternating periods of shallow watertables followed by rainfall which flushes the accumulated salts down to the groundwater and the surface accumulated salts away through surface flow. This usually follows a series of years of alternating higher and lower rainfalls.

The salt profiles for normal, discharge and intermittent discharge show salt accumulation in the soil profile. Salt accumulation below the active root zone depth of the vegetation and above the watertable is a preferred location for the salt because it will have least impact on the landscape.

Under irrigation with low salinity water any salt accumulated below the root zone in the normal salt profile is leached downwards and with saline irrigation water, the soil salt concentration of a normal profile will increase. The salt change in a recharge profile would be less since there is less salt and less capacity to store salt in the soil profile because of the higher soil hydraulic conductivity. An example of this is given in Figure 9 for the Emerald Irrigation Area where low salinity water (EC 0.25 dS/m) has been used for irrigation on two soils. The time since irrigation is indicated and illustrates that the soil salt content comes to a new equilibrium based on the soil properties and quantity of irrigation. This is consistent with what is observed in natural situations where the soil properties, particularly clay content and ESP are dominant factors in determining salt concentration (Shaw 1996). The salt profile for a normal soil, site M3, (clay content 35 to 45%, CCR (cation exchange capacity to clay content as a ratio) 0.75 to 0.85 and ESP at 0.9 m of 14.3) has come to an approximate equilibrium after some 6 years of irrigation.

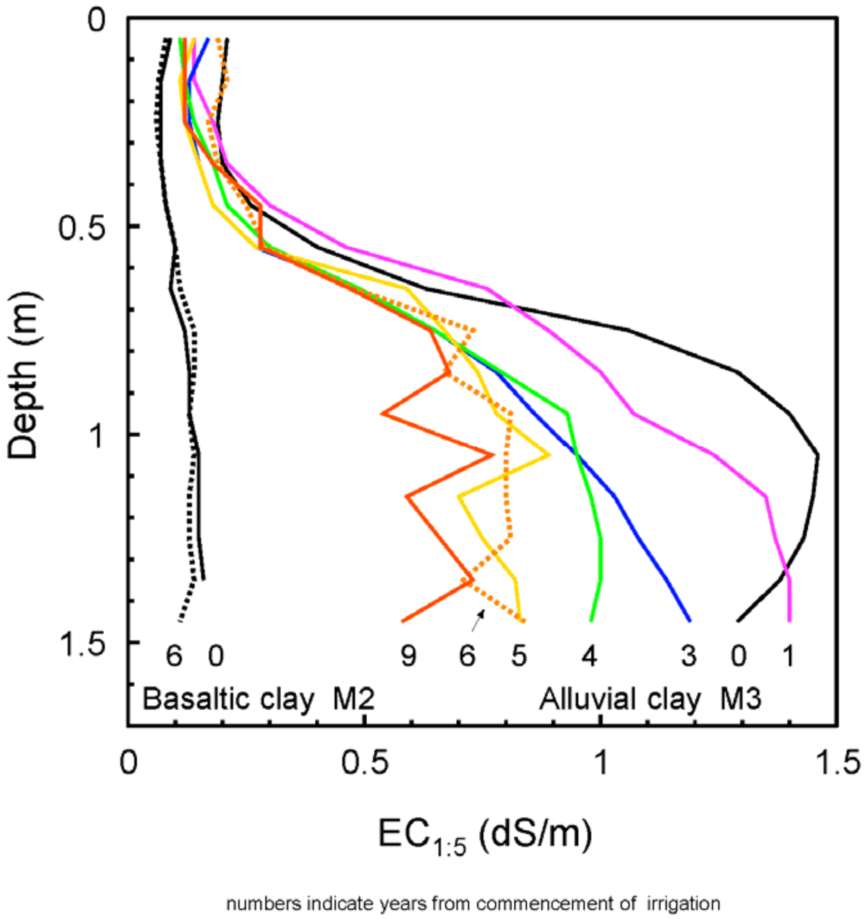

Figure 9. Changes in soil profile salt concentration for two soils in the Emerald Irrigation Area following commencement of irrigation. Site M3 represents a normal soil and site M2 represents a recharge soil profile of Figure 8. Data courtesy of Don Yule formerly of Department of Natural Resources and Water.

Under heavy irrigation, or periods of very high rainfall on consistently irrigated and wet soils, substantial leaching of salts out of the soil can occur. Figure 10 illustrates the impact of irrigation together with episodic cyclones on the salt content of the groundwater for the lower Burdekin region. Salts in the soil and unsaturated layers above the watertable have moved into the groundwater.

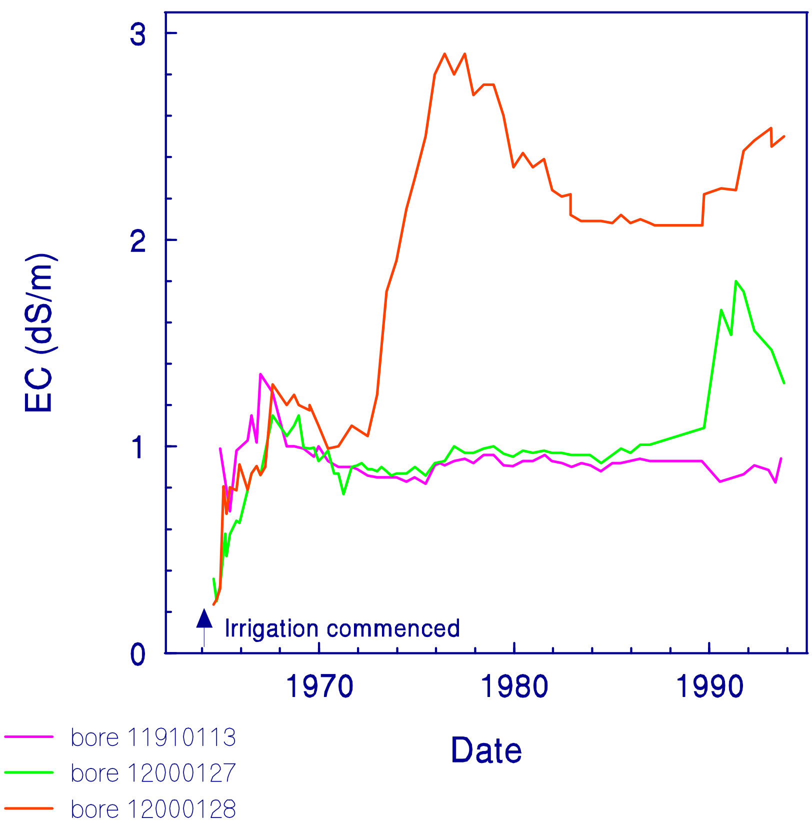

Figure 10. Effect of irrigation and episodic cyclones on salt concentration in the groundwater due to leaching of salt from the soil profile on the left bank of the Burdekin Irrigation Area. Data courtesy of Department of Natural Resources and Water.

Under irrigation with waters of higher salt content, a new equilibrium is established with higher soil salinity. Figure 11 illustrates the changes in soil profile salt content under irrigation with various irrigation water salinities for the Tenthill soil type (Powell et al. 2002) following irrigation with a range of water qualities over various periods of time from sampling in the 1980s (Salcon 1997). Thus, under approximately constant changed hydrology of irrigation, a new salt equilibrium is established. The periods of irrigation for the soils in Figure 11 are 45 years for water with EC 7.4 dS/m, 27 years for EC 3.5, 9 years for EC 2.0 and 30 years for EC 1.6 irrigation water.

The actual response depends on soil properties and the amount of salt leaching that can occur. This is discussed in the next section 2.2.2.1.

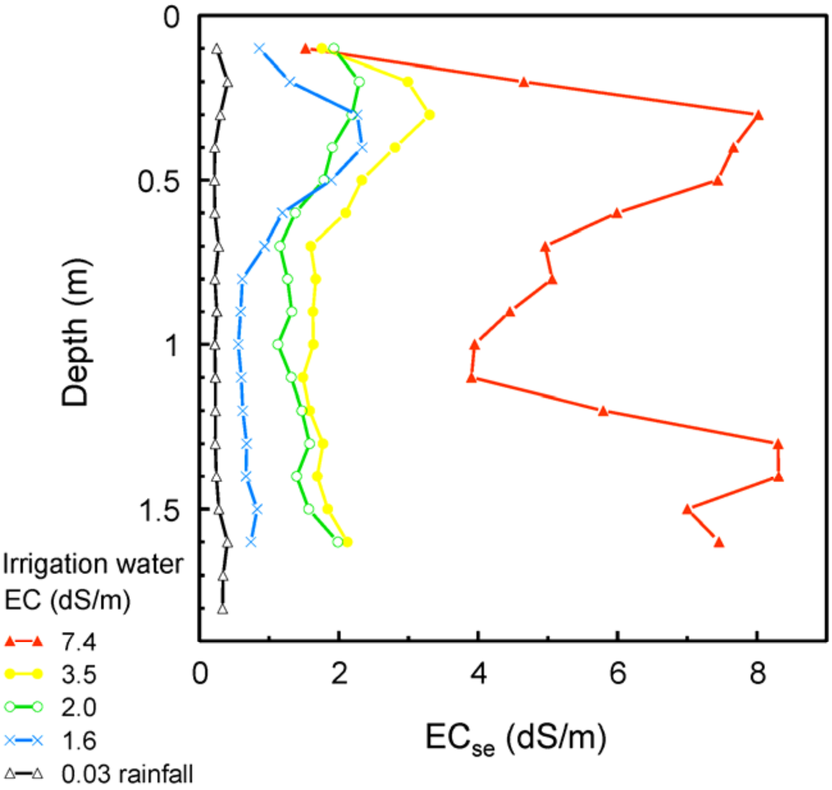

Figure 11. Soil salt profiles in Lower Tenthill following irrigation with waters of different EC for varying periods of time as given in the text. Figure based on Salcon (1997).

2.2.2.1 Mass balance and leaching

Matching irrigation water quality and quantity of applied irrigation water with quantity of rainfall, plant salt tolerance and soil properties means sustainable use of moderately saline waters is possible. The same salt and water mass balance equation as used for watertable salinity at a catchment scale (section 2.2.1.1) can be applied to soil profiles under irrigation to determine the appropriate limits to salinity and sodicity of irrigation water under different situations. Thus the equation of section 2.2.1.1:

$$Q_i c_i = Q_o c_o$$

can be rearranged as

$$\frac{c_i}{c_o} = \frac{Q_o}{Q_i} = LF$$

where:

Q_i is the quantity of water entering the soil (rainfall + irrigation usually expressed as a depth of water)

c_i is the salt concentration of the water entering the soil (weighted by the quantity of rainfall and irrigation water – see below)

Q_o is the quantity of water draining below the root zone; and

c_o is the salt concentration of the water draining below the root zone

LF is leaching fraction, the fraction of total applied water draining below the root zone.

To account for the different salt concentrations of irrigation water and rainfall, a rainfall weighted salt concentration is used calculated by:

$$c_i = \frac{Q_r c_r + Q_{iw} c_{iw}}{Q_r + Q_{iw}}$$

where:

Q_r is the quantity of rainfall

c_r is the salt concentration of irrigation water

c_{iw} is the salt concentration of irrigation water.

Leaching fraction is the means by which the salinity in the root zone can be evaluated and the management of irrigation water salinity adjusted to suit plant salt tolerance. Thus increasing the amount of an irrigation water application that allows leaching of salt below the root zone will reduce the salt accumulation in the root zone, providing the soil properties and soil permeability are suitable. Alternatively, on relatively permeable soils such as the alluvia which have a relatively high leaching rate, management strategies can be used to minimise irrigation water losses below the root zone. This is discussed further in section 6.

Thus for *permeable soils* the quantity of irrigation water used is most important and for *slowly permeable soils* the water quality and quantity are both important. The situation for the Lockyer is outlined in section 5.

Extensive guidelines for irrigation water quality assessment are given in the Australian and New Zealand guidelines for fresh and marine water quality, ANZECC & ARMCANZ (2000) and also in Salcon (1997) with the steps in the irrigation water quality assessment summarised in Figure 12. Important aspects of irrigation water quality for the Lockyer Valley are outlined in Section 5.

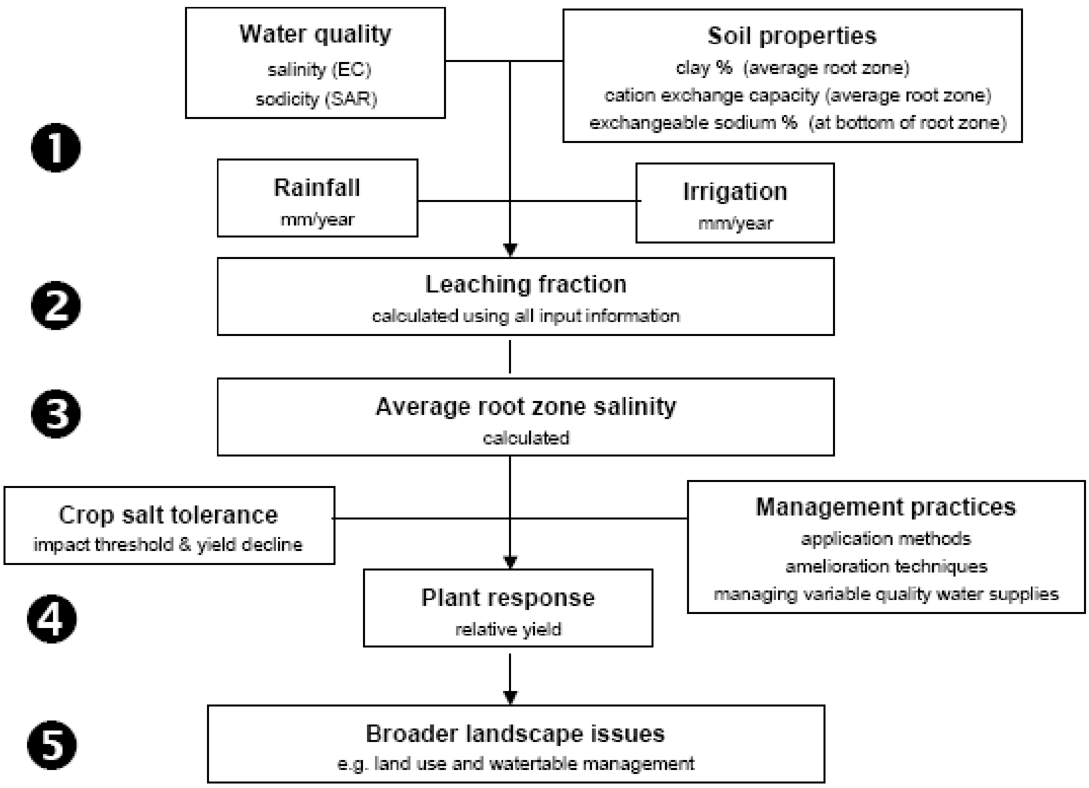

Figure 12. Flow diagram for evaluating the suitability of a water for irrigation, from Australian and New Zealand guidelines for fresh and marine water quality, ANZECC & ARMCANZ (2000). The numbers indicate the important steps to determine the suitability of a water for irrigation.

2.2.2.2 Soil stability

Both the salinity and sodicity of irrigation water together with soil properties are critical parameters in determining the suitability of a water for irrigation. Clay minerals are sensitive to sodium and sodium can have direct effects on soil behaviour. Under various situations the relationship between EC and SAR is a good indicator of the likely soil response to irrigation. High soil sodicity results in soil particle dispersion, surface crusting erosion, poor permeability and limited soil water holding capacity. Dispersibility of soils has been well studied and for most soils, dispersion due to sodicity of a water can be managed by EC within limits (Ayers and Westcott 1976). However, there is an issue under heavy rainfall where the salts in the surface soil layers are leached resulting in increased dispersion.

Figure 13 gives the relationship between SAR and EC based on the relationships developed by Shaw (1996) using an extensive database of subsoils under a wide range of rainfall conditions. It is extrapolated to surface soils under a high rainfall of 1 000 mm/yr. Figure 13 shows a number of features. Stable soil behaviour is maintained for clay soils when there is sufficient salt present to flocculate the clay minerals thus overcoming some of the dispersive properties of sodium (measured as ESP or SAR).

Thus irrigation with waters with EC-SAR combinations that are to the right of the red line of Figure 13 will be stable (except during and after heavy rainfall periods). Soil properties mean a variable response to EC-SAR combinations and the great majority of soils fall between the red and black lines with the most sensitive soils occurring close to the red line and the most stable (sandy) soils occurring closer to the black line. To the left of the black line, there is no EC-SAR combination that is stable for any soil except a siliceous sand because there is insufficient EC to flocculate the soil clay with the sodium present in the water. The blue line of Figure 13 is typical for Lower Tenthill soils and shows a fair sensitivity to SAR.

There is a wide variation in groundwater composition as illustrated by example groundwaters of the Lockyer Valley as the blue dots and example waters of the Great Artesian Basin in western Queensland as the red dots in Figure 13. These dots show that the great majority of waters in the Lockyer Valley derived from basaltic materials are generally good for irrigation and will not cause soil structural deterioration provided only low SAR waters are used. As is well known, Great Artesian Basin waters are not suitable for irrigation because of their very high SAR and low EC values.

Problems arise during high or extended rainfall periods because salts are leached out of the surface soil leaving elevated ESP levels resulting in sodicity and soil dispersion. For example, an irrigation water of about 1 dS/m with SAR of 3 will be diluted to maybe EC 0.25 dS/m after rainfall. From Figure 13, this will be unstable and subject to erosion and hard setting. The soil dispersion issues will be resolved on recommencement with irrigation, although some degradation of surface soil structure will have occurred.

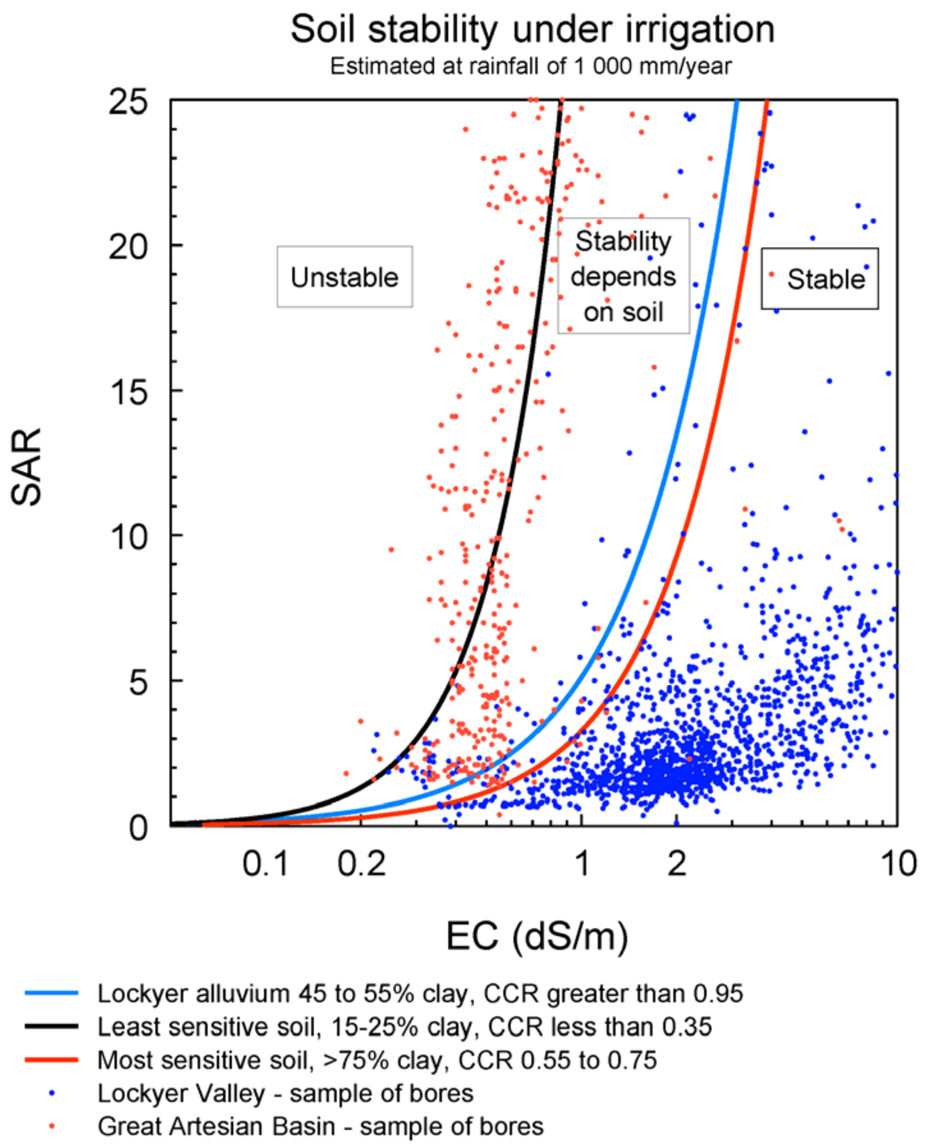

Figure 13. The relationship between EC and SAR in determining soil stability under irrigation. Based on Shaw (1996) and ANZECC & ARMCANZ (2000). The response of soils irrigated with waters between the red and black lines depends on soil properties. The soil response is calculated at 1 000 mm/year rainfall to simulate the effect on surface soil stability following heavy rainfall periods. CCR is the ratio of the soil cation exchange capacity divided by the clay content. Lockyer Valley bore water quality data from QWRC (1982a) and Talbot et al. (1981). Great Artesian Basin water data from Department of Natural Resources and Water.

2.2.2.3 Soil salinity and sodicity equilibrium and resilience

There is a strong relationship between the salinity of a soil (at the bottom of the root zone) and the quantity of water (rainfall or rainfall and irrigation) available for leaching and the properties of the soil matrix which are determined by the packing of the various sized particles in the soil matrix (Shaw 1996). For subsoils, this is determined by the clay content, the mineralogy of the clay (since it determines how well the soil can restructure through swelling and shrinkage) and the ESP since it determines the dispersibility of the clay particles and how well they can move and pack into the pore spaces between the sand particles. For surface soils, the quantity of organic matter and surface soil protection from rainfall are also important.

The salinity in the soil root zone comes to equilibrium with the rainfall input for leaching, the plant water use of available water and soil properties. As salts are leached out of the soil root zone, the soil becomes less flocculated and therefore less permeable. Salt will then gradually build up again to restore the balance. If saline water is applied to the soil, increased flocculation occurs and the permeability is increased with increased leaching. Sandy soils are essentially unresponsive to salt since there are very small quantities of clay present to be affected. Soils with 35 to 55% clay are most sensitive.

Resilience to soil structural decline and soil stability problems varies with the type of clay mineral present and can be represented by:

- *Stable and non-responsive* For weathered soils, kaolinite is usually the dominant clay mineral. It is relatively insensitive to EC and SAR and would align with the black line of Figure 13. These soils are dominated by the mechanical properties of bonding and cementation of clay particles. If there has been considerable sodium present during the formation of these soils, they tend to be compacted and of lower permeability. These soils are not usually irrigated in the Lockyer Valley except in sandy areas.
- *Responsive and low resilience* Soils with a mixed mineralogy of kaolinite and montmorillonite and particularly illite are most sensitive to sodicity, and, because they have only limited ability to swell and shrink on wetting, are less able to restructure and create porosity on wetting and drying. They are less able to restructure from compaction of implements in wet conditions. These soils occur in the Lockyer Valley in alluvial fans and fringe areas of the major alluvial valleys, and
- *High resilience* Soils dominated with montmorillonite clay mineralogy usually derived from basaltic geology and with high clay contents are able to swell and shrink on wetting and drying and are most resilient to sodicity (particularly in the subsoils) since they can recreate porosity. The soils on the alluvial flats in the Lockyer catchment contain mostly montmorillonite and thus are the most resilient to sodicity issues.

3 Watertable salinity in the Lockyer Valley

The readily identifiable patterns of occurrence of watertable salinity in the Lockyer Valley mean that management and prevention guidelines can be specific for the Lockyer Valley.

3.1 Distribution of watertable salinity

The occurrence of salinity degradation for the Lockyer as mapped by John Shaw (1979) is overlaid on his Land Units map in Figure 14. The red elliptical areas in this figure indicate the location of bare salted areas caused by watertable salinity processes. The red line segments in Figure 14 indicate the regions of the major alluvial areas where there is high salinity in the alluvial groundwater. Salinity sites located during the soil survey of the alluvial areas by Powell et al. (2002) have been included together with some sites from field inspections by the author. Salinity is not necessarily currently present at all sites shown in Figure 14 since there has been a long very dry period with reduced recharge leading to lower watertable levels in some situations. The size of the red dots is not directly indicative of the extent of bare saline area at each site. Some locations in Figure 14 are not precisely located.

Figure 14 indicates the very strong association of Winwill conglomerate geology with both watertable salinity and with higher salinity in the alluvial groundwaters of the southern tributaries. Thus it is most likely that processes for watertable salinity and for groundwater salinity in the alluvium of the major southern tributaries are quite similar and have a similar history of development before stream incision in the alluvial valleys occurred.

Restrictions to water flow through the Winwill conglomerate areas is proposed as the consistent pattern resulting in salinity in localised hyrodrologically sensitive areas and the major southern tributaries and is the dominant cause of salt accumulation in the great majority of occurrences in Figure 14. These hydrologically sensitive parts of the landscape align with the catchment restriction form of salting of Figure 4.

3.2 Role of Winwill conglomerate

The Winwill conglomerate is no longer a current stratigraphic term and is now called Gatton sandstone (Geoscience Australia stratigraphic units database) and grouped with the existing Gatton sandstone unit. However, the characteristics of Winwill conglomerate differ from those of Gatton sandstone as described by McTaggart (1963) and cited by McMahon and Cox (1996). "The (Winwill) conglomerate beds and abundant calcite cement form resistant horizons which can form hydraulic barriers to groundwater flow in the alluvium. This warrants consideration of the Winwill conglomerate member as a separate hydrogeologic unit to the non-resistant (to erosion) Gatton sandstone member". Because of the strong association of salinity with Winwill conglomerate, the older term of Winwill conglomerate will be retained in this report. The term Koukandowie formation is now the preferred stratigraphic term to encompass the various formations of Heifer Creek and Ma Ma Creek and Ma Ma Creek sandstone of McTaggart (1963) and Shaw (1979) which overlie Winwill conglomerate as shown in Figure 14. Koukandowie is used in this manner in the salinity report for the neighbouring Black Snake Creek by Ellis et al. (2006).

The narrow throat of alluvium from the catchments in Winwill conglomerate showing salinity is consistent with the catchment restriction form of salting restricting the rate of groundwater movement out of the catchment. Generally there is a very strong association with Black Tea tree, *Melaleuca bracteata,* vegetation in these areas (Photo 2) indicating the strong association with sensitive landscapes and waterlogging. Investigations in some of these saline sites with Black Tea tree also show evidence of calcium carbonate or iron and manganese concretions indicating they have been intermittently but strongly affected by salinity and/or waterlogging in the past. There are small occurrences of salinity in some of the smaller tributaries to the main southern tributaries of Lockyer Creek in the Ma Ma Sandstones and Walloon Coal Measures and while these are small they seem to be more associated with stratigraphic differences and local flows of water. Often Brigalow, *Acacia harpophylla,* is associated indicating both past and present areas of relatively high soil salt content.

For the alluvium of the southern tributaries to Lockyer Creek, Figures 15 and 16 show example longitudinal transects of groundwater salinity from the bores in Ma Ma Creek and Sandy Creek. Sandy Creek shows a pronounced restriction in alluvial width and depth near Blenheim and Ma Ma Creek shows extensive Winwill conglomerate as well as the stream junction with the stronger more consistently flowing Tenthill Creek. The higher salinity levels in the groundwater bores are associated with Winwill areas.

All southern tributaries to Lockyer Creek show areas of high salinity in the vicinity of the Winwill conglomerate exposure, with Laidley and Tenthill creeks having the lowest salinities. This variation in salinity levels has been associated with the relative extent of basalt in the catchments (Talbot et al. 1981) which can be attributed to the relative mean annual creek flow rates. Creeks with high flows will tend to recharge groundwater for longer and result in greater flushing of accumulated salts out of the catchments as shown in Table 4 with data from QWRC (1982). The very restricted Sandy Creek together with the lower mean annual flow is consistent with the highest groundwater salinity of the major southern tributaries of Lockyer Creek. Woolshed and Plain Creeks have higher salinity and considerably lower flows and proportions of basalt in the catchments.

Photo 2. Black Tea tree, *Melaleuca bracteata,* in a wet area of a western tributary to Sandy Creek, Lockyer Valley.

Table 4. Estimated mean annual discharge from southern tributaries to Lockyer Creek, data from QWRC (1982).

Creek	Estimated mean annual discharge (ML)	Period of estimate climatic years #
Laidley	45 931	1890 – 1978
Sandy	9 115	1890 – 1978
Tenthill	24 551	1916 – 1978
Ma Ma	15 807	1910 – 1979
Flagstone	10 684	1910 – 1079

climatic years are calculated from October to September.

The Bureau of Investigation (1949) identified significant differences in stream and groundwater levels over short distances in Laidley Creek which are consistent with the impact of a weathering resistant Winwill conglomerate. Figure 17 shows the creek water level elevation with distance upstream redrawn from their 1949 report with vertical lines added where there are significant water level changes over short distances. It is most unlikely that weirs were constructed on Laidley Creek in 1945 when these measurements were taken, Figure 18 shows the EC of the groundwater in Laidley Creek with the same points of change in the water elevation marked. There is a consistent pattern with higher groundwater salinity levels immediately upstream of the water elevation points strongly suggesting that role of Winwill restricts flow and thus forms “pools” of groundwater that have salts accumulated from past periods of shallow watertables where evaporation and/or evapotranspiration has concentrated salts.

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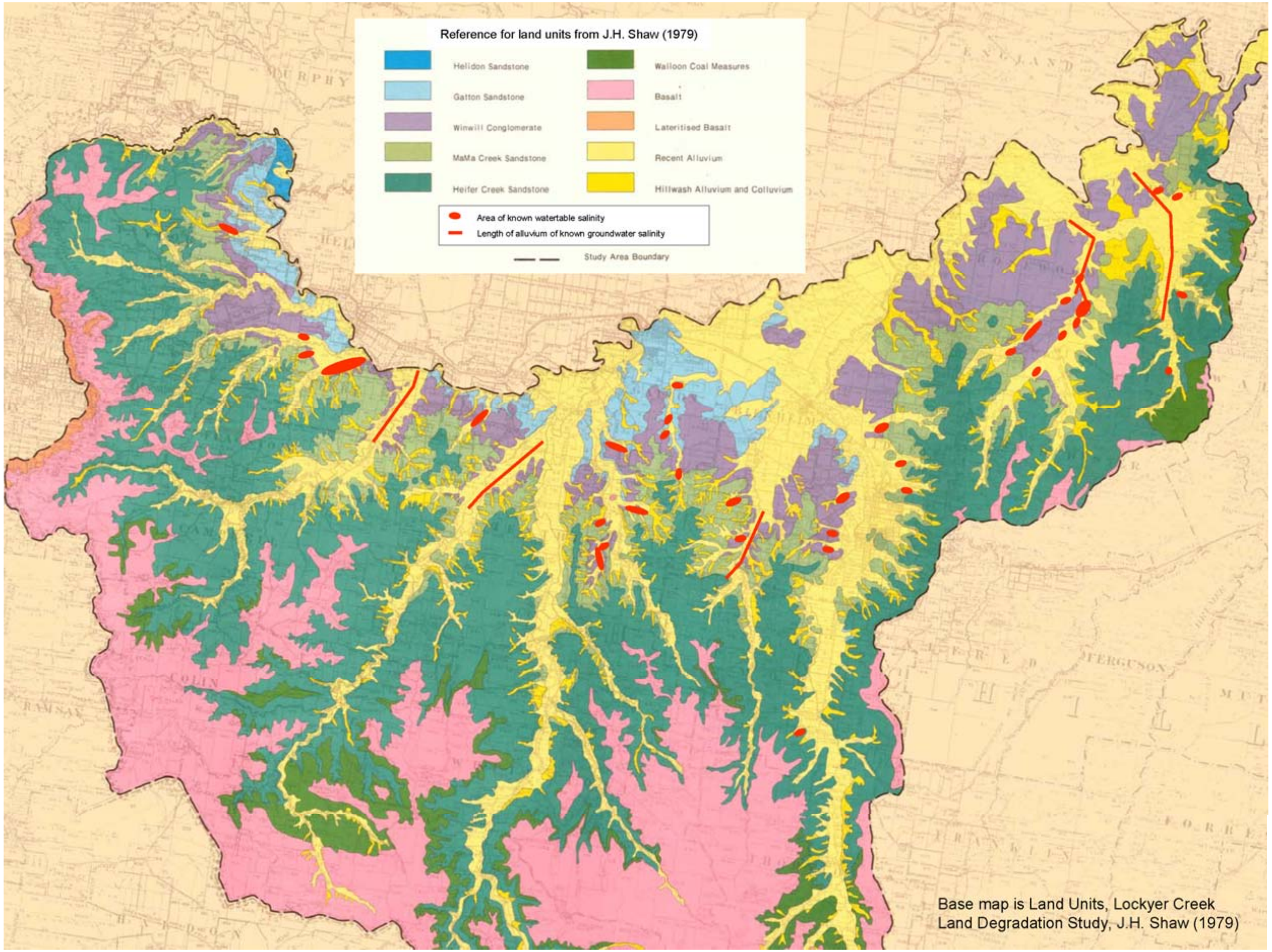

Figure 14. Dryland salinity in the Lockyer Valley as documented by Shaw (1979) and Powell et al. (2002) with some additional sites as red areas. The line segments indicate high salinity in the southern tributaries to Lockyer Creek based on work by the author, Gardner (1985) and Talbot et al. (1981). The very strong association with Winwill geology is evident. The elliptical areas of red are indicative of where watertable salinity occurs and not an indication of the areal extent of salinity at each location. The base map is from Shaw (1979). Small and intermittent salted areas are not shown.

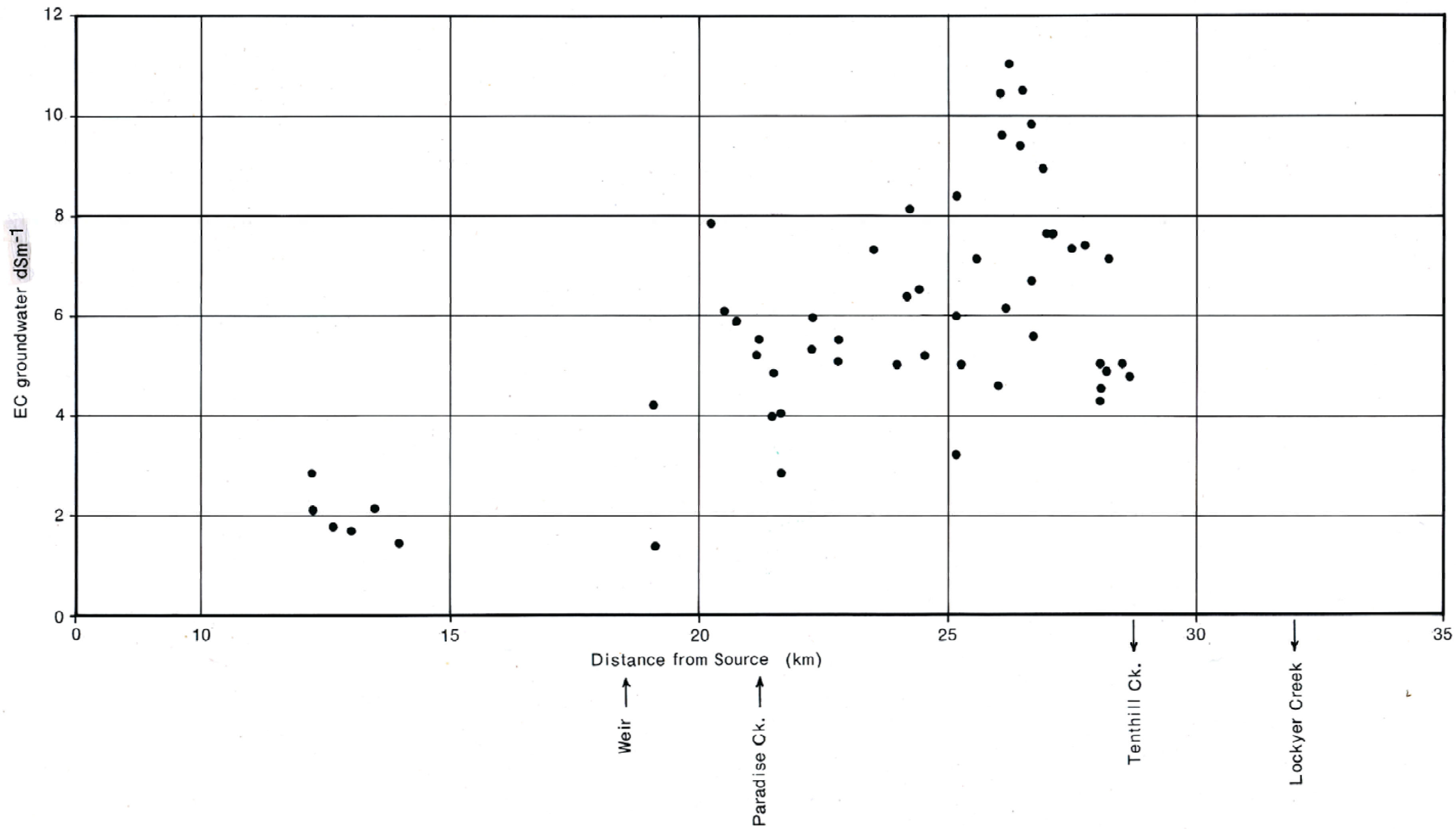

Figure 15. Longitudinal transect of salinity as EC of groundwater bores in Ma Ma creek, Lockyer Valley, as published in Gardner (1985) showing high salinity in the vicinity of Winwill conglomerate and upstream of the junction with Tenthill Creek. Groundwater data from Talbot et al. (1981) and QWRC (1982a).

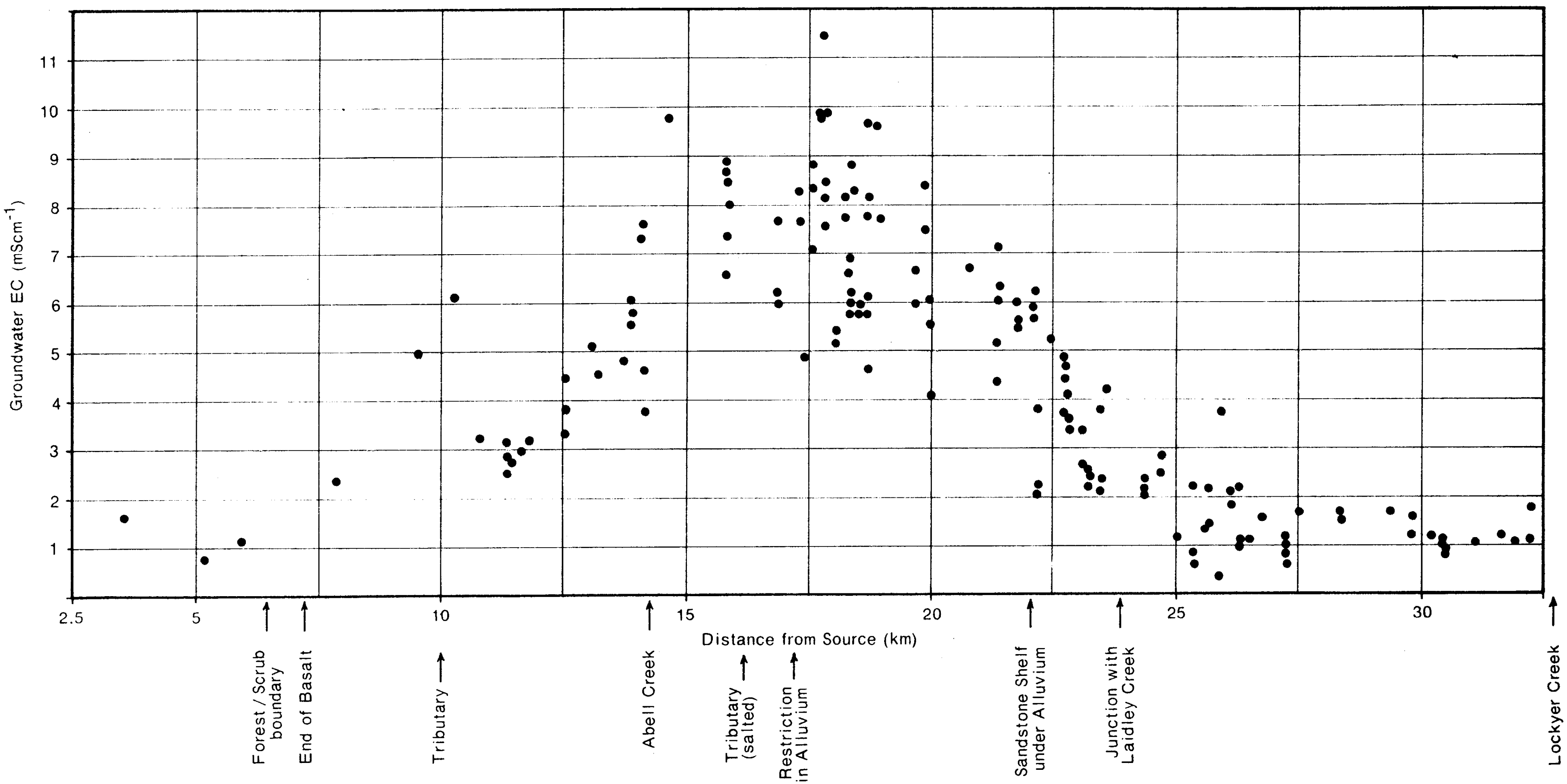

Figure 16. Longitudinal transect of salinity as EC of groundwater bores in Sandy Creek, Lockyer Valley as published in Gardner (1985) showing a peak of high salinity at the point of narrow flow with a restriction by Winwill conglomerate. Groundwater data from Talbot et al. (1981) and QWRC (1982a).

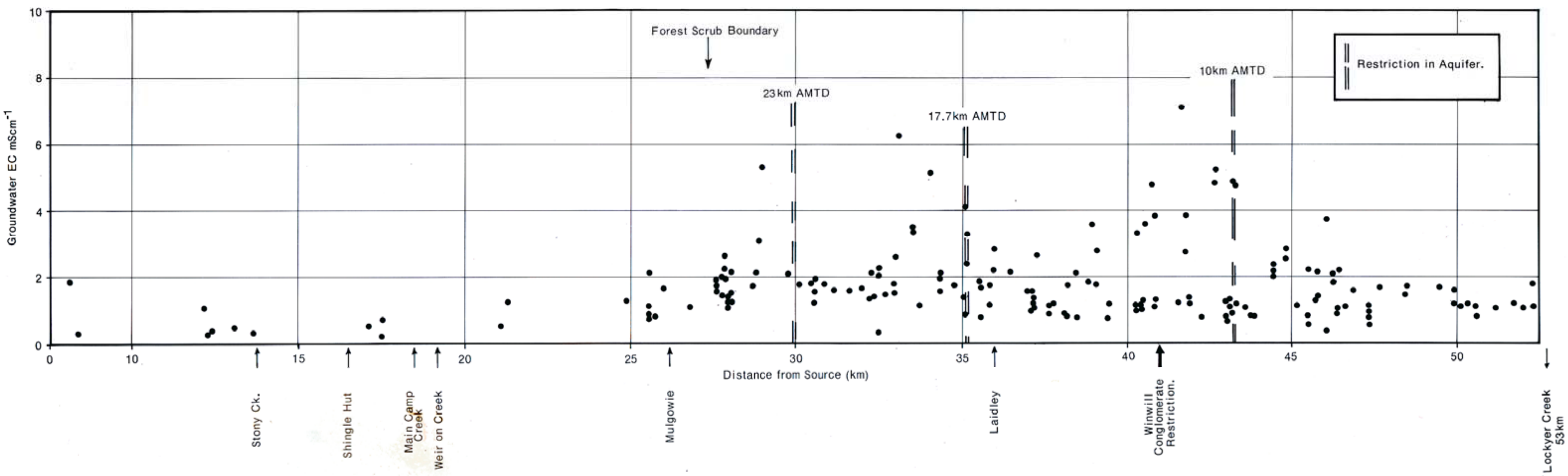

Figure 18. Longitudinal transect of salinity as EC of groundwater bores in Laidley Creek, Lockyer Valley based on data from QWRC. Vertical double lines are located at the same positions as those in Figure 17 indicating possible restrictions to flow by Winwill conglomerate. Groundwater data from Talbot et al. (1981) and QWRC (1982a).

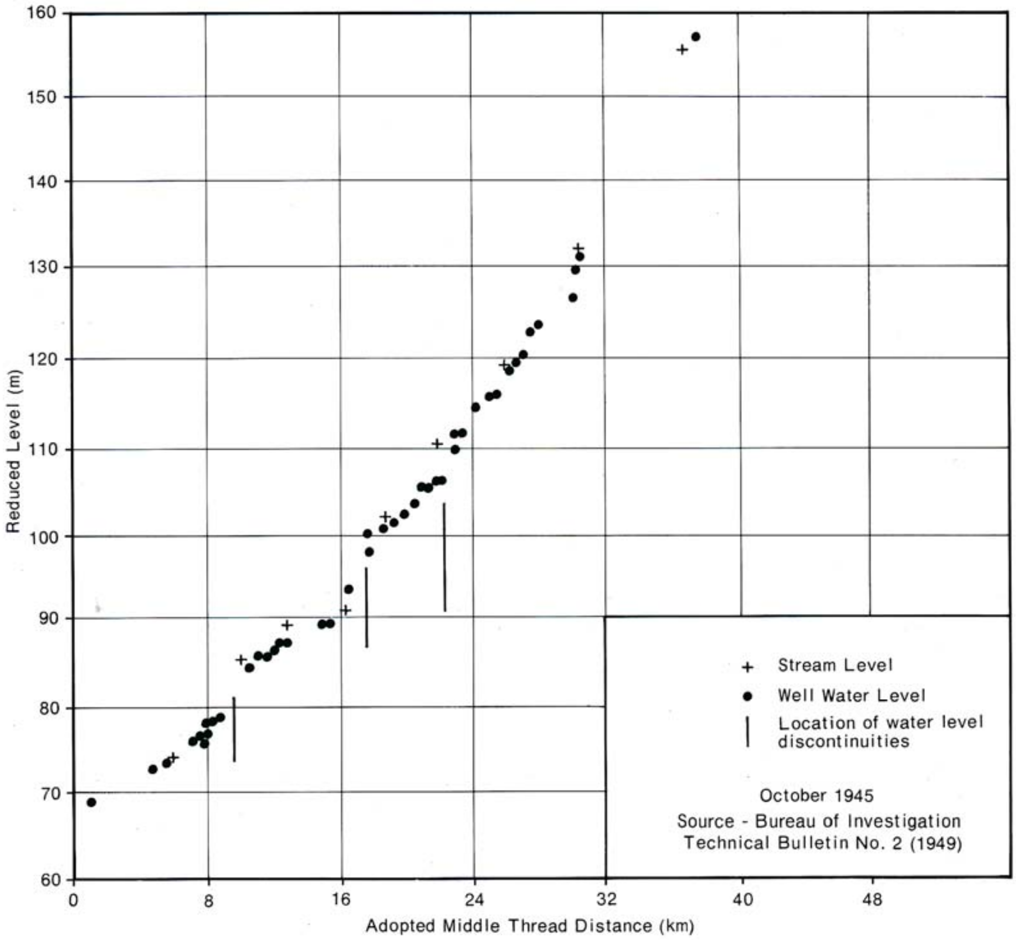

Figure 17. Water level in Laidley Creek and adjacent well with distance upstream (redrawn from Bureau of Investigation 1949) indicating substantial changes in water levels over short distances where the vertical lines occur on the figure. Corresponding groundwater salinity changes are shown in Figure 18.

Thus the pattern of salinity in dryland catchments and the major alluvial aquifers follows the same trend where restriction to local flow caused by Winwill conglomerate appears to be the dominant mechanism causing salinity. This means that management of salinity has to account for the role of Winwill conglomerate as the dominant mechanism causing salinity. The source of salts is discussed in the next section because of its importance in confirming the processes operating.

3.3 Source of salts in the Lockyer Valley

Early arguments about the source of salinity in the Lockyer suggested that the Winwill conglomerate must be the source of the salt and water causing salinity since it contains high to very high salinity groundwaters. If this was correct, the management options for salinity reclamation in the Lockyer would be very different from the case if Winwill was only acting as a hydrologic barrier to water flow. Thus the processes operating need to be clarified. All the available evidence indicates that Winwill conglomerate is acting as a restriction to groundwater flow out of both small and large catchments for the following reasons:

1. The *geology and geomorphological discussion* presented in the previous section showing the very strong association of salinity with Winwill conglomerate as a restriction to water flow. The decrease in groundwater salinity in Sandy Creek downstream of the restriction is interesting (Figure 16) and if there was a major source of salts coming from the Winwill conglomerate, it would be expected to flow to

downstream areas below the restriction as well. The fact that this is not the case is most likely due to recharge through the alluvium as the soil leaching fraction (section 5.1) is quite reasonable.

2. The detailed *water chemistry analyses* as reported in Salcon (1997) pages 95 to 97 clearly show that the salt composition of the groundwater in the alluvium of the southern tributaries reflects the composition of a basalt source which has been concentrated through evaporation and not that of the surrounding sandstone formations. This is also confirmed by Zahawi (1975) who identified high relative magnesium content in the alluvial groundwaters which is strongly associated with a basalt source for the salts. Gardner (1984) and (1985) and Galletly (2007) have come to similar conclusions. McMahon and Cox (1996) suggested that the groundwaters in the Sandy Creek alluvium reflected the hydrochemistry of the Marburg formation. Their analysis based on a limited number of samples did not account for the processes of evolution of saline waters by concentration and salt precipitation as outlined in detail in Shaw et al. (1987) and Salcon (1997). Galletly (2007) concluded his extensive review of data and the literature saying "There is no evidence to support the concept that salinity (in alluvial aquifers) is the result of cross-transformational flow (from Marburg sandstones) and there is a large body of evidence to support the view that baseflow in the Lockyer Valley is outflow from Basalt aquifers on the Main Range".

3. The evidence of the *very low transmissivity of aquifers* in Winwill formation as identified by Zahawi (1975) strongly supports the role of Winwill as a restriction to flow and not a source of salts and water for salt outbreaks. Table 5 shows the relative transmissivity of the aquifers in the different geological formations expressed as cubic metres of flow per metre thickness of aquifer taken from Zahawi (1975).

   Table 5. Transmissivities of aquifers in the Marburg formation and in the alluvium in the Lockyer Valley from the data of Zahawi (1975).

Formation	Transmissivity of aquifer (m^3/m thickness/day)
Marburg formation (upper beds)	11 to 103
Marburg formation (lower beds)*	0 - 1.3×10^{-5} (< 0.000013)
Alluvium	75 – 1625

   *The Marburg lower beds contain the Winwill conglomerate formation

   The values in Table 5 indicate that it is most unlikely that the Winwill is a source of water because it has such a very low aquifer flow capability, but rather acts as a largely impermeable barrier to water movement.

   There are comparatively few bores in Winwill formation and those that are there generally have a high salt content. High groundwater salinities are commonly associated with lower aquifer transmissivities since the salts in the water reflect dissolution of weathering of the geological formation with limited ability for outflow. If significant water flows, the salt concentration tends to decrease due to flushing. This is a similar concept to the difference between recharge soil profiles and normal soil profiles of Figure 8.

4. Gardner (1984 and 1985) evaluated the *salt mass balance* (salt inputs and salt outputs) and salt sources in the southern tributaries of the Lockyer in detail and concluded that the concentration of salts in the alluvial aquifers by evaporation and

evapotranspiration in the past rather than an additional source of salts was the main mechanism. He concluded that “the evidence does not support sandstone water leakage as the major reason for salinity in the alluvial aquifers. Present day aquifer salinity levels are a product of historical hydrogeological processes with most salt accession through stream recharge processes”. The role of Winwill as a restriction to groundwater movement has been confirmed as a major mechanism for salt accumulation for the adjacent Black Snake Creek catchment (Ellis et al. 2006). Gardner (1985) showed that the rate of flushing of salts out of restricted catchments such as Sandy Creek is very slow and will take a very long time to reduce as shown in Table 6. In the southern tributaries of Lockyer Creek which have low salinity, the increased use of groundwater for irrigation reduces the flushing of salts out of the catchments resulting in a slight increase in salinity over time. Woolshed and Plain creeks were not evaluated in the work of Gardner but the processes operating in the major southern tributaries of Lockyer Creek appear consistent with the observed salinity in Woolshed and Plain creeks.

Table 6. Predicted future mean chloride concentration in the aquifers of the southern tributaries to Lockyer Creek from Gardner (1985).

Alluvial aquifer	**Predicted mean chloride concentration of groundwater for the years specified (mg/L)**					
	1975	**1980**	**1985**	**2000**	**2015**	**infinity**
Laidley	165	165	166	166	166	170
Sandy	1 250	1 220	1 200	1 110	1 020	500
Tenthill	290	290	292	300	300	340
Ma Ma	1 720	1 740	1 660	1 440	1 200	350
Flagstone	820	840	800	715	640	175

Pearce et al. (2008) found that the EC of alluvial groundwaters in Flagstone and Tenthill creeks showed minimal variation over the time of monitoring from the 1980s to the present. In Ma Ma creek the groundwater salinity has decreased significantly but Sandy creek has increased. Since the restriction to flow in Sandy Creek is not at the bottom of the catchment, the location of bores becomes significant in interpreting trends. Of the 14 bores Pearce et al. list with trend data, only 4 have increased and the other 10 either have no change or lower EC. If salts were leaking from Winwill, the EC should be increasing over time but that is not the case and the predictions of Gardner (1985) would seem to be more plausible. Further analysis of changes in alluvial groundwater chemistry with time is underway.

Thus there is strong evidence that the Winwill formation acts predominantly as a restriction to groundwater flow in the Lockyer Valley sometimes in association with other forms of salting. Thus the argument that extensive land clearing of the uplands of Ma Ma Creek and Heifer Creek formations has caused the salinity problems in alluvial aquifers is not supported by the evidence. This is important in determining appropriate planning guidelines and management strategies since strategies need to account for processes of salt accumulation and also sources of salts. Thus major revegetation of the upland areas would not have any significant effect on the salinity of the alluvial aquifers of the southern tributaries of Lockyer creek.

3.4 Conceptual picture of salting processes in the Lockyer Valley

A conceptual picture of salting in the Lockyer Valley can be made based on the distribution of watertable salinity and salinity in the alluvial aquifers of the southern tributaries. Figure 19 shows a three dimensional diagram of the salt processes associated with Winwill geology as a restriction to groundwater flow out of a catchment in the Lockyer valley. Under natural conditions, salt accumulated at the bottom of the root zone as shown in Figure 8. If there was an intermittent shallow watertable, then the salt accumulation would move upwards or downwards and show a profile shape similar to an intermittent discharge salt profile in Figure 8. As the watertable rises further, vegetation would be killed and the historic salt moved to the soil surface and a bare salted area would result.

If the watertable rose to the soil surface and extensive seepage occurred, then some of the historic salt would be flushed from the soil surface. If on the other hand, in a normal situation of no surface salting, and local groundwater used for irrigation, it would leach the accumulated historic salt down to the watertable. Thus where intermittent watertable salinity has occurred over past ages, salt will accumulate similar to the intermittent profile of Figure 8. The salt is moved upwards to the soil surface in periods where there are shallow watertables and downwards to the groundwater in periods where there are deeper watertables and evaporation at the soil surface is limited.

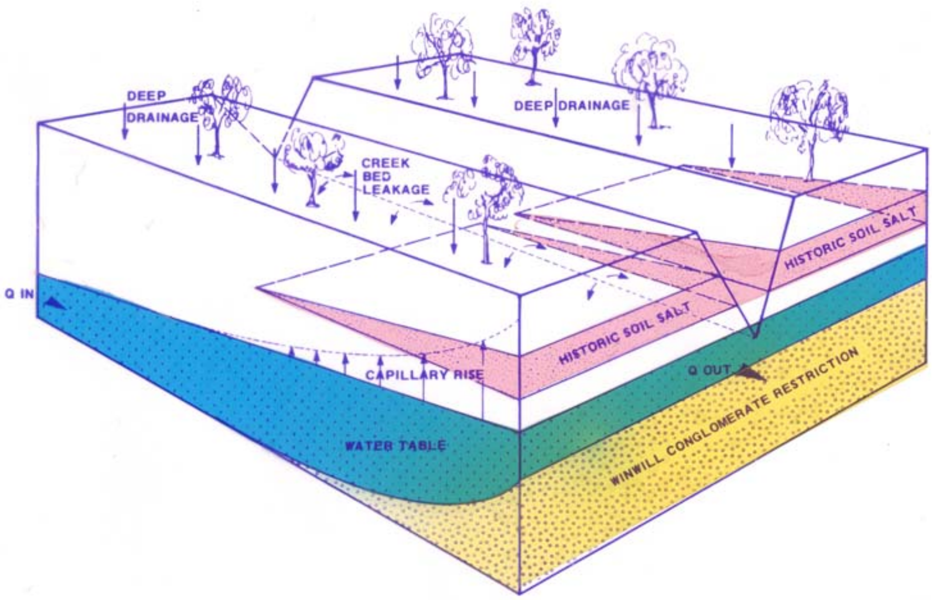

Figure 19. A three dimensional diagram of the salinity processes typical of a salted catchment and also the major southern tributaries in the Lockyer Valley from Gardner (1985).

If irrigation using the groundwater occurs, as commenced in the Lockyer Valley from 1939 (Bureau of Investigation 1949), the salt in the unsaturated zone is flushed to the groundwater as shown in Figures 9 and 10 for the Emerald and Burdekin irrigation areas raising the salinity of the groundwater. This would be observed as an increase in irrigation water salinity. This process occurred in Sandy Creek following the commencement of groundwater irrigation in the 1940s and the salts are now being slowly flushed out of the catchment as Table 6 predicts. The increase in numbers of off-stream storages in Sandy Creek are a direct response to irrigation water salinity and are in fact contributing to the flushing of the aquifer.

Thus the key issue in a salted catchment is being able to manage the watertable level and salt load to minimise impacts over the longer term by maintaining watertable levels at sufficient depth to minimise evaporation of salt on the soil surface or stream bank.

In the past dams were constructed in some of the salt affected small streams draining into the major southern tributaries of Lockyer Creek partly because the areas were wet and also because the narrow valleys and sometimes steep sides made them ideal locations to construct a dam. The presence of a dam has resulted in the equivalent of a ‘hydraulic barrier’ to water flow resulting in salting both upstream and downstream of the dam as a result of the

leaking water filling all the available storage in the limited capacity alluvial materials. Figure 4 shows the processes and Figure 20 shows this effect for a dam near Mt Tarampa. The dam has been in place for over 40 years.
The figure shows that the area above the dam is saturated and has surface salt accumulation from evaporation. Below the dam the stream channel is also saturated and largely bare from salt accumulation and soil erosion. This is also occurring across the valley alluvium partly because the more restricted flow through this alluvium and the already high watertable in the alluvium has meant there is no drainage for the excess water. It is most likely that leaking dams have triggered the salting in other small sub-catchments. In the case of the example near Mt Tarampa, there is a relatively high proportion of Black Tea tree upslope of the dam indicating that this drainage line has always been sensitive to waterlogging which has been exacerbated by the dam. The association of dams with salinity in the Lockyer Valley is very high as described in section 9.3.

Figure 20. Example of the impact of a farm dam on salting in a drainage line in Winwill formation and the alluvium near Mt Tarampa in Plain Creek. The hydraulic barrier of the dam together with leakage has affected the upstream and downstream areas very significantly. Image from Google maps.

In other parts of the Lockyer, roads across wet lower parts of drainage lines have caused similar problems upstream by restricting even further the limited ability of water to flow through the alluvium by soil compaction. A classic example is Darbalara farm, The University of Queensland near Laidley.

In summary, there is a distinct and repeating pattern of landscape features associated with salinity in the Lockyer Valley both in small dryland catchments and also in the major southern tributaries that shows that Winwill conglomerate geological formation is strongly associated with the occurrence of salinity. Winwill conglomerate is acting as a weathering resistant formation restricting the rate of groundwater movement out of the catchments. This means that salinity is due to local and relatively shallow groundwaters. It is unlikely that deeper aquifers are contributing water and salt to the system although some additional investigations may be required to confirm this in situations where water composition may indicate a strong sandstone influence. Thus salinity and watertable management can be targeted to local and shallow systems that respond more quickly and have a greater chance of success from reclamation strategies.

3.5 Salt mass balance of catchments

When there are high salinity levels in creeks, it is often assumed that there will be a large impact on receiving waters. This is only true if there is a reasonable flow rate of high salinity water. The concept of mass balance is important to put salinity into perspective. The salt load is the concentration of salt multiplied by the quantity of flow.

What salt load means is that a large quantity of low salinity water can have a higher salt load (mass of salt) on receiving waters than a low flow of saline water. Since the mass balance is usually conserved unless salts precipitate, that is salts remain in solution, then we can use the same mass balance equations of section 2.2.1.1 to estimate the salt leaving a catchment. Thus annual rainfall (EC 0.03 dS/m) of 800 mm/yr (8 ML/ha) as rainfall input into a catchment can be in equilibrium with a drainage of salty water out of a catchment of EC 25 dS/m.

There is a simple but non-linear mixing relationship between the salt concentration of the base flow of a stream at very low flow and the salt concentration of stream at very high flow which can be roughly approximated by rainfall. Between these two extremes, the salt load out of a catchment is quite dependent on flow rate as illustrated in Figure 21. There is a hysteresis effect where the first high flow is of higher salt concentration and the receding flow of lower concentration.

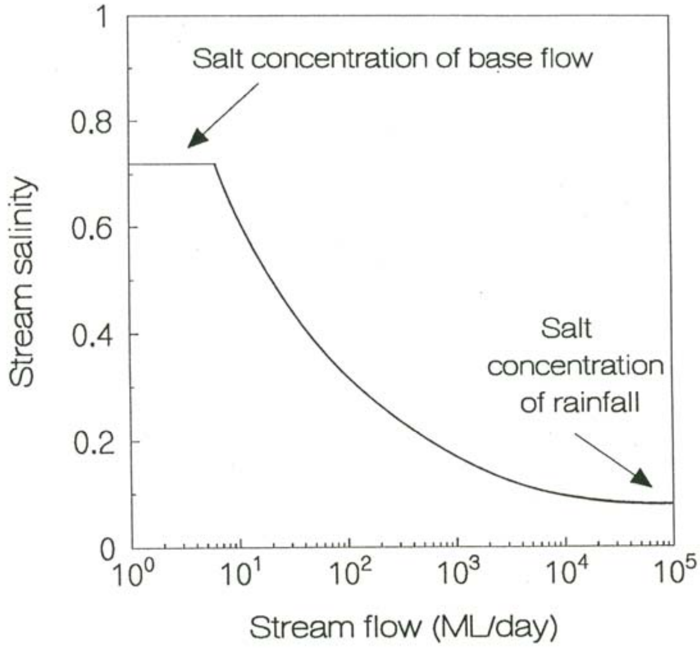

Figure 21. Conceptual mixing model of surface water flow between the extremes of base flow concentration and the concentration of rainfall at high flow.

Using this model and the available data for Purga Creek in the nearby Bremer catchment, and substituting the EC for Woolshed Creek base flow at 25 dS/m for the EC of the base flow of Purga Creek at 7 dS/m and taking a value of EC 0.2 at a flood flow rate of 1 000 ML/day allows a rough estimate of the salt mass balance. Table 7 gives a very approximate example of the mass of salt moving out of the Woolshed or Plain Creek catchments at different creek flow rates. The table shows that the impact of the high salinity of the groundwater will probably only become a problem for Lockyer Creek at moderate to high flow rates.

The pattern of down valley groundwater flow, geological restrictions and the confluence with streams resulting in high levels of salinity due to evapotranspiration of shallower watertables in restricted flow areas is a consistent pattern in many major river valleys in Queensland where basalt derived alluvium has infilled old valleys. All southern tributary creeks to Lockyer Creek show the pattern to varying extents as shown in Figures 15, 16 and 18.

Table 7. Estimated mass of salt moving from Woolshed or Plain Creeks at different flow rates entering Lockyer Creek alluvium.

Surface flow (ML/day)	Estimated EC of stream flow (dS/m)	Mass of salt leaving the catchment (tonnes/day)
0.001 (1 000 L/day)	25	0.02
0.01	25	0.2
0.1	25	2
1	12	8
10	5	33
100	1.5	100
1 000 (1 billion L/day)	0.2	133

The Callide Valley system near Biloela and Dululu as shown in Figure 22 shows the salinity transect and also the transmissivity changes in the lower Dee River where it joins Callide Creek. The pattern of salinity found for the Callide by Dowling and Gardner (1988) indicates a very similar pattern to the stream patterns of the Lockyer. The salinity at the junction of Woolshed and Plain Creeks with Lockyer Creek is at least twice as high as other systems in Queensland and thus of major concern.

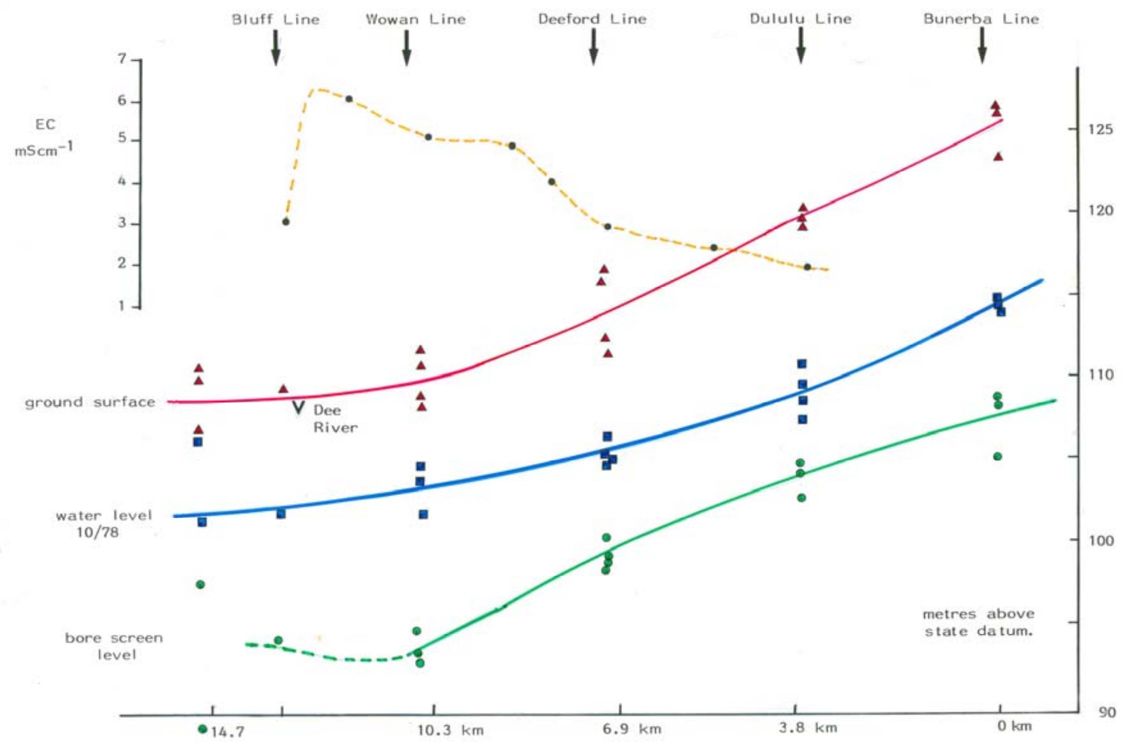

Figure 22. Longitudinal transect through Dee River valley to the junction with the Callide. The transmissivity of the aquifer in the Wowan line was 1 100m^3/m/day and for the Bluff line near the confluence with Callide Creek was 180 m^3/m/day. Data plotted from Queensland Water Resources Commission reports.

3.6 Factors modifying the expression of watertable salinity

Three factors have a large effect in modifying the extent of salinity in a catchment in addition to land use and hydrologic changes. They are hydraulic gradient, incised stream channels and rainfall pattern.

Hydraulic gradient

The hydraulic gradient of the groundwater is an important factor influencing whether salinity will occur because it is the driving force for groundwater flow. This hydraulic gradient is closely related to the slope of the ground surface. Low slope situations are much more prone to show salinity. Hydraulic gradient is a useful overlay on forms of salinity (Figure 4) to allow a more precise evaluation of regional areas.

Incised stream channels

If an incised stream channel is present with all other aspects being equal, there is likely to be a lower incidence of bare salinity areas because the incised channel will tend to lower the watertable level by drainage if the geomorphology is suitable.

Rainfall pattern

Climate and rainfall patterns are important. South-western Australia has by far the worst salinity in Australia with Queensland relatively low. This is due to landform features strongly influenced by climate. SW Australia and Victoria have strong Mediterranean climates with winter rainfall during periods of low evaporation demand (usually < 1 mm/day) while north eastern Australia with a summer dominant rainfall has rain falling when there is strong evaporative demand (of around 5 mm per day). Thus in Queensland the opportunity for recharge is reduced except in very wet months with consistent rainfall.

Rainfall is the source of water for recharge. Thus rainfall patterns over time are important in the expression of salinity. Surface water irrigation, off stream storages and waste water disposal in non sewered subdivisions can also be significant sources of increased recharge. Variations in rainfall patterns over periods of a few years tend to have a large influence on the expression of salinity. A moving average rainfall over a five year period is a simple and convenient way of showing rainfall variability. This is shown in Figure 23 for the DPI weather station at Gatton (040082) where the recent very dry conditions are similar to the 1920s and thus the salinity visible currently is less than would be present in average to wetter rainfall periods. Salinity can be expected to increase considerably when wetter periods return. The rainfall trend appears to show both a short term pattern of variation with a periodicity of around 20 years and a longer term 80 to 90 year cycle based on the records available.

The bare salted area on Darbalara farm, The University of Queensland, as assessed from air photographs shown in Figure 23 appears to follow the rainfall pattern quite closely. Given that clearing appears to have happened in the late 1800s and early 1900s, there has been a relatively long lead time until a new equilibrium was established in the 1970s. This coincided with a series of wetter years.

As the rainfall decreased, the extent of bare area also decreased slightly indicating that the system has come to a new quasi-equilibrium. The year the rainfall is plotted in Figure 23 is actually the average of the previous 4 years plus the year of the plotted value. The bare area is plotted in the year of the air photograph and thus the area of salting appears to react quickly to rainfall. While this is a reflection of how the results have been plotted it strongly confirms the effect of rainfall pattern on the bare area of salting. Given the last several years have been particularly dry and salting is still very evident at Darbalara and many other places in the Lockyer Valley, the concept of reducing recharge by replanting vegetation and deep rooted perennial pastures will never be sufficient alone to reduce the area of salt affected land. It is a 'systematised illusion' whose veracity comes from constant repetition. Areas showing significant salinity in an extended dry period (such as the current period) when there has been little or no recharge indicates that more than revegetation alone will be required if salt affected lands are to be reclaimed in at least the medium term. This is because the system has already flipped into the degraded state and has only progressed part way down the curve of Figure 7.

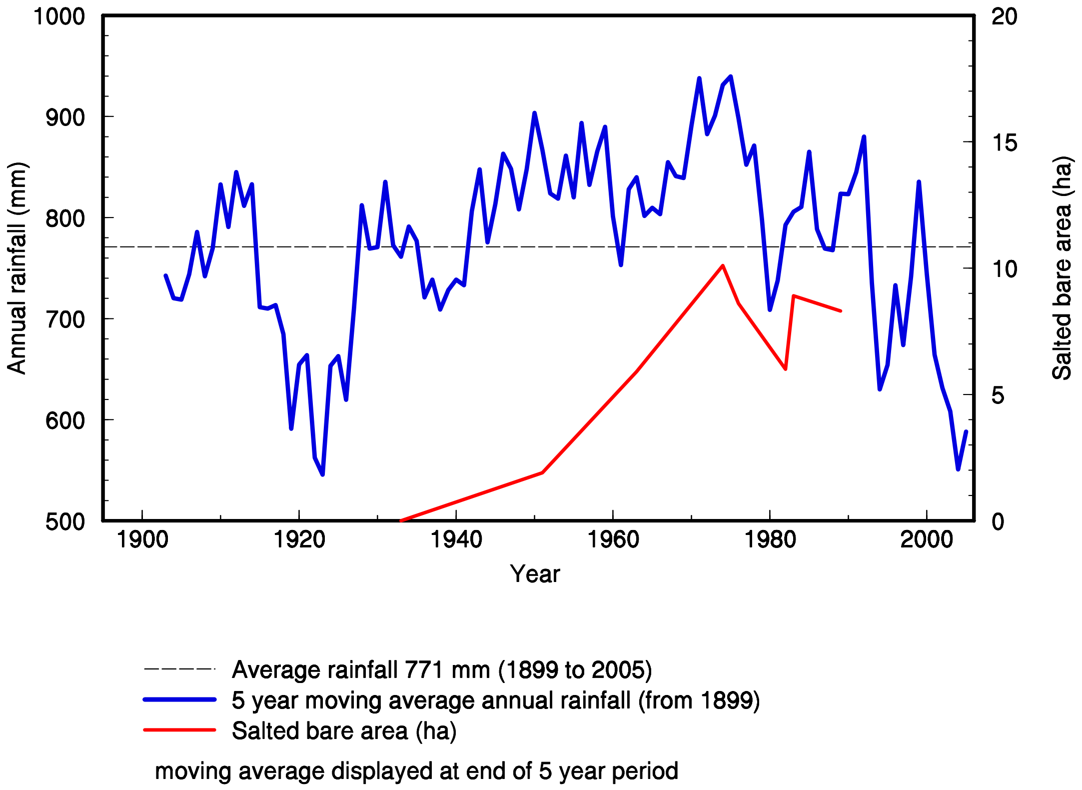

Figure 23. Moving average rainfall for DPI weather station (No 040082) near Gatton and the extent of bare salted area at Darbalara based on air photo interpretation. Rainfall data from Bureau of Meteorology and salted area from Department of Natural Resources and Water.

Photos 3 and 4 show a salted area in Soda Spring Creek in 1994 and 2008 immediately after an extended dry period. The only significant change has been rainfall. Photos 5 and 6 show the change between July 2007 and February 2008 when there was significant rainfall indicating some small surface vegetation changes but no major changes in salted area as expected as more rain is required to change the waterlevels and hence the surface salt accumulation. Photos 7 and 8 show the situation on Darbalara farm, The University of Queensland, near Laidley in 1994 and 2008 where between these dates a plot of revegetation on some higher ground has established well. The limited effect of the series of very dry years on the salt affected area in both these catchments is due to the sites being well above the critical soil salinity threshold of Figure 5 because the depth to the watertable is still shallow enough for significant soil surface accumulation of salt by evaporation. Thus even though recharge is reduced, the watertables are still too shallow for any significant degree of reclamation to occur.

Photo 3. Salted area in Soda Spring creek catchment in December 1994.

Photo 4. The same salted area as Photo 3 in Soda Spring creek catchment in February 2008 after an extended very dry period and rain in late 2007 to early 2008. The red arrows in Photos 3 and 4 identify the same tree.

Photo 5. Salted area in Soda Spring creek catchment in July 2007 after an extended very dry period.

Photo 6. The same salted area as Photo 4 (enlarged) in Soda Spring creek catchment in February 2008 after rain in late 2007 to early 2008 showing no major change in salted area. The red and yellow arrows in Photos 5 and 6 identify the same trees in both photos.

Photo 7. Part of the salted area of Darbalara farm, The University of Queensland near Laidley in December 1994.

Photo 8. The same salted area of Darbalara farm as in Photo 7 in February 2008 after an extended very dry period and rain in late 2007 to early 2008. The large tree on the left of the photos and the same and the red arrows identify the same fence post.

3.7 Current and emerging pressures on watertable salinity

There are five current and emerging pressures that are expected to make watertable salinity issues worse at some of the sites in the Lockyer Valley in the short and longer term.

1. Rainfall expected to increase. Areas of significant salting and shallow watertables are present currently following a period of 10 to 15 years of decreasing rainfall. This indicates that in a wetter rainfall period, salting will increase. Figure 23 suggests the possibility of an increase in rainfall should the pattern for the last 100 years be repeated as seems likely. The rainfall for late 2007 early 2008 supports a change in rainfall pattern. Given the dry conditions and that salted areas are still present, any strategy that reduces recharge as a management strategy (such as replanting recharge areas or discharge areas with trees) will be inadequate to manage salinity in the catchments in wetter periods. It will require many years to lower the watertable and consequently the soil salinity to below the critical soil salinity level.

   Rainfall causes fluctuations in recharge and watertable levels and unless there is sufficient buffer available in the depth to the watertable in drier years to cope with the increased recharge in wet years, without switching back to a degraded state, any gains made through reclamation will be lost. As a guide to watertable depths:

   0.5 m below ground results in maximum salt accumulation
   2 m is marginal for many soils
   > 3 m safe for average situations
   > 5 m provides a good buffer against extended wet periods or where the consequences of salinity occurring are severe.

2. Non sewered residential subdivisions. Since these areas receive reticulated water supply and residents collect and store rainwater, which is then used and disposed of on-site, there is a large additional hydraulic loading from the developments. The work of Ted Gardner (pers comm.) indicates that the water use in non-sewered developments is in the order of 150 to 200 litres per person per day. Assuming 160 L/person/day and given four people per house on 0.5 hectare blocks, and that only about 1/3 of the water is evapotranspired due to over wetting of local areas by the disposal systems and very poor soil permeability in many areas used for rural residential development, then this will amount to an increase of some 154 000 L/block/year. This is equivalent to additional rainfall of 300 mm/yr/hectare of residential area. Waterlogging, wet areas and salinity issues have already occurred and will only get considerably worse in wet periods. Photo 9 shows water flow paths around Rose Avenue in Plain Creek catchment indicating this is already occurring. In the middle upper section where Rose Avenue crosses the local creek there is salting with a creek salinity of EC >20 dS/m. A very similar pattern is also evident in Fairways, the western sub division in Woolshed Creek where following heavy rainfall in January 2008, the flowing gully though the subdivision had an EC of 1.8 dS/m, much higher than expected indicating significant future salinity problems.

   Since the soils on the Winwill geology are sodic and relatively impermeable, surface flows and salinity as well as possible nutrient issues are likely. Many of these subdivisions seem to be developing on Winwill conglomerate which can only make the salinity issues much worse and also result in the small drainage lines out of Winwill becoming permanent saline flows with potential for algal blooms etc depending on how well the disposal systems are maintained and functioning. Gardner et al. (1995) concluded that the commonly accepted disposal area for on-site disposal was far too small to ensure the supply rate of effluent matches the rate of water use of the vegetation in the disposal area. Gardner et al. (2005) found that shallow watertables under septic trenches seriously compromised the efficiency and effectiveness of septic systems, and also, there was a high incidence of grey water runoff in audited areas confirming that future problems are highly likely to occur.

Given the estimate above of around 300 mm/year additional hydraulic loading for the non sewered residential areas per residential hectare and given that the disposal area is only a small part of the residential area then the actual loading on the irrigated area is very high. Given that irrigation water use in the Lockyer is around about 370 mm/ha on average depending on rainfall (section 5.1), then not only is the loading too high but also in wet years, it will be considerably greater than can be reasonably used by vegetation, thus recharge of groundwaters and overland flow into stream lines is inevitable.

Photo 9. Evidence of surface flow from subdivision on Rose Avenue on the east side of Plain Creek. Image from Google maps.

3. Dams and storages on surrounding Winwill formation appear to leak and fill up the unsaturated storage of the drainage line. This is made worse if the dam is close to the heavy clay alluvium which has shallow watertables as shown in Figure 20. Because of recent periods of lower rainfall, the number of dams and off stream storages is expected to increase. These storages reduce peak flows in the main streams, reducing the flushing of salt out of the catchment and maintenance of creek beds. They also reduce recharge of the alluvial aquifers resulting in less flushing of salts present in the main creeks which will result in a steady but slow increase in salinity of the system. Photo 10 shows the large number of dams in 2008 upstream of the Darbalara salted area.

Photo 10. Dams in the upper section of the Darbalara farm where there is significant salting at the bottom of the catchment.

4. Degree of sedimentation in creeks and degradation of riparian vegetation. The degree of sedimentation in creeks, particularly Woolshed and Plain Creeks, is expected to restrict drainage of groundwater from the shallow watertable areas by the creeks and the confinement by the sedimentation is pressurising the saline groundwater so that it now covers a larger area of the catchments. Sedimentation in the creeks was reported from landholder surveys by Hogan (1996). It is quite probable that this will cause shallower watertables further and further upstream because of groundwater confinement. Photo 11 illustrates the current state of Plain Creek near the northern end indicating significant degradation.

5. Vegetation management. Since wholesale clearing is now largely completed areas, any further changes to hydrology are expected to be small although, because of the very long lag times for hydrologic change following clearing, there could be some additional changes in more recently cleared areas. Over grazing of pastures also causes additional recharge to the groundwaters and once the site has reached a critical salinity threshold, salinity will occur. Grasses are an effective means of managing intermittently affected saline areas in that a good grass cover minimises evaporative concentration of salts on the soil surface, slows overland flow and enhances surface flushing of salts. There is a common practice of grazing on salt affected lands without any controls which makes the salinity problems worse in a very short period of time and thus controlled grazing is required. Photo 12 shows the equivalent of grazing as a mowed area on the edge of a salted drainage line near Grantham. The native vegetation is sufficient to control surface evaporation and concentration of salts provided it is not overgrazed or mowed.

Photo 11. Sedimentation in Plain creek near the junction with Lockyer creek alluvium.

Photo 12. Example of a mown area showing salt while the long grass has minimised salt accumulation and bare salted areas. The photo was taken after a rainfall period in early 2008 when surface flushing of salts would have occurred.

4 Biophysical options to prevent, minimise or manage watertable salinity

The following eight options cover ways in which watertable salinity areas can be managed. Often a single option is not sufficient of itself and combinations of options are required. There may be other options that are also effective. It is important to consider any options on a catchment scale rather than just on an individual site basis since the processes are often linked and upstream actions affect downstream impacts. Table 10 in section 8 lists options appropriate for the range of salinity sites in the Lockyer. The options are:

1. Do nothing
2. Stabilise the affected area
3. Reduce groundwater inputs (recharge area)
4. Intercept groundwater (transmission zone)
5. Increase groundwater outputs (discharge area)
6. Store the salt
7. Remove the salt including desalination
8. Recycled water reuse.

4.1 Do nothing

This strategy is appropriate for stages 1, 5 and 8 of Figure 7 depending on other conditions. It is most applicable to situations where:

- The salinity situation is relatively stable
- Bare salted areas are intermittent or small and grazing pressure can be controlled, and
- The saline base flow from the salinity affected area is relatively small in quantity with minimal salt load impact on downstream resources. A rough catchment water and salt mass balance may be needed if there is a reasonable flow rate to be able to make an appropriate judgement.

The preferred approach is:

- 'Fence and forget' to minimise overgrazing and establish vegetative cover to reduce surface soil salt accumulation by evaporation, retain surface water to assist in flushing surface salt accumulation and reduce erosion.
- Revegetate where cost effective and viable provided there is some buffer to possible watertable rises with wetter rainfall patterns, and
- If it is an area of Black Tea tree or Brigalow or other indicators of wetness or salinity as past or present vegetation, these areas need to be substantially protected and vegetation increased in association with other methods to achieve a buffer depth to the watertable to moderate watertable levels in wetter periods to prevent spread of salinity.

4.2 Stabilise

This strategy is appropriate to stages 1, 2, 5, 6, 8 and 9 of Figure 7 if other factors are suitable. To have any chance of long term stabilisation of salinity, the soil salt levels in the upper root zone need to be reduced to below the critical soil salinity threshold level (Figure 5) where they have exceeded it and prevent an increase where they haven't. This means changing the groundwater imbalance of the whole catchment at the same time to reduce recharge. While revegetation of recharge areas is possible and will contribute to some extent, it will not be sufficient of itself. Strategies that use available groundwater where the quality is acceptable and reduce salts in the upper soil profile to below the critical soil salinity level at the same time will be required.

It is possible to overcome some of the soil salinity issues and commence the process by using mounded areas on the edges of salted areas as shown in Figure 24. This reduces surface soil salinity and allows establishment of vegetation.

4.3 Reduce groundwater inputs (recharge area)

This option is most appropriate to stages 2 and 8 of Figure 7 if other factors are suitable and if a recharge area with a higher rate of recharge is identifiable and can be managed. However:

- Recharge areas are usually large and diffuse
- There are usually very long lead times for change. If it takes 70 to 100 years for salinity to develop and come to a new equilibrium then it will take at least that long by revegetation of much of the area for it to possibly reduce to a near normal level given normal rainfall. In cases where additional water is stored and or used in a catchment, there may not be adequate change in hydrology from revegetation alone to make any impact
- Partial revegetation of recharge areas will be insufficient by itself if a catchment is sensitive to hydrology and salinity under natural conditions before land use change
- The option may be useful in combination with other strategies such as using all available groundwater in the upper part of the catchment above any major salinity area
- There are many good reasons for revegetating a catchment, but salinity is not a sufficient reason of itself and it is most unlikely that revegetation alone will make any impact on salinity
- Robins (2004) states that "previous hopes of saving remnant native vegetation along waterways by strategic reafforestation of upslope areas no longer show promise as a universally effective solution", and
- Reducing recharge in the recharge area will only be effective if it can directly affect the watertable level in the discharge area in the short term and can reduce that level to be greater than 2 m below ground (at least) for most of the time. This is very unlikely. Thus this method is only appropriate in conjunction with other methods.

4.4 Intercept groundwater (transmission zone)

This option is most appropriate for stage 2 and 3 with potential in stages 4 to 8 of Figure 7. It works best where:

- There is an identifiable transmission zone with reasonable flow rates, often alluvial channels, or side slopes of more permeable materials before they reach the less permeable alluvial areas
- The quality of intercepted water needs to be suitable for the intended use. Irrigation is most effective since it can use large quantities of water and the area and crop to be irrigated can be matched to the available supply and water quality. For the Lockyer and surrounding areas, irrigation can effectively use about 4 ML/year/ha without causing other problems
- The process is effective if water can be extracted upstream of a restriction where it is likely to be of better quality and can very effectively lower the watertable in the affected area. Given that the porosity of soils with shallow watertables is in the order of 5 to 10% (maximum), removal of 1ML/ha of high watertables should lower the watertable over 1 ha by 1 to 2 metres (where there is no lateral inflow). Thus pumping and using groundwater is very effective in lowering watertables, and
- Evaporation basins also are relatively effective depending on salt concentration and leakage rates but may require setting aside productive areas in the catchment.

4.5 Increase groundwater outputs (discharge area)

This option is appropriate for stages 2 to 8 of Figure 7 depending on other factors. In general:

- Vegetation is not very successful unless there is low salt content (below the critical soil salinity threshold) and a depth to the watertable of at least 1 metre is possible
- Pumping is possible but generally the flow rates are low and linked tube wells may be required. In some discharge areas, flow rates may be so low that this is not effective

- Drainage is effective if there is some more permeable material at depth and it can break through the restriction to groundwater flow. The salt content and flow rates need to be acceptable to downstream users to minimise impacts, and
- Pumping and disposal in an evaporation basin is possible if the salinity level is too high for other productive uses.

One option is to allow salt flushing out of the catchment in periods of high flows since there is a dilution effect as salt leaves the catchment. Figure 21 and Table 7 illustrate this point. A salinity trading system operates on this basis in the Hunter Valley NSW.

4.6 Store the salt

Use available groundwater above the Winwill restrictions with an EC of up to 6 to 8 dS/m by irrigating salt tolerant crops, trees or pastures where feasible or for environmental flows. Since flow rates will be small, linked tube wells can be used or interception trenches if aquifers are shallow.

Since it is important to reduce soil salinity at the soil surface and in the root zone of plants to less than the critical soil salinity level, then mounds are a possible method as illustrated in Figure 24. Place mounds about 0.5 m high and 1 to 2 m wide in longitudinal rows on the salted area beginning nearest to the salted margins and vegetate with salt tolerant grasses and trees and irrigate with water from upstream to move salt downwards in the soil profile and plant vegetation. Cracker dust or alternative material seems to work well providing nutrients and also good leaching of salt that may accumulate. Protection against erosion of upstream leading edges will be required. Once creeping or stoloniferous grasses establish, the stability of side banks would increase. This approach will have two effects;

- providing some productivity from the salted land, flushing surface accumulated salts below the active root zone depth and thus allowing a range of native vegetation to re-establish, and
- lowering of the watertable at the same time because it will use water at a faster rate than evaporation from a bare soils or salted area.

Sprinkler or micro-sprinkler irrigation is much preferred to dripper systems as they provide a wider area for downward flushing of salts and do not generate the surface and lateral salinity concentrations at the edge of the wetted area that drippers do. Surface salt accumulation can result in death of vegetation following rainfall where the surface accumulated salts are washed into the root zone of the plants.

Once stability is achieved, it is critical to manage the depth to the watertable to be at least 1 m below ground level and preferably 2 m or greater, otherwise there is insufficient buffer should a particularly wet rainfall period occur. Once evaporation of salts on the soil surface recurs, the process needs to be recommenced.

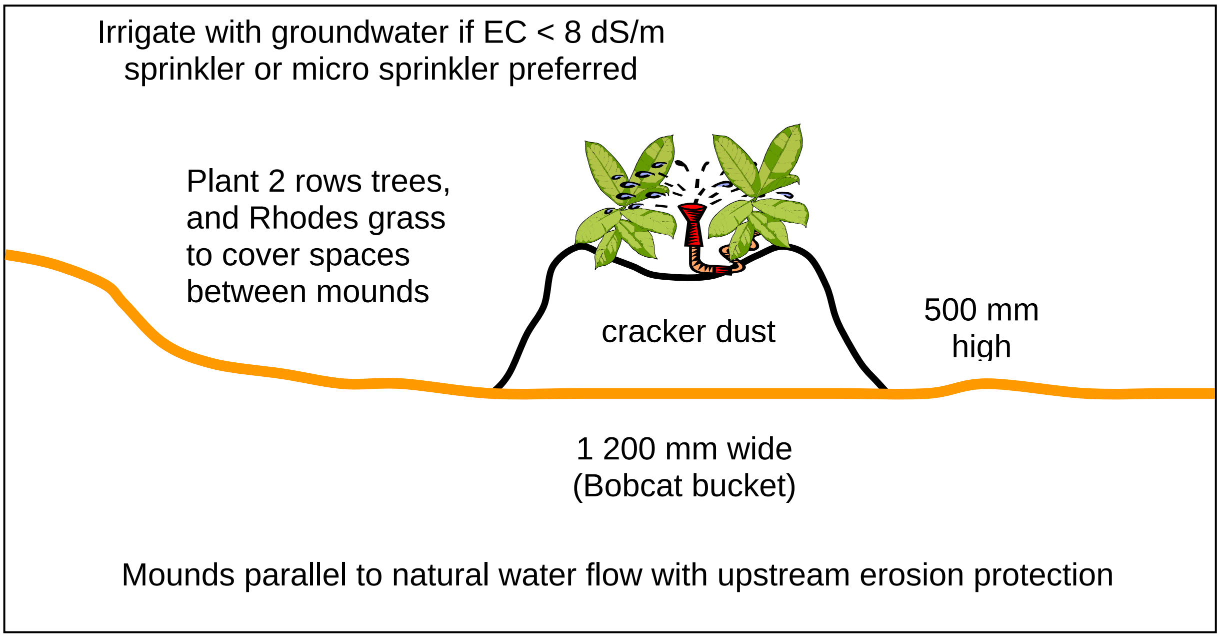

Figure 24. Structure of mounds to place near the edges of salted and bare areas to allow reclamation to occur. Irrigation is optional but desirable.

4.7 Remove the salt

Where the salinity of the groundwater is as high as the bottom end of Woolshed and Plain Creeks, the only viable option is to remove the salt by:

- flood flow release
- transport of evaporated salt
- reverse osmosis techniques, and/or
- solar distillation processes.

Harvesting some of the salt from an evaporation basin and removing it from the catchment is the most cost effective option. This may mean an evaporation basin or where available area is an issue, or no above ground storage is feasible because of hydraulic barriers exacerbating the issues, then a vertical ‘evaporation tree’ is possible using solar heating of the water and pumping and recycling of more concentrated waters. Designs need to maximise surface area for evaporation but have replaceable non-corrosive piping to overcome salt precipitation.

In some situations it may be possible to initiate an evaporation basin for a short period as a preventative control measure and remove a significant amount of water and salt while other measures are implemented in the catchment to bring it into a hydrologic balance.

In some areas, desalination plants for removing salt from groundwater in salted areas have been proposed as a viable option by NDSP (2004) and Burne (2005) although URS Australia (2002) indicate that the technology is only cost effective in limited situations where there is an absence or high cost of traditional water supplies, the system can be operated at maximum efficiency in terms of source water quality, straight forward disposal of hypersaline brine and energy is available at low cost.

Overall several factors need to be considered:

- the potential use of the water. If irrigation is proposed and since sodium is less effectively removed by the reverse osmosis process, waters of moderate SAR can result. Scaling the final EC-SAR of the water to the soil is important if sodicity issues are to be avoided. This is discussed in section 5.2.

- disposal options for the hypersaline effluent stream are required. Estimates are that a minimum of 20% of the input water will be hypersaline effluent to be disposed of which increases as the salinity of the source water is increased (around 40% of source water at EC around 50 dS/m).
- capital and maintenance costs need to be considered in relation to the quantity of water to be removed and the benefits and alternative options to manage the salinity, and
- there may be a need to pretreat the feed water as well. NDSP (2004) conclude that groundwater pumping without desalination would be more cost-effective. There is a possible trade-off between desalination and salt evaporation basins where the water can be reused and the hypersaline effluent evaporated in the evaporation basin depending on demand for the water.

An alternative option more suitable to the Lockyer Valley would be enhanced evaporation using rotating sails and associated smaller evaporation basins where the salt is harvested as proposed as a possibility in Shaw (2007). Considerable development work would be required for this approach but it would be more efficient than an evaporation basin where the net difference between annual evaporation and rainfall is in the order of 800 mm/yr equivalent to 8 ML water/ hectare/year.

4.8 Recycled water reuse

Reuse of greywater from non sewered subdivisions, outputs from wastewater treatment plants or community sewage schemes can reduce the hydraulic loading of non sewered subdivision areas. Health issues and the demand and economic returns for recycled water need to be considered. Woolshed and Plain Creeks could benefit from additional environmental water flows that will flush out salts in the systems depending on the impacts on downstream users.

Heiner et al. (1999) considered the use of recycled wastewater from Brisbane as manageable for the Lockyer Valley subject to further clarification of the SAR values (expected to be between 5 and 6) and indicated nitrate leaching may be an issue requiring some change to fertiliser practices if leaching to the groundwater was to occur.

Use of recycled water to enhance environmental flows is an alternative particularly since there are so many dams and storages that normal creek flows are no longer effective in flushing salts out of the catchment. The use of recycled water is discussed further in section 9.5

4.9 Management options and combinations that are unlikely to be effective for watertable salinity

Soft options of revised management practices, deep rooted vegetation and grazing alone will not be adequate unless the salinity is intermittent and in the sensitive or stressed stages of Figure 7. If the area is already bare and affected and the critical salinity threshold has been exceeded then much more interventionist measures are required that increases watertable depth and reduces surface soil salinity at the same time.

Several resource management practices can compete with each other. Efforts in revegetation of recharge and upslope areas can be negated by leaking dams. Periodic overgrazing of salted areas can cause expansion of salinity even if best management in cropping and other practices are conducted on other areas. Upslope landholder practices may dominate responses in salted areas.

It is difficult to maintain momentum for the required time for implementation of reclamation strategies and thus there is likely to be failure unless set periods for review of progress and ongoing funding are provided, probably for a minimum of 10 years. Aims and expectations of efforts at reclamation need to be clarified. Reclamation of the whole of salt affected areas may well be very onerous whereas if the worst affected area is managed to stabilise it, and some salt is accepted, more realistic and practical reclamation strategies can be implemented successfully.

5 Irrigation water salinity in the Lockyer Valley

The Lockyer Valley has one of the best combinations of soils and groundwater for irrigated agriculture in Australia. In the major alluvial valleys the soils are fertile, resilient to soil chemical and physical degradation under best practice management due to their ability to swell and shrink and restructure. Because the basaltic parent materials continue to weather in situ releasing calcium and magnesium they can counter the effects of sodium in the irrigation water as well as releasing other nutrients.

The soils are relatively permeable because of their good structure and high calcium and magnesium. This aids leaching of accumulated salts below the soil root zone. The composition of the groundwater used for irrigation is good being relatively low in sodium (Figure 13) and although the salt content is relatively high, the high proportion of calcium in the groundwaters precipitates as calcium carbonate in the upper soil root zone raising soil pH to around 8.4 – the equilibrium pH expected and slightly lowering the effective soil salinity.

5.1 Salinity issues

Irrigation water salinity problems have occurred in the past and occur more in dry periods. There is generally an equilibrium reached between the soil root zone salt accumulation and the crop being grown such that there are natural limits and feedbacks that prevent excess salt accumulation for productive agriculture. The most limiting aspect is the quantity of groundwater available for irrigation and its spatial availability.

There is a perception of increasing alluvial groundwater bore salinity by some irrigators, more so during dry periods. There are three likely causes for this:

- In dry periods, irrigators use greater quantities of groundwater for irrigation and in areas using irrigation waters of moderate salinity, there is an increase in root zone salinity because there is less flushing of accumulated salt by rainfall. Figure 25 shows the relationship between irrigation water use and rainfall for the years 1973 to 1981 for the Lower Lockyer irrigation area. This shows a good relationship between how much irrigation water is applied and the annual rainfall. Irrigation is supplemental to rainfall and in general rainfall plus irrigation water used is approximately 1 240 mm/year based on measured water use (Shaw unpublished). This varies somewhat depending on the rainfall distribution. Thus rainfall is a major factor in managing the impact of salinity of irrigation water. Talbot and Bruce (1974) showed that after periods of quite high rainfall, there was a significant leaching of salt out of the soil profile and thus a return to lower salinity conditions. In Figure 25 for the years sampled, irrigation averaged 373 mm/yr ranging from 220 to 580 mm/yr for an average rainfall of 844 mm/yr varying from 480 to 1 190 mm/year, and
- In general the changes in groundwater salinity in the major southern tributaries to the Lockyer are expected to be small as discussed by Gardner (1985) and predicted changes shown in Table 6. The creeks with higher groundwater salinity are expected to have decreasing salinities since there was a flush of unsaturated zone salt into the aquifer when irrigation commenced which is now being flushed out of the system. For the generally good quality groundwater in Laidley and Tenthill Creeks, there is a slight increase in groundwater salinity since more of the groundwater is being used for irrigation and transpired by plants leaving salt behind and also there is reduced flushing of the aquifer. However, these effects are small, and

- There will be changes in some bores within the areas of the major southern tributaries in the region of exposed Winwill formation (Figure 14). Areas of the line segments in Figure 14 may show fluctuating EC and SAR due to the mobilisation of salt in the unsaturated pockets of salty water in these historic salt accumulation zones. Thus there may be periods of several years of elevated salinity. Further work is underway to clarify the processes operating. The increase in off stream storages in this catchment will provide a greater flushing of salts out of the aquifers over the long term.

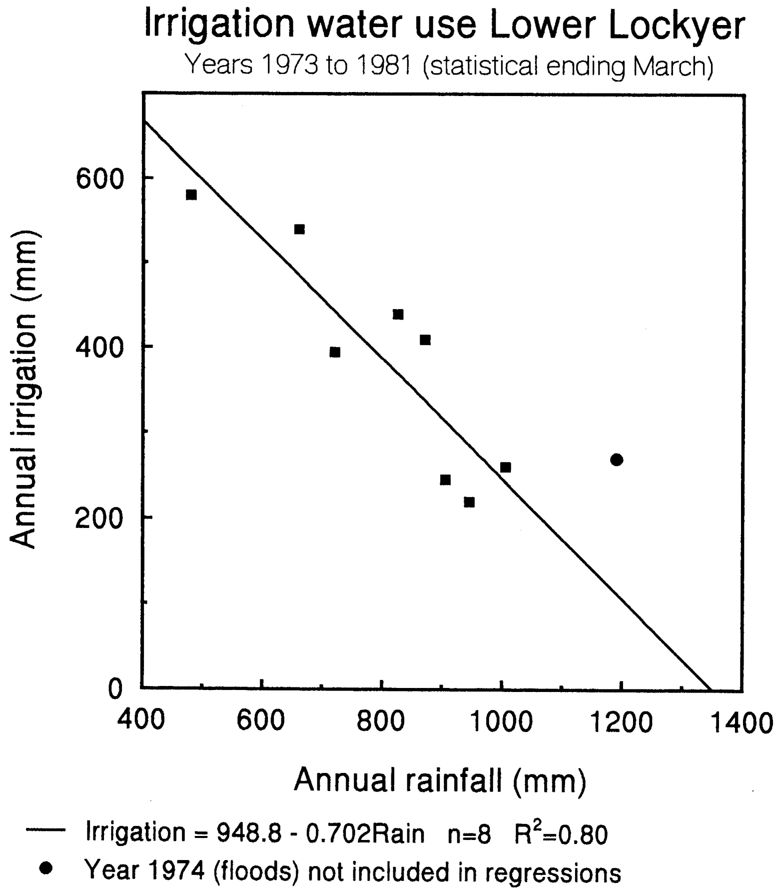

Figure 25. Relationship between irrigation water use and annual rainfall for nine years for the Lower Lockyer irrigation area. Rainfall and irrigation are calculated on a rainfall year April to March. Data from Queensland Water Resources Commission.

The leaching fraction (LF) achievable for Lockyer soils determines the EC of water that can be used for irrigation. Figure 26 shows the measured LF for broad soils groups. LF values are generally good for the clay content of these soils and reflect the highly structured nature of the soils. Figure 27 shows the interaction of the LF and the irrigation water EC for different plant tolerance groups of Maas and Hoffman (1977).

Figure 27 allows the suitability of a water for irrigation of a specific crop to be optimised by considering:

- The irrigation water EC as the determining factor for suitability
- The crop salt tolerance determines the potential use of that water (rainfall needs to be included) by determining the LF required, and
- Soil properties determine if this LF is achievable for the particular soil.

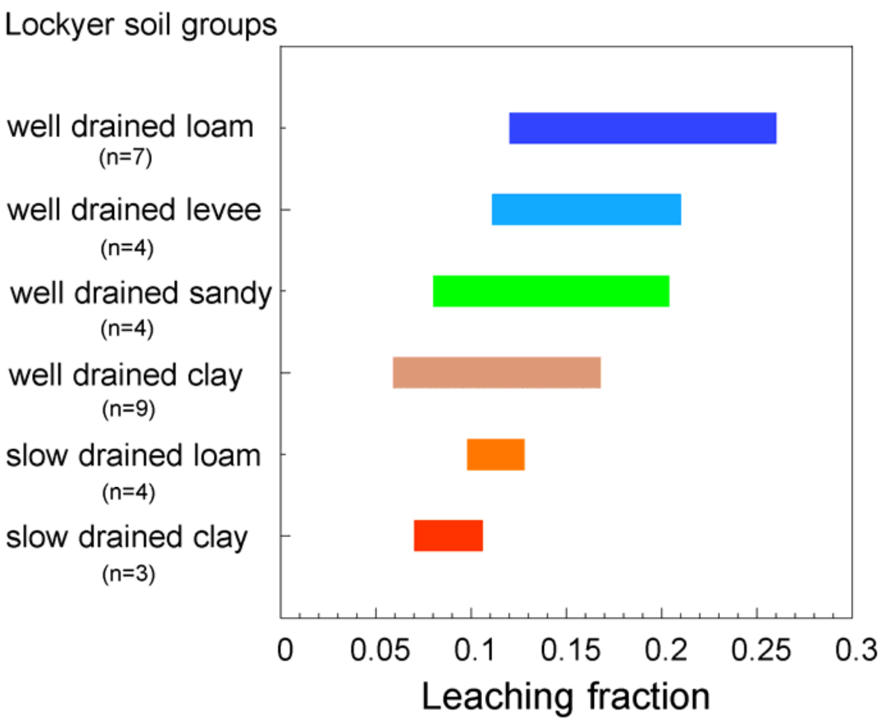

Figure 26. Leaching fraction of various soils in the Lockyer Valley from an extensive sampling in the 1980s. Data redrawn from Shaw and Thorburn (1985).

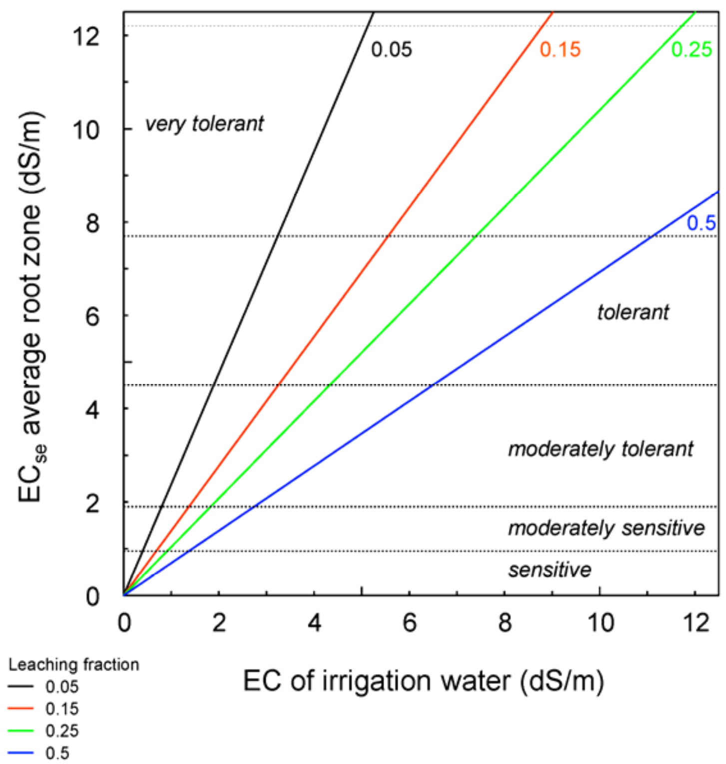

Figure 27. General relationships between leaching fraction and plant salt tolerance groupings of Mass and Hoffman (1977) at 90% maximum plant yield illustrating the impact of leaching fraction and EC of the irrigation water on resultant root zone salinity and hence crop suitability for irrigation.

5.2 Soil stability

A major issue is soil sodicity. If waters of marginal sodicity are used for irrigation, ESP will accumulate and result in soil stability issues. Because of the high cation exchange capacity (CEC) of these soils, this generally takes in the order of > 5 years for surface soils to come to equilibrium. Surface soils with high ESP are unstable under rainfall and lead to crusting, erosion, hard setting and poor water entry. Thus a water should only be used for irrigation where the EC-SAR is to the right of the lines in Figure 13 as rainfall dilutes the salt content.

Higher SAR irrigation waters change soil sodicity and hence soil stability. Soil sodicity is not leached by rainfall; it requires a replacement of the exchangeable sodium with calcium. Figure 23 shows the same lower Tenthill soils as in Figure 11 but for soil ESP. There is an obvious increase in ESP with waters of increasing SAR as expected. For site 2C, the water quality of the first period of irrigation for 5 years is not available. The shape of the ESP profile suggests the earlier water may have had a higher SAR and the new water is gradually restoring the soil to a new lower equilibrium ESP. Based on acceptable SAR for irrigation waters for soils of different clay content and mineralogy, Table 8, a water with an SAR of 6.8 is higher than recommended for these soils although this could be compensated by the periodic addition of gypsum to the soil.

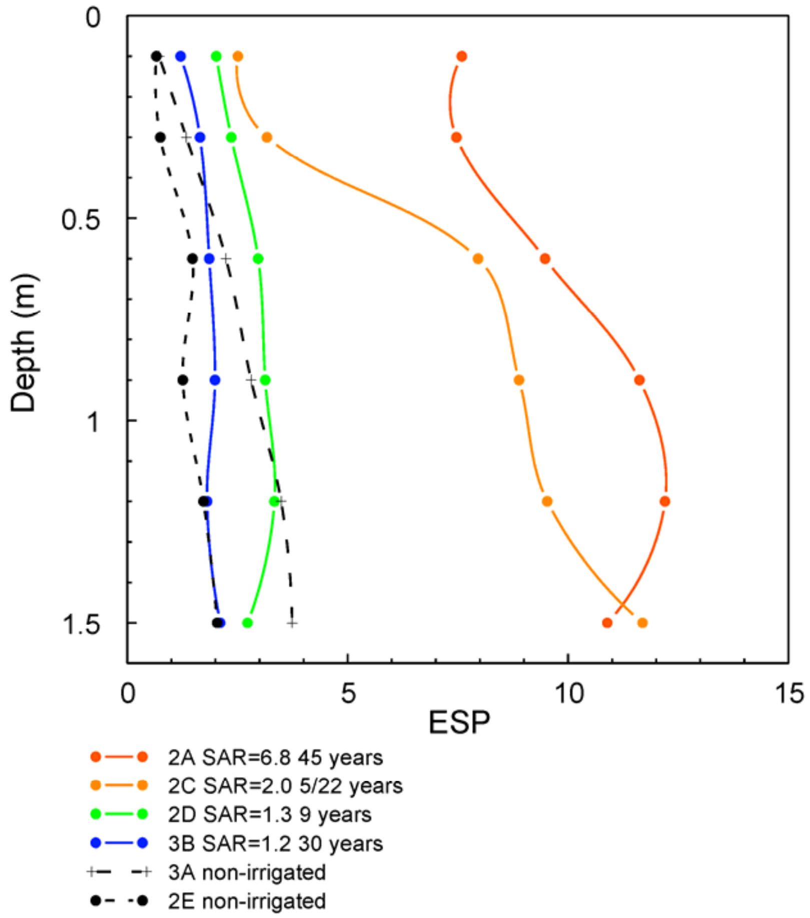

Figure 28. Soil ESP profiles for soils in Lower Tenthill under differing irrigation water SAR values for different periods of time. Figure from Salcon (1997).

Figure 29 shows the impacts of irrigation for a 20 year period followed by no irrigation for the last 18 years for soils in Sandy Creek near Blenheim indicating minimal changes in soil ESP once irrigation had ceased.

There are two different soils at this site represented by the two green unirrigated soil profiles 9E and 9G of around 20% clay in the surface 30 cm and 9E being of heavier texture (around 46% clay in the surface 30 cm) and higher native ESP. The three currently irrigated (EC 7.9 dS/m) soil profiles 9A and 9B (in the 1980s) on the heavier soil with higher ESP and 9H on the lighter soil all show an increase in ESP following irrigation with the water with an SAR of 9.9. Following a period of some 18 years since irrigation, 9C and 9D on the lighter soil and site 9I on the heavier soil, it is obvious that there has been no reduction in surface soil ESP or ESP down the soil profile. Thus there is a definite risk that irrigating with high SAR irrigation waters will probably cause surface soil degradation that will require additions of gypsum to rectify surface soil problems.

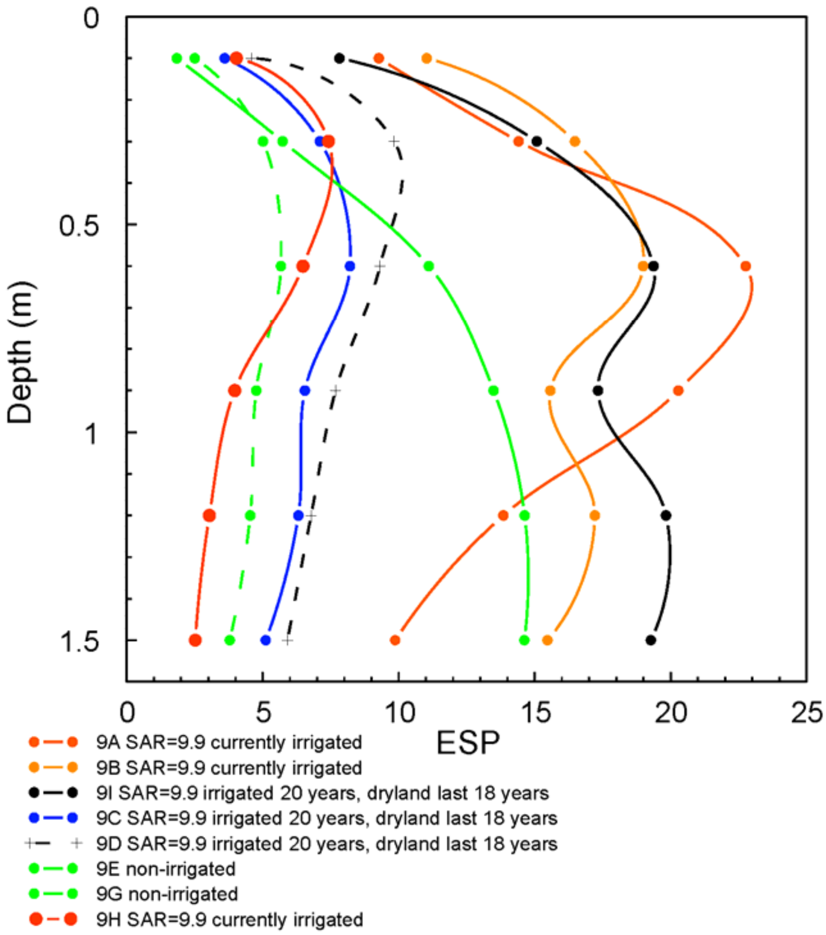

Figure 29. Two non-irrigated soils and the effects of irrigation with an irrigation water SAR of 9.9 (EC 7.0 dS/m) and then not irrigated for 18 years. Site is in Sandy Creek near Blenheim, unpublished data from Department of Natural Resources and Water. The soil profiles are explained in the text.

Table 8 gives the recommended maximum SAR values for sustainable long term irrigation for different soils. Lockyer Valley alluvium derived from basalt generally has a CEC to clay content ration (CCR) of > 0.75 in Table 8.

Table 8. Guide to permissible SAR of irrigation waters to maintain a stable soil surface soil structure under high rainfall[1]. From ANZECC/ARMCANZ (2000) based on Salcon (1997).

Clay content %	Soil texture	Permissible irrigation water SAR				
		Clay mineralogy groups (expressed as CCR)[2]				
		<0.35	0.35 - 0.55	0.55 - 0.75	0.75 - 0.95	> 0.95
< 15	Sand, sandy loam	>20	>20	>20	>20	>20
15 – 25	Loam, silty loam	20	11	10	10	8
25 – 35	Clay loam	13	11	8	5	6
35 – 45	Light clay	11	8	5	5	5
45 – 55	Medium clay	10	5	5	5	5
55 – 65	Medium - heavy clay	5	5	5	4	4
65 – 75	Heavy clay	- [3]	4	4	4	4
75 – 85	Heavy clay	-	-	4	5	5

1 Based on relationships of Shaw (1996) and predicted for a rainfall of 2 000 mm/year to estimate the water SAR in equilibrium with the soil ESP to minimise surface soil dispersion.
2 CCR is the soil cation exchange capacity / clay content as a ratio ($mmole_c$/kg).
3 Insufficient data available for these soils groups with a dash.

5.3 Irrigation water salinity - equilibrium and feedbacks

Since crop productivity is affected directly by water quality, there is usually a natural limit to use of waters with high EC values. As shown by Talbot and Bruce (1974), accumulated salts can be leached downwards out of the root zone under high rainfall. Thus there is a reasonable feedback process to use only waters of EC suitable for a given crop.

However, this is not the case with SAR, since the problems only become apparent under high rainfalls when soil dispersion operates. Since the alluvial soils can restructure by swelling and shrinking to varying degrees there is some resilience in the soils to cope with sodicity. Ensuring waters with appropriate SAR values are used is most important for the long term sustainability of irrigation. Small variations during dry periods will not make large differences. The figures in Table 8 for SAR are conservative and an increase of around 1 SAR value is possible, given the resilience of the alluvial soils in the Lockyer.

5.4 Current and emerging pressures in irrigation water

The biggest pressure on irrigation is lack of groundwater supplies in dry periods. The overall use of groundwater in the Lockyer exceeds the recharge available. This puts pressure on alternative supplies and on more marginal water qualities. Marginal waters are dealt with above through the major issues of EC and SAR.

Recycled water for irrigation from Brisbane has been mooted for the Lockyer for many years and while there have been studies of its feasibility by Kinhill and Heiner et al. (1999), availability under the new recycled water strategy for south east Queensland would seem unlikely. Expanded use of wastewater from Laidley and Gatton or additional treatment plants is a possibility.

There is the possibility of water available from the non sewered subdivisions in the Lockyer if community sewerage schemes are implemented to minimise watertable salinity issues. The location and cost of access of these waters may mean limited availability but the same criteria for SAR need to be adhered to prevent soil deterioration. There is the likelihood that SAR will be higher than recycled water from Brisbane as discussed in section 9.5.

6 Management options for irrigation waters

6.1 Method of irrigation

The method of water application should result in an even distribution of water that has the capacity to leach salts below the active root zone depth. Flood and sprinkler irrigation do this with varying efficiencies of water application. Drippers have shown to have significant problems in lateral and vertical salinity distribution that can cause problems. Surface drippers result in salts on the soil surface due to evaporative concentration. Following rainfall these salts are leached down into the root zone and can kill the plant due to salt stress. This has been reported in Queensland in the Burdekin area on custard apples and other tree crops. Also drippers and microsprinklers if used on annual crops can lead to lateral variation in salinity and if subsequent crops can suffer from high root zone salinities if alignment with previous crop rows is not adequate. Controlled traffic farming can overcome these limitations. Others have buried the drippers at considerable depths to minimise surface soil evaporation and subsequent leaching of accumulated salts into the active root zone.

6.2 Timing of irrigation application

If salt content is marginal for the crop being grown, night time or late afternoon watering will reduce salt crystallisation on leaves and leaf damage. Rainfall following irrigation will be more effective for leaching salts since the soil is already wet. If waters are marginal in SAR, irrigating immediately following heavy rainfall may be required to flocculate surface soils and reduce dispersibility.

6.3 Quantity of irrigation application

Sufficient water needs to be added per application to ensure wetting of most of the active root zone depth to prevent salinity gradients if the water is of marginal salt content. Water quantity should be related to plant salt tolerance and leaching fraction. For slowly permeable soils adequate leaching may not be attainable even though high salinity waters flocculate the soil and increase leaching.

6.4 Mixing water supplies

Some have advocated mixing irrigations waters to achieve acceptable EC and SAR values. The general recommendations are that mixing for salinity control is not viable if the most saline water is more than 50% of the salt tolerance value. This is because once the soil solution reaches the plant salt tolerance value, no more water can be used and the extra salt in the higher salinity water is not aiding plant growth but just adding salts to the soil that then require more leaching. It is better to use higher salinity waters on a short term emergency irrigation basis than to mix waters.

For waters with marginal SAR, mixing with a second water can be beneficial in reducing the SAR to acceptable levels that won't result in soil degradation, provided the EC levels are acceptable. Alternatively, short term emergency use of a higher SAR water is acceptable, provided the salt content of the normal irrigation water source is adequate to result in soil flocculation and there is no adverse effects following heavy rainfall periods. Since soil ESP is very difficult to remedy, acceptable SAR should be the primary emphasis in irrigation water management. In all cases appropriate water quality guidelines should be used unless confirmed as different for local situations and irrigation water quality monitored for trend changes over time. The development of the ANZECC/ARMCANZ (2000) water quality guidelines specifically incorporated Lockyer Valley waters, soils and rainfall and should be applicable to the Lockyer.

7 Managing salinity in the Lockyer Valley

To adequately manage salinity issues requires approaches on several levels concurrently. Biophysical approaches to restore or maintain degraded areas and practices and policies to ensure the minimal salinity risk from future developments. To determine the most appropriate and priority actions, a salinity risk management analysis is suggested.

For landscape and ecosystem situations, and salinity in particular, the following definition is preferred. **Risk management process** is 'the processes, policies, guidelines and practices adopted to avoid, minimise, control, live with or trade-off salinity risk and unintended consequences while realising and encouraging opportunities'.

Because of the complexity of interactions when ecosystems are considered this is preferred to the standard definition of risk management process which is 'The systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing risk' (Standards Australia 2004b).

Risk management requires risk assessment as a comprehensive first step.

7.1 Salinity risk assessment for the Lockyer Valley

Risk is commonly viewed in everyday use as the possibility of adverse consequences. Standards Australia, in AS/NZS 4360.2004, defines risk as "the chance of something happening that will have an impact on objectives" (Standards Australia 2004a). This definition provides a broader perspective than just negative consequences and considers the options of positive effects on achievement of objectives. Hubbard (2007) uses the word risk as "a state of uncertainty where some of the possibilities involve a loss, catastrophe, or other undesirable outcome ".

For this report where the emphasis is on opportunities that salinity provides as well as the negative consequences of salinity degradation and unsustainable systems, the following is the preferred definition:

Risk is the possibility of an event occurring that will have an impact on the achievement of objectives or result in unintended consequences.

Risk is estimated from the likely degree of impact if the event occurred and the likelihood of the event happening and is assessed by estimating the potential impact of stressors (or hazards) on a specified ecosystem under a given set of conditions and within a specified time frame. Because salinity has long lead times for development and long lag times for reclamation from a degraded state, a time period of 30 years is proposed for the Lockyer Valley.

Searle et al. (2007) and Chamberlain et al. (2007) have conducted salinity risk assessments usually at broad catchment or sub-catchment scales using available data, predictive models and various indicators related to salinity to make assessments. For the Lockyer Valley with a uniform geology across the catchment and identifiable salinity in hydrologically sensitive parts of the landscape that has been obvious for over 30 years, a more narrow assessment is likely to give a more specific outcome to meet the objectives of this report. Also some of the many indicators used in these risk assessment do not have well defined causal relationships. As the number of indicators increases, the interactions become complex and difficult and sensitivity in the analysis is lost. Also for the Lockyer, there is very limited data for some of the sites and the data requirements for non sewered subdivision would be very onerous. Biggs et al. (2003) considered the challenges of modelling salinity risk as very large. Also, for this study, an estimate of the suitability and risk of a proposed biophysical management option having the intended effect is being considered. This is quite a difficult judgement to make.

To deal with ecosystem complexity at the catchment scale and where there are multiple pressures or stresses on the system, **Ecological Risk Assessment (ERA)** has been promoted over the last decade or more. ERA can be defined as 'The process of estimating the likelihood (or probability) and consequences (or magnitude) of the effects of human actions or natural events on ecosystems of ecological value and their sustainability' modified from Hart et al. (2005).

The ERA process used by Hart et al. (2005) forms the basis of the approach to salinity risk assessment used for the Lockyer Valley in this report with some modifications.

7.2 Ecological risk assessment process

Hart et al. (2005) identified the steps in the ERA risk management framework, which have been adapted to the Lockyer Valley salinity, as:

1. scoping and formulating the issue
2. identifying the ecological values/assets or the sustainable outcomes perceived to be at risk. This will include downstream impacts as well
3. identifying the pressures (hazards) likely to adversely impact upon these values or outcomes
4. analysing the likelihood and consequences
5. characterising and ranking the risks
6. developing a risk management plan to avoid, minimise, control, live with or trade-off risk while realising opportunities and benefits
7. implementing this plan, and
8. monitoring the system to ensure the management plan is indeed reducing the impact of the priority risks.

Steps 1 to 5 are dealt with in this report in the following sections numbered as (7.2.step number) with some options presented for step 6.

7.2.1 Scoping and formulating the salinity issue

This has been done in detail in sections 3 and 5 of this report with conceptual models of the causal factors operating. In summary, land and water use in the Lockyer Valley has changed the hydrology of the catchment and with it salt movement. Hydrologically sensitive landscapes existed prior to any development associated with the exposure of Winwill conglomerate geology which forms a barrier to groundwater movement. Following land development, a number of these sensitive areas have developed salinity problems due to excess water in the landscape that cannot easily be removed resulting in shallow watertables and salt accumulation on the soil surface or stream banks by evaporative concentration.

The wide use of groundwaters in the alluvial aquifers of the major southern tributaries has resulted in some irrigation water salinity problems and associated soil sodicity problems but more significantly has moved salts accumulated in the soil profile over historic periods into the groundwater with slow changes in groundwater salinity over time. Use of groundwaters for irrigation has prevented any shallow watertable and salinity problems in the major southern tributaries to Lockyer Creek. The high salinity groundwaters in some sections of the Lockyer alluvium together with an overcommitment of available groundwater supplies has led to off stream storages for irrigation.

The very poor supplies and high salinity of groundwaters in the Winwill formation have led to a proliferation of small farm dams which are causing issues for groundwater recharge, salinity and stream flow.

Emerging pressures of non sewered subdivisions, an expected increase in rainfall and economic pressures are expected to increase the incidence and severity of salinity problems in the Lockyer Valley.

The success of salinity reclamation in Australia has generally been poor, very difficult, costly and with long lead times. Thus effective prevention and management options need to be developed and implemented before salinity issues in high risk areas get worse.

7.2.2 Identifying the sustainable outcomes perceived to be at risk

While most ERA approaches focus on the ecological values or assets, there is value in putting this into a wider perspective of sustainability and sustainable livelihoods and includes individual lifestyles and quality of life issues. The conservation and enhancement of ecological assets and services that underpin sustainability is a step in this process.

All Australian governments have signed on to Ecologically Sustainable Development principles and their implementation. While varying interpretations of sustainability exist, the concept is the most appropriate principle by which to assess proposed actions to ensure minimal harm now and in the future and to develop maximum productivity.

A useful definition of ESD is: "Ecologically sustainable development means using, conserving and enhancing the *community's resources* so that *ecological processes* on which life depends are maintained and the total *quality of life*, now and in the future, *can be increased*" (ESD Steering Committee 1992). Emphasis is by the author of this report.

The key principles are highlighted in underlined italics above and form the basis for this ERA. They require an emphasis on stewardship, holistic and integrated approaches from the paddock/lot to the catchment scale and consideration of quality of life, a broader concept than profitability, minimal environmental harm and environmental management which are commonly used.

Sustainable livelihoods as promoted widely by several organisations internationally offers a tangible goal for landholders. Sustainability is a communal process at global, national, regional and business levels that incorporates the sustainable livelihoods of each enterprise and activity.

"Sustainable livelihoods consist of the capabilities, assets (both material and social) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets and provide net benefits to other livelihoods locally and more widely, both now and in the future, while not undermining the natural resource base" (FAO no date). The United Nations Development Program has drawn on the support given to sustainable livelihoods by the international community at the World Summit for Social Development by making the concept central to its operational mandate (UNDP 1999).

Sustainable livelihoods provide a realistic focus and motivation to achieve sustainable outcomes at a property and catchment scale. Taking this approach, we need to consider outcomes that contribute to sustainable livelihoods and are based on ESD principles at the same time. Similar approaches have been adopted by the Murray Darling Basin Commission Landmark project (Clifton et al. 2004) and the major international Millennium Ecosystem Assessment project (Alcamo et al. 2003).

Table 9 lists ten sustainability outcomes that address overall sustainability though ESD and sustainable livelihoods covering environmental, social and economic aspects, modified from Shaw et al. (2005). Table 9 is an amalgam from many sources and the references in the paragraph above and has also been derived from components people consider important in sustainability (for example, USEPA 2004) and arranging them into a consistent framework.

Table 9. Ten sustainability outcomes and their components that form the basis of the ERA framework modified from Shaw et al. (2005).

Sustainability outcome	Sustainability components
1. Landscape health	Soils – capability and health
	Water – quality and quantity
	Floodplains, wetlands and riparian areas
	Vegetation
	Animals and health
2. Coastal and marine health	Wetlands and estuaries
	Coastal stability
	Water quality
	Fisheries
3. Biodiversity	Native and remnant vegetation
	Wildlife breeding and corridors
	Heritage areas and parks
	Fire
	Farming impacts
4. Air quality, climate	Climate
	Greenhouse
	Particulates, dust
	Odour and noise
	Ozone depletion
5. Ecosystem productivity and services	Asset protection and conservation
	Sustainable utilisation
	Exhaustive use
	Flood and drought mitigation
	Energy use
	Wildlife management
	Resilience – environmental, social and economic
	Existence value
6. Enterprise viability and productivity	Property layout and potential
	Food processing
	Product processing and contracting services
	Market access
	Cost benefit analysis
	Skills and capability
	Natural and built resources management
	Infrastructure – property, community and regional
	People management
	Financial management
	Strategic planning
	Succession planning
	Risk planning and management
	E-commerce
	Record keeping
7. Waste and hazard	Off-site impacts
	Biosecurity
	Chemicals and hazardous substances
	Waste recycling and management, composting
	Emergency planning and response
	Fuels and lubricants

Sustainability outcome	Sustainability components
	Workplace health and safety
8. Quality of life	Life goals and priorities
	Family
	Cultural
	Indigenous
	Holistic management
9. Quality assurance	Food safety and ecological integrity
	Monitoring
	Indicators
	Accreditations
	Compliance
	Liability
10. Governance	Adaptive management
	Enterprise
	Catchment, community and regional relationships
	Environmental justice
	Multi-objective decision-making
	Resource use tradeoffs

There is an alignment between the sustainability outcomes listed in Table 9 and the assets, management actions, matters for targets and priorities identified by different regional groups and represented in their regional NRM plans. For example, the landscape health outcome incorporates land and water and weed issues. Coastal and marine health are not a direct issue for the Lockyer Valley.

This table provides a framework for assessing the salinity risk and the processes to manage risk. Sustainability outcomes from the above table of direct relevance to salinity in the Lockyer are:

1. landscape health
3. biodiversity
5. ecosystem productivity and services
6. enterprise viability and productivity
7. waste and hazard
8. quality of life, and
10. governance.

7.2.3 Identifying the pressures (hazards) likely to adversely impact upon sustainability outcomes

Section 3.7 identified the current and emerging pressures on salinity in the Lockyer Valley In summary these are:

- Developments on Winwill formation
- Increasing rainfall
- Construction of dams on catchments or situations where salinity is likely, in particular Winwill formation
- Overgrazing
- Roads across valley areas
- Non-sewered subdivisions where hydraulic loadings exceed the capacity of the landscape to cope with additional water
- Vegetation management practices that increase recharge to the groundwater and/or lead to bare areas increasing evaporation from a shallow watertable, and
- Sedimentation of creek and drainage lines.

7.2.4 Analysing the likelihood and consequences of the pressures on salinity

To assess the salinity risks, a matrix is used which evaluates the *likelihood* of the pressures identified in section 7.2.3. having an effect for each of the sites and the *consequences* and extent of any effect. Likelihood and consequences evaluation are rated on a scale of 1 to 5 as shown below in Table 12 from Hart et al. (2005).

Table 12. Categories of a quantitative assessment of risk based on likelihood and consequence using subjective rating scales of 1 to 5 from Hart et al. (2005).

Likelihood		Consequence				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain	(5)	5	10	15	20	25
Likely	(4)	4	8	12	16	20
Moderately likely	(3)	3	6	9	12	15
Unlikely	(2)	2	4	6	8	10
Rare	(1)	1	2	3	4	5

Subjective ratings are a balance between available data, understanding of the processes operating and any non-linear or complex interrelationships between factors operating and expert and local knowledge. Very high risk is a value of 25 while high risk scores between 15 and 25, medium risk 5 to 15 and low risk < 5.

Because it is a subjective assessment, further investigations will be required to clarify uncertainties and confirm the risk before expensive actions are taken. Trigger levels for change, resilience behaviour and non-reversibility are important aspects that are very difficult to capture and lead to uncertainty in risk assessment. Also in making the judgements in Table 10, no access to private properties was made and thus the assessment of the issue is limited in some situations. In particular further investigation will be required where interception of water upslope of the saline area is proposed as a reclamation option since suitability of water quality and its availability is required.

Based on Figure 14 showing the incidence of watertable salinity, there is usually a surrounding area of sodosol soils (soils affected by salt and sodium during soil genesis) as shown by Powell et al. (2002). The area of these soils is usually considerably greater than the existing areas of bare salted surface soils due to shallow watertables in the Winwill salted areas. While it could be interpreted that these soils formed under historically very wet periods and the extent of sodosol soils could indicate the possible extent of salted affected soils under large hydrology changes, this is not certain as it may also be an indication of the source materials derived from the erosion of the high sodium lower Marburg geological formations in soil forming processes. Because of this uncertainty, the area of sodosols has not been included in the risk assessment.

7.2.5 Characterising and ranking the risks

Tables 10 and 11 evaluate the salinity sites in the Lockyer against a range of criteria and the risk assessment framework described in the above sections. Figure 30 gives the watertable salinity areas from Figure 14 with site numbers added. Sites are numbered down the catchment using prefix letter for the catchment, for example L3 is the third site down valley for Laidley creek. The criteria are given in Table 11.

Of the 29 sites evaluated in Table 10: 6 are very high risk; 8 high risk; 13 medium risk, and 1 low risk.

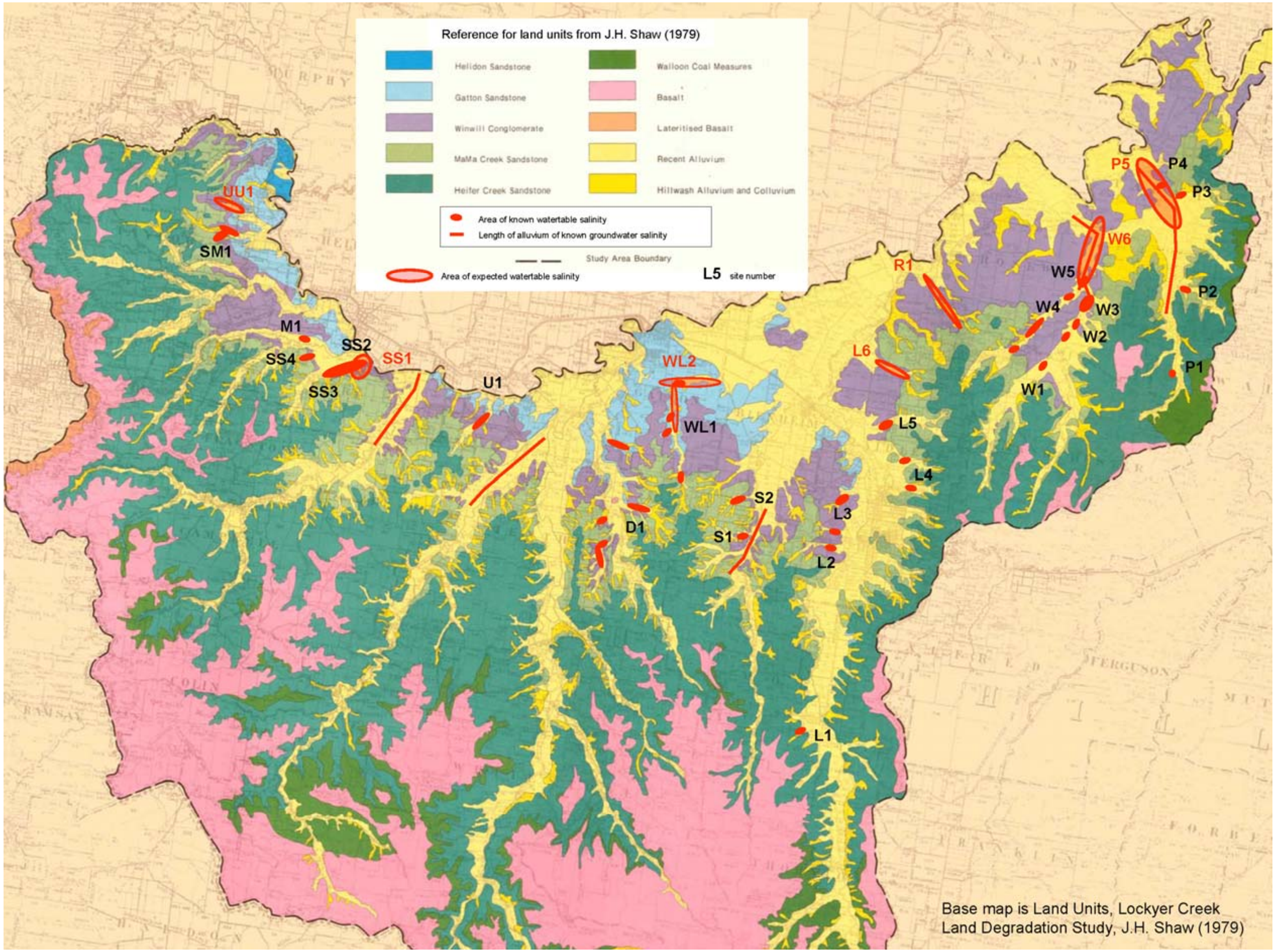

Figure 30. Site numbers of sites assessed for salinity risk and options for reclamation are shown in black and referred to in Table 10. Red ellipses with light filled centres and red site numbers presently do not show salinity but are predicted to show salinity under the listed pressures and are discussed in Table 10 and section 9.1. Site numbers comprise a letter for the catchment followed by a number from the head of the catchment downstream.

Table 10. Characteristics of salinity sites evaluated against a range of criteria as given in Table 11 including a salinity risk under the identified emerging pressures, preferred biophysical options to deal with salinity and an assessment of the reclamation possible of the sites.

Table 11. Criteria used and codes presented in Table 10 for the salinity site evaluation.

Table 10. Characteristics of salinity sites evaluated against a range of criteria as given in Table 11 (following this table) including a salinity risk under the identified emerging pressures, preferred biophysical options to deal with salinity and an assessment of the reclamation possible of the sites.

1 Catchment Name *description*	2 Site No	3 Contributing forms of salinity	4 Salinity stage of development /reclamation	5 Significance of salinity now (last 5 years)	6 Potential for salinity reclamation	7 Emerging pressures and their severity	8 Likelihood of pressures affecting salinity	9 Significance of pressures on salinity	10 Overall risk (columns 8 * 9)	11 Assets most affected and *Sustainable outcomes most affected*	12 Preferred biophysical options	13 Salinity stage of reclamation achievable	14 How easy to achieve this stage	15 Urgency of action	16 Policy required
Plain Creek *South of highway*	P1	AF SC	4	2 BV W	4	I 2 G 2	4	2	8	L V W ***L E EV***	S	5	2	3	Incentives
Rose Ave sub division	P2	CR	3	3 B W	5	I 2 W 4 NS 5 D 4	5	4	20	W R B Bu ***L E W Q G***	RW	7	5	1	Incentives WWTP
Salted area near Mt Tarampa	P3	AF CR D SC	4	3 B BV	3	I 2 D 3	3	2	6	L P V ***L EV W***	S	5	2	2	Code of practice Dam policy
Dam near Mt Tarampa	P4	CR D	4	4 B W E P	2	I 2 C 3	3	2	6	L P V ***L B E EV W Q***	S	7	4	1 (started)	Dam policy
Alluvia upslope of Lockyer Creek	P5	CR SC D AV	2	3 W P	3	I 4 D 3 NS 3 S 4	5	5	25	L P W V ***L B E EV W Q G***	TZ I RS	7	6	1	Radical incentives, co-investment, property and catchment plans
Woolshed Creek *Western tributary south of highway*	W1	CR SC Sedimentation of streams	3	3 W B	3 6	I 2 S 1	3	3	6	W B ***L E W G***	TZ I SS	6	2	3 to 4	Incentives, co-investment
Alluvium south of highway	W2	CR	3	2 W BV E	1 6	I 3 C	4	3	12	W P L R B ***L E EV W Q***	TZ I DA SS	9	3	1	Incentives, co-investment
Area just north of highway	W3	CR	3	5 W P BE	1 6	W 2 I 2 NS 3	4	4	16	L V W R V ***L B E EV W Q***	TZ I S DA SS	7	3	1	Incentives, co-investment
Fairways subdivision and western tributary	W4	CR AV	3	2 W BV	2 6	I 3 NS 5 D 3 R 3 V 3	5	5	25	W B U R L ***L B E EV W Q G***	TZ I S DA SS RW	7	6	1	Incentives, co-investment WWTP
Walnut Drive and Woolshed alluvia	W5	CR AV	4	4 B BV P W	1 6	I 2 NS 3	4	5	20	W P V ***L B E EV W Q G***	TZ I S SS	7	5	1	Incentives, co-investment
Woolshed Alluvia Upslope of Lockyer creek	W6	CR SC AV	3	3 W P	3	I 3 NS 3 D 3 S 4	5	5	25	L P W V ***L B E EV W Q G***	TZ I RS	7	6	1	Radical incentives, co-investment, property and catchment plans

1 Catchment Name *description*	2 Site No	3 Contributing forms of salinity	4 Salinity stage of development /reclamation	5 Significance of salinity now (last 5 years)	6 Potential for salinity reclamation	7 Emerging pressures and their severity	8 Likelihood of pressures affecting salinity	9 Significance of pressures on salinity	10 Overall risk (columns 8 * 9)	11 Assets most affected and *Sustainable outcomes most affected*	12 Preferred biophysical options	13 Salinity stage of reclamation achievable	14 How easy to achieve this stage	15 Urgency of action	16 Policy required
Regency Downs *Lorikeet Ave area*	R1	CR AV	2 to 3	1 W	1, 6	W 2 I 3 NS 4	5	5	25	L V R W R B U ***L B E EV W Q G***	S TZ I RW	9	4 to 5	1	Co-investment WWTP, incentives
Laidley Creek *Beckman Rd near Mulgowie*	L1	AF SC	8	1	1	V 2	2	1	2	L P ***L***	DN	9	1	N	None
South of Laidley Blenheim Road	L2	CR SC	4	3 W	4	I 2 V 2 NS	3	2	6	L W P ***L B E EV***	S	6	4	3	Incentives
Laidley Heights	L3	CR SC D	3	3 B W E	4 6	W 4 NS 5	5	5	25	L V W R ***L B E EV W Q G***	TZ I S RW	6	6	1	Incentives WWTP
North east of Laidley	L4	CR	5	2	2	W 3 NS 3 I 2	3	2	6	L P R *L*	S SS	7	2	2	None
Darbalara farm	L5	CR R SC D	4	4 B BV W E P I	3	I 3 D 5 NS 3	5	4	20	L V W R P ***L E EV W***	S TZ	6	5	1	Dam policy WWTP
Plainland incised drainage line	L6	CR with incised stream	2	0	1	NS 5 I 2	3	2	6	L W V ***L B E EV W Q G***	DN S RW	9	3	2	WWTP, Incentives
Sandy Creek *South of Laidley Blenheim Road* ***No current info***	S1	CR													Probably none
Woodlands Road	S2	CR D S	5	3 B BV E W I	3	I 3 D 3 G 3	3	3	9	L W P R Ro ***L B E EV W***	S	6	2 to 4	1	Incentives
Woodlands Rise *subdivision and drainage line*	WL1	CR D AV	3	4	3	D 5 NS 5	5	5	25	L W V R ***L B E EV W Q G***	S TZ I remove dams?	7	5	1	Dam policy, incentives, WWTP, co-investment
Deep Gully	D1	CR	4	3 B BV E P W	2	I 2 G 3	4	4	16	L V W R P ***L E EV***	S DN	6	4	2	Incentives
Unnamed Near Grantham	U1	CR AV D	4	3 B BV E P W	3	I 3 D 4 G 3 C 3	4	3	12	L W V B R Bu ***L B E EV W Q G***	TZ I S	7	5	1	Major initiatives, experimental, dam policy Co-investment
Soda Spring Creek *near junction Harts Rd and Back Flagstone Creek Rd*	SS1	CR	2	1	2	I 2 D 2 R 1 V 3	4	3	12	L V W *L*	S TZ Remove dam?	7	3	1	Incentives, dam policy
Spa Water Rd closer to Back Flagstone Creek Rd	SS2	CR S	2	2 BV	2	I 2 NS 4 V 3	3	3	9	L *L*	S	8	2	2	Incentives

1 Catchment Name *description*	2 Site No	3 Contributing forms of salinity	4 Salinity stage of development /reclamation	5 Significance of salinity now (last 5 years)	6 Potential for salinity reclamation	7 Emerging pressures and their severity	8 Likelihood of pressures affecting salinity	9 Significance of pressures on salinity	10 Overall risk (columns 8 * 9)	11 Assets most affected and *Sustainable outcomes most affected*	12 Preferred biophysical options	13 Salinity stage of reclamation achievable	14 How easy to achieve this stage	15 Urgency of action	16 Policy required
Spa Water Rd near old Tarino spa	SS3	CR S	4	4 B V P W I	5	I 3 NS 4 D 4	5	4	20	L W V B Bu ***L B EV WG***	S	6	5	1	Incentives, co-investment
Monkey Waterholes Creek *Spa Water Rd further west of site SS3*	M1	CR	2	1	2	I 3	4	4	16	L V ***L***	S	7	2	2	Probably none or incentives
Six mile creek ? *near Murphys Creek Road*	SM1	CR D	4	2 B BV E P W	5	I 2 D 4	2	3	6	L D W ***L W***	S monitor	6	4	1	Dam policy
Unnamed *West tributary nr Lockyer Siding*	UU1	CR AV	1	1 BV	1	I 2 W 2 V 4	4	4	16	L V W P R ***L B E EV W***	S	9	3	1	Incentives, No subdivision or subdivision with WWTP or experimental alternatives

Table 11. Criteria used and codes presented in Table 10 for the salinity site evaluation.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Catchment Name *description*	Site No	Contributing forms of salinity	Salinity stage of development /reclamation	Significance of salinity now (last 5 years)	Potential for salinity reclamation	Emerging pressures and their severity	Likelihood of pressures affecting salinity	Significance of pressures on salinity	Overall risk (columns 8 * 9)	Assets most affected *Sustainable outcomes most affected*	Preferred biophysical options	Salinity stage of reclamation achievable	How easy to achieve this stage	Urgency of action	Policy required
		AF alluvial fan AV alluvial valley C catena CR catchment restriction D dam F fault L lake R road S strati-graphic SC stream confluence	1 sensitive 2 stressed 3 expanding 4 equilibrium 5 stable 6 minimal reclaim 7 good reclaim 8 stressed stable 9 sensitive non-salt	0 none 1 intermittent 2 small 3 moderate 4 high 5 severe __________ B bare BV bare, patchy vegetation E eroded ψ potential to erode further P productivity affected W water quality affected, I Infra-structure affected	1 high 2 moderate 3 possible 4 small 5 minimal 6 use of excess water as resource	C cropping / grazing practices D dams G overgrazing I increase in rainfall NS non-sewered subdivisions R roads across valleys S sediment-ation creeks V vegetation clearing W develop-ment on Winwill ____________ – *Severity* 1 slight 2 small 3 moderate 4 high 5 severe	1 rare 2 unlikely 3 modera tely 4 likely 5 almost certain	1 slight 2 minor 3 moderate 4 high 5 severe		**Assets** Bridges Buildings Diversity In stream Land Productivity Riparian Roads Vegetation Water quality U'ground services ***Sustainable outcomes*** ***L Landscape health*** ***B Biodiversity*** ***E Ecosystem services*** ***EV Enterprise viability*** ***W Waste & hazards*** ***Q Quality of life*** ***G Governance***	DN do nothing S stabilise RA reduce recharge in recharge area TZ intercept flow DA increase discharge area outputs SS store salt RS remove salt RW recycled water use I irrigate ____________ *Specific options (not used) eg Remove dams WWTPs*	4 none – at equilibrium 5 stable degraded 6 minimal reclamation 7 good reclamation 8 very good stressed 9 excellent sensitive	1 easy – turns problem into resource 2 easy - fence & forget &/or conservation cropping 3 relatively easy – water a resource 4 moderate effort & cost 5 difficult, costly & long lead time 6 very difficult & expensive	1 within 1 yr 2 within 2 yrs 3 within 3 yrs 4 within 4 yrs 5 within 5 yrs N no action	

8 A salinity risk management plan for the Lockyer Valley

The relationship between assets and services and how sustainability might be achieved is shown in Table 13.

The logical basis of this hierarchy is that assets are used to provide livelihoods for people. How they are accessed and used is based on beliefs, interests and legislation. Together with science, knowledge and capability and the institutional processes, these assets and rights are maintained and hopefully enhanced. Using recommended practice options and sustainable farm business activities aligned with regional and farm strategies, plans and targets will achieve sustainable livelihoods and the sustainability outcomes as decided by the community.

Table 13. Steps towards sustainable outcomes and the processes that are appropriate for managing salinity are shaded. Table is modified from Shaw et al. (2005).

Processes	Steps towards sustainability
Access to and use of assets provides the basis for sustainable livelihoods	Assets: human, social, natural, physical, financial, infrastructure and ecological services
Access and use are directed by	Beliefs, legislation and policies
These beliefs and 'rules' convey	Rights, responsibilities, access and claims
Based on the principles determined from	Science, knowledge and capability and institutional processes
Managed by	Institutions, processes, accreditation and compliance
Leading to	Assets and ecological services maintained or enhanced
Maintained by following	Recommended practices and codes of practice
Society can then conduct	Business activities and resource uses leading to sustainable livelihoods and enhanced ecological assets and services
Jointly working on having	Strategies, plans and targets met, risks managed and restoration underway where required
Leading to	Profitable and sustainable livelihoods and aesthetic, existence and recreational values enhanced
To achieve	Sustainability outcomes as agreed by the community

8.1 Who benefits and who pays

We all need access to ecological and infrastructure assets and services to be able to live. Where we choose to live has a range of these assets and services as well as inherent limitations. We have come to expect a certain level of quality of life in all environments such that some natural systems are significantly overloaded in meeting these expectations. Traditionally over centuries, humans have not paid the full cost for the ecological services on which life depends as it has been considered an externality and the environment has suffered, been exhausted or has collapsed (such as fishing stocks in certain places) by paying the cost beyond its capacity. The atmosphere has absorbed the costs of the benefits of society using fossil fuels through increasing CO_2 levels. Stream health, riparian vegetation and water supplies have suffered from our changes to the landscape because natural water balances have been disturbed and pollutants added while we have only paid the cost of actual provision of these services.

The benefits of reticulated water to non sewered subdivisions are high but only the cost of provision of water is paid not the costs of the high hydraulic loading on the landscape. The environment is paying that cost where it can. Some degradation is inevitable and this is the trade-off to quality of life and is generally accepted, but degradation must remain within the bounds of resilience for systems to be sustainable in the long term. Salinity is one sign of hydrologic overload. Its effects are unevenly distributed in the landscape and down-stream users in sensitive landscapes are the losers as well as the community if compensation is sought in the future.

The imbalance in the real cost of provision of services is becoming more and more of an issue because the capabilities of ecological services provided by nature are reaching limits in some areas where the additional costs of humans having to provide these services, such as clean water etc (Costanza et al. 1997) will be extremely high. Thus protection and enhancement of ecosystem services is an emerging major issue.

To overcome these inefficiencies and consider the opportunities salinity issues can present we need to:

- Use ecosystem assets and services within the limits of their capability. This is an obligation under ESD principles. It is difficult to do particularly in currently developed areas because we are not aware of all the issues: rarely is the ecosystem actually accounted for in new developments; there are no real precedents; the rights that go with land ownership are very generous; and there are conflicts with people's livelihoods and interests in the short term.
- Grant rights equally to the ecosystem. In the same way rights need to be granted to future generations and downstream users. Then some system of allocation of resource use and trading needs to be worked out. This issue is discussed in detail by Young and McColl (2002).
- A principle be adopted that any reuse of land for an alternative purpose means that it has to be restored to a level of sustainability as a minimum condition of development. This is to preclude declining values because of degradation and to ensure no resource continues to decline to a state where massive investment is required to achieve sustainability.
- Address the 'tragedy of the commons'. Since salinity usually impacts on downstream users and on water quality or drainage lines where upstream saline or waste water enters, nobody bears the responsibility for the common area; private landholders are unable to manage the issues created by upstream users and the scale of its management. All by default are users and beneficiaries. The issue of the tragedy of the commons has been well presented by several authors and although Barnes (2007) offers some hope through trusts and varied property rights, it remains a very major issue for salinity and its reclamation. An example is the highly saline

groundwater at the lower ends of Woolshed and Plain Creeks. It has very limited potential value for agriculture or most other purposes and its salinity level is determined by past hydrogeological processes and by catchment users. How can it be managed or licensed to users for some creative use that will prevent the whole catchment being severely degraded?

- Emphasise the responsibility and accountability of landholders that goes with land and water rights to manage and use the resources within the limits of ecosystem sustainability. Principles, guidelines and education will be required for this to occur.
- Move towards paying the full cost of ecosystem services by implementing some early salinity management processes at a basic level. These could include:
  - All residents within a catchment pay a basic charge to go part way to maintaining ecological services on which life and quality of life depends as an access charge and to provide incentives to carry out required actions
  - This charge goes specifically towards restoring degraded priority ecological services that are required. In this case salinity and thus the charge goes to restore some hydrologic balance to groundwater systems
  - Where a particular resident or user can benefit from the restoration of the ecological services without harming the service, then the beneficiary also pays. For example if the excess water in a catchment that is to be used to restore it to sustainability is available for use, a charge needs to be paid by the person who, because of position in the catchment, has the capability to use the water
  - If no one wants to beneficially use the asset or service, and the water has to be used to maintain sustainability, then the community pays through incentives for joint investment. Incentives may be necessary to allow the level of ecological services required to be provided. Market forces may be the best mechanism, such as auctioning off the rights of access etc. Separation of land and water rights is an important aspect
  - If anyone wants to do something that is not aligned to maintaining or enhancing basic ecological services, then an additional charge is paid for using that practice or resource. Trade-offs, tradeable development rights or alternative management options that may compensate and do not significantly compromise the ecological services may be used to overcome any degradation. An example of major impact is dams and their impact on stream flow and riparian vegetation and stability
  - Best practice options be adopted to reclaim degraded areas and if landholders are not able to comply within say a 5 year period, then additional foreshadowed levies are paid to rectify the issues being caused. If agreed practices are not followed, and there is sometimes good reasons for this in that innovative solutions do not follow from everyone using conventional thinking, then if a deterioration becomes evident after 5 years, trade-offs need to be made or the liability to the ecosystem covered through insurance or bonds etc
  - Reticulated water and effluent disposal in non sewered subdivisions are vexed issues and most likely to result in serious salinity problems and probably health issues in sensitive landscapes. Residents who use reticulated water and dispose of effluent may have to pay for the overload to ecological services by a levy to be used to restore the hydrologic balance through effluent disposal schemes, and
  - If people wish to conduct business or construct or locate infrastructure in areas of higher risk or which poses a higher risk of degradation, or there is a risk it will deteriorate under a proposed development, then environmental insurance needs to be taken out to cover the possibility of degradation within a specified time period of say 10 years and which will ultimately be the responsibility of someone else to fix. Examples are dams in salted drainage lines, roads across salted areas and fallow cropping in salinity sensitive areas. EPA Victoria (2003) discusses some options for environmental insurance.

8.2 Adaptive management

Adaptive management has been the benchmark for planning for natural resource management issues and sustainability for over 30 years, particularly where the available knowledge is incomplete and the outcomes are uncertain. The steps of 'Plan', 'Do', 'Check' and 'Review' are commonly used by many people but not necessarily in a formal manner. Taking action on the best information available at the time is the most appropriate approach for continually changing situations. Variable knowledge, climate, episodic events, markets and ecosystems, and the uncertainty of predicting the best course of action into the future requires an adaptive management approach. This means incorporating performance and monitoring with adjustment of the goals and strategies to ensure the desired outcomes are being achieved.

The advantages of a formal process are that documentation of decisions, background information, criteria for decision-making and the rationale of the plan can be changed and re-assessed over time, as well as being available for others as may be required. Leach et al. (2006) and Shaw et al. (2005) give guidelines.

9 General discussion

It is an easy and a common reaction to deal with symptoms of salinity. A bare area of salinity needs to be revegetated; a salty waterlogged area needs to be drained. These are treatments for symptoms that will never fix a salinity issue because they don't deal with the root cause of the issue to prevent it reoccurring. Drainage sends the problem downstream. Thus while it may look good, if it works (and it often doesn't) lasting solutions treating the causes and that are sustainable are the only effective way to deal with salinity.

9.1 Summary of salinity risk tables

The details of the salinity site evaluations are given in Tables 10 and 11 and sites shown in Figure 30. By including 29 sites, the range of causes, options and risks are included from which some generalisations can be made. Some observations are:

- Over 95% of the sites assessed are associated with Winwill geology and many have confluence of streams as an associated form of salinity
- 50% of the sites are classed as having high or very high risk of salinity based on the emerging pressures
- The 5 sites shown on Figure 30 as ellipses with transparent fill are sites that have a very high risk of developing salinity in response to the identified pressures. The sites currently do not show salinity
- Most sites surveyed are either in an expanding or an equilibrium stage of salinity and show small to moderate severity of salinity
- Even though very dry conditions have existed over the past few years, most sites still show significant salinity indicating that more interventionist and proactive action is required than just reducing recharge if reclamation is to be achieved
- Salinity areas under the most severe pressure are associated with non sewered subdivisions either as already salted areas adjacent to the subdivisions or are showing early signs of significant salinity development
- Infrastructure such as roads, bridges and other built infrastructure is generally not presently affected by salinity. Fifteen of the 29 sites under emerging pressures would show salinity effects on infrastructure if salinity was allowed to develop as expected without remedial action or control of the pressures
- The only road currently affected by salinity in the sites investigated is at site S2, Woodlands Road in Sandy Creek, where seepage caused by a stratigraphic form of salinity has affected the road surface in the past to a small extent. The Clarke Bridge over Deep Gully in Tenthill Creek may be affected in the future from quite saline base

flow from Deep Gully. Houses near Grantham in the unnamed gully site U1 and Soda Spring Creek site S3 are on salt affected areas, and
- Use of excess water in the landscape upslope of the salinity areas is a viable option to manage salinity, where water quality is acceptable. In 13 of the 29 sites opportunities are available to use this water and thus reduce watertables in affected areas provided incentives are available.

9.2 Using excess water to manage salinity

Based on the experience in Brymaroo catchment on the Darling Downs and in other areas, use of excess water upslope of the salted areas is a most attractive proposition to control salinity, provided the water quality is satisfactory. Flow rates will be low and may require an intermediate storage to allow sufficient quantities of water to accumulate for conventional irrigation systems. Issues to be addressed are:
- adjacent areas will be only marginally suitable for irrigation particularly in Winwill areas
- existing landholders will often not have experience or interest in irrigation
- irrigated tree crops may be viable in some areas although water quality generally needs to be of better quality than for agricultural crops
- the sale of water rights to others including those down valley may be more appropriate, and
- In several situations upslope landholders of salted areas have dams in the catchments and thus their interest in additional water is probably marginal.

As outlined in section 4.6, irrigation of mounded revegetation areas on salted sites is a viable management option. Up slope sources of water may be appropriate to flush out salts from sites being reclaimed. However, the addition of water from outside the affected area can impact on groundwater levels that need to be lowered in the affected area and thus this source of water would only be realistically suitable for the short term or during critical periods or if there are other ways that the general groundwater level in these areas being reclaimed can be managed.

Alternatively, use of the water for environmental flows and flushing salts in these catchments would be beneficial depending on downstream impacts. In non sewered subdivision areas, use of excess groundwater where it occurs is possible, particularly at Regency Downs, which may overcome the need for tertiary treatment of waste water in some parts of the subdivisions. Linked wells or bores may be required to access sufficient groundwater flow.

9.3 Dams

The number of small dams in the Lockyer Valley is very high. Many blocks in non sewered subdivisions have large dams as well. I seriously wonder whether these dams and the quantity of water stored can be used. Six of the 29 sites investigated had salinity directly caused by or associated with them. Figure 20 is a severe case but others occur. Woodlands Rise has a very large dam in the adjacent salted drainage line adjacent to the estate. The stability of the dam and the impact on the groundwater is unknown but is likely to be causing an effect. Around 20 years ago many dams in the Lockyer Valley, on Winwill and lower Marburg formations, leaked through the dam wall because of tunnel erosion through the poorly compacted walls due to high soil sodicity. This now appears to be less common suggesting better construction techniques are being used.

Dams are a major issue for salinity for the following reasons:
- dams leak creating salinity problems upslope and down slope of the dam
- even dams that do not leak visually still recharge the groundwater. Assuming a deep drainage of around 0.5 to 1 mm/day, significant quantities of water will move to the groundwater. Once the soil below the dam is saturated, and the aquifer materials are

semi-confined, a pressure head is developed and transmitted to the area above the restriction resulting in shallow watertables developing. There are often dams in the drainage lines of upper sections of salted catchments that are undoubtedly contributing to the salted area
- dams reduce stream flow and peak flows reducing catchment flushing and affect riparian vegetation and down valley groundwater flow. Long-term this will not help the salt balance and will tend to retain salts at the lower end of catchments
- many of the salted areas and particularly those at the bottom of Woolshed and Plain Creeks have significant sedimentation issues in the creeks. Reduced peak flows no longer clear sedimentation because of the number of dams intercepting flow in some catchments. Thus shallow saline groundwater will persist with high salt content creating exacerbated salinity, and
- dams up slope of salted areas such as Darbalara farm near Laidley almost certainly will create much more severe salinity problems downstream at the salted area.

Policies and licensing of dams, particularly in the non sewered subdivision areas need to be developed to minimise the adverse effects and to balance the quantity of detained storage with the needs of the stream and environmental flows. If dams result in salinity developing, guidelines for their removal and/or site reclamation (probably at the cost of the owner) need to be developed and implemented. Because of the sodic nature of the subsoils of dams constructed on Winwill conglomerate, the walls need to be covered by surface soils saved during construction to stabilise against erosion and promote vegetation. Photo 13 is an example of a bad situation.

Photo 13. Example of severe erosion of a dam wall in Placid Hills that couild be managed by covering the sodic subsoil with topsoil to allow vegetation to establish.

9.4 Non sewered subdivisions

Reticulated water to subdivisions is a benefit but comes at a significant cost to the environment in the risk of salinity. Households already pay for the direct service of water but not the ecological consequences. The environment has paid in time by absorbing the excess water until the point is reached when the system tips into a degraded state then technological solutions will be required.

Non sewered subdivisions present a very significant salinity issue in the Lockyer Valley. The salinity effects are already evident in Plain Creek, and are on the tipping point in Regency Downs and Fairways Estate near Hatton Vale. The subdivisions will almost certainly exacerbate existing salinity near Woodlands Rise and Laidley Heights. It is the disposal of wastewater from reticulated water supplies to subdivisions that causes the hydrological loading beyond the capacity of the landscape to cope. It is anticipated that adequately dealing with this excess water will be a costly and difficult issue to resolve. Options that could be used to address this issue in decreasing order of effectiveness are:

- connect households to wastewater treatment plants which treat to tertiary level and water can then be sold to irrigators. Since water is a particularly valuable resource in the Lockyer Valley. It could also be productively used in Plain and Woolshed Creeks on good agricultural lands provided landholders were interested to irrigate and the watertable levels can be managed. Shaw (2007) has identified actions that will make a large difference in Woolshed Creek and implementation of these is currently being investigated
- Community-based sewage treatment plants such as by Biolytix and equivalent systems can be used and effluent treated to tertiary standard. Smaller plants with smaller output quantities can be less expensive. The water could be sold and/or used for environmental flows although there are concerns about the sodicity level of these waters (section 9.5). Department of Natural Resources and Mines (2005) have identified some schemes of potential application for small scale sewage treatment plants, and
- households implement much more efficient wastewater distribution systems on their blocks so that over watering and surface flows to drainage lines are minimised. This will still be inadequate in wet periods but could relieve the hydrologic stress on the whole system. Gardner et al. (1995) raise concerns that this approach will still be inadequate. Treatment levels could be in issue. An advantage is that it gives the lot owner some responsibility for the whole system. This approach could be an example application of best practice that can be voluntarily implemented by households over maybe a three year period and then enforced with levies, if necessary, for non-compliance. Monitoring would be required. There is a potential issue with sodicity of wastewaters affecting soil absorption (see section 9.5).

9.5 Recycled water

While there are good reasons to use treated wastewater in the Lockyer, the water quality needs to meet the water quality guidelines for irrigation discussed in section 5. Of particular concern is sodicity due to the high use of sodium in dish washing machines and laundry detergents. Awareness of high sodium in washing powders is increasing and the market is introducing lower sodium formulations. An example is the information available at http://www.lanfaxlabs.com.au/laundry.htm. However, dishwashing machine detergents are essentially sodium hydroxide which is strongly alkaline and very high in sodium. It is expected that they would make the poor permeability of Winwill soils even worse and result in more overland flow. The situation is expected to be worse for small domestic systems because there are limited calcium inputs to counter the high sodicity. Thus high sodium may be a significant limitation to irrigation. Further investigations are required before this can be assessed.

9.6 Awareness of salinity

It would seem that an awareness of salinity issues and the contributing processes by the community, developers and landholders is really quite low. Many practices are being undertaken in ignorance of the implications because of lack of awareness and use of consensus opinions from misinformation rather than knowledge based information. An education and awareness program would seem to be very timely to allow people some factual information on which to base a change in their practices. The willingness of people to change in the face of an adverse situation has been well established in SEQ with lower domestic water use because of very low water levels in the main dams. The importance of having factual knowledge of processes available to people is well summarised by Theodore Dalrymple (2008).

> *"Many people now end a discussion with the supposedly definitive and unanswerable statement that such is their opinion, and their opinion is just as valid as anyone else's. The fact is that our opinion on an infinitely large number of questions is not worth having, because everyone is infinitely ignorant. My opinion of the parasitic diseases of polar bears is not worth having for the simple reason that I know nothing about them, though I have a right to an opinion.*
>
> *The right to an opinion is often confused (no doubt for reasons of misplaced democratic sentiment) for the validity of an opinion, just as the validity of an argument is often mistaken for the truth of a conclusion."*

9.7 Adaptive management

The adoption of adaptive management can avoid endless and prolonged data collection and analysis phases before on-ground action can commence. The salinity processes operating in the Lockyer Valley are well understood, and if adaptive management is accepted and implemented it can allow 'best bet' management options to be implemented at an early stage at the same time as collecting additional information. Close monitoring of trends means strategies can be adjusted as information becomes available.

9.8 Woolshed and Plain Creeks

The state of riparian zones and degree of sedimentation in both creeks is much worse than expected. There needs to be incentives for riparian revegetation and unobstructed creek and tributary water flow as well as stock removal from riparian zones. The function of these creeks in their present state is expected to result in a larger and wider stream flow which is not at all conducive to managing salinity and the watertable. It is confining the lower aquifers resulting in increased pressure head in the lower reaches and is expected to cause increased salinity issues in the short to medium term.

The potential for salinity degradation in good-quality agriculture lands at the bottom of these two catchments is very high. Salinity of the groundwater at around EC 25 dS/m (half of seawater concentration) and the shallow depth to groundwater at 3 to 4 m in a very dry period in 2007 means that once the trigger point for soil salinity has been reached it will be almost impossible for these catchments to be reclaimed. These two areas are likely to suffer the most severe effects of salinity in the whole of the Lockyer Valley. Detailed salinity management options for these two creeks have been outlined in Shaw (2007). If these actions do not reduce the salinity risk, creek dredging and evaporation basins will be required and even compensation to landholders severely affected by salinity may be necessary.

9.9 Priority salinity sites

The salinity sites of highest risk and priority that need to be addressed at the earliest opportunity based on the evaluation of salinity sites and those with high potential to be affected in the future as presented in Table 10 are as follows.

1. Woolshed Creek because of the severe impacts should salinity develop on the lower alluvium. A whole of catchment strategy has been developed.
2. Regency Downs, Lorikeet Ave and the broad drainage line as a preventative measure to prevent salinity developing

3. Fairways estate development bordering Woolshed Creek with salinity in the tributary draining through the estate
4. Plain Creek lower alluvium for similar reasons to Woolshed creek, and
5. Unnamed creek near Grantham with severe existing salinity but potential for interception and irrigation.

9.10 Policy and planning issues

Section 8 outlined some initiatives worth considering. There is market failure in achieving sustainability and in particular, salinity reclamation is not a winner. Incentives will need to be provided even to take up and maximise opportunities for excess water use, at least in the establishment phases. Perverse incentives exist that discourage innovative ways of managing situations and flexibility in recommended practices. Codes of practice need to be made to avoid unintended consequences and lack of action and to encourage adoption of opportunities that have multiple benefits and don't compromise the ecosystem. Gunningham & Sinclair (2004) offer a range of options for the Swan-Canning region in Western Australia that can be usefully modified for the Lockyer Valley.

10 Conclusions

There is a distinct and repeating pattern of watertable salinity in the Lockyer Valley both in small dryland catchments and also in the major southern tributaries that shows that Winwill conglomerate geological formation is strongly associated with the occurrence of salinity. Winwill formation is acting as a weathering resistant formation restricting the rate of ground water movement out of the catchments. It would appear that many of the areas expected to show salinity in the Lockyer already have salinity or can be relatively well predicted using the pattern with Winwill conglomerate. The few catchments draining out of Winwill that are not already salt affected are sensitive to hydrologic change and will be influenced by the emerging pressures on salinity. It is most unlikely that serious expansion of salinity in the Lockyer will occur but some of the identified areas will expand.

The Lockyer has an excellent combination of soil and groundwater resources, although in limited quantity. Water salinity for irrigation has built in feedback processes and salinity is unlikely to cause degradation. Salinity problems in some locations will always be present. It is expected that salinity of alluvial aquifers in the southern tributaries to Lockyer Creek will very slowly reduce. Sodicity of irrigation water however is a risk if more marginal quality waters are used for irrigation. Guidelines are available to minimise any degradation from sodicity. A sodium adsorption ratio of the irrigation water of 5 to 6 should not be exceeded except under special circumstances where compensating management is undertaken.

There are existing and emerging pressures from an increased number of dams, non sewered residential subdivisions and the high level of siltation and degradation of the major creeks that are influencing the incidence of salinity. Together with a return to normal rainfall patterns, there will be increases in salinity problems in existing and sensitive areas since existing salinity areas are still showing signs of salinity even after a period of dry years.

The concept of reducing recharge in recharge areas by replanting vegetation and deep rooted perennial pastures will never be effective alone in reducing the area of salt affected land. It is a 'systematised illusion' whose veracity comes from constant repetition. Areas showing significant salinity in an extended dry period (such as the current period) when there has been little or no recharge indicates that more than revegetation alone will be required if salt affected lands are to be reclaimed.

Salinity risk areas have been identified and mapped and management actions recommended for each area that should minimise or reclaim areas and prevent further degradation in the catchments. Further investigations are required if expensive reclamation is to be undertaken followed by adaptive management.

Woolshed and Plain creeks are the worst salinity risk followed by areas in or adjacent to non sewered subdivisions. The option of proceeding with an evaporation basin with enhanced evaporative technology and salt harvesting in Woolshed and Plain creeks as well as the options recommended in Shaw (2007) should be considered. Areas in or adjacent to developing non sewered subdivisions are already showing salinity which can only get worse if no preventative strategies are implemented.

The large number of dams in the Lockyer upstream of salted areas as well as the relatively high proportion of dams that leak and cause salinity problems directly are a major concern. Policy is required for water management on a catchment basis to manage dams, flows and stream health.

Since voluntary methods are unlikely to be effective in achieving sustainability and particularly for salinity reclamation, incentives and policy changes have been identified as possible options. More interventionist and structural changes will probably be required.

Priority areas for salinity reclamation and prevention have been identified and action while the rainfall pattern is still in the dry period will offer considerable advantages in managing salinity before wetter periods return. Some experimental salinity areas are identified to begin the process and demonstrate the potential and opportunities that can come with proactive salinity management.

11 Recommendations

1. A salinity strategy is needed for the whole Lockyer Valley that targets prevention and reclamation options to achieve agreed results. Proactive intervention is required beyond commonly recommended recharge area control measures if salinity is to be effectively managed before further areas are affected.
2. Policy options, codes of practice, bonds and/or insurance for developments that pose a salinity threat would improve prevention of future salinity issues.
3. Future non sewered subdivisions need to be carefully evaluated for their cost benefit of incorporation of wastewater treatment systems and recycled water use over time periods up to 30 years. Non sewered subdivisions pose significant salinity threats in hydrologically sensitive Winwill geology areas because of the particular landscape features of these areas that cause salinity, the development on generally lower quality lands which may already have salinity and the wastewater disposal systems which are inadequate to deal with the quantity of effluent produced.
4. A catchment scale water management strategy is required with emphasis on approvals for all dams including intended use, construction, maintenance and procedures when leakage and salinity arise. Dams pose a major issue in the Lockyer because of leakage and salinity. In non sewered subdivisions the numbers of dams are amazingly frequent and of large storage capacity which is predicted to cause considerable issues into the future.
5. An education and awareness campaign on the effects of resource use on salinity in sensitive landscapes is required to minimise the number of practices that are adversely affecting salinity because people are not aware of the implications. An emphasis on rights and responsibilities and duty of care to maintain and enhance the sustainability of the region is not well known, and
6. Agreement to a proactive salinity management strategy for the high risk Woolshed and Plain Creeks is required to prevent the expected large saline areas developing at the northern ends of the catchments and possible compensation claims that may result.

12 References

Alario, M & Brün, M 2001, 'Uncertainty and controversy in the science and ethics of environmental policy making', *Theory and Science* vol. 2,1, viewed 15 March 2005, **<**http://theoryandscience.icaap.org/content/vol002.001/02alariobrun.html>

ANZECC & ARMCANZ (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand) (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Chapter 4 (Primary industries) and Volume 3 Primary Industries – Rationale and background information. National Water Quality Management Strategy. Canberra. viewed 22 Jan 2008, <http://www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality>

Ayers, RS & Westcot, DW 1976, Water Quality for Agriculture. Irrigation and Drainage Paper 29, Food and Agriculture Organisation, Rome.

Barnes, Peter 2007, *Capitalism 3.0: a guide to reclaiming the commons*. Berrett-Koehler Publishers, Inc., San Francisco. Viewed 22 Jan 2008, available free at <http://www.onthecommons.org> .

Biggs, AJW, Power, RE & Brough, DM 2003, A preliminary assessment of salinity risk modelling in the Queensland Murray-Darling Basin. Report QNRM03155, Department of Natural Resources and Water, Brisbane.

Bureau of Investigation 1949, An Investigation of the land and water resources of the Lockyer Valley. Technical Bulletin No. 2, Queensland Department of Lands, Brisbane.

Bureau of Investigation (undated) Lockyer groundwaters with special reference to surface soaks of salt water. Draft for fifth annual report, Bureau of Investigation, Brisbane.

Burne, C 2005, Rural towns seek salinity solution in desalination. *Farming Ahead* No. 161, 48-50.

Chamberlain, T, Silburn, DM, Forster, BA, Wearing, CH, Moss, JB, Reading, LP, Owens, JS & Pearce, BR 2007, Salinity risk assessment of the Fitzroy Basin, Queensland. State Level Investment Project SA04. Department of Natural Resources and Water, Brisbane.

Coram, J (editor) 1998, National classification of catchments for land and river salinity control. A report for the RIRDC/LWRRDS/FWPRDC joint venture agroforestry program. Publication No 98/78, Rural Industries Research and Development Corporation, Canberra.

Costanza, R, d'Arge, R, de Groot, R, Farber, S, Grasso, M, Hannon, B, Limburg, K, Naeem, K, O'Neill, RV, Paruelo, J, Raskin, RG, Sutton, P & van den Belt, B 1997, The value of the world's ecosystem services and natural capital. *Nature* **387:** 253–260.

DNRM 2005, Planning guidelines for water supply and sewerage. Report QNRM05065. Department of Natural Resources and Mines, Brisbane.

Dowling, A & Gardner, EA 1988, Spatial variation in salinity of some alluvial aquifers in Central Queensland – a steady state analysis. *Australian Journal of Soil Research* **26:** 617-626.

Ellis, MD & Bigwood, RC 2006, Landscape and salinity assessment of the Black Snake Creek catchment south east Queensland. Report Department of Natural Resources and Water, Brisbane.

EPA Victoria 2003, Risk, the environment and the role of the insurance industry. Report prepared by the UNEP FI Australasian Advisory Committee on Insurance. EPA Victoria, Melbourne.

Galletly, JC 2007, Baseflow in Lockyer Creek. PhD thesis, The University of Queensland, Gatton.

Gardner, EA 1984, Hydro-salinity problems in the Lockyer Valley – real or perceived. A synopsis. Unpublished report. Department of Natural Resources. Brisbane.

Gardner, EA 1985, Hydro-salinity problems in the Lockyer Valley – real or perceived. In 'Principles of landscape, soil and water salinity' - *Proceedings of the Lockyer-Moreton*

Regional Salinity Workshop, pages D1-1 to D1-9, June 1985, Publication QC 85004 Queensland Department of Primary Industries, Brisbane.
Gardner, Ted, Littleboy, Mark & Beavers, Peter 1995, Using a water balance model to assess the hydrological implications of on-site effluent disposal. Paper presented to the 16th AWWA Federal Convention Sydney, April 1995.
Gardner, Ted 2005, Are on-site systems environmentally sustainable? Can monitoring provide the answer? Paper presented to On-Site '05 Conference, Armidale September 2005.
Gunningham, N & Sinclair, D 2004, Curbing non-point pollution: lessons for the Swan-Canning. *EPLJ* **21:** 181-199.
Hart, B, Burgman, M, Webb, A, Allison, G, Chapman, M, Duivenvoorden, L Feehan, P Grace, M Lund, M, Pollino, C, Carey J & McCrea, A 2005, Ecological Risk Management Framework for the Irrigation Industry, Report to National Program for Sustainable Irrigation (NPSI) by Water Studies Centre, Monash University, Clayton, Australia. Viewed 20 Jan 2008 <http://www.sci.monash.edu.au/wsc/sresearch/eraframework.html>
Hatton, TJ 2002, Engineering our way forward through Australia's salinity challenge. Technical Report 4/02. CSIRO Land and Water, Perth.
Heiner, IJ, Biggs, AJW, Gordon, IJ & Vieritz AM 1999, Sustainability of Agricultural Systems using Recycled Water in the Lockyer Valley and Darling Downs Area, Queensland. Report QNRM01071, Department of Natural Resources and Mines, Brisbane.
Hogan, Kerry 1996, Woolshed/Plain Creek Landholders Inventory Project Report. Lockyer Resource Management Group Incorporated, Gatton.
Hubbard, D 2007, *How to Measure Anything: Finding the Value of Intangibles in Business* page 46, John Wiley & Sons, New York. cited in <http://en.wikipedia.org/wiki/Risk> Viewed 10 Feb 2008.
Leach, G, Bennett, J, Shaw, R, Thomsen, D, Cox, M & Long, P 2006, Enabling adaptive management for regional natural resource management. Technical Report 81, Cooperative Research Centre for Coastal Zone Estuary and Waterway Management, Brisbane.
McMahon, GA & Cox, ME 1996, The relationship between groundwater chemical type and Jurassic sedimentary formations: The example of the Sandy Creek catchment Lockyer. South east Queensland. Mesozoic 96, Mesozoic geology of the eastern Australia plate conference, Extended abstracts **43:** 23-26, Geological Society of Australia, September 1996, Brisbane.
McTaggart, NR 1963, The Mesozoic sequence in the Lockyer-Marburg area, south east Queensland. *Proceedings of the Royal Society of Queensland* **73:** 93-104 cited in McMahon and Cox (1996).
Mass, EV & Hoffman, GJ 1977, Crop salt tolerance – current assessment. *Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers,* **103:**115-130.
NDSP, 2004, Technical assessment of desalination technologies in Australia. TechNote, National Dryland Salinity Program, Land and Water Australia, Canberra.
Pearce, B, Hansen, J & White, T 2007, Hydrogeological investigation of the Lockyer sub-catchment, south east Queensland, Australia. Technical Report QNRM06250. Department of Natural Resources and Water, Brisbane.
Powell, B Loi, J & Christianos, NG 2002, Soils and Irrigated Land Suitability of the Lockyer Valley Alluvial Plains, South-East Queensland. Land Resources Bulletin QNRM01215, Department of Natural Resources and Mines. Brisbane.
QDPI 1985, Principles of landscape, soil and water salinity' - *Proceedings of the Lockyer-Moreton Regional Salinity Workshop.* June 1985, Publication QC 85004 Queensland Department of Primary Industries, Brisbane.
QWRC 1982, Further progress report on Lockyer Valley Water Resources investigation. Queensland Water Resources Commission, Brisbane.

QWRC 1982a Lockyer Valley groundwater water quality 1944 - 1981. Queensland Water Resources Commission, Brisbane.
Rapport, DJ & Whitford, WG 1999, How ecosystems respond to stress: Common properties of arid and aquatic systems. *BioScience* **49:** 193-203.
Robins, L 2004, Dryland salinity and catchment management – A resource directory and action manual for catchment managers. National Dryland Salinity Program, Land and Water Australia, Canberra.
Salcon 1997, Salinity Management Handbook. Publication DNRQ97109. Queensland Department of Natural Resources, Brisbane.
Scheffer, M 2001, Alternative attractors of shallow lakes. *The Scientific World* **1:** 254-263
Searle, R Watling, K, Biggs, A & Secombe, K 2007, Strategic salinity risk assessment in the Condamine Catchment. National Action Plan for Salinity and Water Quality, Salinity Technical Report. QNRM06218. Queensland Department of Natural Resources and Water, Brisbane.
Shaw, JH 1979, Land Degradation in the Lockyer Catchment. Technical Bulletin 39 Department of Natural Resources and Mines. Brisbane.
Shaw, RJ, Hughes, KK, Thorburn, PJ & Dowling, AJ 1987, Principles of landscape, soil and water salinity - processes and management options. Part A in *Landscape, Soil and Water Salinity, Proceedings of the Brisbane Regional Salinity Workshop*, Brisbane, May 1987. Publication QC87003, Queensland Department of Primary Industries.
Shaw, RJ 1996, A unified soil property and sodicity model of salt leaching and water movement. PhD thesis, The University of Queensland, Brisbane.
Shaw, RJ & Thorburn, PJ 1985, Prediction from leaching fraction from soil properties, irrigation water and rainfall. *Irrigation Science* **6:** 73–83.
Shaw, R, Fearon R, MacKenzie, R, Bent, M, Bill, S, Capelin, M & Rodgers, C 2005, A common framework for property level planning and management systems. Technical Report 67. Cooperative Research Centre for Coastal Zone Estuary and Waterway Management, Brisbane.
Shaw, RJ 2006, Stages of salinity development and reclamation. Unpublished paper.
Standards Australia, 2004a, Risk management, AS/NZS 4360.2004, Standards Australia International Ltd, Sydney.
Standards Australia, 2004b, HB436 risk management guidelines – companion to AS/NZS 4360.2004, Standards Australia International Ltd, Sydney.
Talbot, RJ & Bruce, IJ 1974, Effects of leaching on salinity levels and other soil properties of a clay soil in the Lockyer Valley, Queensland. *Queensland Journal of Agricultural and Animal Sciences* **31:** 175-83.
Talbot, RJ, Roberts, MH, McMahon, CR & Shaw, RJ 1981, Irrigation quality of Lockyer Valley alluvia bores during the 1980 drought. Technical Publication No. 5, Queensland Agricultural College, Gatton.
URS Australia, 2002, Summary Report: Introduction to desalination technologies in Australia. Prepared for Agriculture, Fisheries and Forestry – Australia, Land and Water Australia, Canberra Viewed 21 March 2008 <www.environment.gov.au/water/publications/urban/pubs/**desalination**-summary.pdf
White, BA (principal author) 1980, Salinity in the Lockyer Valley: a preliminary evaluation. Report DLUR 80/4, Department of Natural Resources and Mines, Brisbane.
Young, MD & McColl, JC 2002, Robust separation: A search for a generic framework to simplify registration and trading of interests in natural resources. Folio No S/02/1578. CSIRO Land and Water, Canberra.
Zahawi, Z 1975, Lockyer Valley groundwater investigations. Hydrogeological Report. Record 1975/36. Department of Mines, Brisbane.