Economic tradeoffs for managing offsite impacts of irrigation areas.

David Robinson, Shahbaz Khan

CSIRO Land and Water
Sustainable Irrigation Systems
Griffith NSW 2680

Abstract

Many irrigation districts within the southern Murray Darling Basin have imposed external environmental impacts to adjoining landscapes, in particular, high watertables which cause salinity and increased waterlogging. These environmental impacts can cause losses in agricultural production and also degrade the natural ecosystem. Natural depressions are highly susceptible to these external impacts and are compounded by local flooding and ponding events. The level of investment in salinity and waterlogging mitigation works in excess of tangible benefits to protect or reclaim degraded depressions becomes a social choice between the community's willingness to pay for the potential environmental benefits of the mitigation works and the level of degradation the community is willing to accept. The drainage options and level of economic tradeoff to improve the environmental conditions in the Green Gully area are described to provide an understanding of the economic impacts of environmental externalities.

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1 Introduction

Many irrigation districts within the southern Murray Darling Basin (MDB) have imposed external environmental impacts, in particular, shallow watertables which cause regional salinity and increased waterlogging. Shallow watertables in irrigation areas have been caused by deep percolation from poor irrigation, together with the seepage of water from the associated network of water distribution and drainage channels. In a 1990 study (Gutteridge, et al., 1990) it was estimated that areas of high watertables (i.e. watertables within two meters of the land surface) in the Murray Darling Basin would increase to 95 percent of the total area irrigated within 50 years if no remedial actions were taken.

The negative impacts of salinity and waterlogging cause losses in agricultural production and degradation of the natural environment. Natural depressions are highly susceptible to these impacts which are compounded by flooding and ponding events. In areas of shallow watertables, natural depressions have the greatest risk of becoming highly degraded due to saline watertables being at or very near to the soil surface which limits the survival of the remnant native vegetation.

The impact of salinity from high watertables within irrigation districts is largely seen by individual farmers as an externality due to connecting aquifers between farms and the lateral movement of groundwater. Therefore, high watertables are primarily seen as a regional problem which requires community action for its management. Depressions and high value conservation areas also provide environmental benefits to the wider community therefore their preservation also requires some level of physical as well as financial support by the community.

Natural depressions and other high value conservation areas surrounding irrigation districts can be protected with innovative engineering and plant based drainage solutions. Drainage solutions can provide both local and regional benefits and are relatively simple to design but finding solutions for the disposal of highly saline drainage water, which is both economical and environmentally acceptable, is not as simple. Consequently, the preservation of high value conservation areas with drainage solutions can be expensive due to high disposal costs and are most likely to outweigh the value of any agricultural production benefits.

Natural depressions can have a high biodiversity and aesthetic value to the community as well as an agricultural value. The social choice of the level of investment in the preservation of depressions can only be made with better information on the various drainage options and associated tangible net benefit (cost) to the community. Environmental benefits can be difficult to value in monetary terms, but threshold values could be used as a proxy for the value of environmental benefits to assist in making rational choices. The threshold value for potential environmental benefits is the net cost of the drainage project in excess of tangible or measurable benefits. Therefore, threshold value analysis can be used by the community to assess how large the net cost of the investment in salinity and waterlogging mitigation works would need to be for it to exceed the potential environmental benefits. The social choice will then become an economic tradeoff between community’s willingness to pay for the potential environmental benefits of the mitigation works and the level of degradation the community is willing to accept.

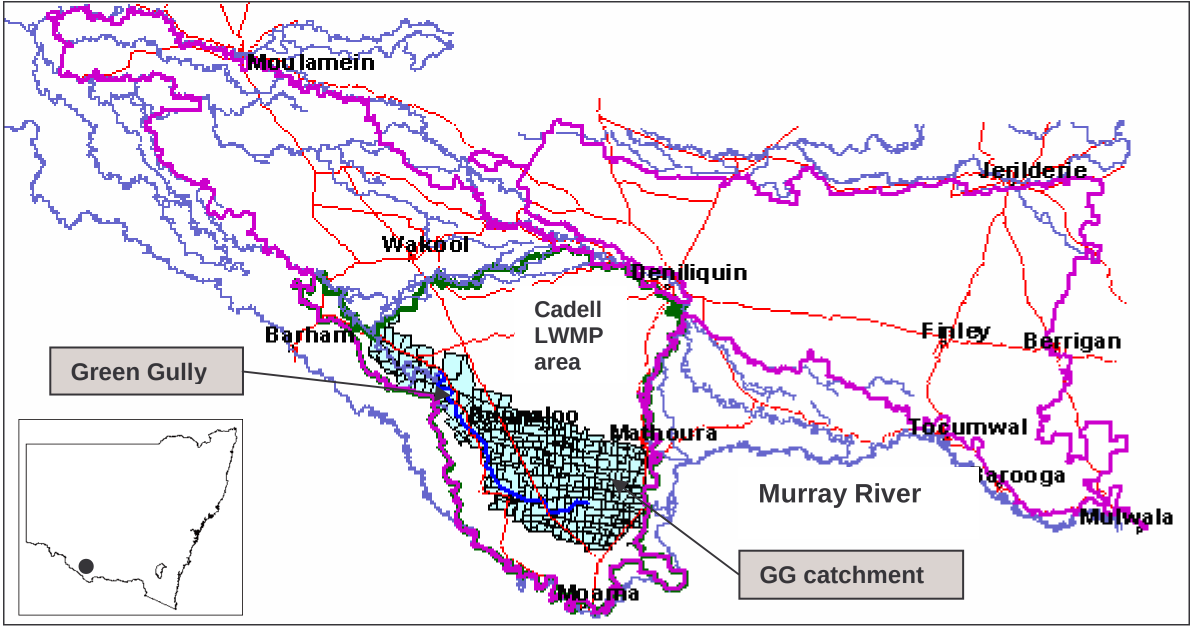
This paper explores the drainage options and economic tradeoffs encountered by the community of Green Gully in the Murray Valley in order to reverse the severe degradation of their local depressions, which have been caused by rising watertables as a result of net recharge from agricultural practices in the surrounding region.

2 Case Study – Green Gully

2.1 Background

Green Gully (GG) is located approximately 75 km south west of Deniliquin (Figure 1) and is a series of major depression within the mixed dryland and irrigation farmland of the Cadell Land and Water Management Plan (LWMP) area of southern NSW. GG is the ancestral bed of the Murray River, which was redirected with the uplift of the *Cadell Fault*. The gully's elevation falls to the north-west and only flows in major flood events (last event was in the floods of 1974). The gully flows into to the Thule Lagoons then into the Wakool River.

Figure 1 Location of Green Gully



For many years GG has been susceptible to salinity and waterlogging problems which has led to significant loss of agriculture production and biodiversity. The problems of salinity and waterlogging have been attributed to a number of factors including the low lying topography of GG, a general rise in the district watertable, high salinity of both soil and groundwater, lack of surface drainage, the area's susceptibility to flooding and the natural and man made obstructions which occur along the course of GG which contribute to drainage problems (Figure 2).

Green Gully being a natural depression which includes some agricultural developments, is susceptible to flooding events. Flood flows are channeled into GG from a catchment area of approximately 95,000 ha. There are also a number of depressions in GG where groundwater is usually at, or very near to, the surface, creating saline and waterlogged conditions. A hydrogeological study of the GG area identified that GG is in a situation where it will increasingly act as a natural sink and evaporation area for rising district watertables (Kulatunga 1992).

There have been many drainage proposals[1] on a regional scale prior and during Cadell's LWMP to alleviate salinity and waterlogging within GG and subsequently increase agricultural production and improve the natural biodiversity in the area. However, any improvement in the

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[1] References covering these drainage proposals include: Anon. (1980), Bogoda, K.R., Kulatunga, N. and Mahendran, A. (1994), Cadell LWMP Working Group (2001), de Vries, G. and Jackson, C. (1995a), de Vries, G. and Jackson, C. (1995b), Gunaratne, N., Wall, L., Marshall, G and Jones R. (1995), Gutteridge Haskins and Davey Pty Ltd (1995), Kulatunga, N. (1992), Raft, S. (1995), Stanton-Hassall Joint Venture (1995).

natural drainage of the gully will result in highly saline flows entering the fresh water in Thule Lagoons and the Wakool River therefore drainage solutions must incorporate disposal solutions for the saline drainage water that is both economic and environmentally acceptable.

Previous drainage proposals have been to:

- Reduce runoff into gully by constructing surface drainage
- Improve gully drainage and isolate the worst salt producing areas with drainage disposal to centralised evaporation areas or back into the river system during high flows
- Provide a drainage system to separate fresh and saline water in all but high runoff conditions
- Provide sub-surface drainage via groundwater pumping and evaporation areas in the gully and adjacent areas

These options are aimed to improve the salinity and waterlogging conditions within the gully however, very little work has been implemented due to problems associated with the storage and disposal of large volumes of saline drainage water. Also, GG is a natural depression which constitutes a very small area of the Cadell LWMP (approximately 1%) with any remedial measures likely to be relatively expensive and uneconomic.

However, there has been extensive work on-farm undertaken by surrounding landholders to minimise and possibly reverse the environmental degradation around the gully. Work undertaken has included earthworks and recycling to prevent farm drainage entering the gully, converting agricultural land use to perennial species such as lucerne to minimise groundwater accessions and extensive revegetation of salt tolerant perennial species (approximately 1000 ha of saltbush and trees) along the sides of the gully to minimise runoff and lower the watertable.

It is the concern of the landholders who have contributed a large investment in salinity and waterlogging mitigation works in GG that there is significant risk a future flooding event is going to cause significant damage to their investment.

The level of investment required for drainage works to protect the saltbush and tree plantings in GG from a flood event is most likely beyond the capacity of the affected landholders. The degradation of the depressions is mainly an externality due to rising district watertables attributed, in part, by the agricultural practices of the surrounding region. Also, there maybe environmental benefits to the wider community by protecting the saltbush plantings and improving the depressions with drainage work. Therefore it will become a social choice by the wider community of whether they are willing to pay for drainage works required to improve the environmental conditions of the depressions within Green Gully and to protect the investment of salinity mitigation works achieved by GG landholders. The social choice will become an economic tradeoff between community's willingness to pay for the potential environmental benefits of the mitigation works and the level of degradation the community is willing to accept.

CSIRO Land and Water undertook an investigative study to review and propose alternative drainage management options to assist in alleviating the salinity and waterlogging problems surrounding GG and to minimise the risk of loss of perennial vegetation from future flooding events. This research was undertaken in two stages to ensure community involvement in the investigation of feasible options. The first stage involved a critical hydrologic and economic review of previously investigated options and to propose any alternative management options which were evaluated and discussed with the Cadell Working Group. The second stage of the study involved an in depth hydrologic and economic evaluation of the preferred options derived from the first stage of the study. The results of the study will provide the community of GG the level of economic tradeoff associated with each drainage option in order to reverse the severe degradation of their local depressions.

After a thorough review of all previous studies, Khan et al. (2002) recommended that the following surface and subsurface drainage options should be evaluated by in depth hydrologic and economic studies to understand the local and wider community impacts of improving GG drainage.

- Linking individual depressions in GG by cutting high areas thereby allowing the free flow through the gully with local disposal options (individual or a large evaporation/retention basins). This option will require an evaluation of interception of saline flows in the cut sections and any possible wider community benefits will result due to improvement of GG drainage.

- Shallow pumping options with a combination of disposal options such as drainage reuse, evaporation basins and controlled release during flooding events in Murray through detention storage.

2.2 Hydrogeological Conditions In the Green Gully Area

To accomplish the hydrologic and economic evaluation of the recommended drainage options, a range of field surveys, farmer questionnaires, surface and groundwater analysis and economic analysis were carried out (Khan et al., 2003).

The Cadell LWMP covers an area of 322,000 ha and in 30 years from 1990, the area of high watertables was predicted to increase from 6,000 ha to 77,000 ha if management practices were not altered (Cadell LWMP Working Group, 2001). The spatial and temporal analysis of shallow piezometers shows that shallow watertables (less than 2m) have persisted in the middle of GG since the early 1970’s and also the groundwater levels during the past 7 years are either stable or gradually declining. This is explained by the overall decline in watertables in the Murray Irrigation Limited (MIL) area due to increased deep groundwater pumping and dry climatic conditions. The soil textural analysis showed the presence of lighter textured soils in the middle of the GG suitable for shallow groundwater pumping.

A groundwater survey of 16 piezometers near the gully in September 2001 showed that groundwater levels ranged from 1.81m to 4.87m in depth. The groundwater salinity in these observation bores averaged 32 dS/m and with values as high as 52 dS/m. A sample was also taken from the bottom of the gully in a pool of stagnant gully water and returned a value of approximately 200 dS/m. This high salinity level is a result of slow drainage and high evaporation rates in the region.

The most severely affected saline and waterlogged areas of the gully lie in the middle section of the gully (Figure 2). These areas have watertables within 2 meters of the soil surface.

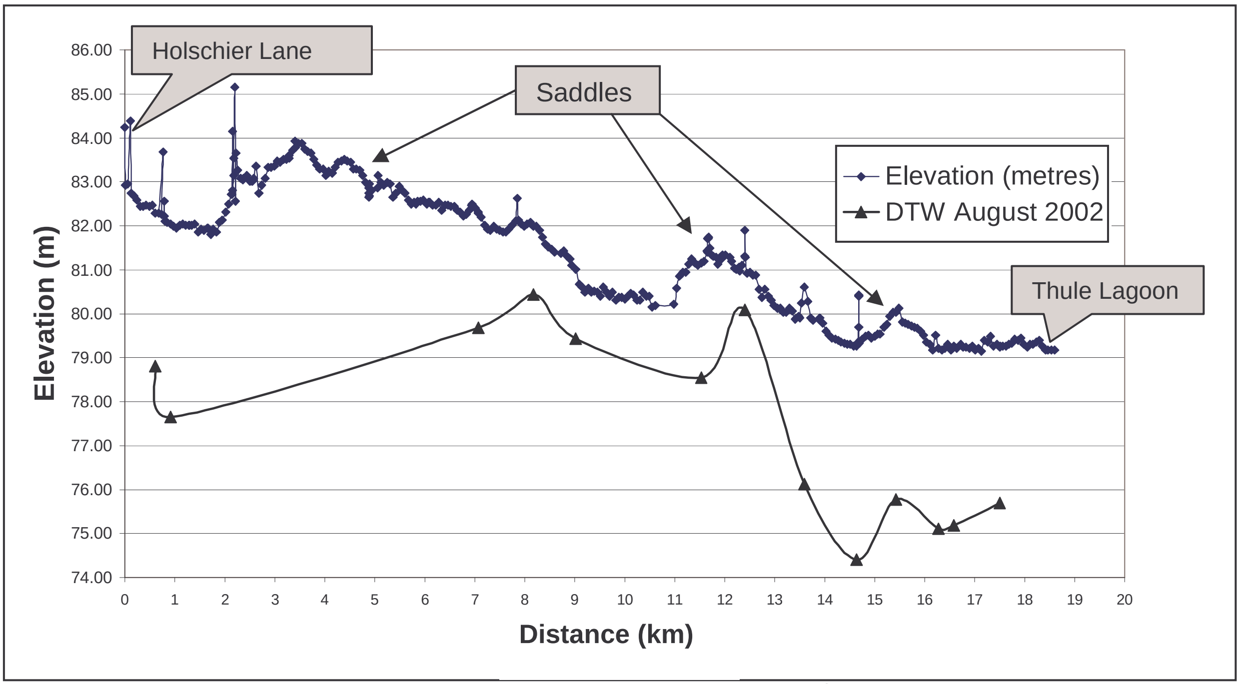

Figure 2 Piezometric levels relative to Green Gully's surface elevation, August 2002

2.3 Economic Evaluation of Drainage Options

2.3.1 Surface Drainage Options

The recommended drainage option for GG was to link the individual depressions in the gully by cutting through the high areas thereby allowing the free flow through the gully coupled with some level of subsurface drainage and local disposal options. Four surface drainage alternatives were considered for hydrologic and economic analysis.

1. Surface drainage of all depressions to cater for a 1 in 5 year storm event;
2. Surface drainage for the stagnant water in depressions following a major flood;
3. Surface drainage using lift pumps;
4. Surface drainage using lift pumps and drainage reuse.

In all these options, there needs to be some level of subsurface drainage to reduce watertables and salinity levels in the middle of the depressions. Subsurface drainage coupled with the capture of initial saline flows will assist in the leaching of salts and therefore will improve the long-term quality of the runoff. This means that over a period of several runoff events, the amount of "initial salt capture" will be reduced and more of the following runoff can be drained down the gully or reused for irrigation.

The disposal of saline drainage into evaporation basins is also an essential part of all the drainage options to reduce downstream impacts.

(1) Surface drainage of all depressions to cater for a 1 in 5 year storm event

The runoff models estimated a peak flow of 1065 ML/day at the start of the first depression for a 1 in 5 year storm event (57mm of rainfall in 24 hours). To provide full drainage for this peak flow and to minimise the interception of the shallow saline watertable the drainage channel would need to be excavated through the three major saddles at a depth no greater than the gradient between the 3 major depressions.

The drainage channel intercepts 4 public roads in which the culverts would need to be replaced to accommodate the peak flow. Incorporating the cost of project survey and design, project management, drainage excavation, culvert installations and a contingency allowance, the total cost of this drainage proposal is $1.7 million.

This option allows for maximum drainage of Green Gully and consequently will permit initially highly saline flows to enter Thule Lagoons at the tail end of the gully. The Lagoons contain fresh water therefore the interception and disposal of the "initial flush" of drainage is required to minimise the salinity impact on the lagoons. The volume of initial runoff with high salinity levels that needs to be captured from a 1 in 5 years storm event in the GG catchment is approximately 50 ML. This is approximately 5% of runoff generated from the middle region of the GG catchment. Therefore an additional cost of evaporation basins and pumps needs to be included in the above estimate.

(2) Surface drainage for the stagnant water in depressions following a major flood

This option looks at the surface drainage required to completely drain the 3 major depressions when full, once the gully has stopped running following a major flood event. The approximate storage capacity of the depressions within Green Gully is 1100 ML and would cover a surface area of 200 ha. Channel design is determined by the channel flow rate required to drain the depressions in a specified number of days. Channel design was based on 7 and 16 day drainage period.

A low cost option assumes that the cost of constructing on-farm drains can be lowered by reducing the need for extensive post excavation costs of site establishment, bank formation, grading, bank compaction and fencing. In addition, the cost of installing on-farm culvert crossings may be lowered if they are installed by farmers.

Assuming a channel grade of 1:6000, the total high cost of this drainage scenario is $943,300 for a 7 day drainage period and $623,300 for a 16 day drainage period. The low cost is $544,900 and $426,500 for each respective drainage period (Table 1).

(3) Surface drainage using lift pumps

The surface drain required to completely drain the 3 major basins by gravity in the above option has a much greater flow capacity to what is required due to complying with the minimum MDBC drainage design specifications (MDBC, 1995). Also, the cost of altering existing culverts in public roadways is expensive. A draining strategy to overcome these problems is to construct shallow drains/channels across the saddles so that existing road culvert function is not compromised. This eliminates the costly exercise of replacing or lowering culverts on the public roads. However, a shallow drain would mean a need for lift pumps to drain the basins. This option also has design flexibility, i.e. the size of drains and pumps and consequent costs will depend on the acceptable length of ponding within the depressions. There would need to be some agreement reached by the community on the maximum salinity level or minimum flow into the basin at which pumping would be disallowed in order to minimise salinity impacts downstream. Alternatively, the initial saline flows need to be captured and disposed of to evaporation basins before lift pumping of the remaining drainage water can commence.

The capital cost of pumps and surface drainage to drain the depressions within 1 week is $631,000 for the high cost option and $443,100 for the low cost option. This is reduced to $302,700 and $177,400 respectively if ponding time is increased to 2 months (Table 1). These calculations do not include evaporation from free surface during the draining periods therefore drainage requirements for extended periods of ponding may be lower which would reduce costs.

These costs also do not include the cost of constructing an evaporation basin to dispose the initial flush of saline runoff.

(4) Surface drainage using lift pumps and drainage reuse

This option looks at draining the depressions after a runoff event, firstly by capturing the initial saline flows and disposing of them into evaporation basins which could be built on or near saline areas within the depressions. The remaining runoff, which will have low salinity, can be pumped into MIL supply channels that are within 1.5 km of the basins or into on-farm storages for irrigation. The marginal value of irrigation water was estimated to be $43/ML (Gunaratne et al., 1995). The costs for surface drainage from depressions with disposal and reuse options are given in Table 1.

Table 1 Local drainage and lift pumps for through drainage

Drainage Option	Drainage Response Time (Days)	High Cost	Low cost
Surface drainage of all depressions to cater for a 1 in 5 year storm event	<7	$1,700,000	
Surface drainage for the stagnant water in depressions following a major flood	7	$943,300	$544,900
	16	$623,300	$426,500
Surface drainage using lift pumps	7	$631,000	$443,100
	15	$447,400	$290,000
	30	$378,300	$238,100
	60	$302,700	$177,400
Surface drainage using lift pumps and drainage reuse	7	$247,819	$191,299
	15	$190,909	$138,469
	30	$126,249	$81,009
	60	$95,974	$54,574

2.3.2 Subsurface Drainage Options

As stated previously, all of the surface drainage options need to incorporate some level of subsurface drainage to reduce watertables and salinity levels in the middle of the depressions. Subsurface drainage assists in the leaching of salts from the soil profile and therefore helps improve the long term quality of the runoff.

Groundwater interception ditch

A 2 metre deep groundwater interception ditch could to be placed in the middle of each depression. The ditch would act as a subsurface drainage by intercepting the shallow watertable and creating preferential flow of groundwater into the drain, which will lower the watertable level in the depression. The ditch would also collect low rainfall/runoff events that are likely to become saline with the mixing of groundwater and therefore would require disposal. The yearly volume of groundwater interception has been estimated to be 15 to 25ML per km of drain depending on the groundwater levels in the area. The initial salts captured by the drain are estimated to be 900 tonnes per km. It is anticipated that the 3 major depressions will require a 3.6 km drain in total therefore the annual total volume of groundwater intercepted by the drains that require disposal is around 90ML. The cost of constructing the drain is approximately $14,000 /km.

Subsurface pipe Drainage

Subsurface pipe drainage could also be included with the interception drain so that the watertable can be lowered beneath the depressions. The proposed system would consist of a 100mm diameter pipe at a depth of 2 metres, spaced 60 metres apart discharging into an open ditch. The subsurface pipe drainage would lower the watertable from near the soil surface to the depth of the pipes, which would enable the establishment of saltbush. Once established, the saltbush aids in minimising discharge into the drains by utilising rainfall and therefore minimising recharge. A small pump would be required at the collection point to pump the drainage into an evaporation basin. The area of the 3 major depressions is approximately 72 ha (3.6 km by 200 m wide). If the average depth of the watertable in the depressions is 1 metre and soil porosity is 10%, the initial volume of water intercepted by subsurface pipe drainage is 1 ML/ha. The cost of installing subsurface pipe drainage is $7/metre. This incorporates the cost of a 100mm drainage pipe, gravel and installation. The total cost of subsurface pipe drainage is $84,000 (i.e. 72ha @ $1,170/ha)

Shallow Groundwater Pumping

The installation of shallow bores near the major depressions would intercept the groundwater discharging into Green Gully and lower the watertable. The saline groundwater pumped from the bores would be disposed of into strategically placed evaporation basins within the gully. The lowering of the watertable below saline areas in the gully will aid in the leaching of salts from the soil surface and therefore will increase the quality of the gully's runoff. It will also enable an opportunity to establish salt tolerant perennials which would assist in controlling the watertable by making more effective use of rainfall and therefore minimizing recharge. From groundwater modeling results, 2 pumps at both the middle ("Myall Hill") and northern depression ("Bultarra") seem adequate. The bores would be approximately 15m to 20m deep with 5m of screen, fitted with a submersible pump with a pumping capacity of 0.7ML/day. The total amount of salts which will be captured per shallow bore is estimated to be around 6500 tonnes/year due to the high salinity level of groundwater The area of influence for the bores located near the middle depression is approximately 3 km x 2 km (600 ha) and for the northern depression is 2 km x 2 km (400 ha) over a 10-year period. If the average pumping days per year were 270 days, approximately 760ML per year would need disposal via evaporation basins.

2.3.3 Evaporation Basins

In all of the options, the initial flush of all runoff events must be captured and disposed of in evaporation basins, which are best located within the saline depressions to minimise lateral groundwater flow. Evaporation basin size is based on the annual disposal requirement from three sources of saline water, which are:

- Initial flush of surface runoff;
- Groundwater intercepted by depression drainage ditch;
- Sub-surface pumping.

The evaporation basins would be best located within the saline depressions as this reduces the risk of negative environmental impacts. As the major depression are approximately 200 m to 250 m wide, an evaporation basin built on the side of the depression with banks no higher than the height of the saddles, will have a minimal impact on through flow.

It is assumed that each evaporation basin will require a geotechnical survey to identify any potential negative environmental impacts when constructed. It is also assumed that associated evaporation basin costs of floor formation, floor compaction and interceptor drains are not required due to their location within the depressions.

An evaporation basin between 2.5 ha and 5ha would be required for each major depression to cater for the disposal of the initial saline runoff from a 1 in 5 storm event and intercepted groundwater, with a construction cost of approximately $40,000. The additional disposal capacity required for groundwater interception by subsurface pipe drainage increases the cost by $2,000 to $5,000 for each basin. The inclusion of sub-surface pumping near the two northern depressions requires much larger basins, approximately 35 ha each. These will cost approximately $87,000 each.

As it is assumed that the basins can be located within the non-productive depressions, there is zero land opportunity cost. However, due to the location of the bores and volume of groundwater from subsurface pumping, the evaporation basins may have to be sited outside the depressions. This may lead to increased basin construction costs such as higher investigation costs, floor formation, floor compaction, interceptor drains and land opportunity costs. For comparison, if these additional costs were included, the cost of the 35 ha basin could be as high as $250,000 to $300,000.

2.3.4 Cost Benefit Analysis of Recommended Drainage Option

Cost benefit analysis was carried out to determine if the stream of net benefits generated by the drainage project over time exceeds the initial investment compared to the “do nothing” option. The “do nothing” option has the potential risk of loss of 260ha of established saltbush within the depressions following a flooding event. If a flooding event caused a complete loss of the saltbush, the opportunity cost would be equal to $260,000 (i.e. the cost of re-establishing the saltbush at a cost of $1000/ha). There is also the cost of lost income from established saltbush equivalent to $350/ha (i.e. assuming a carrying capacity of 10 DSE/ha[2] and a gross margin return for first cross ewes of $35/DSE).

There are varying views about the ability of saltbush plantations to cope with extended periods of flooding. Seedlings are vulnerable to waterlogging however established saltbush is more tolerant. Established saltbush can tolerate up to 6 weeks of waterlogging before substantial losses (pers. comm. R. Condon). Saltbush has been known to survive 8 months of flooded conditions as long as a high percentage of leaf area is not covered by water (pers. comm., Martin Driver, March 2002). Experimental studies (Barrett-Lennard, 2002) for river saltbush (*amnicola*) along the Kabul River in Pakistan suggest that after 2 to 3 days of flooding the tall plants (100 cm or higher) had a high survival rate (97%), while the shortest plants (60 cm or less) had a poor survival rate (36%). Therefore local inundation trials of saltbush for long periods of time are required to understand saltbush vulnerability to prolonged flooding.

The benefits and costs of the providing GG drainage are summarised below:

(a) Benefits of drainage
- Decreased net recharge in depressions;
- Provides the opportunity to plant saltbush further into the depressions even though water ponding in highly salinised areas has zero opportunity cost in terms of agricultural output;
- Protection of established saltbush from waterlogging losses;
- Good quality runoff can be captured and used for irrigation;
- Reduced soil salinity in areas influenced by sub-surface pumping which may increase crop yield.

(b) Drainage costs
- Drainage establishment costs
- Possible increased saline flows downstream
- Where runoff is pumped back into supply, possible lower quality irrigation supply

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[2] pers. comm. Richard Condon, Yowie Bay plus various other unpublished sources

The option to drain the depressions and to dispose of saline water into evaporation basins and where possible, to pump the good quality runoff into an existing supply channel for irrigation use appears to be the most viable option due to its lower capital cost and the added benefit of water reuse. Three scenarios were developed to determine whether this option is viable over a 30 year time frame. Due to time and resource restrictions, assumptions were made on the frequency and volume of runoff events into the depressions based on landholder observations over the past 30 years. Another possible approach would have been to use probability functions for the frequency and volume of runoff events by modeling catchment runoff using historical weather data and validate the estimated runoff by using data from gauging stations.

The three runoff scenarios are:

1. High – average runoff into GG is 367 ML/year
   - 1000 ML every 5 years
   - 500 ML every 2 years

2. Medium – average runoff into GG is 200 ML/year
   - 1000 ML every 10 years
   - 500 ML every 3.3 years

3. Low – average runoff into GG is 153 ML/year
   - 1000 ML every 15 years
   - 500 ML every 5 years
   - 100 ML every 3 years

Assumptions

Other assumptions included in the cost-benefit calculations are:

- Channel and culvert installation costs based on “high” values;
- The percentage of runoff to be captured for disposal is 5% for the first 5 years, 4% for the following 5 years and 2.5% thereafter;
- Subsurface pipe drainage and the interception ditch is the only subsurface drainage ;
- Evaporation basins are built within the gully;
- the marginal value of irrigation water is $43/ML;
- the capital cost of saltbush replacement is $1000/ha and production loss is $350/ha;
- the salvage value is 50% of capital cost;
- the discount rate is 7%;

The results for the three runoff scenarios are summarised in Table 3. Columns 2 to 4 show the NPV, BCR and IRR for the project for the situation where an area of saltbush (0ha, 65ha, 130ha, 195ha and a maximum of 260ha) has the potential to be lost in a flooding event occurring in year 10. Column 5 and 6 show the sensitivity of the IRR (in column 4) to a 20% increase in the capital cost and a 20% decrease in the value of benefits over the 30 year time frame. The break even year in column 7 is the maximum number of years in which the area of saltbush must be lost if the project is to break even (i.e. when NPV = 0).

The results show that if there is a zero loss in saltbush area in the next 30 years i.e. if the saltbush is tolerant to flooding events, the project is not viable (high negative NPV, low BCR and IRR). This means that the marginal benefit of runoff used for irrigation is not large enough to offset the project costs. In this case, the threshold value based on Cadell’s 420 farm holdings is a NPV between $520 and $707. I

If there is a zero loss of saltbush area and if the marginal value of irrigation water is $43/ML, then on average, 1000 ML/year of reuse (ie the total capacity of the three major depressions) is required for the project to break even. Alternatively, the marginal value of irrigation would have to increase to $96/ML for scenario 1, $174/ML for scenario 2 and $238/ML for scenario 3 for the project to break even.

The number of years for which a loss of saltbush has to occur decreases as the average annual runoff into the depressions decreases. With the high average runoff scenario of 367ML/year, 65 ha of saltbush would have to be lost within 5 years, or up to 260 ha lost within 20 years for the project to be viable and with the low average runoff scenario, saltbush losses have to occur within 1 and 17 years respectively.

Table 3 Cost Benefit Scenario Results

Scenario 1 average runoff = 367 ML/year

Saltbush Loss Area (ha)	Saltbush Loss in Year 10			IRR Sensitivity		Break Even Year
	NPV	BCR	IRR	20% increase in capital cost	20% decrease in benefit value	
0	-$218,000	0.5	1.2%	-	-	-
65	-$65,000	0.9	5.6%	4.1%	3.7%	5
130	$88,000	1.2	8.6%	7.0%	6.7%	13
195	$242,000	1.6	11.0%	9.3%	8.9%	17
260	$395,000	1.9	12.9%	11.1%	10.7%	20

Scenario 2 average runoff = 200 ML/year

Saltbush Loss Area (ha)	Saltbush Loss in Year 10			IRR Sensitivity		Break Even Year
	NPV	BCR	IRR	20% increase in capital cost	20% decrease in benefit value	
0	-$279,000	0.3	-	-	-	-
65	-$126,000	0.7	4.3%	3.0%	2.7%	2
130	$28,000	1.1	7.5%	6.1%	5.8%	11
195	$181,000	1.4	10.0%	8.5%	8.1%	15
260	$334,000	1.8	11.9%	10.4%	10.0%	18

Scenario 3 average runoff = 153 ML/year

Saltbush Loss Area (ha)	Saltbush Loss in Year 10			IRR Sensitivity		Break Even Year
	NPV	BCR	IRR	20% increase in capital cost	20% decrease in benefit value	
0	-$297,000	0.24	-	-	-	-
65	-$144,000	0.64	3.9%	2.7%	2.4%	1
130	$9,000	1	7.2%	5.8%	5.5%	10
195	$162,000	1.41	9.6%	8.2%	7.9%	14
260	$316,000	1.79	11.6%	10.1%	9.8%	17

The results illustrate that the viability of this drainage option is quite sensitive to the area and timing of the potential loss of saltbush within the depressions. Without scientific knowledge on the susceptibility of saltbush to flooding, a subjective assessment by the Green Gully landholders would have was made to determine if this option is economically feasible. The project is not viable without the potential risk of loss of at least 25% of the established saltbush located within the gully in the next 5 years unless the marginal value of irrigation water exceeds $100/ML. This option assumes pumping of good quality runoff into existing MIL supply channels, however this may not be acceptable by MIL therefore the alternative would be on-farm storages. This would increase the capital cost of this option and therefore an increase in the marginal value of irrigation water or an increase in the potential loss of saltbush area would be required for the project to break even.

2.3.5 Cost Benefit Analysis of Subsurface Pumping

The cost benefit analysis of the recommended drainage option incorporated subsurface pipe drainage as the subsurface drainage option. Alternatively, the subsurface pipe drainage could be replaced by shallow pumping, which will lower watertables in the gully and surrounding region. It was estimated that two bores located on both the middle and northern depression would pump approximately 760ML and would protect an area of approximately 1000ha. Annual salt disposal would be equivalent to 19,500 tonnes (assuming salinity of groundwater is 40 dS/m, there is approximately 25.6 tonnes of salt per megalitre).

For this option to be viable, the marginal agricultural productivity benefit of protecting crops from yield decline due to salinity must outweigh the initial capital investment and ongoing operating expenses. The total gross margin for the area protected by the bores without salinity losses is approximately $382,000 or $382/ha. This is based on the regions crop mix derived from a landholder survey and average crop gross margins. For the low cost scenario of placing evaporation basins within the gully, the marginal benefit of pumping would have to exceed $40,000 per year (i.e. 10.5% of the protected area’s total gross margin) for the project to be viable. This means that the annual salinity losses in the zone protected by sub-surface pumping must be greater than 10.5% of the average total gross margin for that area. If the evaporation basins have to be located outside the gully, their total cost could rise from $160,000 to $500,000. The increase in the capital cost of evaporation basins increases the annual marginal benefit that needs to be obtained for sub-surface pumping to become viable to $64,000 (or 16.8% of the protected area’s total gross margin). Alternatively, the marginal benefit of pumping required is equivalent to an annual threshold value of $95 and $152 for each Cadell landholder.

This analysis has not valued the benefit of salinity credits i.e. the benefit of intercepting groundwater that otherwise would enter the Murray River. The groundwater flow paths derived from piezometric data (Khan *et al*., 2003) show groundwater flows from the Green Gully region towards the Murray River. The value of salinity credits for this section of river estimated by MDBC is $46/tonne of salt (pers comm., Oscar Mamalai, MDBC, December 2002). The value of this benefit could substantially reduce the required cropping marginal benefit for subsurface drainage to become viable. The threshold volume of groundwater to be intercepted from entering the Murray River to completely offset the cost of subsurface pumping is between 34 ML/year and 54 ML/year (4.5% and 7.1% of total volume pumped), depending on the capital cost of the evaporation basins. This aspect of the work needs to be further investigated to confirm wider environmental benefits of providing subsurface drainage to the Green Gully Area.

An alternative to the construction of evaporation basins for the disposal of groundwater is to use GG as a discharge basin for the entire Cadell area. Currently approximately only 70 ha of land are highly salinised. The remainder of the gully is mainly covered with saltbush and pasture. The most viable option could be to use the highly salinised depressions as evaporations basins for local subsurface pumping and the GG farmers seek stewardship payments from the Cadell LWMP equivalent to the saved opportunity cost of lost productivity from salinity in the area serviced by the pumps. Stewardship payments could also come from revenue obtained from salinity credits. The stewardship payments then could be used to offset further tree and saltbush planting surrounding the depressions to minimise recharge and to intercept groundwater. However, this option does not eliminate the potential risk of the loss of 260 ha of saltbush established within the depressions from a flood event.

3 Conclusions

Green Gully is an example where environmental degradation has occurred as an offsite impact due to irrigated and dryland agriculture from farms within the region. The landholders along the gully have made significant investments in a salinity mitigation program of saltbush and tree plantings to minimise recharge and lower the watertable. Due to the severity of the problem, the depressions require a more innovative drainage solution for its reclamation. Various drainage and disposal options have been identified with associated threshold values estimated. For the preferred drainage option and a marginal value of irrigation water less than \$100/ML, the tangible benefits do not exceed the costs unless 25% of saltbush plantings within the depressions is lost due to a flooding event within the next 5 years. Subsurface pumping in conjunction with surface drainage has wider regional benefits and depending on the level of salinity credits, could have a significant impact on the threshold value for environmental benefits.

The gully has a high biodiversity and aesthetic value to the community as well as an agricultural value. Therefore, the level of investment in salinity and waterlogging mitigation works in excess of tangible benefits to protect or reclaim degraded depressions becomes a social choice between the community’s willingness to pay for the potential environmental benefits of the mitigation works and the level of degradation the community is willing to accept to live with.

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