Lake Bryde Recovery Catchment

Surface Water Assessment and Recommendations

Prepared for the Department of Conservation and Land Management

Photo: Courtesy of G. Garlick

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Engineering Water Management Group

ment of Agriculture Western Australia

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Western Australia

DEPARTMENT OF Conservation AND LAND MANAGEMENT
Conserving the nature of WA

PREFACE AND ACKNOWLEDGMENTS

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Executive Summary

The objective of surface water management planning is to minimise the impact of excess water as discharge or recharge, within the landscape. The planning process must consider localised and whole of catchment issues aimed at controlling the net volume of runoff and recharge generated by rainfall events, and to reduce the impact of prolonged inundation or ponding while promoting the development of water resources within the catchment.

Management planning includes consideration of off site impacts and provision for discharge continuity between adjacent landscapes and property boundaries. Integration of engineering options including water harvesting techniques, and improved water course management with non engineering management options such as modified tillage practices. Incorporating deep rooted perennial crops and re-vegetation strategies will contribute towards achieving the greatest benefit from surface water management planning.

The Lake Bryde Recovery Catchment project area encompasses the upper Lake Bryde catchment, from its origins in the East Lake Bryde and South Lake Bryde sub-catchments, including part of the Lake Magenta Nature Reserve, and the Lakeland Nature Reserve valley floor. The recovery catchment comprises a central valley system of which two distinct hydrological landscapes have been identified, with the majority of salt affected land being associated with the grey clay units located in the valley floors.

Field investigations and topographic landscape modelling have found that significant runoff is contributed to the lower valley systems by upper slopes with a gradient of greater than 3%. The broad valleys are subjected to large-scale shallow inundation that is not drained by a defined channel system. Ponding across the broad valley floors is caused by the number of flow impedance structures, such as raised road formations within the valley, that significantly affect flow continuity.

Development of secondary salinity is thought to have occurred from a combination of upslope recharge and localised inundation resulting in water-table recharge in the valley floors during rainfall events. The frequency and duration of inundation in the Lake Bryde catchment is considered to be greater than the natural or pre-clearing levels normally experienced in these landscapes. The lower level of secondary salinity within the hydro-aeolian system suggests greater infiltration, storage and dispersing capability.

The primary issue for the Lake Bryde Wetland System is the increase in flow volumes that are generated from areas under agricultural production. Anecdotal data implies that the critical wetting and storage threshold for the upper slopes of the Lake Bryde catchment, and for the

Lake Magenta Nature Reserve, both naturally vegetated areas, exceeds the storage co-efficient typically found on small agricultural catchments (Coles 1993; Hauck and Coles 1991).

The major changes in runoff since clearing and the increased likelihood of multiple runoff events within a year, substantially increases the potential for inundation which promotes recharge, salt mobilisation and salt accumulation within the Lake Bryde catchment. Based on available evidence it is unlikely the majority of the existing degradation can be attributed to 'valley scale' groundwater rise suggesting that remediation implemented at a local scale will provide some short term but immediate direct benefits. However valley scale groundwater trends have been predicted to rise for the next 10 to 20 years (SKM, 2000). Therefore the net long-term benefit of remediation works will be dependent upon combining localised protection, with run-off and recharge management implemented at landscape scale.

There is little available data on specific sites that are directly associated with water table rise however when critical recharge or sub-surface interaction areas have been identified local management options will be developed. Surface water influxes in the North Eastern boundaries of the Lake Bryde Nature Reserve have also resulted in root zone waterlogging and the development of an underlying perched system of fresh to brackish water. The preliminary stages of the project are aimed at minimising the extent of waterlogging and inundation and maximise the benefit of recharge management activities.

Between periods of flushing Lake Bryde becomes a salt sink, where salt mass is more important than inflow volumes. As part of the management strategy, it is recommended that smaller flows be diverted away from the inlet area while larger run-off events are allowed to enter the lake system enabling flushing of the system. Degradation in the outer lakes can be managed through the adoption of surface water management structures in the upslope areas to manage inflows to the system. Upstream degradation and increased rising groundwater tables in the valley are likely to have an impact on the Lakeland chain.

Given the absence of potable groundwater supplies and an increasing reliance on surface water in the Lake Bryde Wetland System the development of on-farm water supplies by the adoption of water harvesting strategies should be emphasised. Demonstration to landholders of the benefits of implementing upland management options may facilitate their adoption into the farm business as 'best management practice'.

One of the most critical sites in the catchment is the Lake Bryde Road area between the Newdegate-Pingrup Road and the Lake Bryde inlet culvert, where salinity accumulation and inundation are severe. The most effective management option is to relocate the Lake Bryde Road away from the main drainage line enabling the natural watercourse to be re-established and rehabilitated. Further extension of the watercourse beyond the Lake Bryde inlet will reduce ponding adjacent to Lake Bryde Road and provide the means to divert water away from the Lake inlet area if required.

Similarly, the problems associated with inundation that occurs near Ryans Road during large events, where the road may be flooded for several days, requires an effective management strategy. A broad shallow waterway extending to Lake Bryde will allow excess water to be conveyed through the flats above Ryans Road. Inclusion of an appropriately designed floodway at Ryans Road will allow the water to flow through the road reserve while also addressing the traffic issues associated with regular flooding. Rehabilitation will assist stabilisation of the confluence areas. The works associated with South Lake Bryde and Ryans Road cannot be undertaken until the proposed waterway for the Lake Bryde Road valley has been established as a safe receiving point.

The surface water management plans developed for the Lake Bryde catchment include a combination of integrated options including surface water harvesting to reduce the impact and degradation associated with inflows from agricultural slopes. Constructed waterways will also assist in promoting flow continuity. The plan addresses issues associated with water volumes, velocity and depth, erosion potential, sediment transportation, and includes the use of vegetation as a riparian buffer to control inflows and minmise the impacts related to floods.

Water harvesting is promoted for properties in the upper catchment in order to control water delivery and reduce the discharge volume of run-off events. In addition, further drilling, geophysics and model analysis of the South Lake Bryde flats area is recommended to establish the presence and role of salt sources, recharge areas and geological features that appear to be influencing the hydrology.

However, it is expected that surface water management options in the Lake Bryde catchment have the greater potential to impact on salinity in the short to medium term because groundwater systems are not yet fully interactive or coupled with the perched surficial systems. The medium to long-term requirement is that excess run-off generation in the upper slopes is reduced as much as practicable, without a corresponding increase in recharge. This is best achieved by working with small stakeholder groups to achieve localised outcomes, with net catchment benefits through the effective integration of engineering options with re-vegetation systems and run-off/recharge reduction farming practices.

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1. Introduction

1.1 Overview

The Department of Conservation and Land Management (Katanning, WA) manage the Lake Bryde Recovery Catchment project. The objective of the project is to conserve and protect the range of species and functioning ecosystems found within the Lake Bryde Wetland System. The recovery project is implementing a range of actions, both biological and engineering, to ameliorate the processes causing degradation to the wetland system.

The Engineering Water Management (EWM) group at the Department of Agriculture Western Australia has completed a surface water management study for the Lake Bryde recovery catchment. The aim of this work was to:

- conduct a preliminary assessment of soil hydrological properties, and in conjunction with the DEM and climatic data, provide an assessment of surface water movement, surface water impedance and recommendations for surface water management;
- develop a macro-scale, whole of catchment surface water management strategy;
- develop engineering design options to improve water flow at valley floor impedance points and to develop options for diversion of saline enriched surface water flows into essential waterbodies; and
- to develop a strategy for managing recharge and discharge sites for the recovery catchment.

This report addresses issues previously recognised by J. Davies & Associates (1996) Sinclair Knight Mertz (2000), Kevron (2000), Department of Agriculture (Giraudo, 1995;1996; Giraudo *et al.*1996; Farmer 2001a and b) and subsequent issues identified during this study.

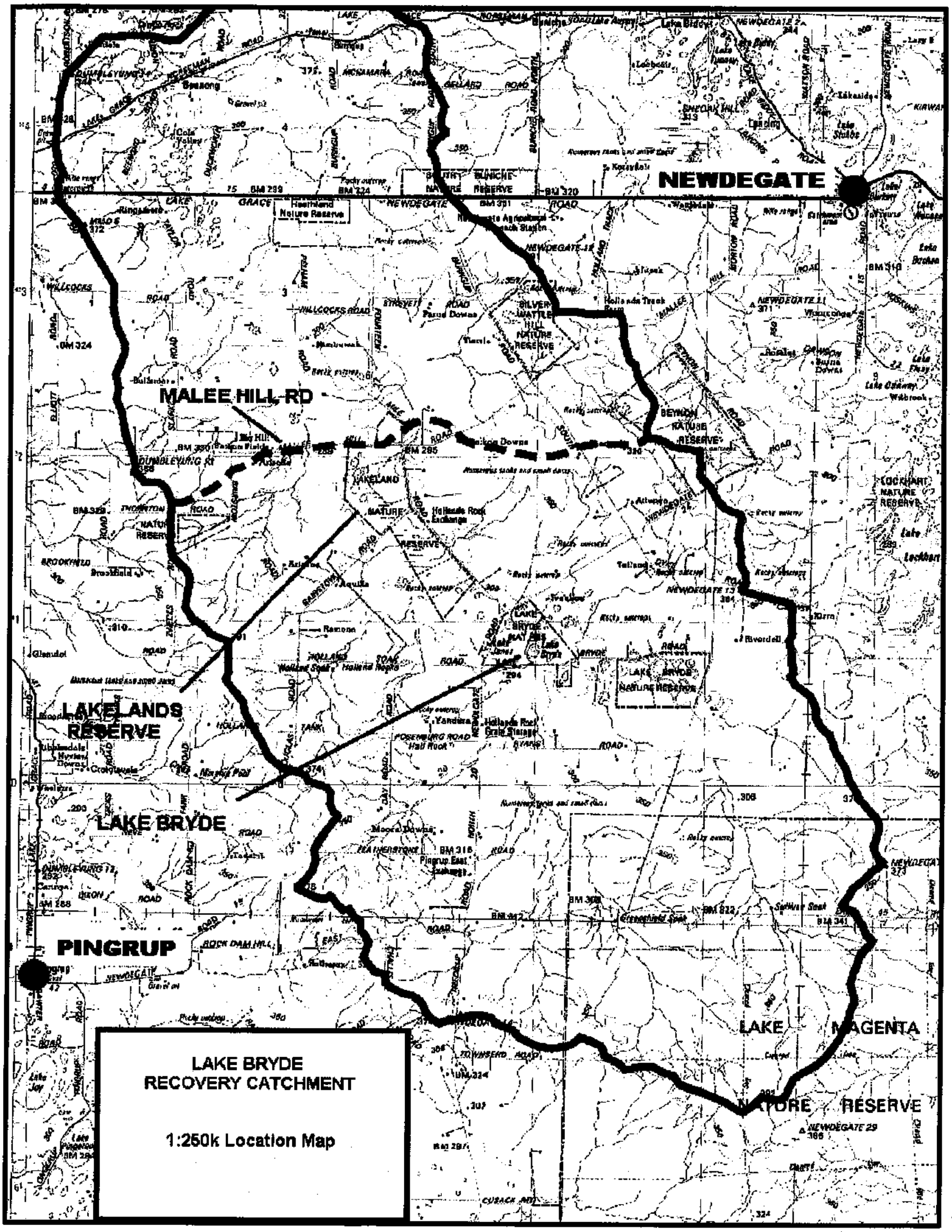


Figure 1: Location map

This Map has been superimposed upon the Newdegate 1:250,000 Topographic Map Sheet showing the Bryde Catchment and the Lake Bryde, Lakeland and Lake Magenta Nature Reserves that provide the biodiversity focus for the Lake Bryde Recovery Catchment

1.2 Extent of study area

The project area extends over the valley floor and contributing sub-catchments of the Lake Bryde Catchment south of Mallee Hill Rd. The area encompasses the upper Lake Bryde catchment, from its origins in the East Lake Bryde and South Lake Bryde sub-catchments, and includes part of the Lake Magenta Nature Reserve (in the south east), and the Lakeland Nature Reserve valley floor and its contributory sub-catchments (Figure 1). Within this area the Lake Bryde valley system, drainage sub-catchments and catchment divide are well defined by the local topography that ranges from 290m to 392m ASL. The lower catchment north of Mallee Hill Road merges into saline valley flats that extend18 km to the Lake Grace-Newdegate Rd. The lower catchment saline valley systems to the north are not addressed in this report.

2. Surface hydrology assessment of the Lake Bryde system

2.1 Generalised hydrodynamics of the Lake Bryde Catchment

The Lake Bryde catchment comprises a broad, well-defined, central valley system into which a series of lateral upslope sub-catchments drain. The valley floors typically exhibit continuous grades of less than 1%, while upper slopes exhibit grades of between 3 and 5% (Figure 2). A Comparative analysis of slope distribution, hydrology and topography has identified two distinctive hydrological landscapes:

- a *receiving* landscape generally dominated by broad flat valleys and the lower valley slopes of contributing sub-catchments where flow gradients decrease and run-off is accumulated; and
- a *shedding* landscape that is comprised of the upper sub-catchment slopes, or interfluve, and the main ridgelines where the majority of run-off is generated.

Intersection of DEM derivatives with soil and landscape mapping units (LMU's) suggest a strong correlation in their geomorphologic development. This correlation has been the basis of detailed landscape mapping for the Lake Bryde Project which was conducted by the Natural Resources Assessment Group, Department of Agriculture Western Australia (Griffen *et al.*, 2002).

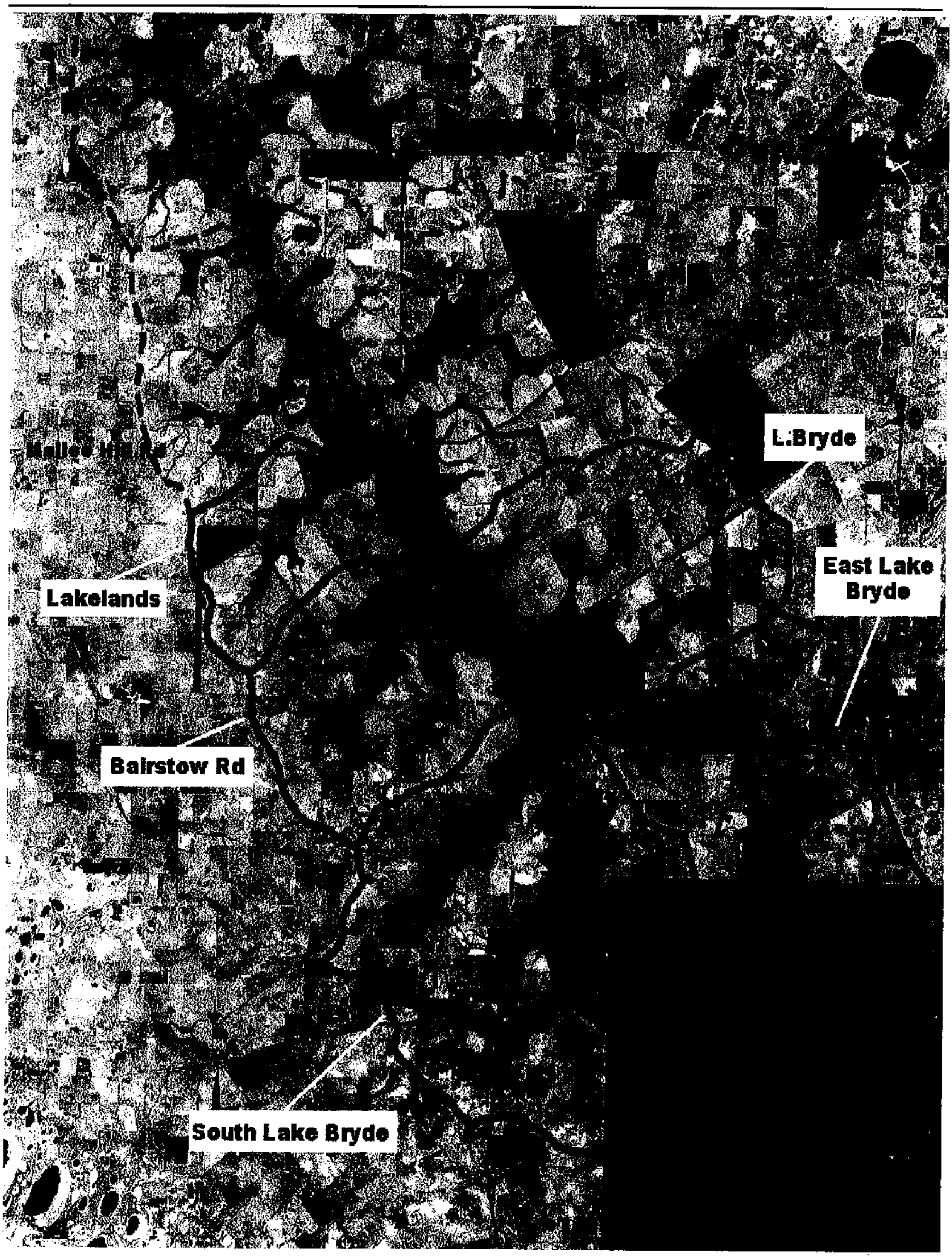


Figure 2: Surface hydrology map of Lake Bryde catchment

Showing major sub-catchments, stream channel network and areas subject to inundation (hatched). Receiving landscapes are shaded blue, shedding landscapes comprise the unshaded portion of each sub-catchment.

2.1.1 Shedding landscape

The shedding landscape are dominated by an etched landscape consisting of duplex soils, gravelly sands and laterite ridges (interfluve). Large sections of these landscape units have slopes greater than 3%. These landscapes contribute significant volumes of run-off to the lower valley systems. Direct run-off volumes entering the lateral valley systems during larger storm events are sufficient to cause inundation at depths of at least 0.5 metres over cross-sections of several hundred metres.

The tendency to shed water is driven by two processes. Firstly, by the presence of shallow duplex and gravel soils in the upper and middle slopes that has low storage capacities and slopes greater than 2%. Secondly, a limited detention capacity (natural or otherwise) in the upper slopes. This combination of features promotes large run-off volumes onto the valley floors.

2.1.2 Receiving landscape

The receiving landscape is readily delineated by the widespread occurrence of slopes of less than 2% that aggregate to form a broad continuous valley system. This zone is predominantly duplex soils in the tributary valleys that merge into a broad valley floor comprised of either deep grey clays or deep sands, often > 0.5m, over sandy clays and clays at depth. Field investigations have identified that the majority of salt affected land is associated with the grey clay units located in the valley floors.

The deep sand landscape unit has been described as a hydro-aeolian surface (Griffen *et al.*, 2002), implying that the landscape has evolved as a consequence of fluvial and aeolian erosion and depositional processes. This land unit is of significance to the biodiversity of the Lake Bryde Wetland system as it contains the majority of the freshwater lakes and swamps, and has a high diversity of vascular plant species. The valley vegetation systems are no longer extensive.

Prolonged inundation is considered to be the dominant hydrological process driving degradation of the flat valley landscapes. Increased run-off generation following clearing has resulted in an increase in the frequency of inundation. Raised road formations within the valley have been identified as a major cause of flow impedance increasing the likelihood of ponding and the flows extending across the broad valley flats (Farmer 2001, Sinclair Knight Mertz 2000 and Kevron 2000). Ponded or slow moving flows within the valleys result in local infiltration and evaporation processes that promote long term secondary salinity through deposition and concentration and/or direct recharge of local water tables. Based on field observations it is considered that the frequency and duration of inundation in the Lake Bryde catchment is considered to be greater than that for which the natural or pre-clearing drainage and hydrodynamics have evolved (Farmer 2001).

The loss of flow continuity, when combined with low gradients of the valley sections and the poorly defined and sedimented channel morphology, has promoted the lateral spreading of floodwaters across broad riparian sections, from 70 to 300m in width, during medium to large flow events. Due to resistance from the riparian vegetation and shallow flow depths there is a loss of momentum during flooding which discourages return flows from the adjacent banks and renders recession flows susceptible to frictional losses and impedance. This causes large scale shallow inundation that is not subsequently drained by a defined channel system.

The Figures displayed in Section 3 illustrate the nature and extent of valley inundation during major flows. The primary consequences of extensive lateral inundation are prolonged waterlogging, which promotes recharge and secondary surface salinisation following evaporation. This outcome is undesirable for both agricultural and natural ecosystems.

2.2 Existing saline sites and degradation areas

Salinity and saline lakes are not an unnatural occurrence in the Upper Lake Bryde Wetland system. There are at least three substantial, naturally occurring salt lakes that occur adjacent to the freshwater lakes. These have high quality, well-developed salt crusts with vegetation systems that are salt tolerant and adapted to these conditions. The most notable of these occurs in the granite and clay belt immediately south of Lake Bryde.

Areas within the Lake Bryde valley showing physical evidence of saline degradation, (labeled S in Figure 3), are actually being impacted by secondary salinisation following deposition and localised accumulation via evaporation.

Sites of note include:

(1) The South Lake Bryde sub-catchment at Ryans Road (S1);

(2) The southern edge of the Lake Bryde Road Reserve boundary near the Pingrup-Newdegate Road (S2);

(3) The Lake Bryde Valley west of the Pingrup-Newdegate Road (S2);

(4) The Fourteen Mile Road area (S6); and,

(5) The southwestern boundary of the Lakeland Nature Reserve (S4, S3).

Sinclair Knight Mertz (2000) attribute much of the observed degradation in the Upper Lake Bryde catchment to 'enriched surface water drainage'. When compared to soil mapping data there is a strong correlation between the presence of grey clay flats and salinisation. This may reflect problems associated with inundation and waterlogging in these areas combined with low infiltration rates of the clay soils and the high evaporation rates experienced in the Lake Bryde area. Presumably the limited development of secondary salinity within the hydro-aeolian system reflects a greater infiltration, storage and dispersing capability.

Inflow and recharge impacts are evident along the North Eastern boundaries of the Lake Bryde Nature Reserve (areas W1 and W2, Figure 3). Local conditions suggest that these are being impacted by influxes of surface run-off that cause root zone waterlogging as a result of a local underlying perched systems of fresh to brackish water, rather than valley salinisation.

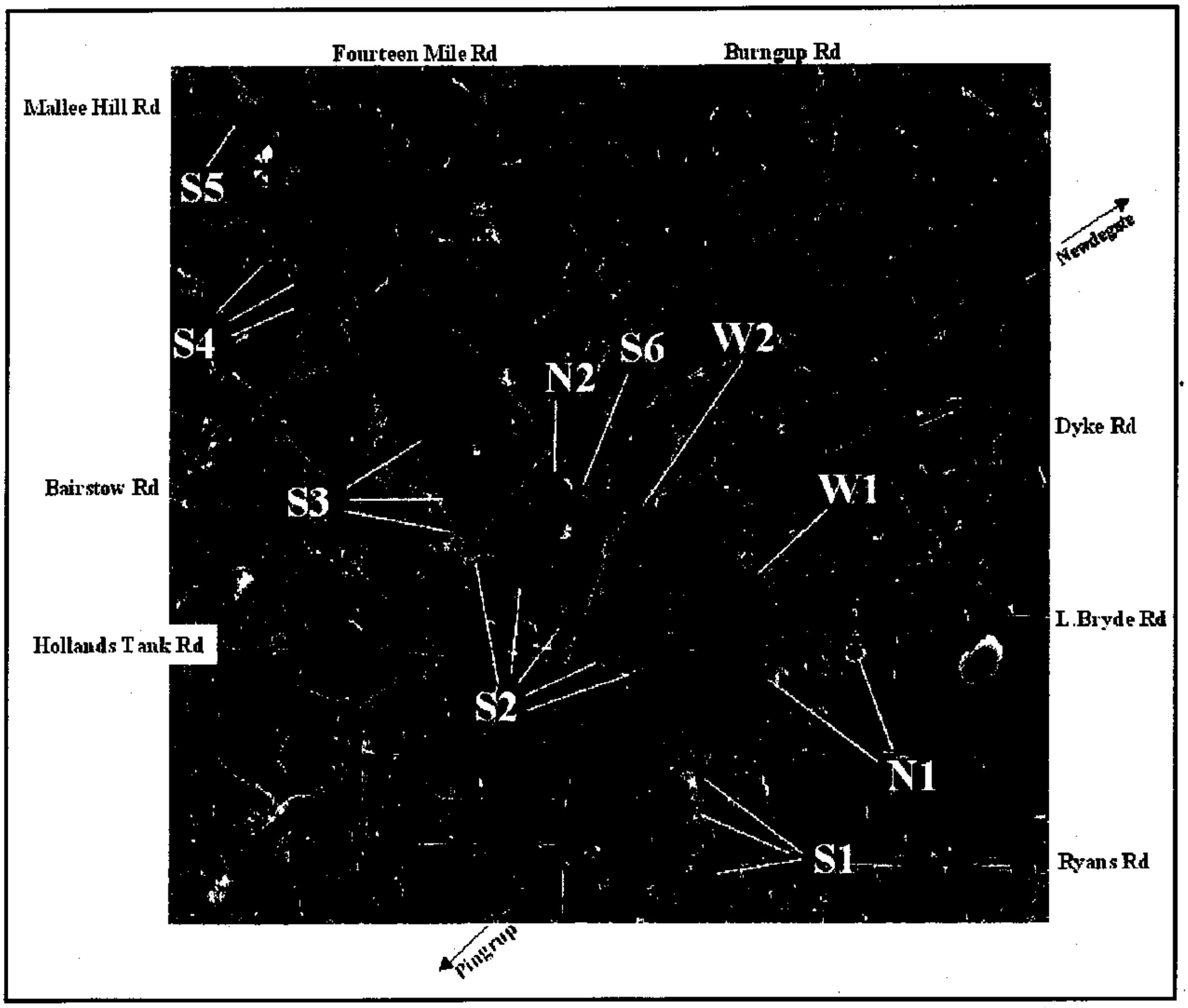


Figure 3: Aerial photo map (Feb2000)

Showing location of salt degradation (S), natural salt lakes (N) and areas adjacent to Lake Bryde Reserve where root zone waterlogging is deemed to be active (W). Residual inundation is visible (dark braided areas) within the Lakeland and Lake Bryde Rd valley systems.

2.3 Impact of modified run-off regimes

Rainfall events in January 2000 resulted in large-scale inundation of the lake systems in the Lochart and Yilgarn drainage systems of the Avon basin. Aerial photography acquired by the Department of Land Administration (DOLA, 2000) some twenty-three days after the main run-off event clearly shows inundated areas in the Lake Bryde Wetland System. The photography has been utilised during the study as a reference for confirming inundation and flow behaviour, and for comparison with observed areas of degradation.

Additional event information has been derived from miscellaneous photography acquired by the Department of Conservation and Land Management and various landowners during large-scale run-off events, and from a field inspection during the run-off event of 15 August 2001. Analysis of specific valley inundation impacts is documented in Section 3.

The primary issue for the Lake Bryde Wetland System is the increase in flow volumes that are generated from areas under agricultural production. Without specific run-off data at the scales of interest (10^1–10^2 km^2) the run-off increase is difficult to quantify. However, the events of January 2000 and August 2001 provide some opportunity to postulate. In natural systems shallow vegetated channels tended to promote inundation as a mechanism to derive the greatest benefit from irregular run-off events. Since clearing, run-off frequencies have increased to the extent that inundation levels are now excessive and degradation is occurring in areas associated with impediments and run-off entrapment or long term detention. Recent roadwork and associated ripping immediately up-slope of a Yate swamp within the reserve (W2, Figure 3), enabled substantial volumes of roadside run-off to infiltrate within 24 hours during a 40mm rainfall event that occurred in August 2001

In January 2000, the catchment generated substantial run-off from 75mm of rainfall received over a 36-hour period. Rainfall totalling 26-30mm fell in the week prior to the main storm. This system was part of a northern residual cyclonic depression of sub-tropical origin. During this event substantial flows occurred in watercourses originating in the Lake Magenta Nature Reserve.

The rainfall event of August 2001 was derived from a series of frontal systems formulated as temperate lows generated in the southern ocean and broke a prolonged dry period. The significance of the August event was that no watercourse flowed prior to 14 August 2001, and then only select sub-catchments generated run-off after a 24 hour period in which 35-40mm of rainfall was received at relatively low intensities. No run-off was generated within the Lake Magenta Nature Reserve. Run-off originating from the shedding landscapes generated sufficient flows to cause minor inflow to Lake Bryde and ponding within some valley sections.

The volume was insufficient to generate valley scale flows and the Pingrup-Newdegate Road and Bairstow Road culverts remained dry.

This data implies that there is a critical wetting and storage threshold of around 40-50 mm for the upper slopes of the Lake Bryde catchment, and approximately 70-80mm for the Lake Magenta Nature Reserve, both naturally vegetated areas. Coles (1993) and Hauck and Coles (1991) found that the storage co-efficient on small agricultural catchments typically ranges between 25-40 mm and that critical rainfall events for agricultural catchments are around 20-50 mm (condition, intensity and wetness dependent).

Table 1: Rainfall data for run-off generating rainfall events in Jan 2000 and Aug 2001

t (days)	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*total*
Jan 2000	3	0	0	0	20	3	3	0	0	0	0	57	18	8	2	0	0	0	0	0	17	12	***143mm***
Aug 2001	1	2	44	0	0	0	4	0	3	2	5	0	6	6	0	1	8	27	3	0	0	0	***112mm***

(data courtesy of A. Parks, I. Kent)

A comparative analysis of 20 day cumulative rainfall events over 25mm indicates that the event of January 2000 was only one of six summer events in the last 75 years to have exceeded 100mm (Figure 4). Only three winter events have exceeded this threshold. The frequency of events above 40mm is substantially greater than for those above 80mm. Lower run-off thresholds after clearing has meant that there is the increased likelihood that multiple run-off events will occur within each year. The outcome is more frequent inundation in susceptible areas and therefore increased opportunity for recharge, salt mobilisation and salt accumulation. From a water management perspective it is evident that run-off derived from rainfall events in the 20-80 mm range (i.e. above the natural frequency) should be the focus of engineering design evaluation.

An analysis of local rainfall data (observations 1980-2000) shows substantial rainfall over the Dec-Feb summer period for 10 years out of the 20-year period. Inflow data for Lake Bryde after summer storms is limited with most recordings being taken in September and November. However the available lake-level data suggests inflows have most likely occurred in 1982, 1990, 1997 and 2000.

Accounting for the potential evaporation losses (approximately 7-8 mm/day) prior to sampling, the residual volumes in Lake Bryde suggest that run-off generation is occurring within some of the contributing sub-catchments for rainfall events below 80mm. Analysis of winter rainfall data and Lake Bryde depths indicate that where average or above average monthly totals are being achieved, above threshold storms are likely to generate run-off.

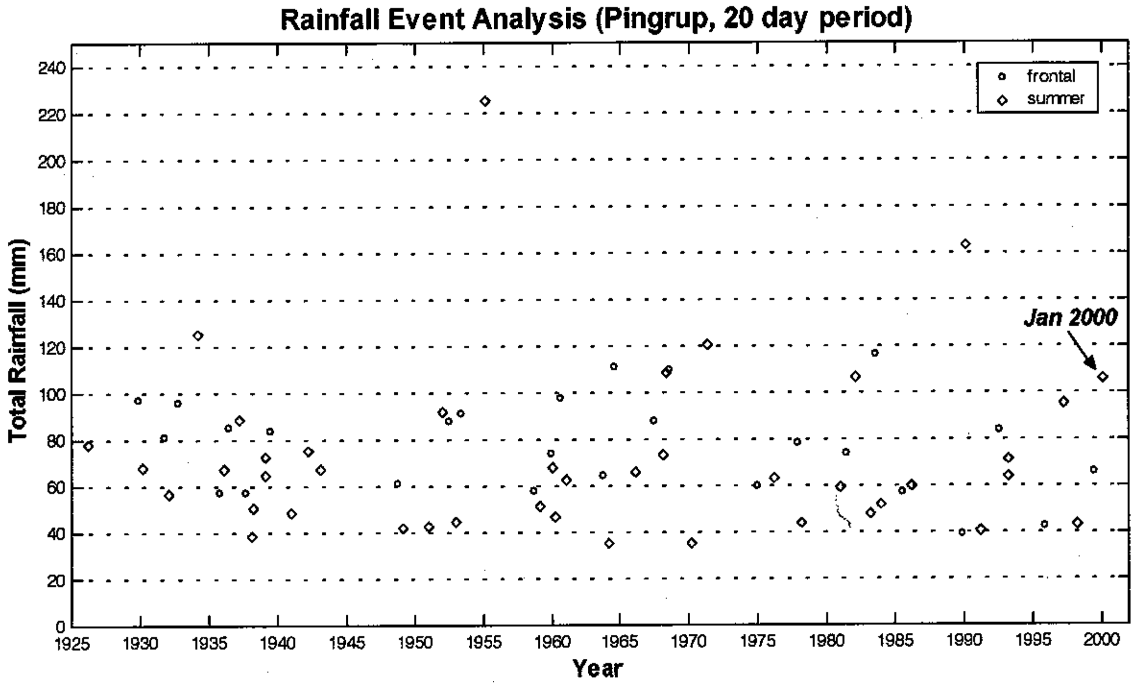


Figure 4: Historical storm 25mm event extraction for Pingrup

Showing occurrence of rainfall events greater than /day within 20 day cumulative rainfall periods that exceeded 30mm.[1]

2.4 Management implications

The demonstrated increased capacity to generate run-off under the agricultural landscapes has resulted in increases in both the recharge opportunity and the frequency, duration and extent of inundation within the Lake Bryde catchment. Available aerial photography and imagery showing flow behaviour suggest that the zone of greatest impact is the receiving landscapes. This is confirmed by observations that water is discharging from the upland and interfluve landscapes in substantial volumes.

[1] Pingrup ~30km from Lake Bryde, appears to receive falls slightly lower than those in South Lake Bryde based on data provided in landowners.

The mechanistic processes dominating many problem sites have developed as a result of changes to localised landscape-scale behaviour driving changes in run-off generating regimes. Anecdotal evidence suggests that it is unlikely the current degradation can be attributed to 'valley scale' groundwater rise. Therefore, it is suggested that remediation implemented at a local scale will provide some immediate direct benefit in the short term. However valley scale groundwater trends have been predicted to rise for the next 10 to 20 years (SKM, 2000) based on rudimentary data sets. Ultimately, the net long-term benefit of remediation works will be dependent upon combining localised protection, with run-off and recharge management implemented at landscape scales.

2.5 Lake Bryde landscape classification and assessment

In the Lake Bryde Catchment the classification of landscape units into shedding and receiving zones is substantiated by the strong correlation between slope boundaries, the boundaries of soil/landscape mapping units and the observed flow characteristics (run-off and flow inhibition). Slope classification data is represented in Figure 2.

The intersection of these data sets has resulted in the identification of four key surface hydrology units in the Lake Bryde catchment (Figure 5). Within each classification the hydrological characteristics are considered to be similar (Griffen *et al.*, 2002) and establish an initial estimation of landscape scale units. The units can be used for risk appraisal and management planning. The boundaries have been intersected with specific road boundaries for ease of categorising landholdings into like groups and to reflect the role played by roads in discriminating flow behaviour at otherwise undefined or marginal unit boundaries. Each broad landscape classification is discussed in the subsequent sections.

The primary units are valley floors (V), valley flats (F), upper valley flats (UF), shedding (S) and upper catchment shedding (US) and natural (N). Numerical references reflect topographical segregation due to sub-catchment boundaries (Figure 5).

2.4.1 Valley floor systems (V)

This unit comprises broad flat valley floors with low gradients. Flow occurs in multiple, poorly defined and braided channels which rapidly merge to become broad flows during large run-off events. Flows are characterised by shallow depths and low velocities. Detention occurs within valley system in lakes, depressions and low-lying areas. Once this has occurred the ponded water either evaporates or infiltrates into the underlying profile

This promotes local water table recharge, the development of perched watertables or systems, and/or the surface accumulation of sediment and salt. The extent of inundation is exacerbated by impediments such as roads or dense vegetation stands. Prolonged and frequent inundation as a result of land use change has caused widespread vegetation degradation within the valley floor system. The degradation processes are accelerated at sites within the catchment where flow discontinuity and run-off accumulation on semi-impervious grey clays combine to promote long term inundation.

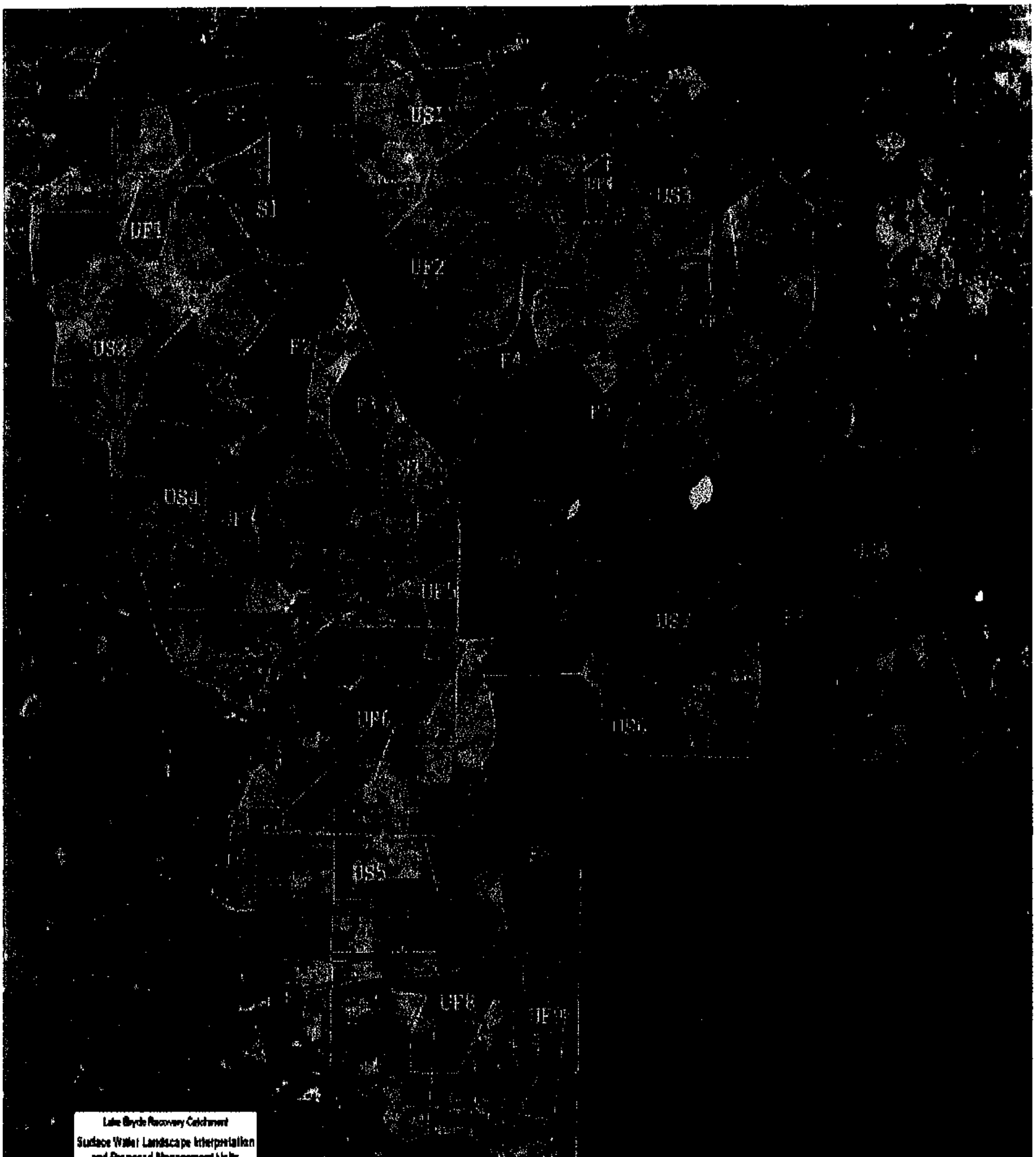


Figure 5: Surface hydrology classification for the upper Lake Bryde catchment.

2.4.2 Valley flats (F)

This unit comprises broad areas of low gradient that receive run-off from upland sub-catchments. Flow occurs in shallow channels, or braided channel systems, which are surcharged during large events producing broad, shallow flows. The spreading potential is at its greatest near the boundary fringes where change of slope from the faster upper valley and adjacent shedding landscapes into the flats causes a loss of flow momentum. The tendency to inundate wide areas of the valley floor often leads to the degradation of cultivated paddocks and direct recharge of local or perched water tables. Underlying groundwater systems can also be recharged through these saturated soil profiles and via preferred pathways.

Depressions and ponding areas within flow paths are accumulation zones for sediment and salt transported from upper slopes. In many instances these vegetated swamps and thickets have subsequently become degraded due to sedimentation and salinity impacts. This has modified flow behaviour causing erosion and expansion of the degraded areas as new channels develop, or water is forced to find alternate paths. During dry periods these scoured areas are often subjected to further degradation by wind erosion.

The ability of this unit to concentrate water from multiple inflows into a single broad uncontrolled flow becomes a major management problem during large run-off events. The subsequent increase in volume and flow energy can produce destructive flows causing channel scour, soil degradation, increased inundation and nutrient losses. Where these flows are poorly accommodated or become constricted i.e. road crossings, there is a tendency for water to pond and cause widespread flooding outside of the main channel area.

Such processes are most evident in the South Lake Bryde sub-catchment where substantial volumes of run-off generated over an extended area of the upper sub-catchment are significantly slowed by a pronounced loss of gradient. This results in the accumulation of sediments and degradation on the areas south of Ryans Road and the riparian valley system to the north of the road.

2.4.3 Upper valley flats (UF)

This unit comprises smaller relatively low gradient flats in the mid-upper portion of the lateral tributaries or interfluves. The unit is distinguished from the broader valley flats by more confined flows in better defined channel systems. Typically these are the primary receiving areas where run-off from the shedding slopes converge and water is usually of good quality (fresh to brackish). Channels are typically flat, shallow, 'u' shaped and often vegetated. Detention areas such as shallow swamps and sandplain areas occur in the wider valley sections or sections with lower gradients. Average gradients typically exceed 1% and flow momentum is usually consistent. These areas normally experience higher flow velocities than valley flats (F) and there is a greater potential for localised damage and erosion activity.

An important issue for this unit is the obvious impact increased run-off following clearing that has resulted in channel broadening and sediment mobilisation. Where channels are now inadequate to contain flow volumes, uncontrolled sheeting and localised waterlogging can become a problem. If not managed the loss of productive soil and recharge of ground water tables will continue.

Two other areas of concern have been identified. Firstly, small channel diversions caused by 'overflows' from narrow within-channel remnant vegetation corridors, that are often enhanced by sediment and organic material built up by wind action. Secondly the lack of riparian buffers between channels and cultivated land has left the agricultural areas exposed to damage from high flows and the impacts of wind erosion. These areas are likely to respond to conventional Landcare activities based on integrated re-vegetation and engineering management options. Given that the excess water generated is of reasonable quality, there are direct benefits in adopting management options whereby run-off can be converted into a water resource through storage or redirection.

This unit is one of the main drivers of water-related degradation in the lower valley flats and valley floors. The combination of enhanced run-off generation and poor detention storage results in substantive flow accumulation over very short periods. As a consequence discharge rates are 2-3 times that of the discharging capacity of the valley flats. Therefore these areas act as a confluence for run-off generated in the upper slopes that is then directed onto the valley floors.

2.4.4 Shedding slopes (S) and upper shedding slopes (US)

The shedding landscapes comprise upland hillslopes with slopes exceeding 1% and are the primary source areas for run-off. Hillslope subsurface inter-flows and overland flows are dominant. In large run-off events these areas promote high run-off velocities which have the potential to severely erode soils. In the Lake Bryde Wetland System there is a general lack of detention features such as swamps, depressions and channel pooling within these units. Upper shedding slopes (US) discharge onto the valley flats (F) and upper valley flats (UF) while shedding slopes (S) tend to discharge directly onto the valley systems (V), (Figure 5).

Under agricultural regimes these areas generate run-off more frequently and in greater quantities than under fully vegetated conditions. This effect is compounded by high shedding-to-receival area ratios (approximately 3:1 for the Lake Bryde catchment). The shedding areas identified do not necessarily reflect the impact of changes in hydrological behaviour caused by clearing and hence the potential benefit of remediation works in these areas can be overlooked. In the case of shedding hillslopes (S) there are often signs of direct valley floor degradation at the break of slope. This is of particular concern to vegetation systems within the Lakeland Nature Reserve.

2.4.5 Natural landscape (N)

Mallee-heath and some woodland vegetation associations dominate these landscapes and comprise the majority of the Lake Magenta Nature Reserve and the upper parts of Lake Bryde sub-catchments. Run-off generation from these areas is normally generated at rainfall threshold above 70-80mm, which is much higher than cleared catchments (Section 2.3).

Flows from these catchments are normally limited to substantial run-off following large rainfall events, resulting in widespread flooding and inundation. Given the frequency and magnitude of these events it is not recommended that engineering options are adopted as a management practice. As part of a management strategy it is suggested that run-off be incorporated into appropriate receiving, conveyance and detention structures adjacent to the reserve boundaries where degradation issues can be identified.

2.6 Summary of surface water management options

The primary objective of surface water management for the Lake Bryde catchment is to minimise the impact of excess water within the landscape. This involves a range of localised and whole of catchment considerations that aim to control the net volume of storm generated run-off and to reduce the impact of prolonged inundation. Where possible, solutions should actively promote the development of water resources that utilise excess run-off.

The management of surface and sub-surface water crossing farm boundaries is the primary recommendation of this report and delivery of run-off into the lower valleys from the upper slopes should be such that it reduces the incidence of prolonged inundation and soil and vegetation degradation. Modifications to the landscape response to rainfall can be achieved through on-farm activities such as modified farming systems, water harvesting and storage on-farm i.e. water supply development, or the redirection of run-off using earthworks to address problems identified on a farm by farm basis.

2.6.1 Management options in receiving landscapes

The key water management problem in the broad flat valley systems is low gradients, impedance structures, and loss of flow continuity that causes widespread inundation. The predominant driver within this system is the lack of flow continuity caused by the loss of momentum.

In many cases there is limited scope to control flows during large events due to the volumes of water involved. Confining flows to limit broad-scale expansion may caused impacts downstream if peak flows, velocities, volumes and flow energy are significantly modified. Riparian vegetation communities have an environmental water requirement, which is usually derived from localised inundation on an intermittent basis. These requirements would need to be addressed in a well-developed water management strategy.

2.6.2 Valley floor management options

The use of broad, shallow, non-leveed waterways, through major inundation areas will reduce the impact of ponding. During peak flows these waterways will quickly exceed their capacity with water spreading laterally onto the valley flats as would occur under natural flooding conditions (Figure 6). As flows recede small constructed surface channels will assist shallow ponded waters to flow back into the waterway. The modification of road crossings and approaches to accommodate local waterways will improve low flow efficiency. In smaller events, specifically those below the natural threshold events, there is scope for the waterways to convey most of the run-off generated at low velocities.

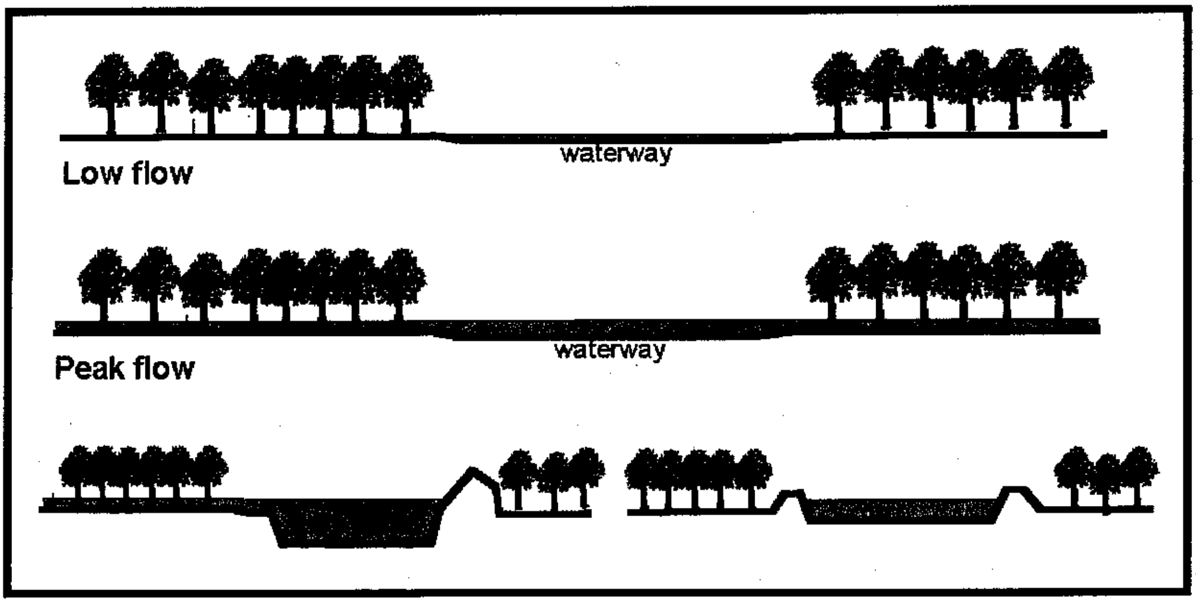


Figure 6: Schematic showing the notional benefits of unconfined broad, flat waterways through vegetated inundation landscape systems.

The benefit of a low velocity waterway structure is derived through the removal of retarding vegetation and the provision of a clear continuous flow pathway. Management of minor flow events offers significant opportunities to re-establish a more natural riparian inundation regime. The provision of nominal depth below the valley floor will provide a hydraulic gradient to assist lateral inflows during the recession period. The waterway should be levelled, compacted and stabilised to promote low velocities and minimise turbulence.

During large run-off events, when flows exceed the capacity of the waterway, the presence of riparian vegetation will provide flow resistance and energy dissipation. Such design ideology is in contrast to leveed systems where the confining of flows serves to increase flow depth and accumulate energy.

Ideally, the waterway should be discontinuous and integrated with natural channels, inundation flats and valley lakes as required to the control of design run-off. Where degradation risk is high, opportunities exist to bypass valley sections. The deliberate use of broad shallow channels with a limited depth capacity creates a permissible surcharge threshold that is width dependent, at which point larger flow events will fail to be diverted and flood run-off will revert back to natural flow routes.

2.6.3 Valley flat management options

The management strategy for this unit is to address the occurrence and extent of uncontrolled flows and prolonged inundation. In most cases the generalised solutions are those widely recommended for run-off management in dryland agricultural areas (e.g. Keen 1998; Green 1990). The use of leveed cross slope waterways (Figure 7) and broad grassed waterways (Figure 8) are appropriate in most instances. These earthworks will manage flows by redirecting water away from areas of undesired convergence and by providing flow continuity through or around accumulation and recharge areas. However the application of such options will not be 'generic' and must be designed on a site-specific basis.

Reconnaissance of various degradation sites within the Lake Bryde Catchment has shown that while the structures chosen may not vary greatly, there is considerable local heterogeneity that each management strategy or design option must address. Each option must also consider the off-site impacts and provide for discharge continuity between adjacent landscapes and property boundaries. The most efficient designs are those that are coupled with flow reduction activities in the contributing upslope run-off shedding areas. These include controlled detention, flow delay through the promotion of low velocities using design waterways and the use of water harvesting and storage to create water supplies from smaller events where possible.

Figure 7: Cross slope waterway, Lake Bryde August 2001

(Photo: courtesy of G.Garlick)

Figure 8: Broad grassed waterway during peak flow event, Lake Bryde 1992

2.6.4 Management options in the upper sub-catchments

The containment and diversion of water generated through run-off or via seepage areas within the shedding slopes provides the best opportunity to reduce excess water on the adjacent lower slopes and valley floors. The benefits derived by constructing earthworks to improve water management in the upper catchment landscapes are significantly better than those achieved by constructing earthworks in the down-slope flats and valleys alone. This is a direct consequence of the volumes of water involved, the extent of flatland earthworks needed and the much greater ratio of shedding hillslopes to receiving valleys experienced in the Lake Bryde catchment.

Long term non-engineering options for the upper sub-catchments reflect those that have been advocated for some time through the auspices of Landcare and the Department of Agriculture programs that address recharge. These include approaches such as modified tillage practices, incorporation of perennial and deep rooted cropping systems and re-vegetation strategies. However, due to the volumes of water and rates of run-off generation involved, there is need for these to be integrated with engineering water management options to derive the greatest benefit.

Achievement of the projected benefits from the planned and co-ordinated design of catchment scale earthworks requires across farm boundary implementation and hence the need for multiple landowner commitment. Small scale implementation will be limited to engineering options applied to specific degradation sites to obtain short-term benefit. By adopting an integrated catchment management approach to medium-term objectives it is possible that short term activities and objectives can be implemented as the first phase of a whole of catchment plan. This compartmentalised approach to earthwork construction, in addition to other management strategies, will allow for variations in landowner commitment, seasonal impacts on income, prioritised allocation of available funds and design evaluation in the longer term.

The basis of the proposed surface water management strategy is to employ water harvesting techniques, improve watercourse management and construct detention or storage structures to manage water within or out of the catchment with limited risk. The integration of strategic on-farm revegetation with engineering options offers the potential to specifically target run-off accumulation and seepage areas (George, 1991), functionally improve natural waterways and control degradation sites (Penn, 2000). In this respect the integration of vegetation with engineering management options may provide the most effective benefit from small-scale application in the short to medium term.

2.6.4.1 Shedding landscapes (slopes >1.5%)

Run-off harvesting and interception structures permit water to be relocated more than 150-300m away from the original course per metre fall (construction gradients of 0.2-0.5% in hillslopes with slope greater than 1.5%, (Bligh 1989)). By combining low flow velocities, i.e. 0.5 m/s, within slope detention, i.e. a 4000 m^3 farm dam, this can translate into a delay equivalent to the interception capability of 30 Ha of vegetation (based on 10-15mm interception rate for vegetation). This could address a net 50% run-off reduction from ~60 Ha of farmland based on a 60-70mm rainfall event, provided initial storages are low.

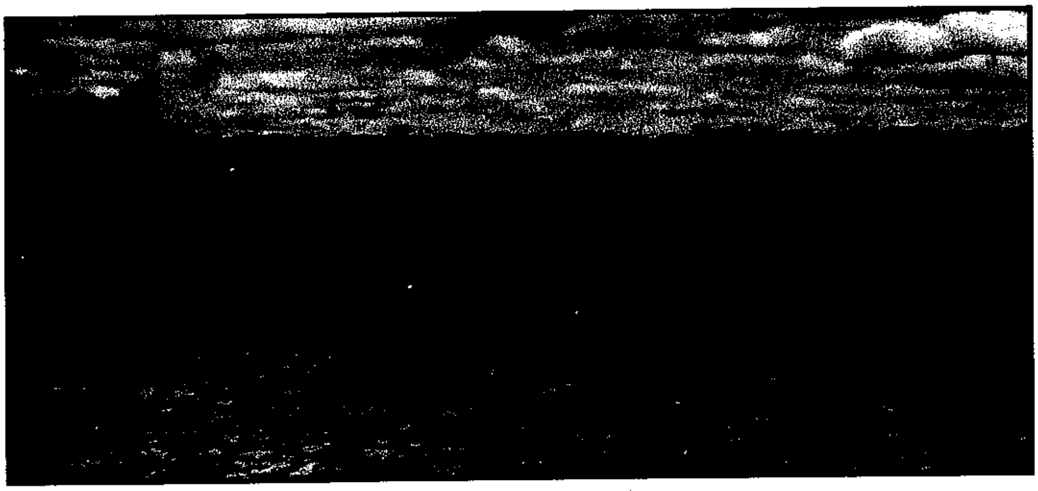
Such a management approach is suitable in areas such as the Lake Bryde Catchment since run-off events are naturally episodic (minimal seasonal signature in flow regimes). A combination of water harvesting, deep rooted perennial vegetation, perennial phase cropping systems and riparian re-vegetation buffers could substantially increase run-off delay or detention within the critical receiving areas.

The basic structure utilised in upper slopes for water harvesting is a broad roaded bank. These are generally constructed with a grader to intercept the clay horizon in shallow duplex soils and are generally much cheaper to construct than those requiring a bulldozer (or excavator) such as interceptor banks. When conditions are favourable these structures can be designed to allow for cultivation of the back-slope, thereby reducing the area of land lost to production. In gravel soils, bank design will depend upon the slope shedding characteristics. A broad, level compacted bed promotes low velocity run-off, minimises bank recharge and offers major advantages over absorption and storage-tending banks that offer greater recharge opportunity.

2.6.4.2 Upper valley flats

The upper valley flats have channel gradients typically exceeding 1% and flow routes are usually defined. Remediation works in the upper flats should address water velocity and depth. Where possible the design should seek to reduce erosive potential, sediment transport and volumes, (through detention rather than infiltration), before flows enter the valley flats. This may involve modifying and managing the waterways to accommodate changed flow regimes, i.e. circumventing natural erosion processes.

Cross slope waterways and broad collector banks can slow water and reduce the impact of sheet flows, offering an efficient means to harvest water. Within the valley profile, broad shallow waterways for designed flows offer the best means of conveying water.



Figures 9, 10 and 11: Comparison of banks and waterways

Grade banks which encourage broad, shallow flows along gradients of 0.2-0.6% (top) offer significant advantages over alternate bank designs (centre) which often tend to either store water or generate greater flow volumes due to their depth. Grassed shallow waterways (bottom) offer the most effective alternative for conveying water across areas of low gradient.

The use of vegetation as a riparian buffer outside of the channel is encouraged since these will act to control inflows and minimise the impacts in the adjacent paddocks during overflows. Opportunities for velocity reduction and sediment/nutrient stripping such as detention basins, flow control and artificial wetlands, should be considered where conditions are favourable and impact risks are low. The period of inundation following events can be reduced through the use of shallow drainage features such as W-drains.

Addressing issues involving remnant vegetation corridors and their environmental water requirement is complex. Consideration must be given to why water is moving around the vegetation and what impact changes in flow might have on vegetation community stability. Options may include increasing the corridor width and thinning the immediate channel area (including removal of sediments if possible). Perimeter waterways may be needed to collect water from the corridor and/or run-off from adjacent paddocks.

2.6.5 Management of recharge areas

A review of the existing information and literature relating to groundwater behaviour (Giraudo *et al* 1996; SKM 2000) provides little specific evidence of any sites that are directly associated with water table rise. The recharge characteristics used within the forecast modelling were landscape based (SKM 2000). However Sinclair Knight Mertz (2000) identified variability in chemical signatures and bore behaviour suggesting variability in aquifer connectivity and recharge regimes. Giraudo *et al* (1996) suggest that groundwater interaction is promoted through faults and dykes in the South Lake Bryde catchment. This is similarly acknowledged by the Lake Bryde SKM Report (SKM, 2000) though no substantial conclusions are drawn. Seasonal recharge trends are probably unlikely since Department of Agriculture bore hydrographs do not appear to reflect upward sinusoidal trends.

Should future investigations establish associations between structural geology and surface water within the South Lake Bryde catchment then appropriate action may be taken to minimise the recharge risk. Within the valley floors and flats local inundation recharge rather than regional-scale recharge of water tables is thought to be the driver for local degradation issues. This theory is supported to some extent by Lewis (2000) and SKM (2000) who suggested that recharge is predominantly episodic and normally localised.

Surface water flows have been observed east of Grant-Williams Rd, yet there is an inherent lack of surface flow expression within the reserve (and beyond into Roe Location 426). The East Lake Bryde Nature Reserve comprises a deep sand plain profile and is thought to be either a major recharge zone or a substantial sub-surface storage. In this case further investigation is required to adequately define the morphology and function to enable management strategies to be developed that reduce the volume of water flowing over Grant-Williams Road.

Once critical recharge or sub-surface interaction areas have been identified then local management options could be extended to provide diversion and/or inflow reduction. In most cases the primary objective will be to minimise the extent of waterlogging and inundation in susceptible sites in order to maximise the benefit of recharge management activities such as trees and landscape restitution.

2.6.6 Management of inflow to the lake systems

A feature of the Lake Bryde Wetland System is the widespread occurrence of lakes and playas. Lakes located within the hydro-aeolian system tend to be brackish rather than saline. A dominant characteristic is for lakes to be offset from the main channel systems and connected by a defined inlet/outlet cutting through bordering lunettes or sand ridges. The in-channel lakes are typically limited to swamps and depressions and more commonly occur in the valley flats. Where height observations were taken (Lake Bryde, Lake Janet, Lakeland Nature Reserves) it was found that lake-bed water levels and inflow/outflow is generally controlled by a clay/sand sill within the inlet channel. Other than Lake Bryde and East Lake Bryde there is limited limnological data for the lakes and wetland systems.

2.6.6.1 Lake Bryde system

The lake bed supports a Threatened Ecological Community (TEC) consisting of unwooded fresh water lakes dominated by *Muehlenbeckia horrida* subspecies *abdita,* and *Tecticornia verrucosa* across the lake floor. The lake is also utilised for recreation purposes (eg. Skiing). Prior to the initiation of the recovery catchment project, which covers the entire wetland system, the historical focus was primarily on Lake Bryde itself. Data collected by the Department of Conservation and Land Management shows fluctuations in salinity levels followed by a pronounced salinity increase during the late 1990's. Increasing salinity was expected to be an ongoing long-term trend until the major inflow event in January 2000 provided a substantial flush.

Lake Bryde monitoring data (Halse 2001) suggests salinity levels at Lake Bryde are sensitive to periods of frequent small run-off events that result in minor lake inflows. These small events are thought to drive salt mobilisation and accumulation within the lake system. Between periods of flushing the Lake essentially becomes a salt sink, where actual salt mass is more important than inflow volumes. The water holding regime of Lake Bryde is subject to some conjecture, however it is suggested from the data available that the underlying storage trend is dominated by episodic peak inflow as opposed to a seasonal inflow regime.

Analysis of the run-off regime of the natural system and the apparent hydraulics of the inlet indicates the 'regular inflow regime' now established is probably a post-clearing phenomenon. If this case can be established then it is not necessary for the smaller flows to enter the lake in order to maintain this system. These can be diverted away from the inlet area. Larger run-off events that might result in flushing will still be able to enter the lake system.

2.6.6.2 East Lake Bryde lake system

The East Lake Bryde lake system consists of small ephemeral lakes that have a lower storage capacity than Lake Bryde. As the majority of the catchment associated with the lake is in the fully vegetated Lake Magenta Nature Reserve, large-scale rainfall events are required to generate significant run-off and consequently major inflows are infrequent.

Available inflow data for East Lake Bryde supports this observation with significant depth increases occurring after infrequent large storm events but only small increments for normal seasonal rainfall. Water level and salinity trends are much less pronounced than in Lake Bryde. The infrequent surface flows experienced by East Lake Bryde have resulted in the development of poorly defined waterways.

Only limited engineering intervention may be required with respect to surface water inflows, lake water level and water quality management within this system. A potentially greater threat is that posed by recharge and storage. There is limited data available to asses the impacts of recharge but it is likely behave in a similar manner to the regional aquifer system that has demonstrated groundwater rise. Significant water-table rise and associated salt mobilisation will impact detrimentally on the lake and Reserve. Data obtained from the proposed drilling program may provide additional information to enable a groundwater management plan to be devised.

2.6.6.3 Lakeland Nature Reserve

Inspection of lakes within the Lakeland and Lake Janet nature reserve during winter of 2001 suggests that regular drying is a feature of the majority of lakes. Few of them were showing signs of saline degradation and shoreline vegetation was generally in reasonable condition. The February 2000 aerial photography shows them to have been substantially filled by the January 2000 event (DOLA, 2000).

In August 2001 there was no substantial valley flow and the lakes visited were found to have low storage (<0.2m) that had accumulated during the winter (2001). Playas closer to the western boundary and adjacent to agricultural land show evidence of more regular inflow (overland run-off pathways) and visible stress and degradation of shoreline vegetation. In some cases samphire communities have established.

The apparent good condition of the Lakes within Lakeland is thought to be a direct consequence of the lack of upstream flow continuity. These systems are located on the hydro-aeolian land unit where there is little evidence of salt accumulation. In the long term, continuing upstream degradation and subsequent development of shallow groundwater tables in the valley are likely impact upon the Lakeland chain.

Degradation in the outer lakes can be addressed by reducing uncontrolled inflows by adopting surface water management controls in contributing upslope areas. There is some risk that the provision of flow continuity within the Lakeland Nature Reserve (Projects 3.4a and 3.4b) may increase the wetting regime within the valley sections below Bairstow Road. Careful selection and preparation of detention points above the main lake chain, ideally within the grey clay landscape, is expected to address this issue.

The provision of a bypass may become a long-term necessity in the event that waterway impacts cannot be appropriately managed. Inundation and inflow within the lake chain and its channel network during larger run-off events is a natural phenomenon and is unlikely to be impacted by the structures or diversionary system proposed.

This situation is expected to be similar for Lake Janet. This system will be bypassed by waterway flows during events below the natural threshold and able to interact with valley scale inundation at its inlet channel during larger flow events.

2.6.6.4 Privately owned riparian lakes and swamps

Notable storage occurs on Roe Location 2558 (Kent), Roe Location 422 (Smart), Roe Location 2586 (Russell/Kuchling), Roe Location 426 (Presser), Roe Location 2552 (Grant-Williams), Kent Location 1761 (Altham) and Roe Location 2574 (Ryan). There is also evidence of swamps and riparian thickets within other properties along the valley flats and upper valley flats at confluences, or where geomorphology promotes a reduction in flow velocity and water accumulation.

By the nature of their location many of these systems are either degraded or subject to degradation risk. Common issues are sedimentation, salinisation, surface and sub-surface water impacts and loss of protective vegetation buffers. The development of management strategies will be site specific. However in most instances direct protection can be achieved through water management on contributing upper slopes to minimise or divert minor inflows, coupled with re-establishment of vegetation buffers.

2.6.7 Implementation of management options

The general upland management options presented here tend to expand upon suggestions made by Giraudo (1996). Despite this information being available to landholders, on-ground implementation of the recommendations has been limited. An effective water management strategy can have a number of obstacles to implementation. These are:

(1) a perceived indifference to the problem;

(2) a perceived lack of benefit to the landholder;

(3) concerns associated with a perceived loss of productive land; and

(4) limited access to one on one expertise and advice.

The challenge is to adequately demonstrate landholder benefits from these activities in order to facilitate their voluntary adoption into the farm business and/or to provide incentive for adoption by an alternate mechanism.

One noticeable aspect of the Lake Bryde Wetland System is the absence of potable groundwater supplies and the increasing dependence on surface water. Small-scale water harvesting using minor roaded catchments to increase water collection is already being implemented. Recent dry seasons, the decline of the Lake Bryde drought-relief water supply and loss of farm dams due to increasing salinity all provide impetus for wider adoption of water harvesting strategies. Where requirements can be met, there is opportunity to attract funding for on-farm and community water supply development through the Farm Water Grants Scheme managed by DEWCaP.

Properly implemented water harvesting activities can provide both soil conservation (reduced erosion and sedimentation) and surface water management (Coles and Ali, 2000). Many progressive farmers advocate production benefits through the incorporation of Landcare, water harvesting and surface water management activities within their farm business (e.g. Yeomans, 1968 and Millar 2001).

There is scope within the Lake Bryde Recovery Catchment Project to provide short term financial incentives to critical landholders and pro-active landholders through the extension of the Department of Conservation and Land Management's cost sharing arrangements to include the design and construction of earthworks. (B. Bone and G. Mullen, CALM, *pers comm*). The investigation of financial incentives are outside the scope of this report but warrant further specialised investigation.

3. Sub-catchment surface water issues and management proposals

The Lake Bryde wetland system is representative of a complex and highly heterogeneous landscape. Consequently, issues and solutions vary between sub-catchments, and the landscape units and their hydrological behaviour dictate run-off responses. To facilitate the development of a surface water management strategy and the application of recommended management options it is necessary to critically examine the landscape units at local scales.

Following are the results of the initial field reconnaissance and identification of 14 key catchment areas that are considered primary recovery 'projects'. Each of these has been subject to a preliminary investigation sufficient to establish landscape trends and recommend draft management options. These outcomes are intended for use in planning and budgeting recovery activities. Prior to implementation each project will require full review, impact assessment and design evaluation. Structures shown in figures are indicative only and are considered to offer the best approach to problem management based on the available data. A summary of the projects and their perceived priority are given in Table 2 and are shown in Figure 12.

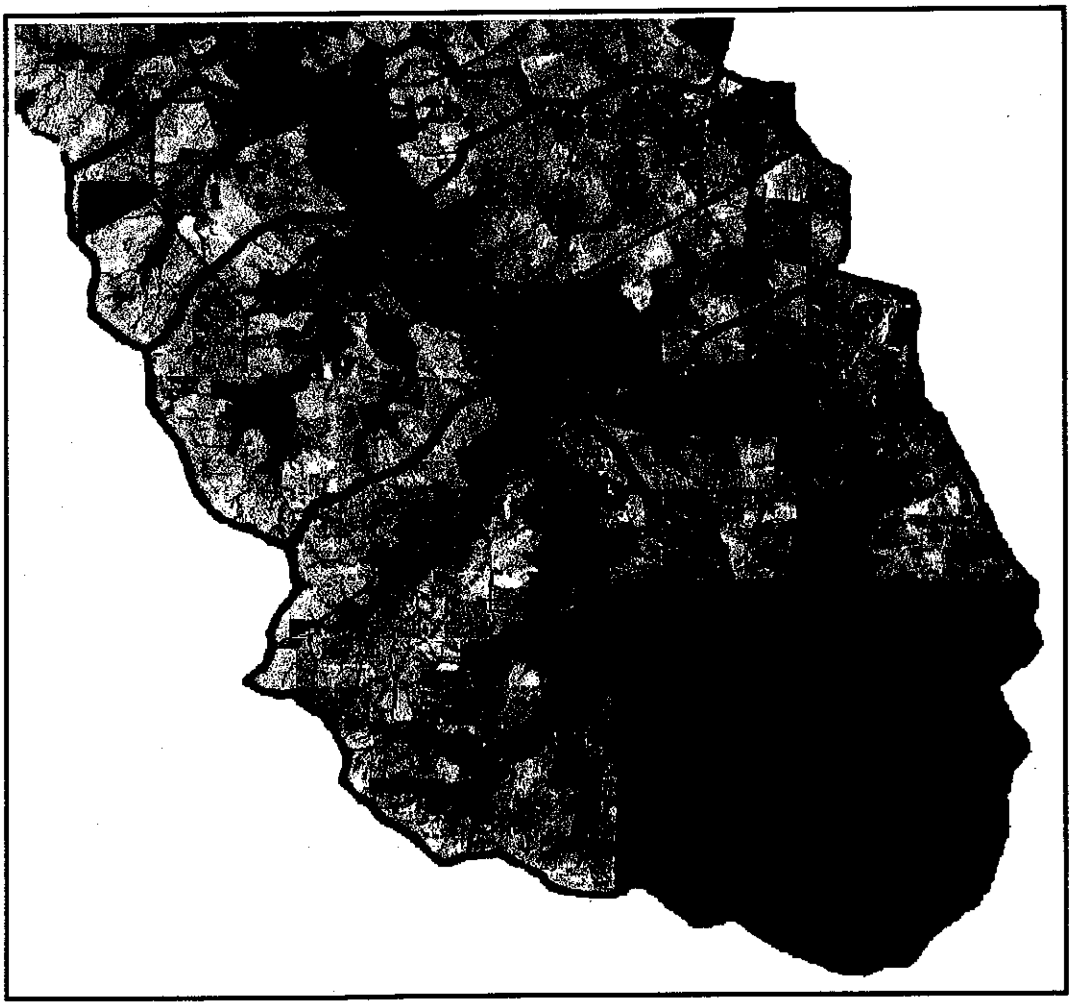


Figure 12: Proposed surface water management projects for the Lake Bryde Catchment.

Table 2: Proposed Lake Bryde surface water management projects..

LABEL	PROJECT	NATURE	EXTENT	PRIORITY
1	Lake Bryde Rd Valley	Provision of improved flow continuity and reduced inundation time-scales.	4 km 250 Ha	URGENT
2	Ryans Rd	Provision of improved flow continuity and reduced inundation time-scales. Reduction in salt/sediment impacts and accumulation.	6.5 km 2000 Ha	HIGH
3a	Fourteen Mile Rd/Olivers	Reduction of ponded volumes and recharge potential above Lake Bryde Reserve. Addressing of salinity degradation associated with floodways on Fourteen Mile Rd.	3.5 km 1000 Ha	HIGH
3b	Olivers upper watershed	Surface water management and run-off reduction. Water harvesting opportunities.	8 km 4300 Ha	MEDIUM
4a	Lakeland Valley (Newdegate Rd – Bairstow Rd)	Waterway restoration and improved flow efficiency. Addressing vegetation degradation issues.	9.5 km 2100 Ha	HIGH
4b	Lakeland Valley (Bairstow Rd – Mallee Hill Rd)	Improved flow efficiency and lake protection. Waterway restoration and receival point establishment. Addressing vegetation degradation issues.	5.3 km 1600 Ha	HIGH
5	Days Creek/Needilup Rd	Surface water management and flow volume reduction.	13 km 7000 Ha	MEDIUM
6	Lake Bryde Eastern inflow	Surface water management and flow volume reduction. Reduction of ponded volumes and recharge potential above Lake Bryde. Water harvesting opportunities.	18 km 9700 Ha (2000 Ha)	MEDIUM-HIGH
7	East Lake Bryde	Surface water management and flow volume reduction. Reduction of inundation volumes and recharge potential above East Lake Bryde sand plains. Water harvesting opportunities.	10.5 km 4900 Ha	MEDIUM
8	South Lake Bryde Flats	Surface water management and flow volume reduction. Reduction of inundation volumes and recharge potential.	8 km 4800 Ha	MEDIUM
9	Upper South Lake Bryde (East Road)	Surface water management and flow volume reduction. Flood control. Water harvesting opportunities.	10 km 8300 Ha	MEDIUM
10	Hollands Soak Rd Sub-catchment	Surface water management and flow volume reduction. Water harvesting opportunities.	12 km 13500 Ha	MEDIUM
11	Malle Hill Rd South-West Sub-Catchment	Surface water management and flow volume reduction. Water harvesting opportunities.	13 km 7500 Ha	MEDIUM
12a/b	Lakeland East Slopes	Surface water management and flow volume reduction. Water harvesting opportunities.	7 x 8km 4700 Ha	MEDIUM

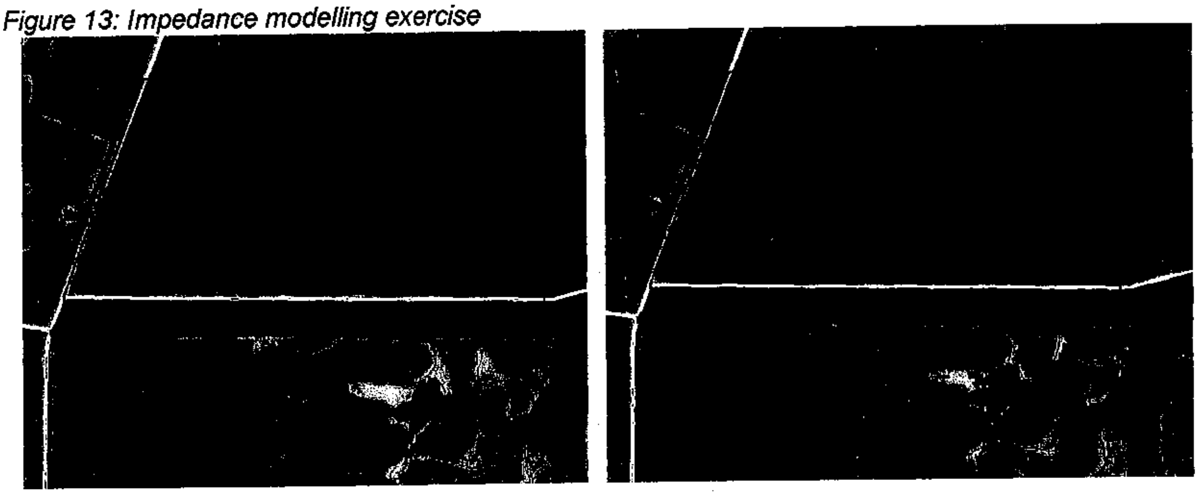
3.1 Lake Bryde Road and Lake Bryde (project 1)

The Lake Bryde Road area between the Newdegate-Pingrup Road and the Lake Bryde inlet culvert has been identified as a problem area in almost all previous studies (JDA, 1995; SKM 2000, Giraudo, 1996) and it's potential as a site of salinity accumulation and inundation is widely acknowledged. Preliminary modelling suggests that the primary issue is the lack of flow continuity throughout this section, which serves to explain why localised solutions such as culvert and road modifications have had a limited impact.

A simple inundation study (Figure 13) clearly demonstrated that the minor impedance to flow caused by Newdegate-Pingrup Rd and the existing culvert greatly exacerbated upstream inundation and recharge potential (Farmer, 2001b). The modelling data suggested that an upgraded culvert of greater lateral capacity in conjunction with water management was required to reduce the impact of post-event ponding and improve post-event and low flow opportunity. Extensive ponding is regularly observed in this area following run-off events. During the relatively small rainfall event in August 2001 streamflow reached the Lake Bryde Road valley where it accumulated and was retained within vegetation areas adjacent to the road for more than a week. No flow was observed at the Newdegate Road culvert.

Management options are highlighted in Figure 14. To improve flow and reduce the inundation, priority should be given to the construction of a low velocity waterway that promotes flow continuity with the system.

Figure 13: Impedance modelling exercise



Impedance impact caused by the Newdegate-Pingrup Rd (left) when existing culvert is working at "low flow" discharge (i.e. 0.15-0.2m depth within pipe) and (right) during a large event that results in floodway flows, e.g. Jan 2000. Results are superimposed on Feb 2000 imagery, dark areas show actual ponded water. It is evident in the left image that Lake Bryde Road (not explicitly modelled) is having an additional impact that results in a larger area being inundated than that caused by the Newdegate-Pingrup Rd culvert alone.

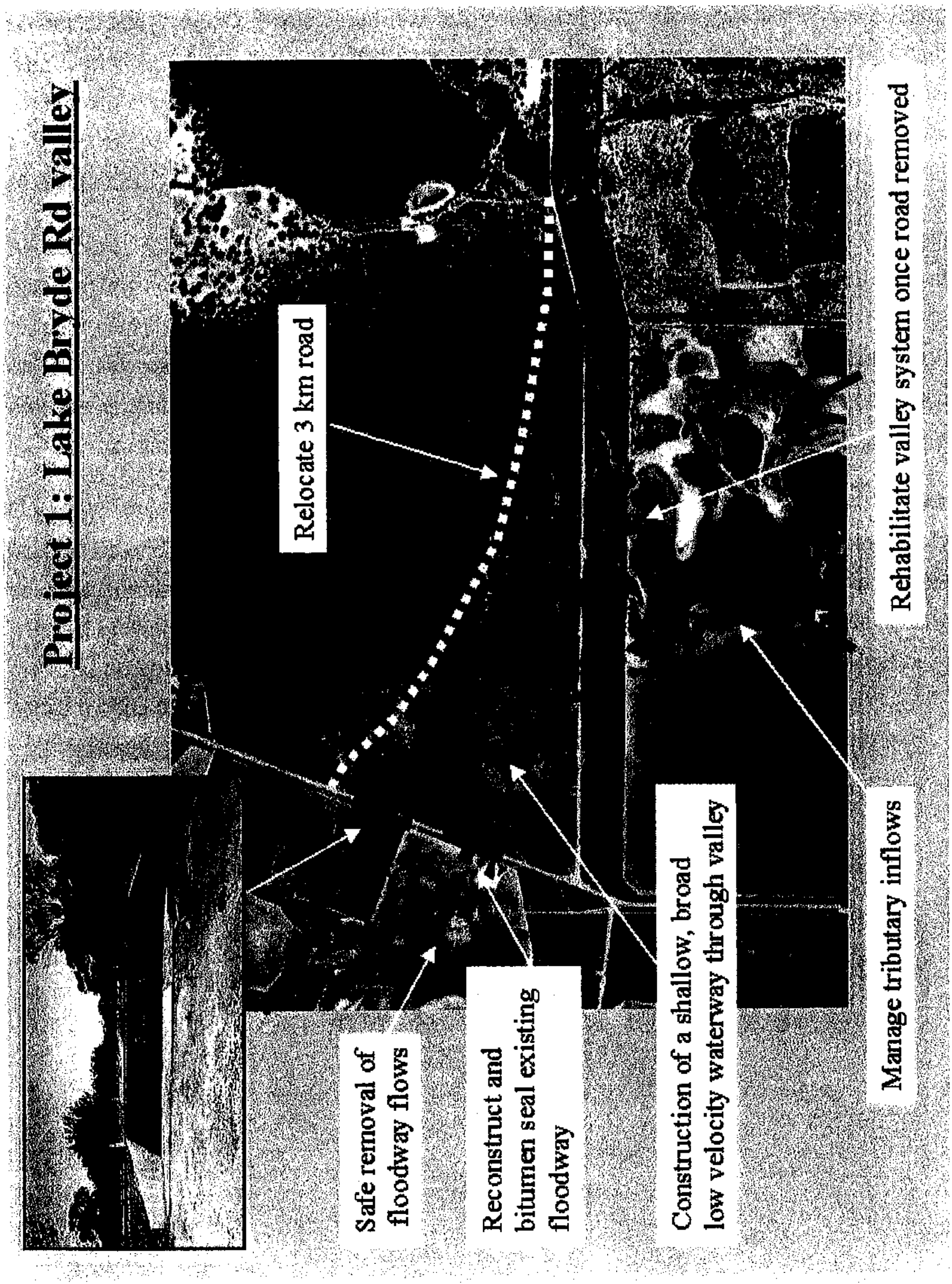


Figure 14: Proposed management options for Lake Bryde Road valley.
Routes shown are indicative only and subject to proper assessment and design.

The actual route and extent of construction of the waterway will depend upon the need to accommodate the Lake Bryde Road and to provide waterway crossings within the existing road formation. Under the existing design facilitation of flow continuity on both sides of the road along the two primary channels evident in Figure 13 should be considered. This proposal will necessitate the placement of the waterway in the road reserve and the removal of vegetation.

An alternate option is to relocate some 2-3 km of the Lake Bryde Road away from the main drainage line and into the Lake Bryde Nature Reserve as shown in Figure 14. The expected cost of relocating Lake Bryde Road is expected to be comparable to the cost of incorporating the existing road within the waterway design. The primary benefit of the road relocation proposal is that the natural watercourse route can be re-established and rehabilitated once road construction is complete. Any proposal will need to be fully reviewed and budgeted.

Currently, salinity trends in the Lake Bryde valley floor are strongly correlated to the occurrence of deep grey clays. Figure 15 indicates that this is the dominant soil in the valley sections that underlie the Lake Bryde Rd and adjacent lands. Low transmissivity promotes ponding of water within the valley that can extend back to the Lake Bryde inlet. Relocating the road away from this area will provide more effective management of the potential risks posed by long-term inundation.

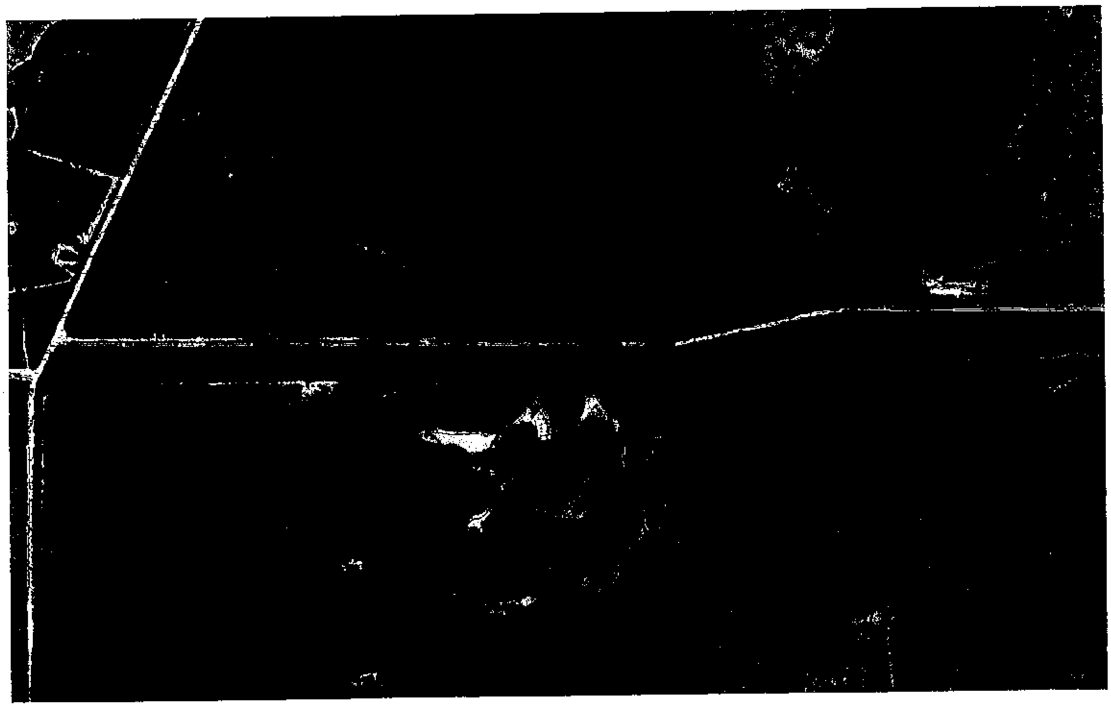


Figure 15: Major soil type locations in Lake Bryde Road valley.

Blue shaded area represents deep grey clays while the yellow shaded area represents hydro-aeolian (deep sands and sands on clays).

Lake Bryde inflow

The existing inlet-outlet system allows for the interaction of small flows with Lake Bryde via water accumulating in the low-lying depression immediately south of the Lake Bryde Road culvert. This water originates from run-off in the South Lake Bryde catchment and in the catchment and Pingrup-Newdegate Road reserve above Needilup Road (Days Creek). Field survey data identifies that ponded water must exceed a depth of 0.6m before it can flow westward into the main valley channel system.

Based on the field observation of flows within the Lake Bryde Catchment and model assessment of small event inflow behaviour into Lake Bryde it is proposed that the waterway be extended beyond the inlet culvert as shown in Figure 14. This will reduce prolonged ponding adjacent to Lake Bryde Road and provide the means to divert water away from the Lake inlet area if this is deemed necessary. A waterway of the style proposed will be ineffective in diverting the peak flows generated by larger run-off events and therefore will not interfere with the type of inflows required to flush the lake and naturally inundate the Lake Bryde Road valley system.

Figures 16 and 17: Lake Bryde Road

Extensive flooding along Lake Bryde Road, January 2000 (left). Even during small events such as August 2001 the road formation presents an impediment that encourages water to pond in adjacent vegetation (right).

3.2 Ryans Road (project 2)

Inundation adjacent to Ryans Road has been identified as a major management issue. During large events a substantial section of road can be flooded for several days. Giraudo *et al* (1996) identifies the South Lake Bryde sub-catchment flats immediately upstream of Ryans

Road as 'exhibiting by far the worst salinity in the entire Lake Bryde Catchment[1] and the most likely source of saline inflows into Lake Bryde'. Flooding and associated impacts extend over much of the land between Ryans Road and Lake Bryde Road. Field inspection identified saline dams above Ryans Rd, vegetation degradation in the road reserve and salinity impacts in properties to the south, Smart, Roe Location 2216 and Rosenberg, Roe Location 2575, and north, Ryan, Roe Location 2574.

Land immediately above Ryans Road, Roe Location 2216, has been unsuitable for cultivation for some time (W. and K. Smart, *pers comm*). Salt scalds, erosion and ponding impacts were observed throughout much of the valley flats. During the relatively minor run-off event in August 2001 the area above Ryans Road was substantially inundated (Figures 16 and17) though flows across Ryans Road were minimal.

Water crossing Ryans Road from South Lake Bryde and flows from Days Creek has caused substantial degradation within Roe Location 2574 (Ryan). Sedimentation and salinity has completely degraded two depression lakes within this location (Figures 18-21).

In the lower portion of Roe Location 2574 a drain constructed some 15 years previously has partially filled with sediment. Natural erosion and deposition processes have established it as a sandy waterway (Figure 22). The drain alignment now provides a shallow, preferential flow route that has helped reduce impacts upon adjacent remnant vegetation. This vegetation is in good condition with extensive self-seeding and regeneration of multiple species evident.

Management strategies for this landscape primarily involve providing flow continuity. The failure of numerous road modifications along Ryans Road reflects the inability for the adjacent landscape to convey water. Use of a broad shallow waterway in conjunction with an appropriately designed floodway of reasonable width (200-300m) will provide the means to convey excess water through the flats above Ryans Road (Figure 23) and safely pass water across the road reserve. The inclusion of a bitumen seal and concrete edging can reduce the maintenance and trafficability issues that have hindered modifications in the past. Once flow continuity has been established, existing waterways and W-drains within Roe Location 2216 (Smarts) can be upgraded to better manage inundation and provide improved opportunity for rehabilitation.

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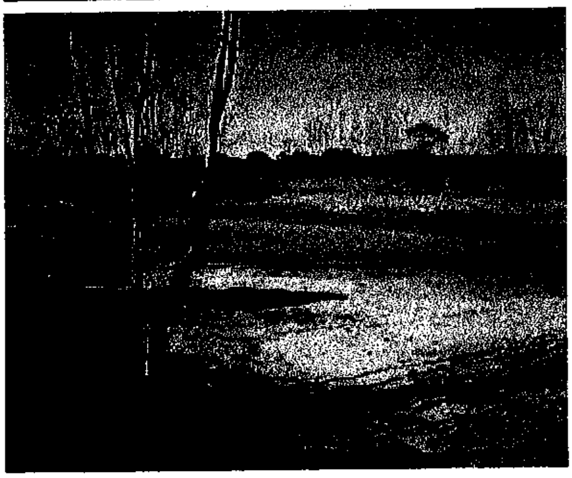
[1] In this case 'Lake Bryde catchment' refers only to those sub-catchments contributing to Lake Bryde.



Figures 18, 19, 20, 21, 22: Ryans Road

Management issues associated with the Ryans Road project include inundation above Ryans Road (top left, top right) and degradation of the natural watercourses (centre right) and detention swamps (centre left). A drain constructed 15 years ago (bottom) has been partially filled with sediment and now provides a waterway through remnant vegetation in the north of Roe Location 2574. The vegetation appears healthy and self-seeding is evident.

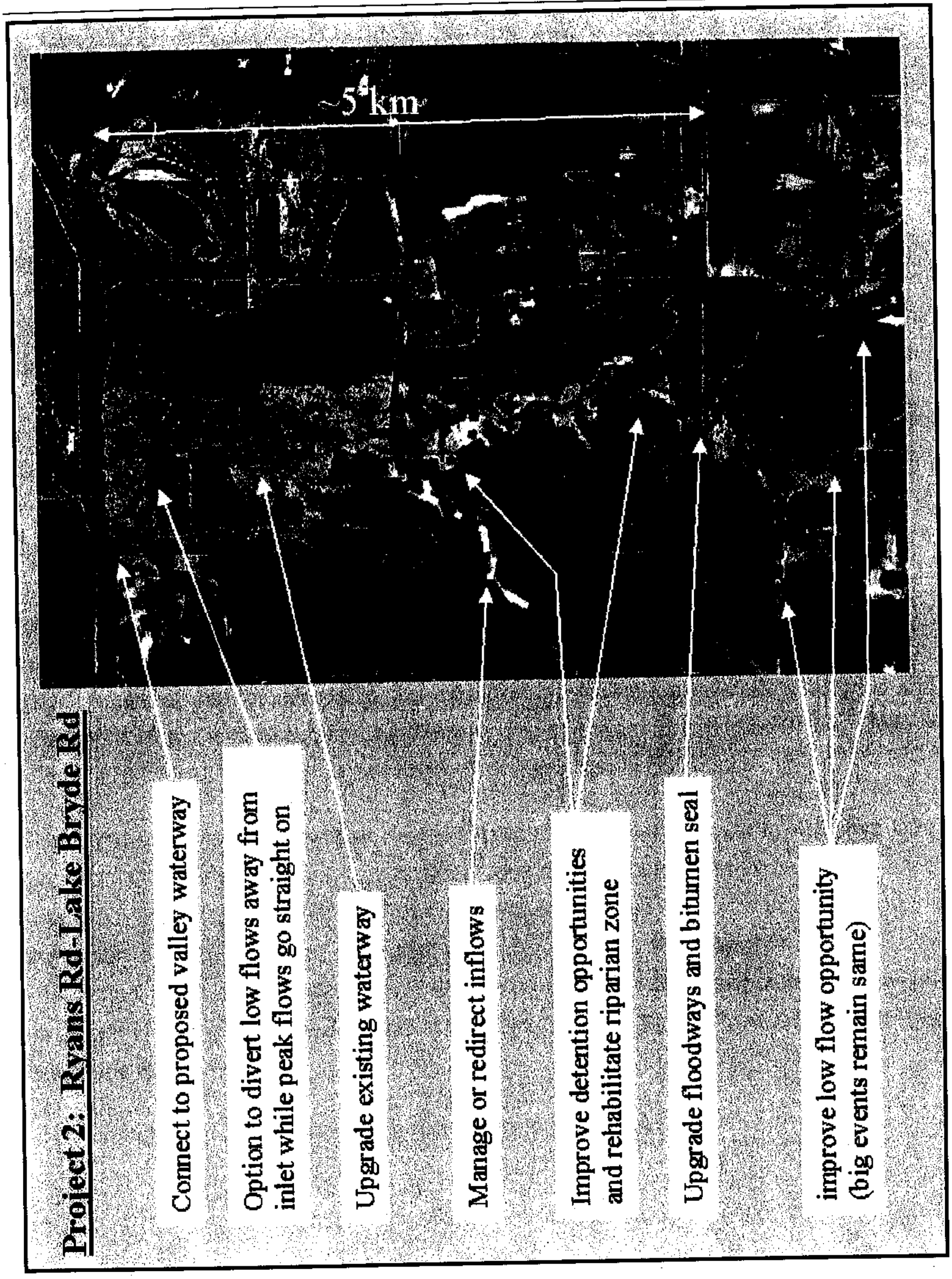


Figure 23: Proposed management options for Ryans Road flats and the valley section from Ryans Road to Lake Bryde Road.

Works shown are indicative only and subject to proper assessment and design.

Below the floodway, the waterway should be extended into Roe Location 2574. Sediment should be removed from the natural flow route and the swamp area and riparian systems within Roe Location 2574 are re-established within the main channel. The condition of the self-seeded vegetation in the lower northern portion of Roe Location 2574 indicates that riparian re-establishment is likely to be successful once surface water impacts are managed. Low flows should be prevented from entering the Lake Bryde inlet area, as they are likely to become more saline and would thus contribute to the salinisation of the lake system. This can be achieved by directing minor flows away from the inlet and directly into the waterway to the west. The provision of a simple low, reinforced bank, or a diversion structure will enable larger and/or flood flows to be redirected into the lake inlet area.

Lateral flows from Roe Location 421 (Days Creek from Needilup Road) are essentially large volumes of mainly fresh water. These flows are poorly confined except during low volume flows. Flow disperses at the boundary of Roe Location 2574 and results in sediment remobilisation and deposition. Surface water management within Roe Location 421 will require assessment and modification to ensure better delivery into Roe Location 257 through continuity across property boundaries via a waterway or other suitable earthworks. Re-establishment of the natural swamp depression would facilitate a suitable confluence and detention point in the landscape prior to flows turning northward toward Lake Bryde. Options exist to divert a portion of the total flow northwards within Roe Location 421.

Completion of works in this section is expected to reduce the risk to the lake system from water inundation and rising salinity. However, due to the inherent risk of increased saline inflows into Lake Bryde once flow continuity occurs above Ryan Road, the project cannot be undertaken until the waterway proposed in Section 4.1 has been established as a safe receiving point or connecting structure. Failure to properly complete these projects in tandem may result in the salinity and degradation problems south of Ryans Road extending to the Lake Bryde Road.

3.3 Fourteen Mile Road – Yate swamp flats (projects 3a and 3b)

Roe Location 2585 (Oliver) situated at the junction of Newdegate-Pingrup Road and Fourteen Mile Road has been identified during field reconnaissance as a major recharge zone immediately up-gradient of the Wooded Yate Swamp in the northern portion of Lake Bryde Reserve. The lower flats of Roe Location 2585 are subject to substantial ponding that is exacerbated by a lack of defined drainage lines and flow impediment caused by the Newdegate-Pingrup Road. This area will be subject to further flow impacts upon completion of the proposed realignment of the Fourteen Mile Road junction, scheduled for 2001-02.

The run-off source for this area is 5000 Ha of upper catchment shedding landscapes and upper valley flats. As is the case for most sub-catchments east of the Lake Bryde valley, grades in the catchment are substantive. The flats comprising Roe Location 2585 (~450 Ha) represent the major receiving point. Extensive sheet flows occur during large events and there is substantial evidence of surface erosion within the paddock. Attempts have been made to facilitate excess water disposal, however it is evident that the minor relocation afforded by the current drainage is causing excess water problems in adjacent road reserve areas.

In the natural system the creek passing through Roe Location 2585 discharged into the Wooded Yate Swamp within the Lake Bryde Nature Reserve. However it is likely that original streamflow volumes would have been substantially less than those now experienced. While the road profile currently acts as a flow barrier, it is suggested that had it not been in place then surface water degradation along the northern edge of Lake Bryde Reserve would be much more substantial (i.e. similar to that experienced on the western boundary of Lakeland Nature Reserve). The scale of degradation occurring below the road reserve floodway drain, approximately 1 km north of the junction supports this assessment. However detaining water within Roe Location 2585 and the adjacent road reserve has increased the recharge potential. The resulting water table rise will impact directly upon the reserve. For example, the large volumes of water that ponded along the bitumen road during the August 2001 event infiltrated within 24 hours.

Effective surface water management is critical to maintaining the condition of the vegetation systems within the Lake Bryde Reserve and the adjacent road reserves. There is already degradation occurring on farmland and the road reserve adjacent to the Fourteen Mile Road. Transfer of excess water into the Lake Bryde reserve is no longer an option due to the negative impacts that can be expected. Medium to long term impacts from water table recharge, irrespective of salinity levels, is expected to be more significant. At present there is no monitoring of water table rise along the boundaries of the Lake Bryde reserve to quantify this risk.

Management options for this area need to independently address both the problem and the cause. Project 3 comprises two components. Project 3a will provide initial relief to the lower flats within Roe Location 2585 in order to manage the ponding and provide protection to the northern Lake Bryde Reserve boundary. The second phase, Project 3b, must address a reduction in the net export of water from the upper catchment.

Project 3a will deal with a substantial volume of water generated during run-off events. As it is undesirable to promote additional flows into the Lake Bryde Reserve an alternate outlet is required. Field inspection identified the watercourse, which extends along the northern paddock to the floodway on Fourteen Mile Road (Figure 24). Water on Roe Location 2585 can be relocated in transit using cross-slope waterways with a final waterway/bank parallel to the road boundary fence to convey remaining water following flow events. These works will address road and drainage problems associated with the realignment of Fourteen Mile Road. It is likely that water shedding from the road formation and the small rise in the northeast corner of the Lake Bryde Reserve during large rainfall events will provide the inflow volumes necessary to inundate the swamp.

The earth-works design should ensure that the excess run-off is not channelled into areas where it will become a new inundation problem. Initial inspection suggests that it will be necessary to convey water across the floodway on Fourteen Mile Road and into (and if necessary through) Roe Location 2586 (Russell) via an old drainage line that discharges into a natural salt lake. Below this point there is a chain of small depression storage lakes that lead into the Lakeland nature reserve. The transfer of water away from the Newdegate-Pingrup Road, through the floodway and into the salt lake is viewed as a limited alternative that is dependent upon a medium-long term reduction in run-off volumes from the catchment above Roe Location 2585. At present a saline scald is developing in the paddock immediately above the floodway and a recently constructed short drain section below the floodway has produced a saline surficial detention area within the sandy profile (Figures 25-28) that has degraded a 2-3 Ha area of road reserve vegetation.

Various management options exist for the upper catchment. Run-off reduction should be promoted where possible by either biological or engineering techniques that are acceptable to the landholders. However, water harvesting and storage are likely to have the most beneficial impact in the short-medium term. Run-off volumes produced by the upper catchment during the August 2001 event were sufficient to fill three large farm dams (I. Kent, *pers comm*). Limited water reached the lower valley flats. With improved harvesting structures it is expected that the volume removed during larger events could be considerably more. One option, given the state of existing emergency supplies at Lake Bryde, is to consider constructing and servicing a community water supply of some 15,000-25,000 m^3. During an informal meeting with landowners it was ascertained that there is interest in considering water-harvesting opportunities to increase on and off farm water supplies.

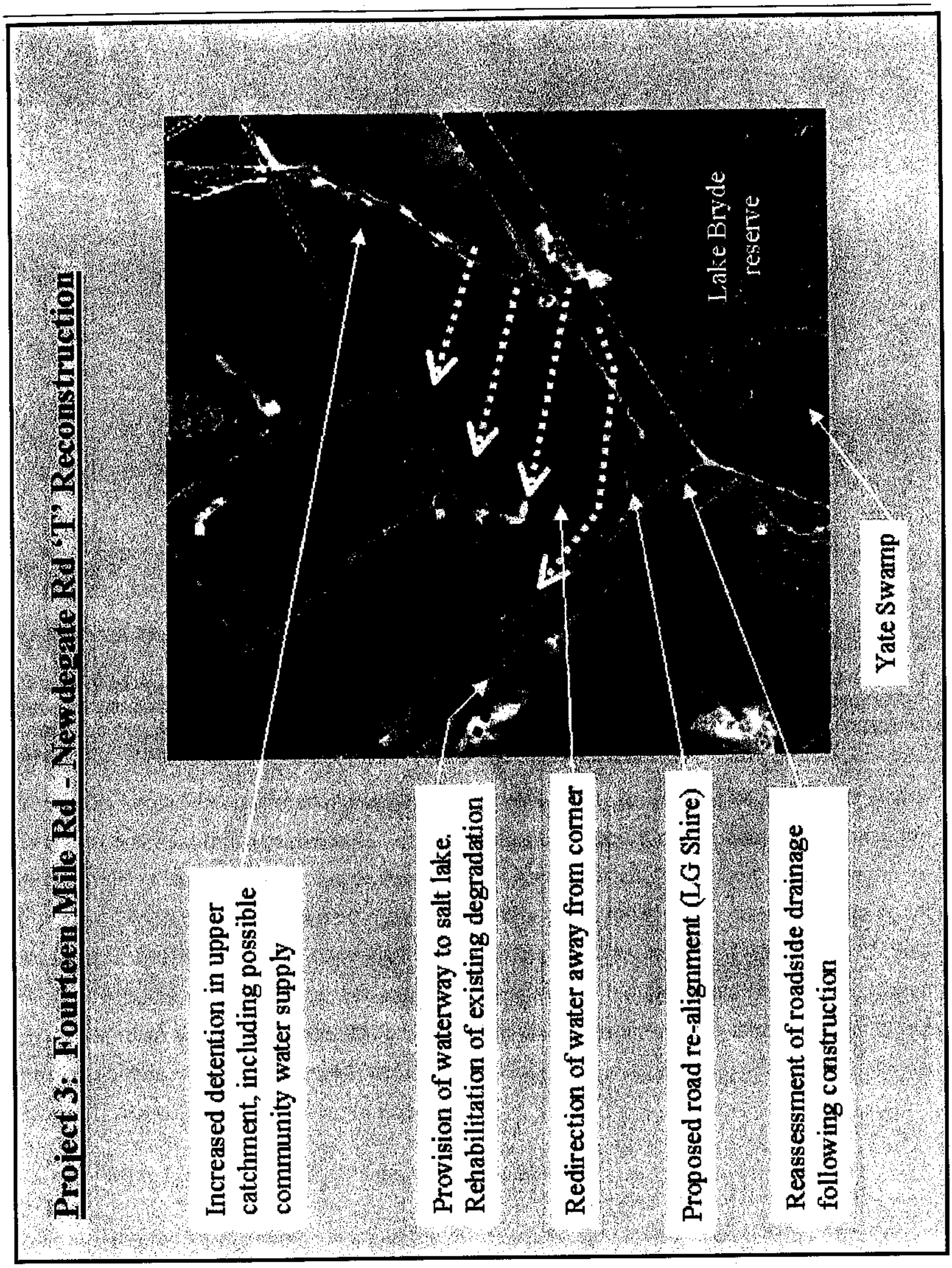


Figure 24: Proposed management options for Roe Location 2585 (Olivers) and adjacent road reserves.

Extension of the project to the west into Roe Location 2586 (Russell / Kuchling) permits incorporation of off-site impact management. Routes shown are indicative only and subject to proper assessment and design.

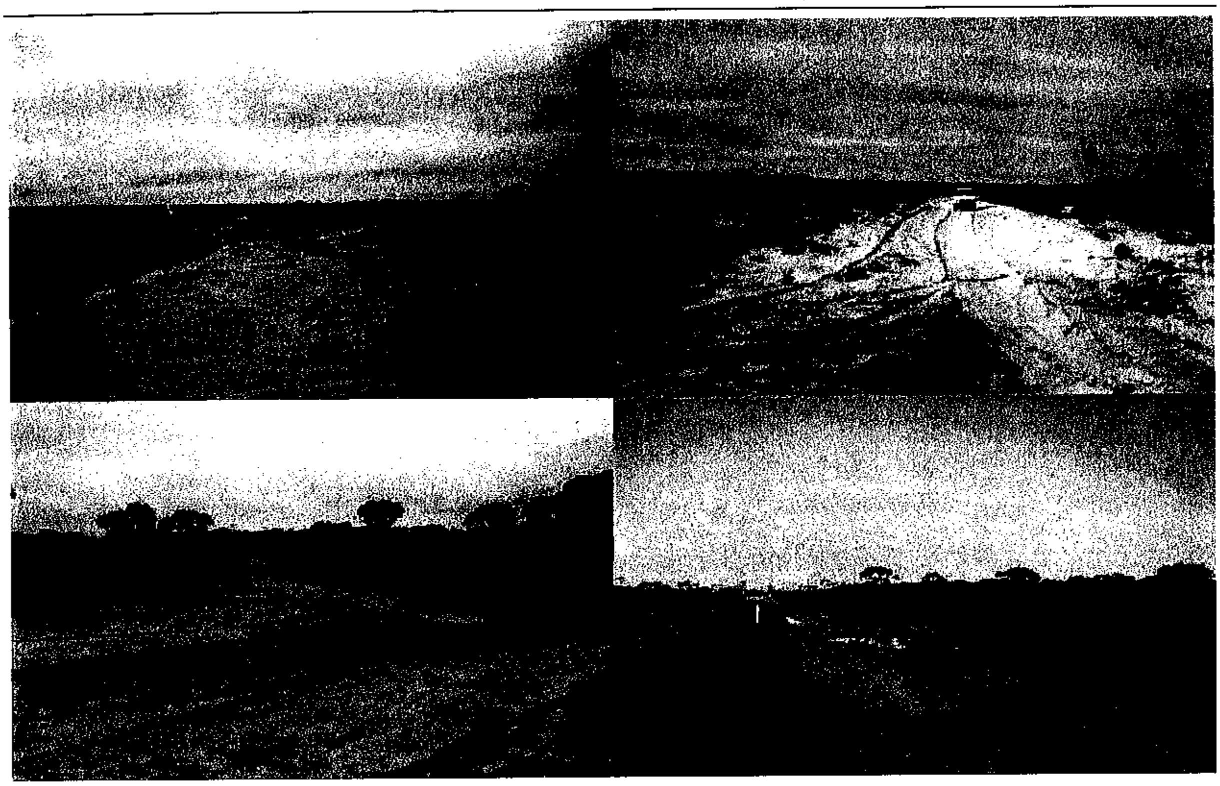


Figure 25, 26, 27 and 28: Fourteen Mile Road

Surface erosion caused by sheet flows in Roe Location 2585 (top left). Degraded sand plain area at end of drain from Fourteen Mile Road (top right). Recently constructed diversion drain (bottom left) adjacent to Newdegate-Pingrup Road that diverts water into roadside infiltration areas and directly into Lake Bryde Reserve via culverts (bottom right).

Project 3a should be commenced with some urgency due to the Shires proposed works. Given the potential drainage benefits to the road there is opportunity to use Shire equipment where practical to complete some of the work. Assessment and resolution of the use of the salt lake in Roe Location 2586 as a receiving point is an extremely high priority. In the event that the salt lake area cannot cope with long term impacts (particularly if run-off reduction is not achieved) then it will become necessary to consider moving the water through the system to join the main waterway proposed for Lakeland nature reserve. This latter solution is not desirable due to both the expected cost and the additional stress that will be placed upon the receiving point within the Lakeland nature reserve.

3.4 Lakelands Nature Reserve (projects 4a and 4b)

The Lakeland nature reserve represents the downstream exit point of the Lake Bryde wetland system. This situation makes it a receiving point for bypassed water that may cause local degradation if not managed correctly. As a natural valley feature the Lakeland nature reserve is susceptible to the impact of secondary salinisation (i.e. the accumulation of off site salt) and local water table impacts. Initial signs of degradation already exist within parts of the reserve, though these are typically limited to reserve boundaries adjacent to cultivated areas. The localised nature of the current degradation suggests that these primarily relate to excess surface run-off.

At this time there is limited evidence of valley scale degradation that might be applicable to generalised underlying groundwater rise. This inference is supported by the apparent good condition of the small swamp and surrounding vegetation in the hydro-aeolian soil profile at Mallee Hill Road. Lakes within the main Lakeland nature reserve group also show little sign of degradation. However those along the western boundary are already showing rapid succession to samphire, and death of riparian vegetation.

Proposed management options deal with the Lakeland nature reserve in two parts. The upper portion being that between Bairstow Road and Newdegate-Pingrup Road, which also includes Roe Location 2586 (Russell / Kuchling). The lower section between Bairstow Road and Mallee Hill Road is exclusively nature reserve and comprises the main lake chain.

3.4.1 Lakeland Nature Reserve - Newdegate-Pingrup Road to Bairstow Road (project 4a)

The upper section comprises two distinct landscapes; Roe Location 2586, which is mainly cleared except for some minor stands of remnant vegetation, low quality valley land and Reserve 29023. Deep grey clays dominate much of the valley area and demonstrate the bulk of saline degradation. The valley cross-section through the reserve is well defined and most of the Lakeland nature reserve's western boundary is located on or near to the break of slope. Flow continuity and prevention of degradation spread are the main objectives for the upper Lakeland valley system. Within Roe Location 2586 a number of substantial salt scalds have developed on significant low land sections and these no longer support cultivation. There has been some attempt at land-care through re-vegetation and fencing, however the spatial extent is small and the benefit perceived to be minor. In peak flow events Roe Location 2586 receives sheet flows originating from both the culvert and the floodway on the Newdegate-Pingrup Road. These are both natural landscape flow routes that originated from a confluence geomorphology prior to construction of the roads. Except for some basic surface drainage the issue of excess water has not been addressed.

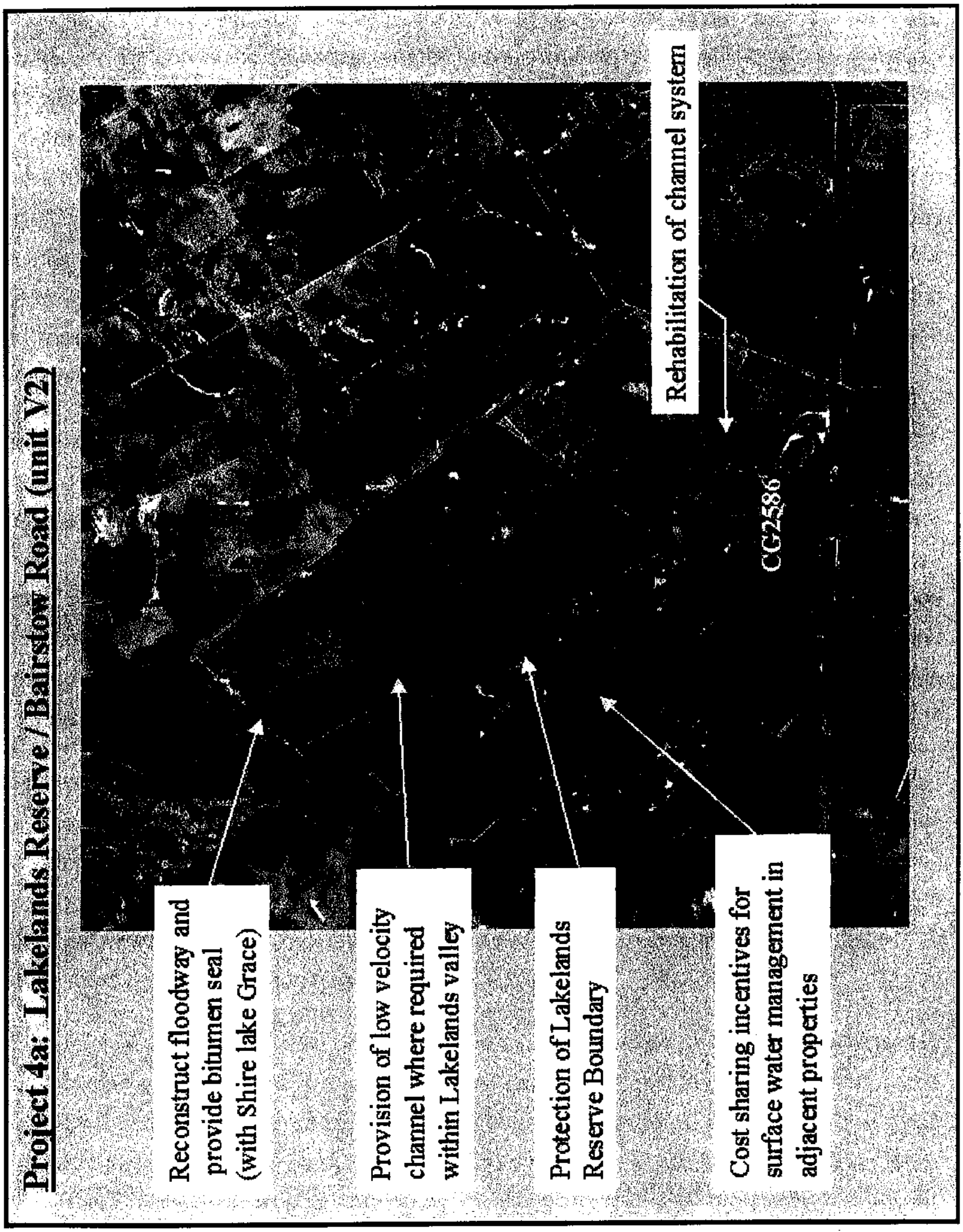


Figure 29: Proposed management options for the Lakeland Reserve valley section from Pingrup-Newdegate Road through to Bairstow Road.

This section involves a substantial area of degraded riparian landscapes within Roe Location 2586 (Russell / Kuchling). Works shown are indicative only and subject to proper assessment and design.

Management options for Roe Location 2586 need to address the further expansion of saline scalds and the continuing degradation of the riparian system. A broad, low velocity waterway structure is required to provide flow continuity from both the floodway and the culvert on the Pingrup-Newdegate Rd, through the main valley channel (Figure 29). This waterway should link into the waterway in the Lake Bryde Road valley. Local shallow drainage can be used to provide post-event inundation relief. It is recommended that the full width of the valley and riparian fringe be fenced off and substantially rehabilitated. Material excavated during the waterway construction can be utilised to repair degraded areas (e.g. filling low-lying areas and depressions) and provide raised beds to encourage the establishment of rehabilitation vegetation and minimise the impact of waterlogging.

Grade banks and roaded banks for water harvesting should be implemented in both Roe Location 2586 and Roe Location 2587 to reduce the impact and degradation associated with lateral inflows at the reserve's south-western corner and along the western boundary. Where up-slope engineering cannot be effectively implemented then a major intercepting structure could be constructed along the reserve boundary near the break of slope. Upper slope conditions are suitable for water harvesting, thereby providing options for cost sharing and utilising the excess water as a resource. Tributary inflow issues should be considered in conjunction with Projects 10 and 12.

Inundation upstream of Bairstow Road is an identified degradation issue (Kevron 2001; Sinclair Knight Mertz 2001). The presence of the road and dense vegetation is an impediment to shallow valley flows, primarily though loss of momentum. Local modifications to the road have historically had minimal benefit. Floodway reconstruction and incorporation of a shallow waterway to deliver and remove water from the road reserve area is deemed to be the most appropriate option (Figure 29).

Given the low usage of Bairstow Road and the number of alternate routes, it is recommended that the road be reconstructed to a ground level floodway formation of some 50-100m, and concrete edged to protect the road formation. There is limited scope for a culvert pipe since any minor installation would be hydraulically inefficient given the depth to water spread ratios for the area. Consideration should be given to either bitumen sealing or restricting access during wet periods to minimise formation damage when saturated. The waterway structure should continue through the flats on the downstream side.

Proposed options within the valley will need to consider continuity of the waterway between Lake Bryde and Pingrup/Newdegate Road. There is necessity for constructed sections through numerous natural detention points where channels are poorly defined and vegetation stress evident. Waterways may not be required where natural channels are better defined, however consideration must be given to minimising the potential impact of changed delivery scenarios.

3.4.2 Lakeland Nature Reserve - Bairstow Road to Mallee Hill Road (project 4b)

The northern section totally comprises the Lakeland nature reserve. Degradation is occurring adjacent to the western boundary where miscellaneous inflows and tributary inflows are causing obvious stress. A number of near boundary playas and depression lakes are showing evidence of increased wetting and salinity impacts through loss of vegetation and establishment of Samphire. Degradation is generally less advanced within the valley and channel systems, except in the flats immediately below Bairstow Road and within some low lying sections located on grey clay profiles.

The substantial number of lakes within this section provides a natural, large capacity detention point within the Lake Bryde wetland system. Limnological data is limited. It is probable that many of the larger lakes do not fill substantially except during large events when continuous valley flows are experienced. The apparent good condition of the larger lakes is thought to be a consequence of upstream flow impediments preventing inflows from smaller flow events from. In January 2000 substantial volumes were observed crossing Bairstow Road (E. Bramwell, CALM, *pers. Comm.*) and aerial photography shows all lakes holding water (DOLA, 2000). Although there was no system flow during August 2001, sufficient run-off occurred from adjacent agricultural slopes for a number of degraded low-lying areas and lakes to experience ponding.

The first priority for this section is the protection of the western boundary ecosystems from agricultural run-off. This can be achieved by direct interception of miscellaneous off-paddock influxes from Roe Location 2595 and Roe Location 2594 via a combination of on-farm surface water management and interception structures at the reserve boundary, or within the reserve where the boundary is above the break of slope (Figure 30).

The potential for a successful outcome is higher than similar projects proposed to the south (Project 4a) due to the involvement of one landowner (Wilcocks), short relatively steep slopes and limited tributary inflows.

Reconnaissance of low-lying areas at the northern-western boundary of the Lakelands system (i.e. adjacent to Mallee Hill Road) identified significant saline impacts. As for other valley degradation there is a strong association with the grey clay soil classification similar to those observed in other valley sections. Lakes and vegetation within the hydro-aeolian landscape appear to be less affected, though there is some death among larger trees north of Mallee Hill Road. It is suggested that excess surface water (inundation, waterlogging and

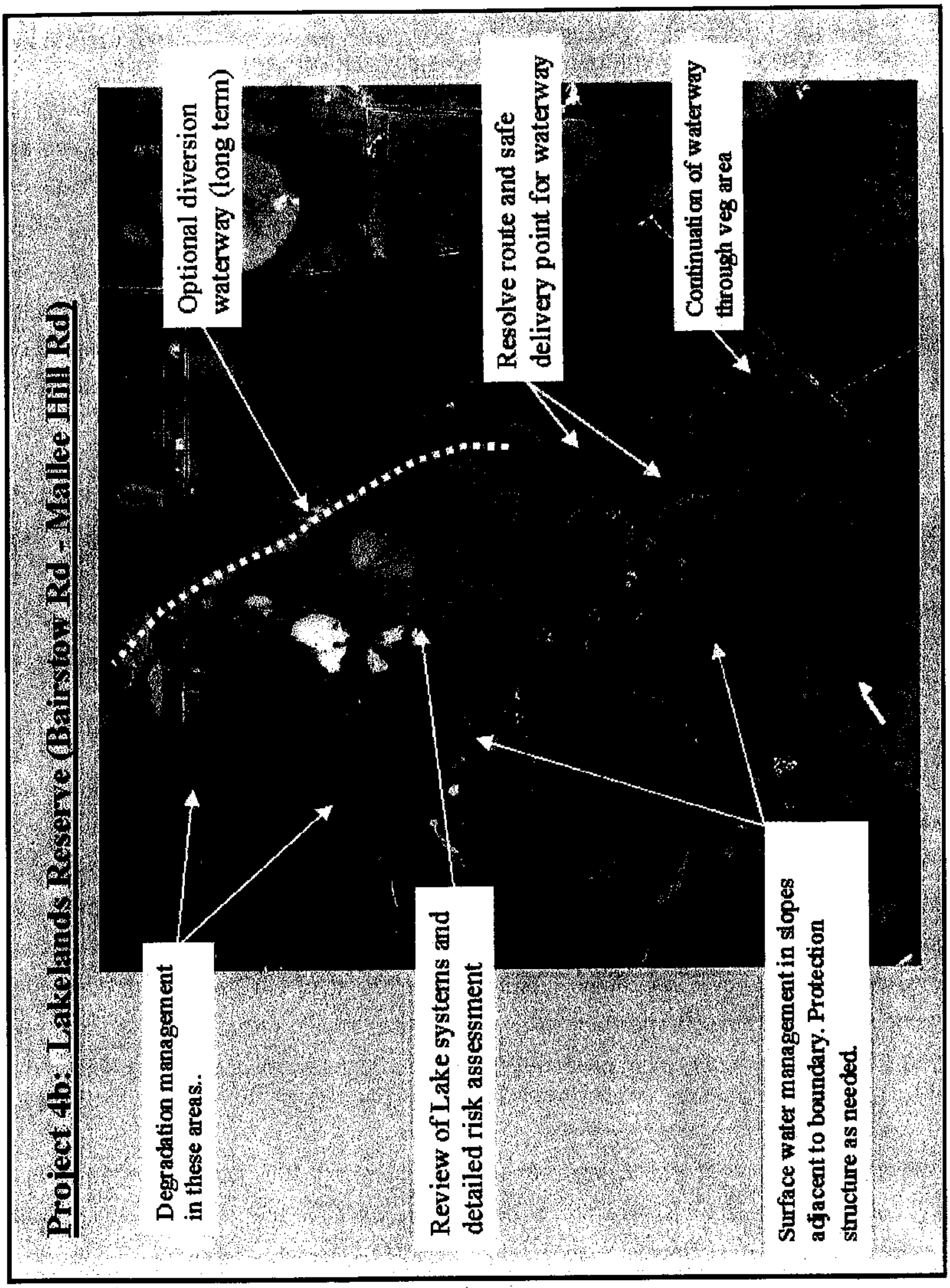


Figure 30: Proposed management options for the Lakeland nature reserve valley section from Bairstow Road through to Mallee Hill Road.

Works shown are indicative only and subject to proper assessment and design.

surficial salinisation) continues to dominate degradation processes though there is suggestion of a more substantial groundwater or broad water table impacts north of Mallee Hill Road. Further investigation and better monitoring is required to establish the short and medium term risk of these areas before an appropriate management strategy can be recommended.

An important aspect of Project 4b is the resolution of an acceptable termination strategy for the proposed waterway structures (Figure 30). It is important to note that these are not intended to facilitate ongoing drainage but simply to manage incompetent flows through the valley system until these can be safely delivered back into the natural system. There is significant scope to take advantage of evaporative depletion within purposely-selected lakes provided local recharge and degradation can be acceptably managed. Such an outcome could be achieved by continuing the shallow low velocity waterway from Bairstow Road along the current channel and then diverting this with a bend to the west to allow entrance to the minor lake chain connected by a series of spillway channels (Figure 30).

The total storage capacity required depends directly upon design outcomes from Projects 1, 2 and 4a and consideration of any environmental issues determined from a hydrological and biological assessment of the nominated lake and channel areas. In the event that termination within the Lakelands Reserve is not desirable then further consideration of a diversionary option using the depressions east of the main channel would warrant further investigation.

3.5 Days Creek / Needilup Rd (project 5)

The creek running through land parcels along the Pingrup-Newdegate Road above Needilup Road is one of the fastest sub-catchments in the upper South Lake Bryde sub-catchment. Landscape mapping identified it as a high shedding zone characterised by an etched interfluve. At Ryans Road, approximately 100m past Needilup Road, flows spread broadly across the landscape before joining the South Lake Bryde creek in Roe Location 2574 (Ryan), and continuing to the Lake Bryde Rd inlet culvert. Run-off generation is enhanced by the presence of the bitumised Newdegate-Pingrup Road that runs downslope and provides a substantial catchment in its own right, capable of generating more than 5,000 kL from a 20mm rain event.

During rainfall in August 2001 the drain beside the road was observed to flow and complete its discharge within hours. The main creekline flowed for some 24-36 hours. The Needilup Road floodway was active for at least 12-18 hours of this period. Run-off caused a 50m wide flow across Ryans Rd (near Newdegate Road intersection) and across Roe Location 421 (Smarts). Figures 7, 32 and 33 demonstrate this event. These flows comprised the bulk of water that entered Lake Bryde. In a visual inspection of the Lake Bryde area during August 15-16, 2001, only the nearby Steele Road catchment generated similar volumes.

Run-off water from this sub-catchment is not saline. The inherent velocities involved, even during small events, are responsible for much of the erosion damage and sedimentation seen throughout the flow route in Roe Location 421 and upon its discharge into Roe Location 2574. Both the volume and velocity present an issue for management activities in the lower flats.

Lewis (2001) identified water spreading in Roe Location 421 as a potential source of episodic recharge. Though evidence was limited by insufficient event data during the analysis period it is possible that post event recharge might be a significant outcome from large events where extensive inundation occurs across Roe Location 421. During August 2001 it was observed that water management within the existing channel and surface water management structures were sufficient to promote flow continuity throughout the event and hence substantial ponding did not arise. However, there is no doubt that the structures in place would have been inadequate for a larger flow event, thereby leaving considerable scope for recharge to occur as paddocks become inundated.

Prior to reaching Needilup Road there is substantial opportunity for creek water to be developed as a resource. It is therefore recommended that water harvesting activities be promoted in upper catchment properties in order to reduce catchment discharge volumes during smaller events and to provide a means minimising peak flow velocities during larger events. A reduction in run-off behaviour is required to complement improved surface water management structures within Roe Location 421 (Smart) and mediate delivery into the riparian system recommended for Roe Location 2574 in project 2.

Figures 32 and 33: Flows at Needilup Rd generated by road and sub-catchment run-off during the August 2001 event.

The catchment has a low shedding threshold and readily generates run-off. Upon reaching Needilup Road the water tends to spread, before flowing into the flats below Ryans Road. Management options seek to reduce the run-off generated by smaller rainfall events.

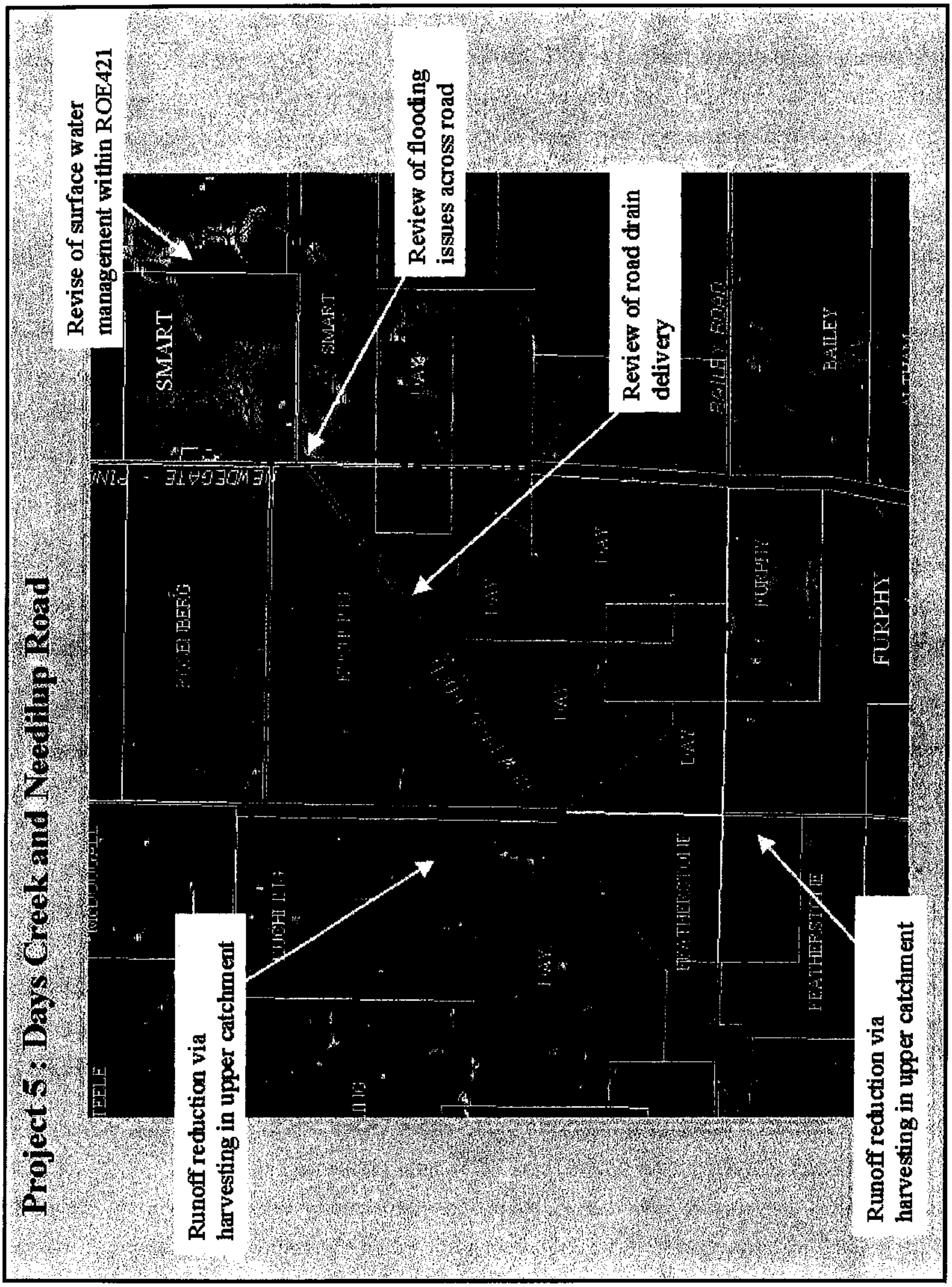


Figure 31: Proposed management options for Days Creek.

This catchment has direct interaction with the Pingrup-Newdegate Road, which is the source of a fast initial flow during rain events. Below Needilup Road the sudden change of grade results in substantial spreading across Ryans Road and into Roe Location 421 (Smarts). Water quality and rapid run-off generation in this catchment is ideal for water harvesting .

A potential issue with establishing management objectives for the Days Creek system is the perceived benefit of the run-off water to Lake Bryde. This is evident among local landholders who have expressed reservation towards reducing flow volumes. However, even with a net storage capacity of 30,000 to 50,000 m^3, surface water management is unlikely to impact upon medium-large events. On these occasions the Newdegate-Pingrup Road alone is likely to generate volumes of 13,000-18,000 m^3 in a discharge period of less than 24 hours, while the full catchment area of 7000 Ha is likely to deliver a volume exceeding a million cubic metres over the total flow period[1]. The harvesting recommendations made in this proposal are intended to attenuate delivery and reduce the impact of run-off events below natural thresholds.

3.6 Lake Bryde north-eastern inflow (project 6)

The sub-catchment to the east of Lake Bryde extends some 18km and 9,700 Ha. The high priority portion is the 2000 Ha located immediately to the east of the lake. This land is an upslope recharge area that could be managed to provide fresh water recharge and flushing opportunities to Lake Bryde.

Immediately east of Lake Bryde, and within the reserve, inflow inundates a defined shallow valley. Aerial photography clearly shows this valley to be holding water following the January 2000 event (DOLA, 2000). Field inspection found the area to be an elongated swamp on grey clays with water level staining at 200-300mm depth. The valley is 1.6 km long and confined by a sandy ridgeline of open woodland and gums. Stereo interpretation and contour data generated from the Kevron DEM identify two outlet watercourses that link the valley to Lake Bryde (Kevron 2001). Using RTK-GPS it was established that there is a sill between the swampy valley and Lake Bryde that requires a depth of approximately 0.5-1.0m within the main swamp area for inflow to occur (Figure 35).

Preliminary assessment of the valley morphology suggests a notional threshold volume of some 100,000 m^3 over an inundation area of 22 Ha. Ground inspection identified that flows probably occur through the watercourse that leads to the lake during very large events. Based on modelled outcomes, an inflow from the upper catchment of approximately 8 m^3/s over a four-hour period is considered to be sufficient for inflow to occur. Figure 34 shows

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[1] equates to 14 mm per unit area from a 3-4 inch or 75-100mm-rainfall event. It is probable that this figure is underestimated for very large events.

waterway flows above the reserve boundary during an event of 1992 from property Roe Location 2572, which meet these criteria.

Inundation within the Lake Bryde reserve valley, and upslope farmland, is expected to promote local recharge. The condition of *Melaleuca* species around the swamp is reasonable though deaths have occurred for larger species within the valley and along the fringes. Within remnant vegetation on Roe Location 2558 there is evidence of salmon gum fatalities and succession to *Melaleuca* species at location E 671900, N 6310360 (AMG84). General vegetation condition, lack of degradation in the vegetated swamp on Roe Location 2558 and inspection of an excavation 300m to the north suggest that *in situ* conditions are probably not saline. Degradation, probably due to saline waterlogging, is evident in the larger depression 1km to the NNE (E 671270, N 6310946).

Properties Roe Location 2558 (Kent) and Roe Location 2572 (Garlick) are receiving landscapes. In Roe Location 2572 surface water is being managed in the south-western corner by broad grassed waterways (Figure 34) which tend to channel water into the valley beside Lake Bryde and reduce local ponding. It is recommended that surface water management plans be implemented for the remnant vegetation area on Roe Location 2558 and extended within Roe Location 2558/Roe Location 2572 to the common boundary with Roe Location 2557 with some priority. This would address uncontrolled overland flows and localised recharge. Slopes within Roe Location 2558 are suitable for water harvesting.

Water harvesting and surface water management within Roe Location 2557 and Roe Location 2558 may offer an opportunity to establish an alternate fresh water inflow regime for Lake Bryde. Harvested fresh water and non-saline flows from the upper slope during large rainfall events can easily be routed via the existing natural route into Lake Bryde. Removal of 0.5m material from the sill area is a practical management option that would increase event inflow into Lake Bryde and alleviate adverse recharge from the swamp area inside of the reserve boundary.

The upper catchment (Roe Location 2557, Roe Location 2556, Roe Location 2559 and Roe Location 2560) comprises some 6,500 Ha of shedding slopes and defined valley flow channels. Channel characteristics at Dykes Road suggest quite rapid flow velocities in this area. There is a need for surface water management and water harvesting in order to reduce or delay run-off volumes onto the flats. Management options should be implemented to meet these objectives, regardless of the lake inflow proposals described above, in order to protect water quality and reduce lower valley degradation along the Lake Bryde reserve eastern boundary.

Figure 34: Run-off entering the Lake Bryde reserve from Roe Location 2557 during 1992.

Management of water delivery and deliberate freshwater harvesting could provide non-saline water to effect more efficient flushing of Lake Bryde (photo courtesy G.Garlick).

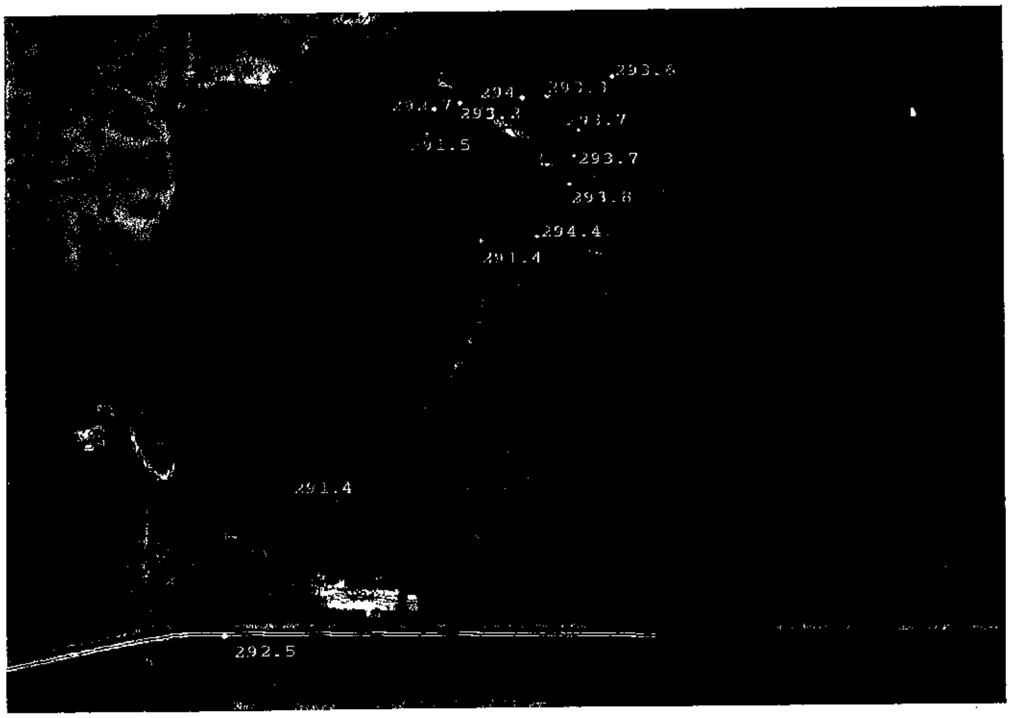

Figure 35: Ortho-image showing topography and spot heights for the Lake Bryde inlets and lunettes.

The two natural inflow channels on the NE edge of the lake are evident. The underlying aerial photograph (DOLA 2000) shows ponded water within the elongated swamp area to the east of the lake. The blue colouring represents the grey clay profile (the remainder is within the hydro-aeolian profile).

Figure 36: The NE inlet channel.

The channel is a 4-5m wide watercourse that cuts through elevated open woodland sand ridges. Vehicle is parked within watercourse at track junction.

3.7 East Lake Bryde sub-catchment (project 7)

The East Lake Bryde sub-catchment comprises three distinct management units. Approximately 16,000 Ha are located within the Lake Magenta nature reserve, some 1,500 Ha are comprised of deep sand profiles within the East Lake Bryde nature reserve, and the remaining portions, some 6,000 Ha, are agricultural landscape units. Review of the catchment suggests that 4,900 Ha comprising the East Lake Bryde nature reserve, properties Roe Locations 2552 and 2553 (Grant-Williams), and adjacent run-off generating slopes, should be the primary focus of management activities. The sub-catchment within Roe Locations 426 and 427 (Presser) and Roe Location 2555 (Dykes) is treated as a separate entity.

A major feature of the East lake Bryde sub-catchment is the apparent lack of surface connection to the main Lake Bryde wetland system. The valley morphology is well defined yet lacks a route beyond the salt lake inflow at E 674050, 6307254 N (AMG84) on Roe Location 426. Observations by landholders in the area suggest that this valley system rarely flows even during larger events. Data for East Lake Bryde suggests that volumes within the lake do

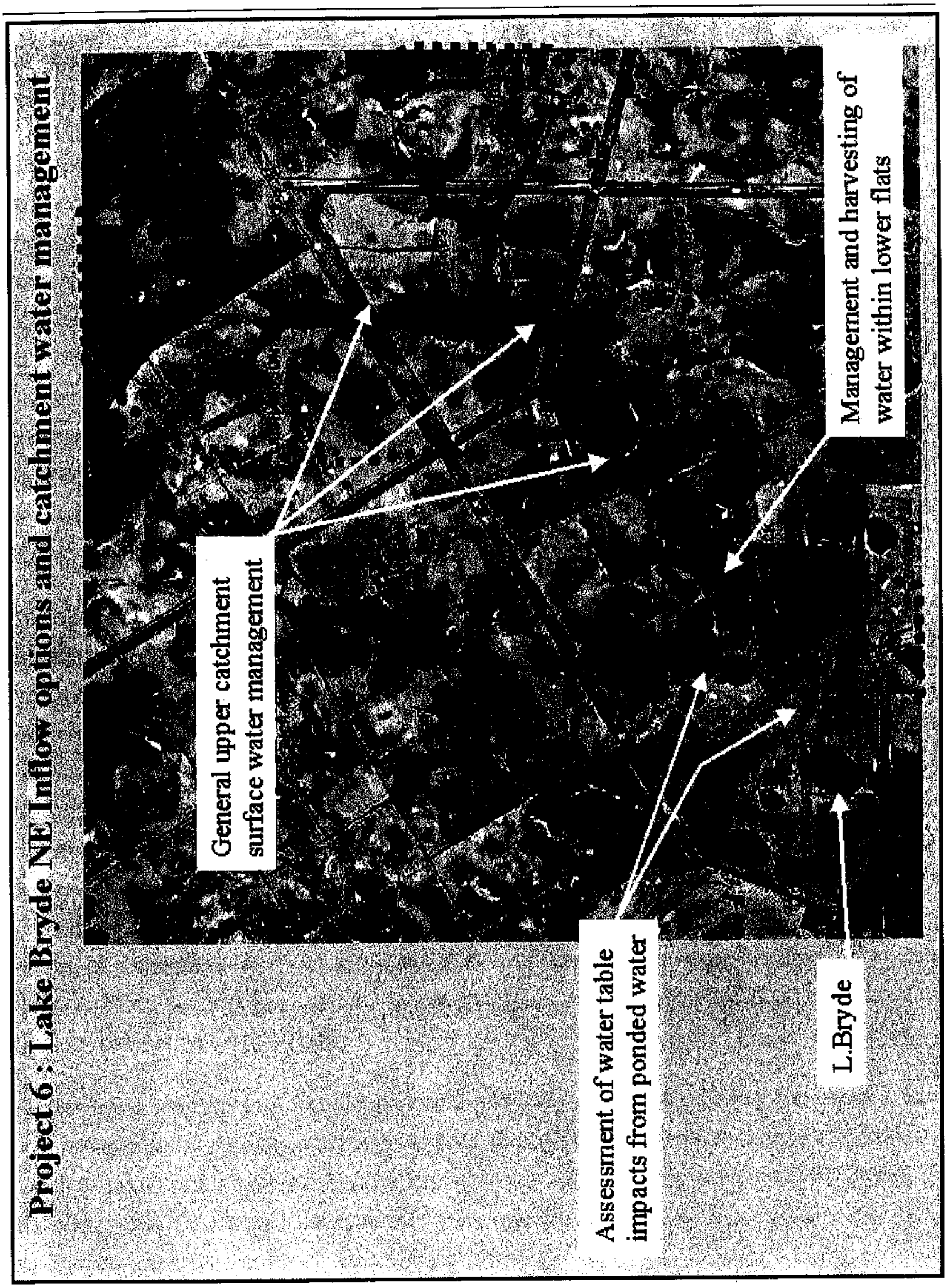

Figure 37: Proposed management options for the Lake Bryde NE inlet and its catchment.

not accommodate the flow volumes observed in the landscape to the east of Grant-Williams Road below the Lake Magenta nature reserve (Figure 39).

The deep sands to the west of Grant-Williams Road may provide a substantial recharge mechanism that is not adequately understood. Giraudo *et al* (1996) identified that the valley is aligned to a section of the Magenta Sheer Zone and suggested that the area is strongly compartmentalised. Sinclair Knight Mertz (2000) do not address the area specifically, other than to identify the potential role played by sandplain mechanisms. It is suspected that because of the presence of the deep sand profile, the structural geology and the obvious interaction with substantial surface water volumes, the significance of this area to the Lake Bryde wetland system may be different to that implied by continuity modelling used in the SKM assessment. For example, downstream and adjacent to natural freshwater wetlands are two substantial salt lakes within Roe Location 426 and RES29021 with bed profiles and geomorphology that imply a natural occurrence rather than a more recent transition.

Given the extent of native vegetation, and its condition, within the East Lake Bryde nature reserve valley system, specific management strategies west of Grant-Williams Road are probably not needed in the short term. Discharge behaviour from the Lake Magenta nature reserve is likely to be 'natural' and therefore within reserve management is not desirable at this time. The focus of management activity should therefore concern run-off and recharge management within the agricultural landscapes between the two reserves. In the upper slope portions minimising run-off using water harvesting and surface water control should be a priority. Within the valley flats flow braiding and sheeting are evident (Figure 39). The use of grassed and cross slope waterways is recommended to control ad-hoc flows and avoid water-logging of recharge areas. The option exists to divert some of the water into the lake on Roe Location 2552. Appropriate water management through Roe Location 2553 and Roe Location 2552 should maintain water quality.

The receiving area within Roe Locations 426 and 427 has numerous small depressions that hold water for short periods after run-off events. It is probable that these depressions directly recharge underlying aquifers. Field reconnaissance suggests Roe Location 2555 (Dyke) is the primary run-off source. Slopes in this area, and the relatively small sub-catchment size, make water harvesting an ideal management option.

Surface water management within Roe Locations 426 and 427 can be used to isolate depressions from unnecessary inflows. Consideration should be given to run-off reduction across the boundary between Roe Location 2555 and the East Lake Bryde nature reserve, though degradation is not extensive at this stage.

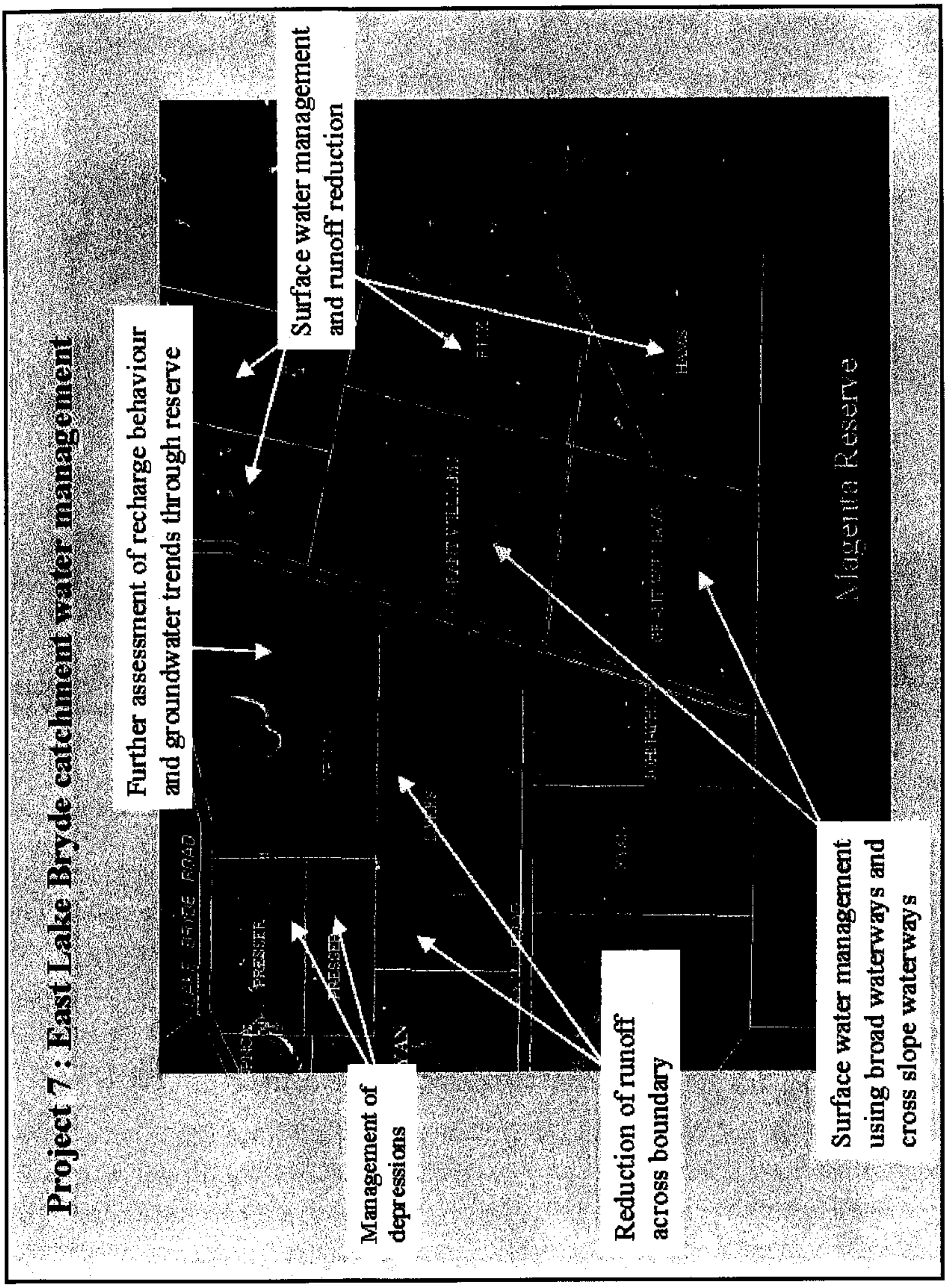

Figure 38: Proposed management options for East Lake Bryde.

Figure 39: Uncontrolled braided flows in agricultural landscapes east of Grant-Williams Road (Jan 2000).

In larger events substantial volumes of run-off are generated in the Magenta Reserve. Water flows northward through agricultural landscapes before crossing the road and flowing into the East lake Bryde Reserve. (photo courtesy E. Bramwell, CALM)

3.8 South Lake Bryde flats (project 8)

The South Lake Bryde flats are subject to massive inundation and are the primary source area for salts entering Lake Bryde and the Bryde valley system. The South Lake Bryde valley flats have been the main focus for landcare and catchment activities to date. Much of the work has centred upon generic approaches that have been implemented in a localised fashion. To achieve a more substantial water management objective at a catchment scale it is necessary to adopt a multiple property scenario that is of a scale equivalent to that of the problem.

Giraudo *et al* (1996) and Sinclair Knight Mertz (2000) have identified potential geological influences throughout this area that may act as conduits for groundwater into the system, or act as barriers to subsurface flows. A program of drilling, geophysics and model analysis is recommended to establish the presence and role of these features. Field reconnaissance and topographic analysis suggest that the flats are receiving and recharge landscapes that are strongly influenced by excessive surface water interaction. The tendency to accumulate run-off is due to a small 1500 Ha area receiving the total run-off volume generated by 28,000 Ha of sloping catchment. Approximately 14,000 Ha of this is located in the Lake Magenta nature reserve and is only likely to contribute during large or very intense rainfall events. In this area it is likely that up-gradient groundwater recharge and flow mechanisms are insignificant compared to *in-situ* recharge and evaporation processes occurring within the flats. Extensive re-vegetation in this area may be of limited benefit in managing the recharge unless the large volumes of off-site water (Figure 41) are also managed to reduce the frequency and duration of an inundation event.

The primary objective for the flats is to reduce the accumulation of off-site water. A reduction in up-slope run-off is required wherever possible. Upslope management should aim to reduce or eliminate excess run-off from small-moderate events such as that of August 2001. Vegetation integration would be most effective in fringe areas where channelled flows spread to sheet flows, or deeper sand profiles occur.

Recovery efforts within the flats should aim to control braiding and sheet flows, and to re-establish riparian buffers. To minimise impediment and re-routing in narrow corridors, channels should either not be vegetated or lightly vegetated and regularly thinned. Riparian buffers will assist in containing flows and provide some recharge control during small-moderate events. During large events they will reduce overflow impacts. Cross-slope and grassed waterways can be used to divert incoming flows around confluence areas in order to reduce inundation volumes at vulnerable sites. Break of slope structures can be used in conjunction with surface water management in local contributing slopes to keep water out of the main inundation areas altogether.

Where geological structures and major recharge locations can be reliably ascertained, surface water control can be used to manage flows through, or around these areas. Flow, inundation and recharge processes within the South Lake Bryde flats between Ryans Road and East Road are extremely complex. To assess these in conjunction with recharge trends is outside the scope of this preliminary study. It is strongly recommended that this area be subject to a thorough study with the aim of better defining management areas, and properly assess the delivery of water into the Ryans Road culvert area.

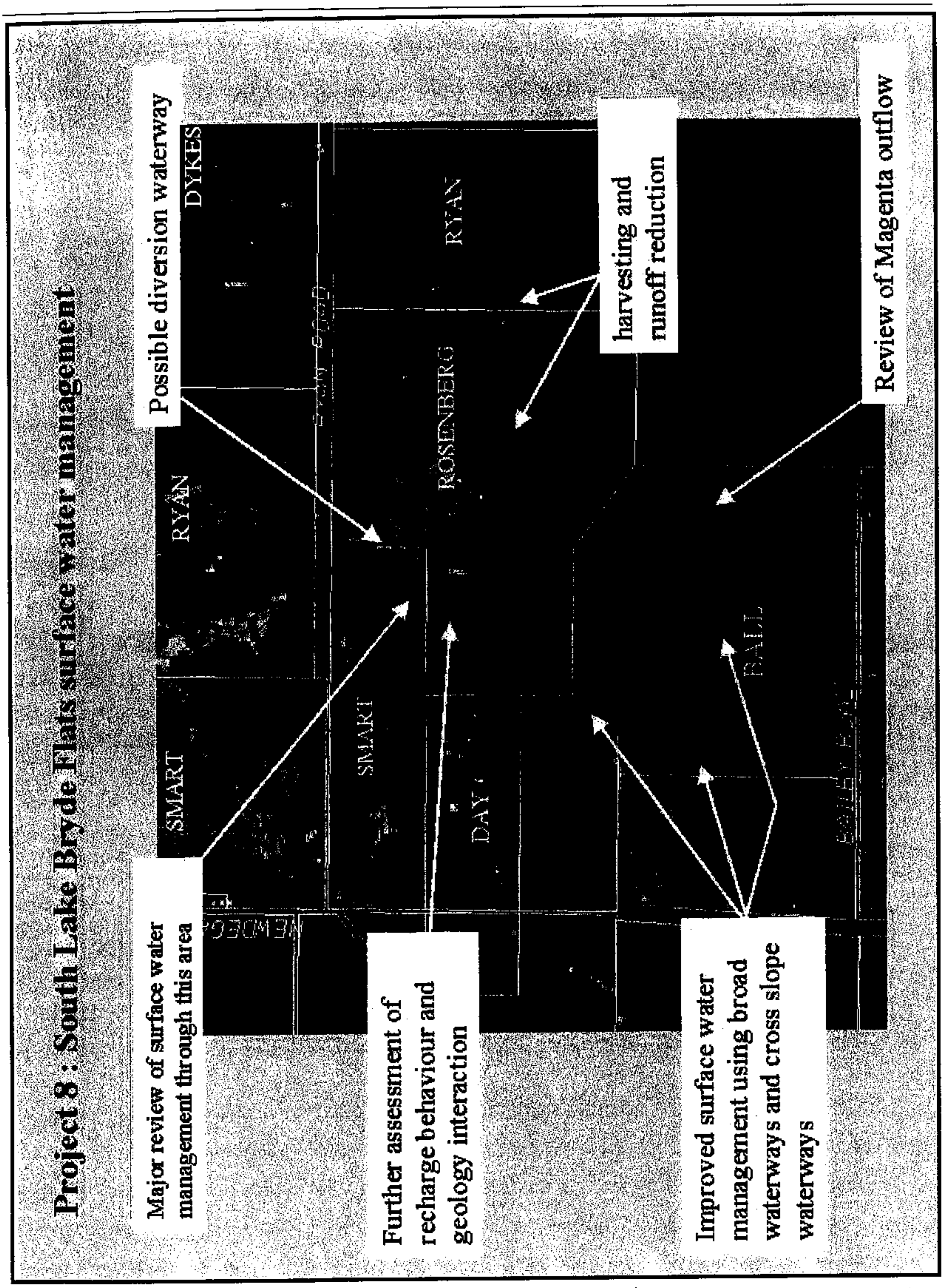

Figure 40: Management issues and options for the South Lake Bryde flats above Ryans Road.

The area is subject to substantial inundation and is suspected of being a major source area for salt and sediment. It is thought that recharge water may be adversely interacting with the underlying geology at this site. Works shown are indicative only and subject to further assessment and design.

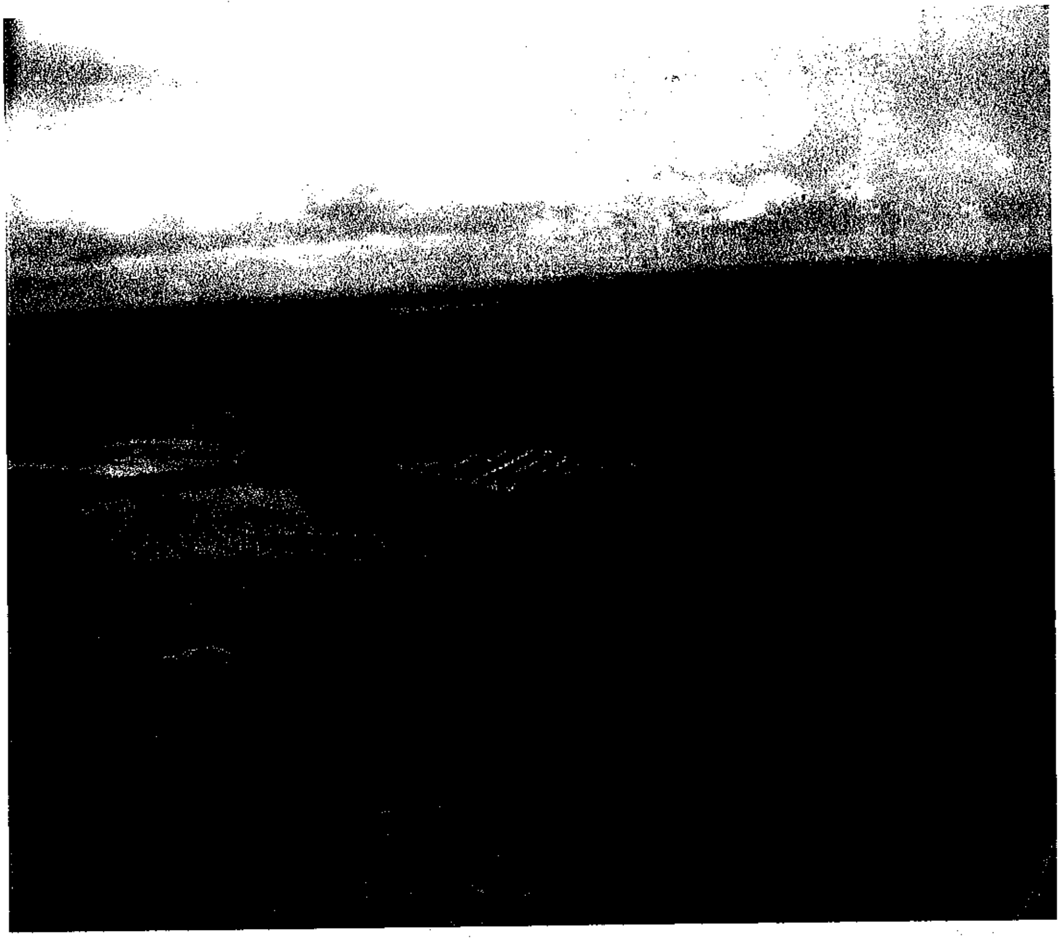

Figure 41: Large scale inundation in the South Lake Bryde flats above Ryans Road (Jan 2000).

Poor flow continuity in low permeability clay soils is causing prolonged ponding, which is expected to be adversely interacting with the underlying geology. Dams within this area are saline, and there is saline surface scalding in low-lying areas. Landcare activities involving trees, modification to the Ryans Road, some contour banking and local surface drainage have not been effective, highlighting the need for management options to be implemented at a scale applicable to the problem. (photo courtesy E. Bramwell, CALM).

3.9 Upper South Lake Bryde sub-catchment - East Road/Needilup Road (project 9)

The upper portion of the South Lake Bryde catchment comprises areas above East Road and watercourses along Needilup Road. The landscape typically comprise steeper slopes and better defined drainage lines that generate substantial volumes of run-off very rapidly. It is quite distinct from the broad flat receiving landscape between Bailey Road and Ryans Road. During moderate to large run-off events substantial flooding occurs across roads, and trafficability is severely impacted. The rapid rate of run-off generation and delivery results in water quickly inundating in the flats about Bailey Road where channel gradients flatten. Landholder observations suggest that run-off generated within hours in the upper catchment can pond and flow for days within the flats below Bailey Road.

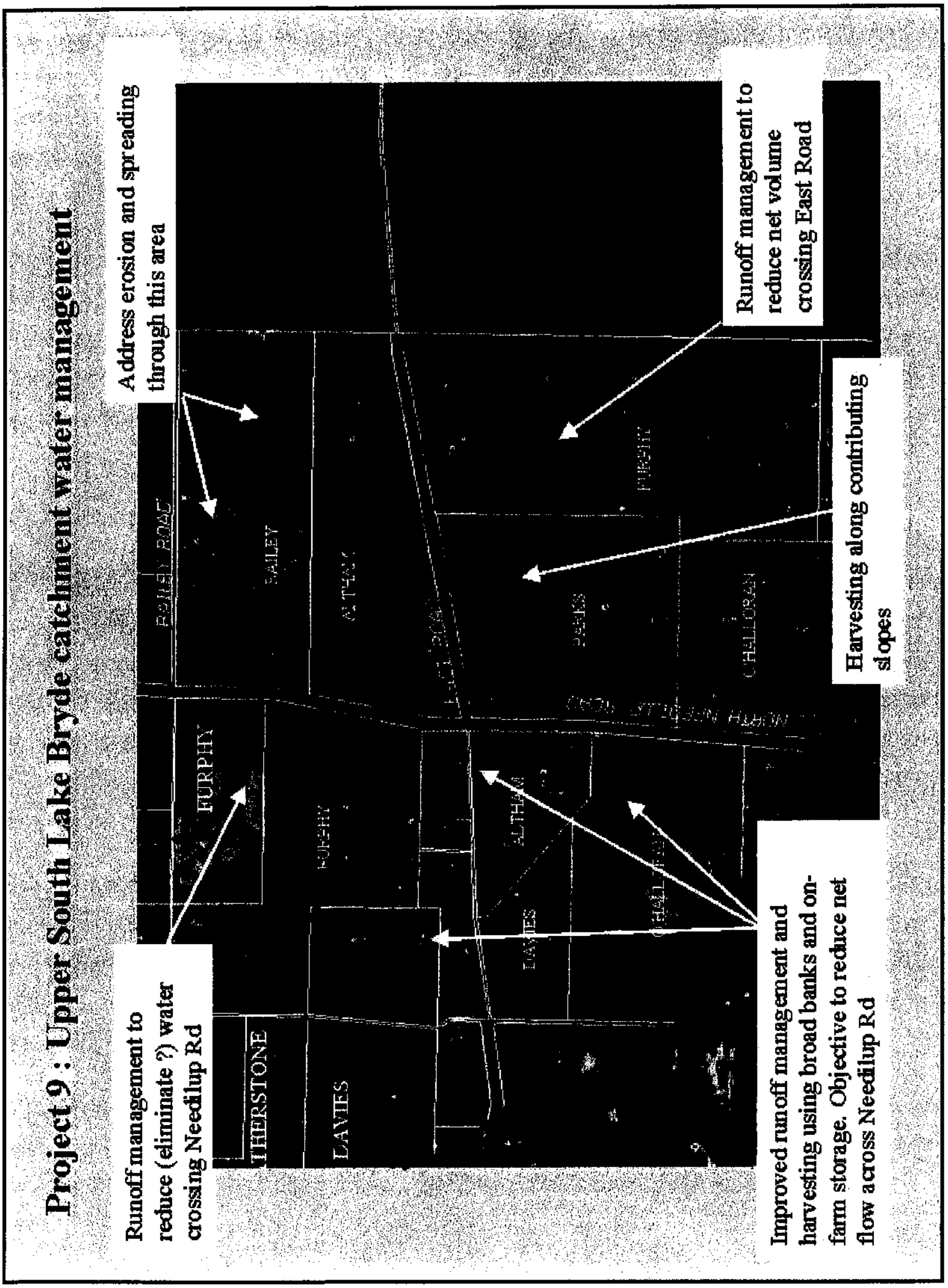

Figure 42: Proposed management options for the upper South Lake Bryde sub-catchments.

In these landscapes the main issue is the reduction of excess run-off to levels that minimise their impact upon local roads and lower slope areas.

In order to reduce impacts in the South Lake Bryde flats it is necessary to better control run-off accumulation in the shedding landscapes. Once established, flow volumes are substantial and extremely difficult to manage. At present, on ground surface water management is limited. Contour banking in the WISALT style is currently being used in Kent Location1773. Sub-catchment scale works should be planned and implemented in order to minimise run-off generation to levels that address the present 'flash flooding' tendencies. This can be achieved by either delaying or harvesting run-off.

Typically the recommended management structure will be broad grade banks at gradients of 0.4-0.6%. These banks can be incorporated into a harvesting system or simply used to delay water by increasing total flow distance. Detention within properties is encouraged. Construction costs for this style of run-off management is typically less than that for WISALT style banks as they require less digging and are often able to be constructed using lower cost equipment, thus providing a cost benefit to landholders.

3.10 Hollands Soak Rd sub-catchments (project 10)

The shedding landscapes to the south-west of the Lakeland valley are similar to that of the upper South Lake Bryde. At this stage the area has been subject to a cursory inspection only. Steeper slopes and better defined drainage lines typically generate and convey run-off rapidly. However, it is suspected that instantaneous flow volumes may be less than that experienced at East Road. This is evidenced by the nature of watercourse channels, road crossings and lower drainage density. Discharge points along the Lakeland nature reserve boundary similarly do not reflect large influx volumes.

It is understood that some WISALT and soil conservation style bank control has been implemented on some properties. The effectiveness of these, other local management issues and sub-catchment run-off characteristics can be resolved during a catchment landholder meeting. It is recommended that depth gauge monitoring be implemented at key locations as previously recommended (Farmer 2001a).

The suggested management strategy is to minimise flow volumes in two distinct zones. A strategy to achieve a net reduction in flows across Holland Soak Road (zone 1) and to reduce run-off generation in properties north-east of Holland Soak Road (zone 2).

The recommended management structure will be broad grade banks at gradients of 0.4-0.6%. These banks can be incorporated into a water harvesting system or simply used to slow water by increasing total flow distance. Detention within properties is encouraged. An advantage for landholders is that construction costs for broad grade banks is typically less than that for WISALT style banks currently used in some properties.

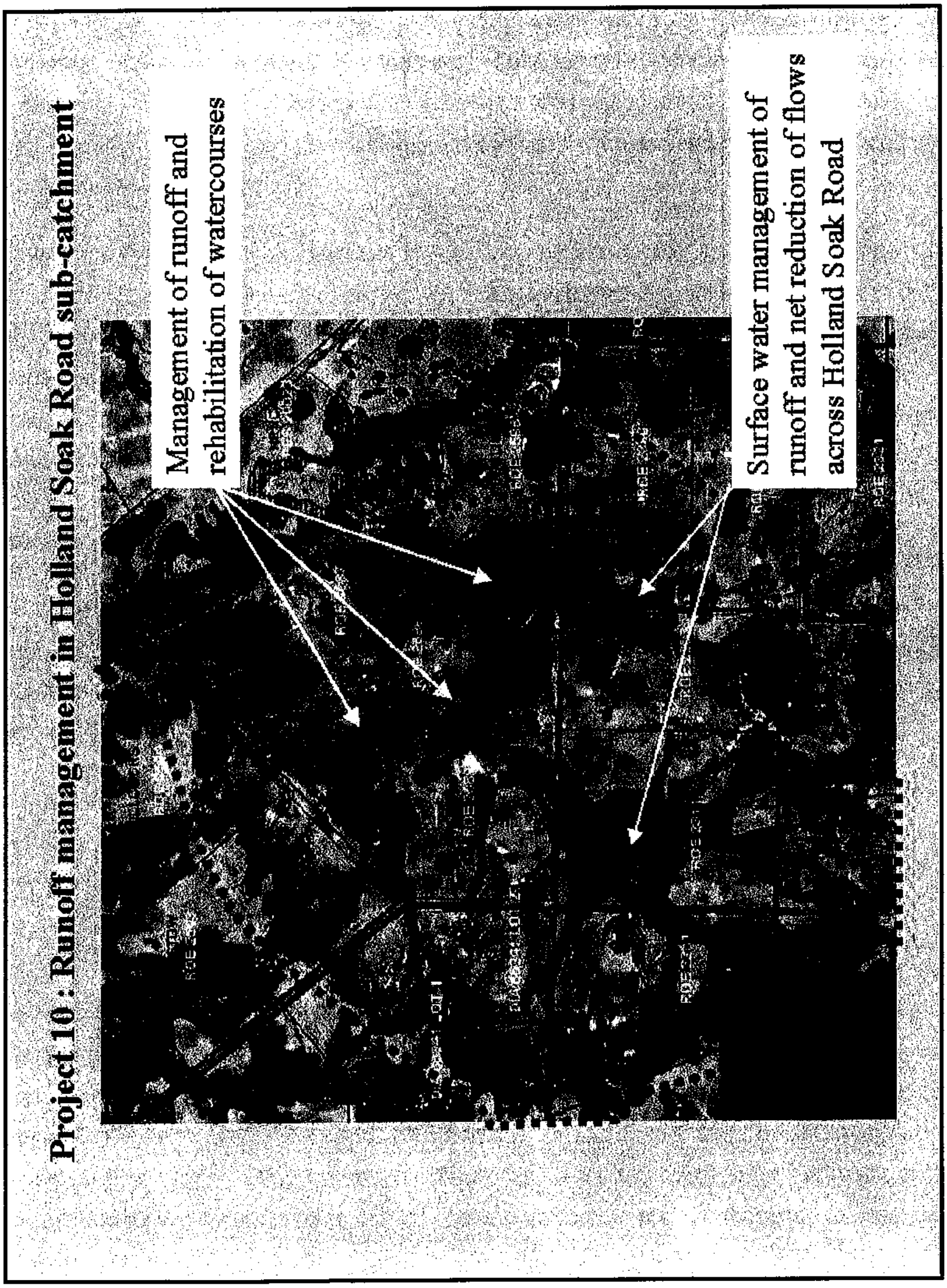

Figure 43: Proposed management options for the Holland Soak Road sub-catchments.

In these landscapes the main issue is the reduction of excess run-off to levels that minimise their impact upon local roads and the valley flats.

3.11 Mallee Hill Rd sub-catchment (project 11)

Theoretically the sub-catchment above Mallee Hill Road does not directly impact upon the Lakeland Nature Reserve. However, it is incorporated within the Lake Bryde Recovery Catchment project as it falls within the upper Lake Bryde Catchment, and because it is perceived to be contributing to degradation in the saline valley areas adjacent to Mallee Hill Road. These impacted watertables will migrate back into Lakeland Nature Reserve (according to groundwater modelling).

At this stage the area has been subject to a cursory inspection only. Its visible characteristics are somewhat similar to that of the other western sub-catchments. Steeper slopes and better defined drainage lines typically generate and convey run-off. The watercourse broadly discharges out into the valley in Roe Location 2595 (Wilcocks) before crossing Mallee Hill Road. The northern boundary of Roe Location 2595 shows sign of degradation and stress. Salinisation is evident in the adjacent land to the north of Mallee Hill Road. Inspection showed that some WISALT and soil conservation style bank control has been implemented on lower sub-catchment properties.

The recommended management strategy for this area is a reduction of run-off generation in upper sub-catchment properties and direct management of degradation and excess surface water within Roe Location 2595. Roe Location 2595 has already been identified for works in Section 3.4. Recharge management may need to be considered in Roe Location 2596.

Typically the recommended management structure will be broad grade banks at gradients of 0.4-0.6%. These banks can be incorporated into a water harvesting system or simply used to slow water by increasing total flow distance. Detention within properties is encouraged.

3.12 Lakeland Nature Reserve east slopes (project 12)

The east slopes above the Lakeland nature reserve comprise a number of small sub-catchments where surface discharge is controlled by floodways along the Fourteen Mile Road. In these cases watercourses flow across vegetated slopes within the reserve prior to entering the valley. Unlike the opposing western sub-catchments there is little evidence of substantial degradation along the reserve boundary. This is thought to be the result of the sub-catchments discharging higher in the Lakeland landscape and the presence of vegetation in the lower slopes .

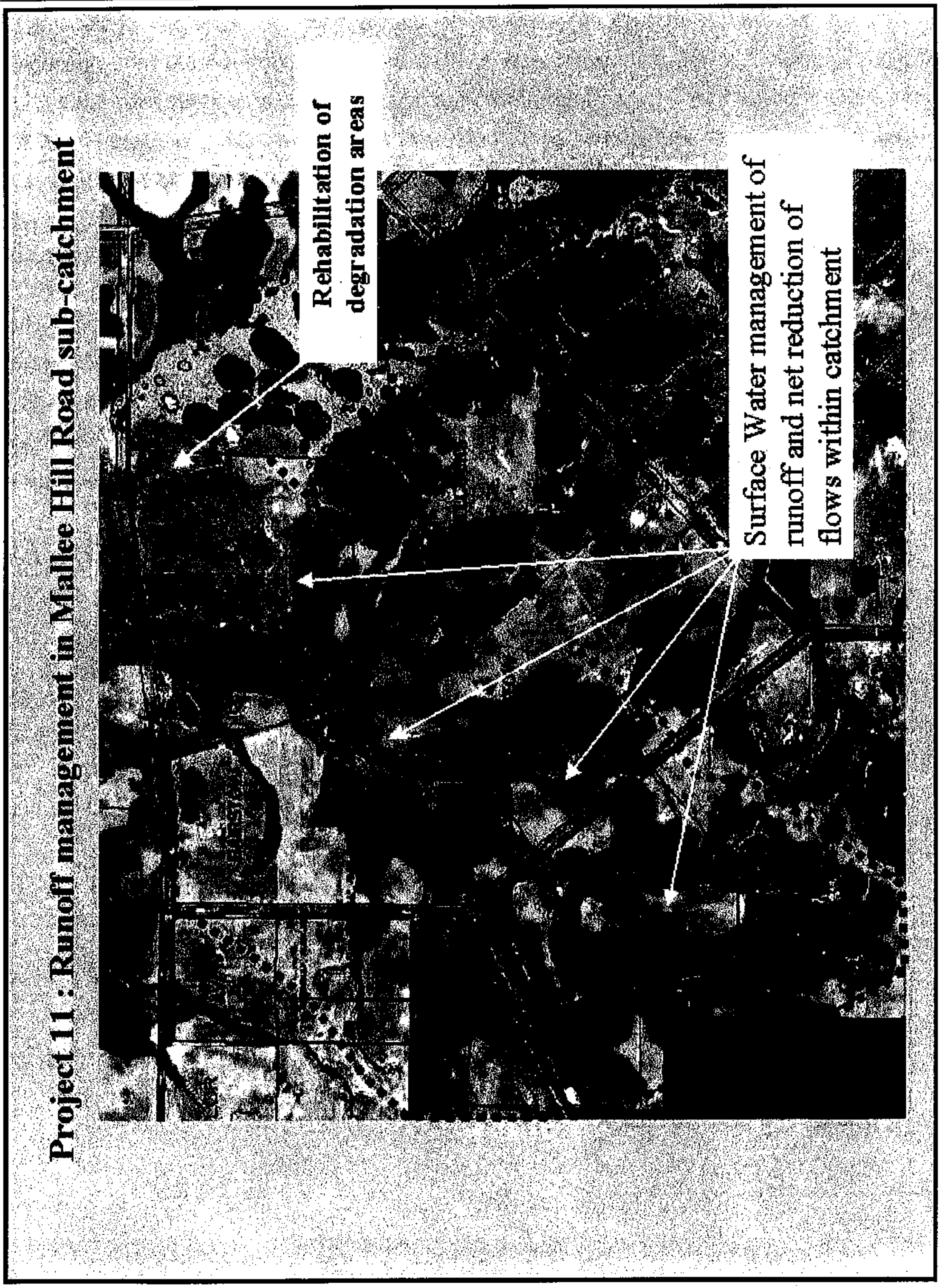

Figure 44: Proposed management options for the Mallee Hill Road sub-catchments.

Though this catchment does not actually flow into the Lakeland Reserve, excess water is contributing to degradation in the adjacent flats. Strategies will involve a combination of run-off reduction, surface water management and addressing of degradation issue in the lower flats.

At this stage the area has been subject to an aerial photo assessment and a cursory inspection from the Fourteen Mile Road only. It is expected that the minimising of run-off across the road reserve in the main sub-catchment properties of Roe Locations 2583 and 2584 will provide preventative management of any future degradation. Broad grade banks at slopes of 0.4-0.6% to either harvest or delay run-off are recommended. There are already a number of watercourse dams and sections of vegetated watercourse within the properties concerned.

It is suggested that sub-catchment landholders be invited to a meeting and any potential issues identified at that time. The February 2000 photography suggests that the more critical inflows are those coming from Roe Location 2583 at E 662450, N 6318000 (AMG84) and E 662100, N 6320400. Small surficial lakes in Roe Location 2584 at E 665000, N 6313700 may warrant further investigation.

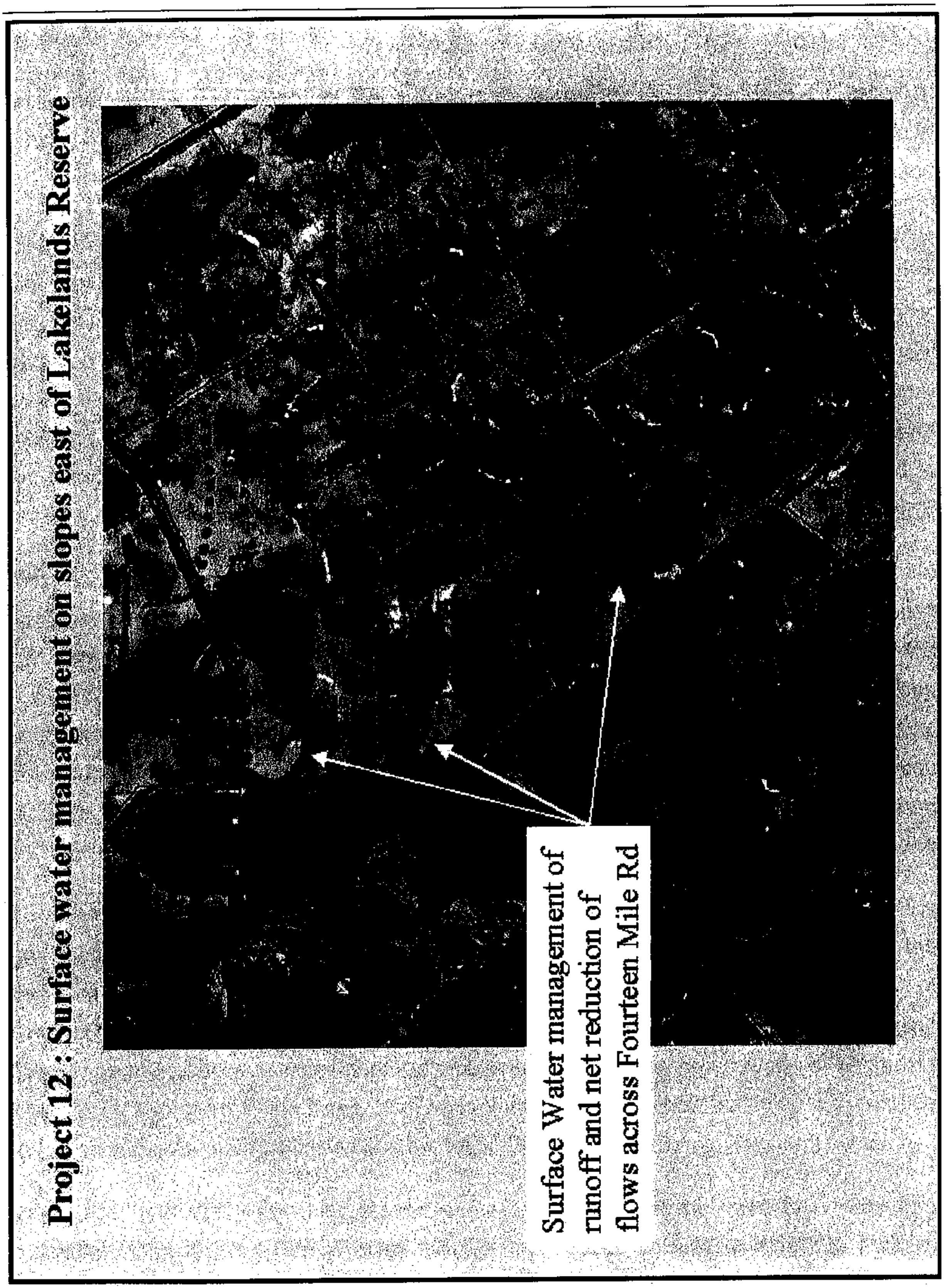

Figure 45: Proposed management options for the Lakeland nature reserve eastern slopes.

In these landscapes the main issue is reducing excess run-off as much as possible. Current impacts are low, however there is scope to further reduce run-off crossing Fourteen Mile Road.

4. Summary and conclusion

A surface water assessment of the Lake Bryde catchment has identified a number of functional management units with various levels of degradation observed and investigated. In most instances degradation occurs in the valley floor and valley flats where excess surface water is causing inundation, local recharge and waterlogging.

Comparison of hydrology and soil-landscape mapping has identified that the majority of the degradation is associated with grey clays. Within the major reserves degradation is more common along boundary zones where uncontrolled sheet flows from adjacent farmland are causing localised impacts. Issues relating to potential local watertable impacts, resulting from localised recharge by ponded water, have been identified along the northern and eastern boundaries of Lake Bryde Reserve. Regional groundwater impacts appear to be limited at present.

The area of greatest surface and sub-surface interaction appears to be that of the South Lake Bryde valley flats above Ryans Road. This area is a primary source area for salt mobilisation and concentration, and there is suggestion that there may be a strong interaction with the underlying geology. Large volumes of surface run-off also appear to be infiltrating in the deep sand profiles west of Grant-Williams Road in the East Lake Bryde sub-catchment. Questions remain as to nature of the interaction and potential impacts that redistribution and inundation by large volumes of surface water has on groundwater aquifers and medium to long term salinity trends.

The initial evaluation of the Lake Bryde catchment and its hydrological functionality is that the generation of excess run-off in upper slopes, which causes extensive inundation of the receiving landscapes and the valley floors, poses a greater risk than upper catchment recharge processes in the short to medium term. Hence run-off, inundation and waterlogging management typically dominates short-term objectives. However, groundwater development poses a serious threat in the longer term and management initiatives that integrate recharge reduction in the upper catchments will be required to address medium to long term outcomes.

Valley floor and valley flat management strategies focus upon the need to provide flow continuity. A proposed option involves the use of a broad, shallow waterway to address uncontrolled ponding, and ultimately provide waterlogging relief by re-establishing inundation regimes similar to that of the pre-clearing environment.

Road impediments have been addressed for culverts and floodways on the Pingrup-Newdegate Road, Lake Bryde Road, Bairstow Road and Ryans Road. In all cases it has been found that modifications to the road formations have historically been ineffective due to the lack of hydraulic potential and prolonged flow opportunity to facilitate the movement of water through and beyond road reserve areas. Incorporation of surface water management structures with proposed modifications will improve the delivery and disbursement of water accumulating as a result of identified road impediments.

The primary objective behind the proposed management strategies is a net reduction in the occurrence of discharging streamflows and the volume of water discharged onto the receiving landscape during smaller events. This strategy arises from the recognition that reduced run-off thresholds on farmland catchments are causing more frequent inundation in susceptible areas that natural vegetation systems simply cannot cope with. In most instances this can be achieved by adopting modern water harvesting and run-off interception methods. An added benefit of these techniques is that they offer an opportunity to increase both on-farm and community water supplies and resources. The proposed engineering options are most effective when appropriately coupled with re-vegetation systems and run-off/recharge reduction farming practices.

To facilitate an effective and achievable option for surface water management, fourteen separate projects have been identified. Each of these projects relates to a specific section of the Lake Bryde catchment. Localised management strategies provide a smaller focus so that management options can be more efficiently implemented with smaller landholder groups.

Surface water management options in the Lake Bryde catchment have the greater potential to impact on salinity in the short to medium term because groundwater systems are not yet fully interactive or coupled with the perched surficial systems. Engineering provides an immediate mechanism to redistribute water around or away from problem areas. The medium to long-term requirement is that excess run-off generation in the upper slopes is reduced as much as practicable, without a corresponding increase in recharge.

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