Wetland basins for saline drainage water disposal Bodallin and Elachbutting Catchments, eastern wheatbelt, Western Australia

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WETLAND BASINS FOR SALINE DRAINAGE WATER DISPOSAL, BODALLIN AND ELACHBUTTING CATCHMENTS, EASTERN WHEATBELT, WESTERN AUSTRALIA

P.P. de BROEKERT AND N.A. COLES

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Wetland Basins for Saline Drainage Water Disposal
Bodallin and Elachbutting Catchments, Eastern Wheatbelt, Western Australia

P.P. de Broekert and N.A. Coles

October 2004

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SUMMARY

Deep drains are becoming widely constructed in the central and eastern wheatbelt of Western Australia as a means of lowering water tables and reclaiming land affected by waterlogging and secondary salinity. Commonly, the deep drains are placed along major natural drainage lines where the groundwater is usually most saline and shallow. Disposal of the saline drainage water is typically poorly considered during drainage design, and generally occurs as an uncontrolled release to natural wetlands (playas, etc.) along the valley floor that are too saline to have been cleared for traditional agriculture. Often, however, these are important buffers to flood flows and may also form relatively intact pockets of native vegetation and wildlife habitat which are of significant nature conservation value.

This report provides an assessment of two large deep drainage schemes within the lower reaches of the Bodallin and Elachbutting Catchments nearby to Merredin, wherein groups of isolated wetland basins have been utilised for evaporative saline drainage water disposal. In both cases, the storage capacity of the basins has been exceeded, leading to flooding and death of the surrounding native vegetation. In order to quantify the storage capacity of the wetland basins and the volume of water delivered by the deep drains, a simple water balance model was constructed in which the major water inputs and outputs to the drain and wetland basins were incorporated as separate variables.

The water balance model shows that the natural hydrology of the wetland basins at Bodallin and Elachbutting is dominated by water derived directly from rainfall and localised surface runoff, and perhaps also from perched aquifers developed within permeable basin-margin sediments. Groundwater from the shallow underlying regional aquifer contributes large amounts of solutes to the basin floors, but its rate of inflow is small in comparison to the surface water sources. Basin morphology and vegetation distribution appear to be adjusted to relatively infrequent, large rainfall events, leaving additional space within the basins for the evaporative disposal of saline drainage water during an average rainfall year.

The modelling results indicate that groups of small wetlands basins can usually be used for saline drainage water disposal provided the following three conditions are met. Firstly, catchment-wide surface runoff must be prohibited from entering the deep drain, or at least it must be removed from the drain before it discharges to the wetland basins. Failure to do so results in widespread flooding and death of the surrounding native vegetation, as appears to have occurred in both of the study catchments. Secondly, large sections of deep drain should be constructed during summer, when the initial pulse of water produced by valley floor dewatering is best able to be evaporated. A high volume of dewatering water appears to have been an important cause of flooding and vegetation death at the Elachbutting Catchment. Thirdly, the combined area of wetland basins used for evaporation must be sufficiently large to evaporate the groundwater conveyed by the deep drain, and furthermore, the drainage water must be distributed to all of the wetland basins more or less concurrently, and equally in terms of depth. The distribution of drains at Bodallin and Elachbutting indicates that this is very difficult to achieve, involving the construction of numerous carefully surveyed channels to connect one basin to another, and perhaps also pumps where increases in elevation are involved.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.2. Background and objectives</td>
<td>1</td>
</tr>
<tr>
<td>1.3 Nomenclature</td>
<td>2</td>
</tr>
<tr>
<td>2. REGIONAL SETTING</td>
<td>5</td>
</tr>
<tr>
<td>2.1 Location</td>
<td>5</td>
</tr>
<tr>
<td>2.2 Geology and landforms</td>
<td>5</td>
</tr>
<tr>
<td>2.3 Climate</td>
<td>8</td>
</tr>
<tr>
<td>2.4 Natural drainage</td>
<td>9</td>
</tr>
<tr>
<td>3. METHODS</td>
<td>11</td>
</tr>
<tr>
<td>3.1 Field work</td>
<td>11</td>
</tr>
<tr>
<td>3.2 Drain–wetland water balance model</td>
<td>11</td>
</tr>
<tr>
<td>4. BODALLIN DEEP DRAIN AND DISPOSAL BASINS</td>
<td>15</td>
</tr>
<tr>
<td>4.1 Drain construction, placement and discharge</td>
<td>15</td>
</tr>
<tr>
<td>4.2 Wetland basin geomorphology, hydrology and storage capacity</td>
<td>18</td>
</tr>
<tr>
<td>4.3 Drain–wetland water balance</td>
<td>20</td>
</tr>
<tr>
<td>4.3.1 Water balance without drain discharge</td>
<td>20</td>
</tr>
<tr>
<td>4.3.2 Water balance with drain discharge excluding surface runoff</td>
<td>21</td>
</tr>
<tr>
<td>4.3.3 Water balance with drain discharge including surface runoff</td>
<td>21</td>
</tr>
<tr>
<td>5. ELACHBUTTING DEEP DRAIN AND DISPOSAL BASINS</td>
<td>23</td>
</tr>
<tr>
<td>5.1 Drain construction, placement and discharge</td>
<td>23</td>
</tr>
<tr>
<td>5.2 Wetland basin geomorphology, hydrology and storage capacity</td>
<td>24</td>
</tr>
<tr>
<td>5.3 Drain–wetland water balance</td>
<td>29</td>
</tr>
<tr>
<td>5.3.1 Water balance without drain discharge</td>
<td>29</td>
</tr>
<tr>
<td>5.3.2 Water balance with drain discharge excluding surface runoff</td>
<td>29</td>
</tr>
<tr>
<td>5.3.3 Water balance with drain discharge including surface runoff</td>
<td>30</td>
</tr>
<tr>
<td>6. SUMMARY AND CONCLUSIONS</td>
<td>33</td>
</tr>
<tr>
<td>7. LIMITATIONS</td>
<td>35</td>
</tr>
<tr>
<td>8. ACKNOWLEDGEMENTS</td>
<td>37</td>
</tr>
<tr>
<td>9. REFERENCES</td>
<td>39</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 2.1 Swan–Avon drainage basin with location of the Bodallin and Elachbutting study catchments. ............................................................ 5
Figure 2.2 Bodallin Catchment with location of deep drain and wetlands used for saline drainage water disposal .................................................... 6
Figure 2.3 Elachbutting Catchment with location of deep drain and wetlands used for saline drainage water disposal. ......................................... 7
Figure 2.4 Annual rainfall at Merredin for 1950 to 2003. ................................. 8
Figure 2.5 Average monthly rainfall and Class-A evaporation at Merredin. .......... 9
Figure 2.6 Daily rainfall at Merredin for 2003. .................................................. 9
Figure 2.7 Daily stream flows in the Yilgarn River at Gairdners Crossing for 2001. .. 10
Figure 3.1 Schematic diagram showing major components of water balance in drain–wetland basin system. ......................................................... 13
Figure 4.1 Location of deep drain within the lower Bodallin Catchment. .......... 15
Figure 4.2 Photograph of deep drain within the lower Bodallin Catchment. ........ 16
Figure 4.3 Wetlands and drains within the lower Bodallin Catchment. .......... 17
Figure 4.4 Wetland basin 3a in the lower Bodallin Catchment with near-shore zone of dead vegetation caused by overfilling of basin with saline deep drainage water. .................................................. 20
Figure 4.5 Results of water balance model for the lower Bodallin Catchment. .... 22
Figure 5.1 Location of deep drain within the lower Elachbutting Catchment. ...... 23
Figure 5.2 Wetlands and drains within the lower Elachbutting Catchment. ....... 25
Figure 5.3 Recently dead vegetation within the floor of basin 6 in the lower Elachbutting Catchment caused by discharge of saline water from deep drain. ........................................................................... 27
Figure 5.4 Recently dead vegetation on open (unleveed) side of drain within lower Elachbutting Catchment caused by overflow of saline drainage water during a flood event. ................................................................. 27
Figure 5.5 Historical (pre-drain) vegetation death within floor of wetland basin 2 in the lower Elachbutting Catchment. ................................. 28
Figure 5.6 Results of water balance model for the lower Elachbutting Catchment .... 31

LIST OF TABLES

Table 4-1 Size characteristics of wetland basins in the lower Bodallin Catchment. ... 19
Table 4-2 Historical levels of inundation within wetland basins in the lower Bodallin Catchment. ................................................................. 19
Table 5-1 Size characteristics of wetland basins in the lower Elachbutting Catchment. .................................................................................. 26
Table 5-2 Historical levels of inundation within wetland basins in the lower Elachbutting Catchment. ................................................................. 29
1. INTRODUCTION

1.2. Background and objectives

Agricultural development in southwestern Australia has been characterised by the replacement of deep-rooted, perennial shrubs and trees with shallow-rooted, annual crops and pastures. The much lower capacity of crops and pastures to intercept and transpire rainfall, especially that which occurs outside of the growing season or becomes stored at depth, has resulted in an excess of water in the landscape which has then contributed to a variety of forms of land degradation. Foremost amongst these are higher rates of surface runoff leading to hillslope erosion and inundation of valley floors, waterlogging in areas of poor subsurface drainage, and increased rates of groundwater recharge leading to regional water table rise and the development of secondary salinity (Nulsen 1981; McFarlane et al. 1992; George et al. 1997). Remote sensing surveys indicate that about 821,000 ha (4.4%) of the agricultural region is currently affected by salinity alone in southwestern Australia (McFarlane et al. 2004), with this figure set to increase as groundwater levels continue to rise and ultimately reach a new equilibrium.

Measures to reduce the amount of excess water in the landscape through increased plant water use, such as tree planting, improved cropping rotations or the establishment of perennial pastures, have met with limited success due to low economic returns and the large area of land required (Clarke et al. 1998; George et al. 1999). Additional constraints exist in the eastern wheatbelt where plant growth is limited by a low rainfall and high rates of potential evaporation, and where very low hydraulic gradients produce groundwater systems that are essentially one-dimensional and therefore only locally responsive to revegetation treatments.

Artificially constructed banks and drains provide another means of managing excess surface water, assuming particular importance in the eastern wheatbelt where re-vegetation based options are most limited. On valley sides, banks can be used to reduce hillslope erosion, slow the passage of flood peak flows, drain waterlogged areas and fill farm dams. On valley floors, shallow drains can be used to reduce waterlogging and inundation by improving the continuity of flow along the natural drainage line. Deep drains situated along valley floors perform the same functions as shallow drains, but in areas with shallow water tables have the added advantage of draining groundwater and leaching salt for a distance on either side of the drain that is dependent on the hydraulic gradient and soil permeability (Chandler and Coles 2003). Many farmers have adopted deep drains as the preferred method of surface and groundwater control in major valley floors, to the extent that over 10,000 km of deep drains are estimated to have been constructed in the wheatbelt (Ruprecht, pers. comm., 2004).

Surface and near-surface water collected by banks and shallow drains can generally be safely disposed of along natural drainage lines because of its ephemeral flow and relatively high quality. By contrast, groundwater seepage collected by deep drains typically flows throughout the year and is of a very poor quality (high salinity, low pH). Disposal of deep drainage water is therefore problematic and under current practice generally occurs as an uncontrolled release into natural wetlands along the valley floor that are too saline or wet to have been cleared for traditional agriculture. However, these may be important buffers to flood flows and may also form relatively intact pockets of native vegetation and wildlife habitat which are of significant nature conservation value (Coleman 2003a,b). Environmental criteria for the disposal of saline deep drainage water to natural wetlands have been proposed (Coleman and Meney 2000; Sinclair Knight Merz 2001), but require further...
development and are in any case rarely considered during deep drain design and construction.

This report provides an assessment of two large deep drainage schemes in the eastern wheatbelt (Bodallin and Elachbutting), both of which use natural wetlands to dispose of saline drainage water. Using field observations and a simple water balance model, the investigation primarily seeks to assess the capacity of the natural wetlands to 'absorb' the additional water delivered by the deep drains, and ascertain if this has already resulted in environmental degradation. The results of the investigation have important implications for future drainage design and Notice of Intent to Drain (NOID) assessment, particularly since the construction of new deep drains, and the expansion or amalgamation of existing deep drainage schemes, will place an ever greater pressure on natural wetlands for saline water disposal.

Thus, for the Bodallin and Elachbutting drainage schemes, the objectives of this study are to:

- map the natural wetlands used for saline deep drainage water disposal and delineate the extent to which the wetlands have been inundated, either as a consequence of natural water inputs, drainage inflows, or some combination of the two;
- note the extent of any vegetation death or other form of land degradation associated with the influx of drainage water;
- construct a simple water balance model for the drain–wetland system that allows for the environmentally acceptable storage capacity of the wetlands to be quantified and the relative importance of the different water inputs to be established; and
- make recommendations for future deep drain design and NOID assessment.

1.3 Nomenclature

The terminology relating to both drains and wetlands is complex and inconsistent, creating the potential for misunderstanding and confusion. A detailed discussion of drain and wetland terminology and classification is beyond the scope of this study, but the following comments are provided to clarify some of the essential aspects.

Following Chandler and Coles (2003), a ‘deep drain’ is used here to refer to an open, unlined, channel designed and constructed to intercept and transmit groundwater. Clearly, this definition is restrictive in that it emphasises the source of water as opposed to the physical characteristics of the structure, which would be of greater importance in an engineering-based system of drain classification.

The shallow basins which form such a conspicuous feature of many wheatbelt valley floors have been variously referred to as dry lakes, salt lakes, playas, playa-lakes, pans and salinas (Jutson 1917; Bettenay 1962; Killigrew and Gilkes 1974; Bowler 1981; Goudie and Wells 1995). Commonly these terms have been applied indiscriminately and without consideration of their formal meaning. A salt lake, for example, is defined in The Glossary of Geology by Bates and Jackson (1987) as ‘an inland body of water in an arid or semi-arid region, having no outlet to the sea, and containing a high concentration of dissolved salts’, of which there are none in inland Western Australia. Whereas the term ‘playa’ (defined by Biere (2000) as ‘an intracontinental arid zone basin with a negative water balance for over half the year, dry for over 75 per cent of the time, with a capillary fringe close enough to the surface such that evaporation will cause water to discharge, usually resulting in evaporates’) adequately describes many of the larger valley floor basins in the wheatbelt, there are many basins that are dry for over 75 per cent of the time but still situated well above the regional water table.
To avoid complications posed by nomenclature, use of the generic term ‘wetland’ (defined by Semeniuk and Semeniuk (1995) as an ‘area of seasonally, intermittently or permanently waterlogged soil or inundated land, whether natural or otherwise, fresh or saline’) is preferred. Parameters that can then be used to define the ‘type’ of wetland include:

- landform type (e.g. basin, channel, trough, flat, slope);
- landform shape (e.g. irregular, circular, ovoid, elongate and linear for basins; straight, sinuous, anastamosing and braided for channels);
- landform size (ha) or length (m), as appropriate;
- for basins in particular, proximity to and degree of connection with the natural drainage line (e.g. throughflow, semi-throughflow, closed/isolated);
- for basins connected by channels, position relative to other basins within the wetland ‘complex’ (e.g. upper, central, lower, terminal);
- substrate composition in terms of primary (kaolin clay, quartz sand, granite bedrock, etc.) and secondary (halite, gypsum, calcite, dolomite, sulphide, organic, etc.) components;
- hydroperiod (e.g. seasonally waterlogged, or episodically, seasonally or permanently inundated);
- depth and depth variation of inundation (seasonal and longer term);
- depth and depth trend of regional water table;
- ground and surface water chemistry (salinity, pH, etc.); and
- floral and faunal composition of wetland waters and surrounding land.

These parameters may be described separately or combined to form a classification, such as developed by Semeniuk and Semeniuk (1995) based primarily on the key defining parameters of landform type and hydroperiod (e.g. permanently inundated basin = lake; intermittently inundated basin = playa; seasonally waterlogged basin = dampland; seasonally inundated channel = creek; intermittently inundated channel = wadi; seasonally waterlogged channel = trough). Simplified classifications tailored for wetlands within a specific area are also possible. For example, in a study of wetland basins in the Moore River Catchment, Sinclair Knight Merz (2001) identified 10 ‘lake’ categories based principally on geological setting and landscape position, of which the Category 1 lakes (small lakes located in short tributary valleys on the Darling Scarp or within the Zone of Ancient Drainage) and Category 2 lakes (lakes located within the flat valley floors of the Zone of Ancient Drainage) are best represented in the eastern wheatbelt.
2. REGIONAL SETTING

2.1 Location
The Bodallin and Elachbutting catchments are situated within the eastern wheatbelt, some 60 km NE and 120 km NNE of Merredin, respectively (Figure 2.1). The Bodallin catchment has an area of about 132,400 ha and is situated entirely within the agricultural region, whereas the Elachbutting catchment has an area of about 725,000 ha of which only 94,600 ha (13%) is in the agricultural region. Bodallin falls within the Southern Cross (SH 50-16) 1:250,000 map sheet. Most of the Elachbutting Catchment occurs within the Lake Jackson (SH 50-12) map sheet, with a small section extending west onto the Bencubbin (SH 50-11) map sheet.

![Figure 2.1. Swan–Avon drainage basin with location of the Bodallin and Elachbutting study catchments.](image)

Figure 2.1. Swan–Avon drainage basin with location of the Bodallin and Elachbutting study catchments.

2.2 Geology and landforms
Basement rocks in the Bodallin and Elachbutting catchments are dominantly composed of Archaean granite, adamellite and banded gneiss, locally intruded by Proterozoic mafic dykes (Gee 1981; Chin and Smith 1983). Also forming a prominent part of the basement, especially in the Elachbutting Catchment, are north-westerly trending greenstone belts, composed principally of banded iron-formation and metamorphosed basalt (Figure 2.2 and Figure 2.3). Deep weathering of the Archaean basement is widespread, reaching a
maximum in areas of granite, where 30–40 m of saprolite and saprock formation are
common.

Figure 2.2. Bodallin Catchment with location of deep drain and wetlands used for saline drainage water
disposal.
Unconformably overlying the Archaean basement rocks is a sequence of Cenozoic clastic sediments. These are poorly mapped, but by analogy to other parts of the wheatbelt (George 1990; de Broekert 2003) are likely to be dominated by aeolian yellow quartz sand (‘sandplain’) along the interfluves, and red–light grey clayey quartzo-feldspathic sand deposited as unconfined sheetwash along the valley sides and alluvium along the major valley floors. Drilling by the Geological Survey of Western Australia at Merredin (de Broekert, unpubl. data, 1996) indicates that the alluvial sediments reach a thickness of 45 m beneath the major valley floors where they probably infill narrow palaeovalleys eroded into the weathered Archaean bedrock. Preservation of feldspar within the sediments indicates that they were derived from outcrops of fresh granite and were deposited after the last major
phase of deep weathering, which is likely to have occurred in the Oligocene (de Broekert 2002).

Landforms within the region closely reflect the lithology and structure of the underlying Archaean basement, with banded iron-formation and meta-basalt in the greenstone belts forming prominent rocky ridges and hills (e.g. Mt Jackson at Elachbutting). Also forming prominent high points are dome-shaped outcrops (monadnocks) of fresh granite, though these have a lower relief than the greenstone hills (60 m compared to 150 m) and may occur in almost any landscape position.

Except for areas formed by greenstone strike ridges or granite monadnocks, the valley interfluves are broad and convex, passing through long, gently inclined (2–10%) slopes to wide, flat valley floors which have very low longitudinal gradients in their lower reaches (0.1-0.05%). The valley floors host various wetlands, the most conspicuous of which are large playas, such as Hamersley Lakes at Elachbutting and Lakes Baladjie and Warrachuppin at the down-stream end of the Bodallin Catchment (Figure 2.2 and Figure 2.3).

2.3 Climate

A semi-arid climate, with hot, dry summers and cool, wet winters characterises the eastern wheatbelt. The average annual rainfall for Merredin from 1950 to 2003 is 327 mm (Figure 2.4). Most rain falls during the winter (Figure 2.5) associated with the passage of eastwardly moving cold fronts, whereas most summer rain comes from thunderstorms, or less frequently, from southerly moving tropical cyclones that have degenerated into rain-bearing depressions by the time they reach the eastern wheatbelt. As shown in Figure 2.6, summer rainfall events are infrequent, but may be of high intensity and magnitude, leading to widespread runoff and flooding of the valley floors. Potential evaporation exceeds rainfall throughout the year, reaching a maximum of ~11 mm/d during January and a minimum of ~2 mm/d during June and July (Figure 2.5).

![Average annual rainfall (327 mm)](image)

Figure 2.4. Annual rainfall at Merredin for 1950 to 2003 (Bureau of Meteorology 2004).
2.4 Natural drainage

The Bodallin and Elachbutting catchments form tributaries of the Yilgarn River, which drains the northeastern part of the Swan–Avon drainage basin (Figure 2.1). Owing to the region’s semi-arid climate, streamflow is ephemeral, being active only after high magnitude or closely-spaced low magnitude rainfall events during the winter and spring, and less commonly after high intensity rainfall events during the summer. For example, at the Gairdners Crossing gauging station near Kellerberin, which is closest on the Yilgarn River to Bodallin and Elachbutting, there were only 9 days during 2001 (an above average rainfall year) with a streamflow greater than 10 L/s (864 KL/d) (Figure 2.7).
Except for trunk streams along the major valleys floors, drainage lines within the Bodallin and Elachbutting catchments are poorly integrated (Figure 2.2, Figure 2.3). Many of the low-order tributary stream channels are defined in their upper reaches only, reflecting the transition from channelised flow along the upper and middle valley sides to unconfined sheetflow as the streams enter the wide, flat valley floors.

Surface scalding, resulting from waterlogging and secondary salinity, is widespread along the trunk drainage line at Bodallin, and also the lower reaches of the trunk drainage line at Elachbutting. Increases in the severity and extent of surface scalding up-gradient of impediments to surface flow, such as road embankments, suggests that the waterlogging and secondary salinity are largely the result of surface water ponding, although shallow water tables may be an important contributing factor, especially in the lower reaches of the catchments.
3. METHODS

3.1 Field work

A preliminary field trip to the Bodallin and Elachbutting catchments was conducted during the first week of April 2004 and was followed by a second field investigation during the last two weeks of the same month. Deep drains and natural basins within the wetlands were located with a GPS and mapped onto 1:25,000 colour aerial photographs. For a representative selection of basins, the vertical distance between the basin floor and the position of the ‘average’ high-water shoreline (as determined from the lower extent of healthy vegetation, upper extent of shoreface sand, or limit of driftwood deposition) was obtained by a laser-level. Along with estimates of basin surface area, this allowed for the maximum acceptable storage volume of the basin to be calculated. The depth of any standing water within the wetland basins was noted, as was the condition of the fringing vegetation. Past (pre-drain) levels of inundation were assessed using historical aerial photography and Landsat TM imagery.

Flow rates at several points along the drains were measured using a bucket and a stop watch, or where this was not possible, calculated using the depth and velocity of flow through culverts at road crossings. Having been taken at the end of summer and not closely preceded by any major rainfall events, these measurements are interpreted to represent flow to the drain from groundwater. However, the absence of piezometers or observation bores near the drains prevented an assessment of whether this water was sourced from the deep/regional or a shallow/perched saturated zone (baseflow), or from unsaturated drainage of the upper regolith profile (interflow). Indeed, a major limitation of this study is the lack of historical data regarding the source, quality and quantity of water collected and conveyed by the deep drains, and a similar lack of information regarding the hydrology and hydrogeology of the receiving wetlands.

3.2 Drain–wetland water balance model

A simple spreadsheet-based water balance model was constructed to provide an indication of the relative magnitude of the water inputs and outputs, and test various scenarios including the effect of excluding surface water flows from the deep drain and hence the receiving wetland. Following in large part a similar study by Peck (2000), the drain–wetland water balance equation used is as follows:

\[ D_{si} + D_{gi} + (P \times D_a) - (E_{cf} \times D_a) + W_{si} + W_{gi} + (P \times W_a) - (E_{cf} \times W_a) - W_{so} - W_{go} = dWS \]

where

- \( D_{si} \) = surface water flow into the drain, in \( m^3 \) (KL)
- \( D_{gi} \) = groundwater flow into the drain, in \( m^3 \)
- \( W_{si} \) = surface water flow into the wetland, in \( m^3 \)
- \( W_{gi} \) = groundwater flow into the wetland, in \( m^3 \)
- \( W_{so} \) = surface water flow out of the wetland, in \( m^3 \)
- \( W_{go} \) = groundwater flow out of the wetland, in \( m^3 \)
- \( D_a \) = surface area of drain, in \( m^2 \)
- \( W_a \) = surface area of wetland, in \( m^2 \)
- \( P \) = rainfall, in mm
- \( E_{cf} \) = effective evaporation, in mm
- \( dWS \) = change in wetland storage volume, in \( m^3 \)
The model was run on a daily time-step, using as primary inputs daily values of rainfall and potential evaporation. These, and the other variables used in the drain–wetland water balance model, are shown schematically in Figure 3.1 and discussed below.

**Surface water flow into the drain (D_{si})**

Surface water inflow to the drain (D_{si}) applies only to deep drains situated along the natural drainage line that are unlevelled on one or both sides and therefore open to surface water inflow, as occurs both at Bodallin and Elachbutting. The value of D_{si} in each case was calculated as the volume of runoff generated from a strip of land extending 1 km on either side of the main (trunk) natural drainage line. For each daily time-step, the previous day’s storage (in mm) was added to by rainfall (if any) and depleted by potential evaporation in proportion to the quantity of water held in storage. If the new storage exceeded a threshold of 30 mm, corresponding to the minimum amount of rainfall expected to generate runoff from a soil profile with no water in storage, the difference between the new storage and storage threshold was added to the drain as surface runoff. Clearly, this method provides a gross indication (underestimate) of surface runoff only, because flows produced outside of the 1 km buffer zone are ignored, as are flows generated by high intensity rainfall events leading to infiltration-excess runoff. Calculations of surface runoff based on statistical relationships between rainfall and streamflow measured at a gauging station (Peck 2000) provide a better estimate of the total annual or monthly magnitude of runoff, but are less useful for predicting daily runoff because the antecedent soil moisture storage conditions are not accounted for.

**Groundwater flow into the drain (D_{gi})**

Groundwater flow to the drain (D_{gi}) was set at a constant rate based on measurements of flow in the deep drains at the end of summer, corrected for the rate of evaporation at the time of measurement. As used here, it therefore represents the total amount of seepage that occurs through the drain batters, which due to evaporation or some other form of loss from within the drain, is invariably more than what is measured at the drain outlet. It is important to note, however, that the rate of baseflow to the drain is likely to be considerably higher during the winter and spring than it is at the end of summer (Ali et al. 2004), so that the value of D_{gi} used here is conservative.

**Surface water flow into the wetland (W_{si})**

For small wetland basins isolated from the main drainage line, such as at Bodallin and Elachbutting, surface water flow to the wetland (W_{si}) is that portion of rainfall which runs into the wetland directly from its immediately adjacent surface water catchment. The value of W_{si} is poorly known, but is likely to be fairly high owing high rates of runoff from steeply-sloping marginal lunette dunes. It has therefore been set at 20 per cent of rainfall from a 100 m wide strip of land surrounding each wetland basin.

**Groundwater flow into the wetland (W_{gi})**

Groundwater flow into the wetland (W_{gi}) will occur where the wetland floor is connected to the regional unconfined groundwater system and where the regional water table adjacent to the wetland is higher than the water level within the wetland (Davies et al. 2000). Large amounts of dissolved or crystallised salt within a wetland basin suggest that the water table is shallow and that the discharge of saline groundwater has formed a prominent part of its water balance (Bowler 1986; Jacobson 1988; Jacobson and Jankowski 1989; Shaw and Thomas 1989; Salama 1992). However, the rate of upward groundwater flow is likely to be low because of very low hydraulic conductivities and gradients within the underlying aquifer. Furthermore, the wetland basins at Bodallin and Elachbutting are situated within valleys that are externally draining so that they do not form the locus for all of the catchment-wide groundwater discharge, as would occur in basins that have no surface or sub-surface outlet.
and that are therefore truly internally draining (e.g. Jacobson et al. 1988). Even if this were the case, the maximum amount of groundwater discharge that would occur to a 'typical' wetland basin in the study area; for example one with a perimeter of 3,000 m, situated over a 20 m thick sedimentary aquifer with a hydraulic conductivity of 0.5 m/d and a hydraulic gradient of 0.001; would be 30 m³/d. Distributed evenly over the basin floor (300,000 m²), this would yield a discharge of only 0.1 mm/d - about 20 per cent of the minimum rate of daily effective evaporation (see below), and therefore this contribution is ignored for the purposes of this exercise.

High rates of groundwater discharge, albeit localised, are likely to occur in large playas where a zone of springs commonly develops within permeable sediments at the shoreline as a consequence of regional groundwater being deflected upward by a pool of dense brine situated beneath the basin floor (De Wiest 1965; Bowler 1986). Another source of groundwater for springs along the shoreline may be from perched aquifers developed within thick sequences of permeable sediments, such as lunette dunes or sheets of yellow sand ('sandplain') situated alongside the wetland basin margin. Although potentially an important source of water for small wetland basins in particular, this has been excluded from the water balance model used here.

![Figure 3.1. Schematic diagram showing major components of water balance in drain–wetland basin system. Water levels and flow directions shown both for shallow and deep regional groundwater systems.](image)

- **$D_s$** = surface water flow into deep drain
- **$D_{gi}$** = groundwater flow into deep drain
- **$W_s$** = surface water flow into wetland basin
- **$W_g$** = groundwater flow into wetland basin
- **$W_{so}$** = surface water flow out of wetland basin
- **$W_{go}$** = groundwater flow out of wetland basin
- **$P$** = rainfall
- **$E_{ef}$** = effective evaporation
Surface water flow out of the wetland ($W_{so}$)

Surface water flow out of the wetland ($W_{so}$) will clearly depend on the morphology of the wetland and its connectivity with the natural drainage line or other wetlands in the group. For isolated basins, such as at Bodallin and Elachbutting, surface water flow out of the wetland will only occur when the basin is filled well above its acceptable storage capacity. As with $W_{gi}$, it was therefore set to zero in the water balance model.

Groundwater flow out of the wetland ($W_{go}$)

Groundwater flow out of a wetland ($W_{go}$) will occur where the regional water table is deep providing a large positive head to drive water down through the basin floor. Lower amounts of groundwater outflow may also occur in wetlands surrounded by a shallow water table when the wetland fills with surface runoff and discharges water through more permeable sediments at the shoreline. Wetlands containing abundant healthy vegetation and no obvious outflow channel probably have a water balance in which vertical leakage is dominant (Bowler and Teller 1986; Shaw and Thomas 1989). Groundwater flow out of a wetland basin is difficult to quantify, but similar to Peck (2000), was calculated using $W_{go} = K/B \times (h_1 - h_2)$, where $K$ and $B$ are the saturated hydraulic conductivity and thickness of the basin floor sediments, respectively; and $h_1$ and $h_2$ are the water levels within and adjacent to the basin, respectively.

Rainfall ($P$) and effective evaporation ($E_{ef}$)

Daily values of rainfall ($P$) and evaporation ($E$) for Bodallin and Elachbutting were obtained from the Patched Point Dataset accessed through the WA Department of Agriculture, Client Resource Information System.

Evaporation rates from wetlands (and drains) are likely to be considerably less than the Class-A pan evaporation rates recorded at meteorological stations principally because of the lower temperature reached by large water bodies compared to a pan (Lake Factor), and the lower saturation vapour pressure of saline water compared to fresh water (Salinity Factor). These factors are reasonably well established (Coleman, pers. comm., 2004), and for the purposes of this study the Lake Factor was set at 0.65 and the Salinity Factor was set at 0.9, reflecting the fairly low salinity of the bulk of the water to be evaporated from the wetland basins. When combined, the Lake and Salinity factors produce an effective evaporation rate ($E_{ef}$) equal to 0.6 times class-A pan evaporation, which was adopted in the drain–wetland water balance model.

Surface area of drain ($D_a$) and wetland ($W_a$)

The surface area of the drain ($D_a$) was obtained by multiplying the width of the drain by its length, whereas the area of the wetland ($W_a$) was measured directly from aerial photography using a geographic information system. For the purposes of simplicity, the surface area of the wetland basins were assumed to be invariant of water depth and volume, although in reality the surface area is likely to increase as a function of the water level, reflecting the very slight concave-upwards shape of most wetland basin floors (Peck 2000). A consequence of this simplification is that the rate of effective evaporation has probably been slightly overestimated.

Water resulting from valley-floor dewatering during drain construction

Not included in the drain–wetland water balance equation shown above is the substantial amount of water initially produced by dewatering of the valley floor during drain construction. In the absence of field data, this was calculated using a specific yield of 0.1 and a drawdown of 1.5 m at the drain shallowing linearly to 0 m at 50 or 100 m on either side of the drain, depending on soil permeability. The volume of water so derived was then distributed evenly over the period of drain construction, which in each case was assumed to be 90 days.
4. **BODALLIN DEEP DRAIN AND DISPOSAL BASINS**

4.1 Drain construction, placement and discharge

About 30 km of deep drains were constructed in the lower reaches of the Bodallin Catchment during 2001–2002, of which 22 km are within agricultural land and the remaining 8 km are within the area of remnant vegetation and wetlands used for saline drainage water disposal (Figure 4.1). Within the agricultural area, the deep drains fulfil their intended purpose of draining groundwater from the upper regolith profile, but within the area of remnant vegetation, the deep drains are principally used to convey the saline groundwater to one or more basins for evaporative disposal.

![Figure 4.1. Location of deep drain within the lower Bodallin Catchment. Note placement of deep drain along the natural drainage line and poor definition of drainage lines as they enter the valley floors.](image-url)
The deep drains typically have vertical batters and a depth and width of about 2 m and 1 m, respectively (Figure 4.2). Shallower depths occur where the sediments in which the drains are constructed have been strongly cemented by iron-oxides (e.g. between McDowell and Boodarockin roads), or where the drain approaches a basin used for groundwater disposal. Spoil resulting from drain construction has normally been placed within 1–2 m of the drain along one or other (alternate) sides of the drain only.

Within the area of agricultural land, the deep drain is situated within a short distance of the deepest part of the natural drainage line and the spoil bank has been constructed on the up-hill side, making the drain completely open to surface water inflows (Figure 4.2). The drain continues to follow the natural drainage line into the area of remnant vegetation, where it eventually discharges into a small wetland basin immediately to the south of the Koodra–Southern Cross Road (M40) (Figure 4.1, Figure 4.3). Continuous flow into the small basin has caused it to overflow and discharge via a culvert beneath the Koodra–Southern Cross Road into several other small basins to the north of the road, which have also become partly to wholly filled with drainage water. The downstream extent of inundation is unknown, but in May 2004 when evaporation rates were still high, it was observed not to extend as far as Lake Warrachuppin (Figure 2.2).

Immediately before the deep drain enters the area of remnant vegetation, a second deep drain has been constructed to allow diversion of the drainage water into a series of isolated wetland basins for evaporative disposal (Figure 4.3). The diversion drain was used during early–middle 2002, but following rapid filling of the wetland basins to levels above their natural high-water shoreline, was abandoned in favour of the route currently in use. A culvert with a narrow PVC pipe has been placed at the start of the diversion drain in an attempt to
exclude high volume flows resulting from surface water inflows to the drain, but it is not known when this was installed or if it proved to be effective.

A flow rate of approximately 8 L/s was measured in the deep drain at the culvert crossing with Boodarockin Road (Figure 4.1). Taken over the total drain length of 14.4 km above Boodarockin Road and corrected for evaporative loss, this produces an average inflow rate to the drain of ~53 L/d/m (KL/d/Km). Because there were no contributions of surface water to the drain at the time of measurement, it can be inferred that the inflow was derived entirely from groundwater as baseflow or interflow.
The electrical conductivity of drainage water within the agricultural area ranged from 6500–7,200 mS/m, equating to a TDS of 35,000–40,000 mg/L. Similarly, the pH of the drainage water varied between 3.1 and 4.6 and showed no clear relationship with corresponding values of electrical conductivity.

4.2 Wetland basin geomorphology, hydrology and storage capacity

Three north–south oriented zones of wetlands can be recognised within the 1,600 ha of land left uncleared to the south of the Koodra–Southern Cross Road (Figure 4.3). The eastern zone is dominated by a broad straight channel which forms the trunk drainage line of the Bodallin Catchment and the route along which the deep drain, currently in use, has been constructed. A number of smaller drainage lines created and maintained by runoff from a bedrock ridge form the westernmost wetland zone. The shortest of these drainages terminate in small wetland basins, whereas the longest passes through several small basins before terminating in a relatively large basin some 300 m to the south of the Koodra–Southern Cross Road (Figure 4.3). Occupying a broad ridge between the eastern and western wetland zones is a central zone composed of about 11 isolated wetland basins (Figure 4.3). These are separated from the natural drainage lines to the east and west and were for a short time used for saline drainage water disposal (see basins 1, 2, 3a and 3b linked to the diversion drain in Figure 4.3). The elevation of basin floors within the group decreases from ~316.5 mAHD for basin 1 in the south to ~315 mAHD in basin 10 in the north.

The isolated basins within the central wetland zone range in size from about 1 to 30 ha (Table 4-1). All have smooth outlines and a moderate to high degree of ellipticity, reflecting the influence of wind-driven water currents on sediment erosion and deposition, and hence the prominence of standing water in the basin’s natural hydrological cycle (Killigrew and Gilkes 1974; Bowler 1986). This is substantiated by pre-drain aerial photography and Landsat TM imagery (Table 4-2), which show that the basins are in their natural state typically inundated during the winter and spring and dry during the summer and autumn.

Thin but extensive salt crusts formed on the floors of some the basins (e.g. basins 4 and 5) during summer indicate that the regional water table is shallow and able to supply abundant solutes to the landsurface for evaporative concentration. This is confirmed by the presence of highly saline (~110,000 mg/L) water at a depth of 0.3 m within an isolated section of deep drain formerly used to link basins 5, 6 9, and 10 (not shown in Figure 4.3). Well developed, relict (vegetated) quartz and gypsum lunette dunes along the southern and southeastern margins of the wetland basins (Figure 4.3) indicate that evaporite formation and aeolian deflation were once of much greater significance and that the basins probably originated during arid phases associated with high latitude glaciations during the Pleistocene (Glassford 1980). Although groundwater has played and continues to play an important role in basin sedimentology and hydrology, its rate of discharge is very small and overshadowed by the much larger volumes of water sourced from direct rainfall, local runoff and perhaps lateral seepage from perched aquifers developed within permeable marginal sediments.
Table 4.1. Size characteristics of wetland basins in the lower Bodallin Catchment

<table>
<thead>
<tr>
<th>Basin</th>
<th>Area (m²)</th>
<th>Perimeter (m)</th>
<th>Depth* (m)</th>
<th>Volume (m³)</th>
<th>Catch. area* (m²)</th>
<th>Cumulative Area (m²)</th>
<th>Cumulative Volume (m³)</th>
<th>Cumulative Catch. area (m²)</th>
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<td>979710</td>
<td>366675</td>
<td>1258223</td>
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</tbody>
</table>

* Depths in italics were measured, remainder were estimated.
** Based on 100 m wide strip surrounding basin.

Table 4.2. Historical levels of inundation within wetland basins in the lower Bodallin Catchment

<table>
<thead>
<tr>
<th>Basin</th>
<th>10/01/1983¹</th>
<th>19/04/1994²</th>
<th>26/10/1999³</th>
<th>12/05/2000³</th>
<th>22/08/2002³</th>
<th>2/09/2003³</th>
<th>26/04/2004⁴</th>
</tr>
</thead>
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<td>1</td>
<td>D</td>
<td>D</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>H</td>
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<td>D</td>
<td>D</td>
<td>D</td>
<td>M</td>
<td>M</td>
<td>D</td>
</tr>
<tr>
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<td>D</td>
<td>D</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>3b</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>D</td>
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<td>M</td>
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<td>D</td>
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<td>H</td>
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<td>M</td>
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<td>D</td>
<td>D</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>D</td>
</tr>
</tbody>
</table>

D = dry; L = low (0–0.2 m); M = moderate (0.2–0.5 m); H = high (> 0.5 m)
1 = 1:50,000 black & white aerial photography; 2 = 1:25,000 colour aerial photography; 3 = Landsat TM imagery; 4 = field observation
Dates in bold fall within period during which diversion drain was probably used to convey water to basins 1, 2, 3a & 3b.

Based on the position of the lower boundary of healthy vegetation and the upper limit of shoreface sand and driftwood deposition, it can be inferred that the maximum water depth in the basins ranges from 0.1 to 0.5 m and averages about 0.4 m (Table 4-1). The total acceptable storage volume of the 10 basins is therefore ~370,000 KL. Any filling of the wetland basins above their natural high water level is likely result in extensive death of the fringing vegetation, especially where the water is from the onset highly saline. This is clearly demonstrated in the case of basins 1, 3a and 3b, which were for a short time supplied saline water via the diversion drain (Figure 4.3, Figure 4.4). Indeed, in the case of saline drainage
water, it is likely that vegetation death will begin to occur before the wetland basins are filled to their natural high water shorelines, making the acceptable storage volumes used here overestimates.

![Wetland basin 3a in the lower Bodallin Catchment with near-shore zone of dead vegetation caused by overfilling of basin with saline deep drainage water. Note healthy trees on flank and crest of lunette dune in the background.](image)

**Figure 4.4.** Wetland basin 3a in the lower Bodallin Catchment with near-shore zone of dead vegetation caused by overfilling of basin with saline deep drainage water. Note healthy trees on flank and crest of lunette dune in the background.

### 4.3 Drain-wetland water balance

#### 4.3.1 Water balance without drain discharge

Application of the water balance model without inputs from the deep drain shows that the wetland basins at Bodallin have a natural hydroperiod characterised by long periods of dryness interspersed with relatively short periods of inundation mainly during the autumn and winter (Figure 4.5A). A similar hydroperiod is indicated by pre-drain aerial photography and Landsat TM data (Table 4-2).

Over the period modelled (1/3/2001–9/5/2004), the basin water depth reached a maximum of 78 mm, representing 20.9 per cent of the total acceptable storage depth of 400 mm. It would therefore appear that the historical high water shoreline positions, determined largely from the distribution of vegetation, relate to rainfall events of greater magnitude than included in the rainfall records used. Alternatively, it may be that surface runoff and perhaps groundwater discharge from marginal sediments contribute more water to the basin than allowed for in the model. More monitoring data is required to resolve this uncertainty. In any case, it is clear from Figure 4.5A that the natural water depth in the basins is controlled by rainfall and evaporation, with high rainfall events in the winter months leading to the longest periods of inundation due to the lowest rates of evaporation.
4.3.2 Water balance with drain discharge excluding surface runoff

The effect on basin water levels of including discharge from the deep drain, except that which is derived from surface runoff (Dsi), is shown in Figure 4.5B. A maximum water depth of 255 mm is reached, representing about 68 per cent of the total acceptable storage depth of 400 m. It is important to note, however, that this is based on the drainage water being distributed simultaneously and equally in terms of depth to all of the 11 wetland basins, a procedure which in practice may be very difficult to achieve. Acceptable water depths may still be achieved if one or two of the smaller basins are bypassed, but this does not extend to any of the larger basins. The exclusion of basin 10, for example, results in a maximum water depth of 446 mm in the remaining basins, representing 139 per cent of the total acceptable storage volume.

Dewatering of the valley floor during drain construction forms a major component of the drainage water delivered to the wetland basins (Figure 4.5B). The marked increase in basin water depth at the beginning of the modelled period results from the final phase of drain construction having taken place during a period of fairly high rainfall and declining evaporation at the end of summer. To reduce the chance of overfilling wetland basins with dewatering water, construction of deep drains is therefore best conducted during summer when evaporation rates are at their highest. In this case, for example, the dewatering rate of ~3,700 KL/d can readily be compensated for by the effective evaporation rate of ~6,000 KL/d that is possible from the combined area of the 11 basins during summer.

Initially, the baseflow component of drain discharge has considerably less impact on water levels in the wetland basins than the dewatering flow because of its much lower magnitude (~760 KL/d). During the summer, up to half of the baseflow component, i.e. that amount of water which seeps through the drain batters, is lost to evaporation from within the drain (Figure 4.5B), with the remainder readily evaporated from the wetland basins. During the winter, less water is evaporated both from within the drain and the wetland basins, so that the principal effect of baseflow is to cause the depth and duration of inundation brought about by direct rainfall and localised runoff to increase (Figure 4.5B). The combined size of the wetland basins then becomes critical, with all 11 basins in this case being required to avoid overfilling, which, as already noted, may in practice be very difficult to achieve.

4.3.3 Water balance with drain discharge including surface runoff

The effect on basin water levels of including all discharge from the deep drain, i.e. also that which is derived from valley floor runoff (Dsi), is shown in Figure 4.5C. A maximum water depth of about 9.2 m is reached, representing 2,449 per cent of the acceptable storage volume using all of the 11 basins. In reality, overflow of the basins would prevent such a high depth of water from ever being reached, but it is nevertheless abundantly clear that the delivery of valley floor surface runoff to the wetland basins via the deep drain causes the storage capacity of the 11 wetland basins to be greatly exceeded. Furthermore, this applies to even the smallest of rainfall events which lead to runoff, because although the depth of runoff may be small (Figure 4.5C), the area from which runoff occurs is very large, and hence so is the total volume of runoff generated. For example, the relatively small runoff event of ~7 mm at the beginning of the modelled period resulted in a major influx of water to the basin system from which the model calculates it took more than one year to recover (Figure 4.5C). These findings are supported by observations of drain system performance during 2002, 2003 and 2004 (Wheaton and Watson, pers. comm., 2004).
Figure 4.5. Results of drain–wetland water balance model for the lower Bodallin Catchment. A. Natural (non-drainage related) gains and losses of water in wetland basins with resultant water depths. B. Gains and losses of water in deep drain (excluding surface water inflows) with resultant water depths in disposal basins. Initial high water depth primarily caused by dewatering of valley floor during drain construction. C. Quantity (mm) of water produced along valley floor by saturation-excess runoff, and greatly increased water basin depths produced where surface runoff is allowed to enter drain and be conveyed to the wetland basin system. (Base shift of 25 mm has been added to surface runoff to drain, Dsi.)
5. ELACHBUTTING DEEP DRAIN AND DISPOSAL BASINS

5.1 Drain construction, placement and discharge

About 46 km of deep drains were constructed in the lower reaches of the Elachbutting Catchment during early 2002, of which 39 km are within cleared land and the remaining 7 km are within an area of remnant vegetation and wetlands used for drainage water disposal (Figure 5.1, Figure 5.2). A number of short spur drains in addition to those than shown in Figure 5.1 appear in the NOI proposal, but it is not known if these have been constructed. The drains within the agricultural land typically have a width of 2 m and a depth 1.2–2 m, and are situated either along the central part of the natural drainage line or slightly offset from it. The spoil has been placed on one or other side of the drain only, making it completely open to surface water inflows.

Figure 5.1. Location of deep drain within the lower Elachbutting Catchment. Note placement of deep drain directly along the natural drainage line.
Within the area of remnant vegetation the drain is somewhat wider and shallower, being primarily used to convey water to wetland basins for evaporative disposal. To the south of basin 1, the drain bifurcates with the northern branch delivering water to basins 7 and 6 and the southern branch delivering water to basins 11 and 12 (Figure 5.2). When examined in May 2004, these basins were more or less filled to capacity. Short spur drains have been constructed to allow for the pumping of water from the northern drain into basins 1 and 5, and from the southern drain to basin 9 (Figure 5.2). The pumps are currently not in use and it seems likely that their primary purpose was to redistribute high volumes of water produced by valley floor dewatering during drain excavation.

Another measure taken to deal with high initial flow volumes has been the construction of bunds at the outlets of basins 11 and 12 in an attempt to increase their storage capacities (Figure 5.2). Owing to flooding of the natural drainage lines to the north of basin 12, possibly resulting from the uncontrolled release of drainage water to the southeast of basin 6 (Figure 5.2), water has flowed south along a spoon drain following Cunderin Road and severely scoured the back of the bund wall. Future filling of basin 12 is therefore likely to cause the bund to fail, resulting in substantial damage to the road, and flooding of the remnant vegetation and agricultural land situated further downstream.

A flow rate of about 9 L/s was measured in a culvert crossing comprising two 15 cm diameter PVC pipes at the point where the drain bifurcates south of basin 1. Taken over the total drain length of 39.8 km above the culvert and corrected for evaporative loss, this produces an average inflow rate to the drain of 24.6 L/d/m (KL/d/Km). As with Bodallin, this water was probably derived entirely from groundwater. The much lower seepage rate per metre of drain at Elachbutting suggests that the soils are less permeable, or that the water table is locally deeper.

At the end of May 2004, the electrical conductivity of drainage water within the agricultural area ranged from 7,300–7,800 mS/m (40,000–43,000 mg/L TDS), and the pH varied from 3.07–3.36. The groundwater at Elachbutting is therefore slightly more saline and acidic that at Bodallin.

5.2 Wetland basin geomorphology, hydrology and storage capacity

Except for basins 8, 11 and 12, the wetland basins at Elachbutting have no obvious surface water connection with the natural drainage line, which splits to form a fork-like pattern within the wetland area (Figure 5.2). However, on account of the very flat topography, it seems likely that some of the basins which are currently isolated from the natural drainage become connected to it during flood events. This is supported by Landsat TM imagery for mid May 2002 (Table 5-2), which shows high water levels in most of the basins following a period of high rainfall (~70 mm) some two months before.
Figure 5.2. Wetlands and drains within the lower Elachbutting Catchment. Drain bifurcates with northern branch conveying water to basins 7 and 6, and southern branch conveying water to basins 11 and 12. Diesel pumps (currently not in use) allow for additional discharge of water to basins 1, 2, 5 and 9. Major areas of recent vegetation death occur along the unveleed side of the deep drain and within most of the wetland basin floors, including those apparently not used for saline drainage water discharge. Uncontrolled release of drainage water southeast of basin 6 has caused flooding of natural drainage lines, with flood waters being diverted by spoon drain along Cunderin Road and causing scouring of bund at basin 12.
The combined area of the 12 wetland basins incorporated in the water balance model is about 37 ha, with individual basins ranging in size from 1 to 10 ha (Table 5-1). As at Bodallin, the basins have smooth, circular outlines and well-developed quartz and gypsum lunette sand dunes on their southwestern and southern margins. The basins were therefore most likely formed during arid phases when groundwater discharge and aeolian deflation were prominent, but continued to develop under the forested condition when groundwater tables were probably deep and basin hydrology was dominated by surface water.

Table 5.1. Size characteristics of wetland basins in the lower Elachbutting Catchment

| Basin | Area (m²) | Perimeter | Depth* (m) | Volume (m³) | Catch. Area (m²)** | Cumulative
|-------|-----------|-----------|------------|-------------|-------------------|-------------
|       |           |           |            |             |                   | Area (m²) | Volume (m³) | Catch. Area (m²) |
| 1     | 10785     | 396       | 0.6        | 6471        | 39641             | 10785     | 6471        | 39641             |
| 2     | 22964     | 628       | 0.6        | 13778       | 62826             | 33749     | 20249       | 102467            |
| 3     | 32370     | 697       | 0.6        | 19422       | 69714             | 66119     | 39672       | 172180            |
| 4     | 17638     | 573       | 0.6        | 10583       | 57282             | 83757     | 50254       | 229463            |
| 5     | 20744     | 523       | 0.6        | 12447       | 52777             | 104502    | 62701       | 281740            |
| 6     | 15040     | 458       | 0.6        | 9024        | 45832             | 119541    | 71725       | 327572            |
| 7     | 12066     | 419       | 0.6        | 7240        | 41913             | 131607    | 78964       | 369485            |
| 8     | 11791     | 401       | 0.6        | 7075        | 40113             | 143399    | 86039       | 409598            |
| 9     | 37577     | 710       | 0.6        | 22546       | 70971             | 180975    | 108585      | 480569            |
| 10    | 20575     | 528       | 0.6        | 12345       | 52757             | 201550    | 120930      | 533326            |
| 11    | 64103     | 922       | 0.6        | 38462       | 92177             | 265654    | 159392      | 625503            |
| 12    | 104227    | 1835      | 0.6        | 62536       | 183497            | 369881    | 221928      | 809000            |

* Depths in italics were measured, remainder were estimated.
** Based on 100 m wide strip surrounding basin.

Unlike at Bodallin, most of the basin floors do not contain salt crusts and are well vegetated, although much of the vegetation is either dead or dying. Dying or recently dead vegetation is prevalent in basins 1, 5, 6 and 7 (Figure 5.3), which given their direct or indirect connection to the deep drain, can readily be attributed to increased levels of inundation and salinity brought about by the discharge of saline drainage water. A strip of recently dead vegetation developed along the unveleved side of the deep drain between where it enters the area of remnant vegetation and turns sharply to the east (Figure 5.4), provides even clearer evidence of vegetation death caused by the influx of saline drainage water. For such areas of recently dead vegetation, it would therefore appear that the pre-drain regional groundwater was sufficiently deep and/or that flushing with fresh flood waters was sufficiently regular to prevent the accumulation of salts in the near-surface.
Figure 5.3. Recently dead vegetation within the floor of basin 6 in the lower Elachbutting Catchment caused by discharge of saline water from deep drain. Note survival of trees on crest of lunette dune in the background.

Figure 5.4. Recently dead vegetation on open (unleveed) side of drain within lower Elachbutting Catchment caused by overflow of saline drainage water during a flood event.
Importantly, however, the widespread occurrence of dead vegetation within the floors of basins 3 and 4, which apparently have not received saline drainage water (Figure 5.5), indicates that regional water table rise resulting from land clearing was already well established and that vegetation death within the floors of other basins would eventually have occurred, even if they had not been used for saline drainage water disposal. This illustrates the complexity of assessing the suitability of natural wetlands for drainage water disposal and highlights the importance of basing the assessment at least in part on the depth and rate of groundwater rise in the regional aquifer.

Based on the lower extent of healthy vegetation along the margins of basins 1–3 and the position of water marks on the trunks of dead vegetation situated within their floors, it can be inferred that the maximum ‘natural’ water depth in the basins is in the order of 0.6 m, resulting in a total acceptable storage volume of 222,000 KL (Table 5-1). Inclusion of basin 3 (not used for drainage water disposal) in the measurements indicates that the maximum ‘natural’ water level in this case relates to the pre-drainage condition, which on account of the presence of dead vegetation within the basin floor, almost certainly does not equate with the ‘pristine’ condition that existed before land clearing. Similarly, the depth to groundwater parameter ($h_2$) used in the water balance model to calculate leakage through the basin floors ($W_{go}$) was taken to reflect the modern condition (i.e. approx.1.5 m below ground level), even though the wetland basins probably developed under conditions of a deep regional water table, which in conjunction with episodic surface flooding, ensured that salt did not accumulate to critical levels within the basin floors.

![Figure 5.5. Historical (pre-drain) vegetation death within floor of wetland basin 2 in the lower Elachbutting Catchment. In this case, death of the vegetation has been caused by regional water table rise and the increased periodicity and depth of inundation brought about by land clearing.](image-url)
5.3 Drain-wetland water balance

5.3.1 Water balance without drain discharge

Historical aerial photography (Table 5-2) and application of the water balance model without inputs from the deep drain (Figure 5.6A) indicate that the wetland basins have a ‘natural’ hydroperiod very similar to those at Bodallin — that is long periods of dryness punctuated by relatively short periods of inundation mainly during the winter and autumn. Over the modelled period (1/2/02–13/6/04), the basin water depth is predicted to reach a maximum of 75 mm, representing only 12.5 per cent of the total acceptable storage depth of 600 mm (Figure 5.6A). As with Bodallin, it would therefore appear that the maximum acceptable high water shoreline position used in the model relates to rainfall events of higher magnitude than included in the input data, or more likely in this case, that the basins receive water from some other source not accounted for in the model, such as episodic flood flows or seepage from permeable sediments around the basin margins.

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D = dry; L = low (0–0.2 m); M = moderate (0.2–0.5 m); H = high (> 0.5 m).
1 = 1:50,000 black & white aerial photography; 2 = 1:25,000 colour aerial photography; 3 = Landsat TM imagery; 4 = field observation.
Dates in bold are for after drain construction.

5.3.2 Water balance with drain discharge excluding surface runoff

The results of including discharge from the deep drain in the model, except that which is derived from surface runoff ($D_s$), is shown Figure 5.6B. A maximum water depth of about 760 mm (126% of the total acceptable storage volume) is reached, assuming that the basins are fully isolated from the natural drainage line and that water is delivered in equal depths to all of the basin floors. The large amount of water produced by dewatering of the valley floor (~3,300 KL/d) during the assumed 90 day period of drain construction is principally responsible for the excess in drainage water inflow at the start of the modelled period, even though this was calculated using a 50 m impact width on either side of drain, as opposed to the 100 m used at Bodallin.

Evidence for high rates of dewatering flow actually having occurred is provided by the bunds used to increase the storage capacity of basins 11 and 12, and the use of pumps to distribute the drainage water to as many basins as possible (Figure 5.2). Comparison of Figure 5.6A
with Figure 5.6B shows, however, that this could have been avoided if the drains were constructed during the middle of summer when effective evaporation rates from the combined basin area (37 ha) almost completely compensate for the dewatering flows, assuming of course that the basins are initially dry and that they do not receive water from any other sources.

Baseflow at the drain outlet corrected for evaporation ($D_{gi}$) is slightly higher than at Bodallin (980 KL/d compared to 760 KL/d), but the increased drain length at Elachbutting allows for a much larger proportion of this to be evaporated from within the drain before it reaches the wetland basins, especially during the summer (Figure 5.6B). The impact of baseflow is therefore greatest during winter when evaporation rates both within the drains and basins are lowest, and the chance of the basins receiving water from direct rainfall, local runoff and some other source are also the highest. Furthermore, the model assumes that the drainage water is equally distributed in terms of depth to all of the 12 basins, which probably does not reflect the reality of the situation.

5.3.3 Water balance with drain discharge including surface runoff

Figure 5.6C shows the effect on basin water levels of adding all discharge from the deep drain, including that which is derived from the valley floor runoff ($D_{si}$). Assuming that the 12 basins are filled equally with drainage water and that all are isolated from the natural drainage line (i.e. have no natural surface water inlets or outlets), this produces a maximum water depth of 4.7 m, representing about 750 per cent of the total acceptable storage volume. Although basin overflow would prevent such a high water depth from being reached, particularly in the case of basins 11 and 12 which form part of the natural drainage line (Figure 5.2), it is from that the unrestricted access of surface runoff to the drain and then the delivery of all of this water to the wetland basins causes their storage capacity to be greatly exceeded.
Figure 5.6 Results of drain–wetland water balance model for the lower Elachbutting Catchment. A. Natural (non-drainage related) gains and losses of water in wetland basins with resultant water depths. B. Gains and losses of water in deep drain (excluding surface water inflows) with resultant water depths in disposal basins. Initial high water depth caused by dewatering of valley floor during drain construction. C. Quantity (mm) of water produced along valley floor by saturation-excess runoff, and greatly increased water basin depths produced where surface runoff is allowed to enter drain and be conveyed to the wetland basin system. (Base shift of 25 mm has been added to surface runoff to drain, \(D_{si}\).)
6. SUMMARY AND CONCLUSIONS

Modelling of the drain–wetland water balance in the lower reaches of the Bodallin and Elachbutting catchments suggests that the majority of isolated wetland basins, such as occur in these catchments, have the capacity to safely evaporate limited amounts of saline water delivered by deep drains. The modelling results and field evidence clearly show that the isolated wetland basins have their own hydrological system that is dominated by surface water inflows as opposed to groundwater inputs, even where the regional water table is shallow and actively discharging to the basin floor. Surface water is predominantly sourced directly from rainfall and to a lesser extent from local surface runoff, especially where marginal dunes produce steep slopes leading to the basin floor. Consistent differences in the depth of water predicted by the model and the elevation of the high water shoreline inferred largely on the lower extent of vegetation indicate that basin form and vegetation distribution are dominantly adapted to high water depths produced by unusually large rainfall events. Assuming that filling of the basins to their natural high water shoreline with saline drainage water does not result in death of the fringing vegetation, this provides the extra storage space for drainage water to accumulate during the winter and then be evaporated in the summer during an average rainfall year.

With respect to water balance alone, there are, however, three conditions that must be met before isolated wetland basins can be safely used for saline drainage water disposal. In the first instance, catchment-wide runoff must be prohibited from entering the deep drain, or at least it must be removed from the drain by a flow reduction structure before the drain enters the wetland system. The former is preferable because deep drains are rarely designed and constructed to withstand the high volumes and velocities associated with floods and because flow reduction structures are rarely well maintained. The isolation of surface runoff from a deep drain can be either achieved by the construction of levees on both sides of the drain, in which case it can be left in the natural drainage line providing it has been constructed to withstand flood flows, or more effectively by placing the drain outside the riparian zone and beyond the influence of all but the largest of flood events. Both options pose technical difficulties and may entail substantial extra cost.

Secondly, deep drains should only be constructed and connected to wetland basins during the summer when evaporation rates are highest and the basins are mostly dry. Clearly, the amount of water produced during drain construction will depend on the original depth to groundwater, the impact width of the deep drain (largely a function of hydraulic conductivity and gradient), and its total length. The sum of these components may exceed the capacity of the wetland basins to evaporate the water during a single summer, in which case it will be necessary to stagger drain construction over a number of years.

The third constraint to using isolated wetland basins for saline drainage water disposal is that the drainage water must be delivered to basins with a sufficiently large total surface area, and then in a manner which results in the water being delivered more or less equally in terms of depth. In practice, this may be very difficult to achieve, involving the construction of numerous carefully surveyed channels to connect one basin to another, and perhaps also pumps where increases in elevation are involved. Furthermore, the connector drains must not be allowed to pass below the regional water table since this will result in the drainage water simply being delivered to the groundwater and not to the basin floor where it can be most effectively and safely evaporated. Clearly, saline drainage water should not be allowed to discharge to basins supporting a healthy cover of native vegetation over their floors, especially where the vegetation does not face imminent death as a consequence of regional water table rise or increased inundation brought about by clearing.
Use of the wetland basins in the lower Bodallin Catchment for saline drainage water disposal appears to have failed on account of the first and third conditions not having been satisfied. The current practice of releasing the saline deep drainage water to a naturally saline part of the drainage line from where it can flow to Lake Warrachuppin (193 ha) is probably the most satisfactory option under the present circumstances, although ponding on the up-stream side of the road is likely to result in deterioration of the road formation.

More widespread vegetation death within wetland basins and channels in the lower Elachbutting Catchment appears to be due to all three conditions not having been adequately satisfied. A further difference with Bodallin is that there are no medium to large wetland basins nearby that can be used to accommodate and evaporate the saline drainage water should the linking of smaller basins fail. Continued disposal of the drainage water using the existing, now largely degraded, system of wetland basins at Elachbutting is possible, but only after catchment surface runoff has been excluded or removed from the deep drain before it reaches the wetland basins.
7. LIMITATIONS

Clearly there are other factors, in addition to water storage capacity, which require consideration when assessing the suitability of wetland basins for saline drainage water disposal. These have been discussed in some detail by Coleman (2003a,b), Coleman and Meney (2000, 2003), and Sinclair Knight Merz (2001) and include salt load, salt concentration, pH, ionic composition, dissolved heavy metals and nutrient and sediment loads of the drainage water inflows, and the conservation values of the disposal wetlands. Nevertheless, it is the storage capacity of the wetland basins which will usually be the limiting factor and therefore of greatest initial concern. Most wetland basins are already severely adversely impacted by regional water table rise and increased rates of inundation as a consequence of clearing, so that increased salt loads and concentrations, for example, may have little additional negative impact at least in the short term.

A second and more pertinent limitation of this study is the lack of data which can be used to calibrate and refine the drain-wetland water balance model. Further monitoring of drain flows in terms of the quantity, quality and source of water is urgently needed, as are further investigations of wetland hydrogeology and hydrology, which up to the present time have been regarded as being of marginal interest. Wetlands are perhaps the most dynamic and complex environments within the wheatbelt landscape, which in itself makes them a highly worthy and rewarding subject of study.
8. ACKNOWLEDGEMENTS

This report benefited from initial assessments of the deep drains and disposal wetlands at Bodallin and Elachbutting performed by Darren Farmer and Travis Cattlin. Andrew Watson, Buddy Wheaton, Brian Beetson and Richard George are thanked for their constructive reviews.
9. REFERENCES


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