Drummond Natural Diversity Recovery Catchment recovery plan 2011–2031

August 2013

Department of
Parks and Wildlife

Department of Parks and Wildlife
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

August 2013

Questions regarding the use of this material should be directed to:
Manager, Natural Resources Branch
Department of Parks and Wildlife
Locked Bag 104
Bentley Delivery Centre
Western Australia 6983
Phone: (08) 9334 0209

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Note

This plan was prepared by the Department of Environment and Conservation (DEC), which on 1 July 2013 separated to become the Department of Parks and Wildlife (DPaW), and the Department of Environment Regulation. While the Department of Parks and Wildlife printed this plan in July 2013, many actions outlined were already underway by the then DEC.

This document is available in alternative formats on request.

Disclaimer

Supporting information

The document *Drummond Natural Diversity Recovery Catchment supporting information* includes detailed information on physical characteristics of the catchment. The separate supporting information document, referred to in this plan as Appendices, also develops and explains important issues that would otherwise need significant diversions in the recovery plan. The intent is to improve the readability of the document. An attachment is included as part of this recovery plan.

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Summary

This recovery plan describes the biodiversity values threatened by altered hydrology, particularly salinity, in the Drummond Natural Diversity Recovery Catchment (DNDRC) and provides the management actions that will guide the conservation of these values for the planning period. The plan is a source of information and a management guide for catchment managers, land-holders and community members.

Natural diversity recovery catchments are a state government commitment under the *Salinity Strategy* and are one response to secondary salinity, a major threat to the biodiversity of south-west Australia. Recovery catchments provide a focus for government and community actions to protect regionally significant, high priority biodiversity assets, especially wetlands at risk from altered hydrology. Recovery catchments are managed by the Department of Parks and Wildlife, which has a statutory responsibility to conserve biodiversity in Western Australia.

The primary goal of recovery catchments is biodiversity conservation; however, they are also important for investigating and implementing solutions to salinity. This secondary goal recognises that successful management of recovery catchments requires research and development of sustainable forms of agriculture, which are environmentally sensitive and economically viable.

The DNDRC was established in 2001 as the sixth recovery catchment. Selection was informed by the results of the wheatbelt biological survey and by addressing the recovery catchment criteria. The catchment covers an area of 37,866 hectares and is located approximately 100 kilometres north-east of Perth in a long-established farming area, with less than a third of the catchment remaining as native vegetation. The management focus within the catchment is two relatively undisturbed freshwater claypan wetlands situated within Drummond Nature Reserve (DNR). These claypans are examples of wetland types that are rare in the wheatbelt. The DNR claypans are in near-pristine condition and contain a priority ecological community, a number of declared rare and priority flora, and high aquatic invertebrate richness.

The goal of the DNDRC was determined by describing and prioritising the cultural values of biodiversity assets threatened by altered hydrology in the catchment and is:

To deliver the scientific and educational values, opportunity values and system benefits values derived from the current (2011) composition and structure of biodiversity assets of the DNR threatened by altered hydrology for the next 20 years.

To achieve the goal and deliver the priority values of science and education, opportunity and system benefits, it will be necessary to conserve the 2011 composition and structure of native biota threatened by altered hydrology. In the context of the goal, the most important biodiversity assets are the two vegetated claypan wetlands in DNR. As our understanding of the hydrology of DNR is incomplete, other biodiversity assets may also be threatened by altered hydrology and therefore further hydrological investigation is required.

A biophysical threat analysis was undertaken to evaluate the key ecosystem processes that must be managed to protect the biodiversity assets and achieve the goal. As a result, the most important management issues that are considered likely to cause goal failure include:

- hydrological processes, including salinity
- environmental weeds
- nutrient cycles, including eutrophication
- detrimental fire regimes
- attitudes toward saving assets from salinity threats, in particular, inadequate understanding of the contribution by biodiversity assets to human quality of life.

The threat analysis indicates that with additional management the probability of goal failure can be reduced to an acceptable level for all the above management issues. Key management actions to assist in goal achievement have been identified such as: more detailed investigations of biodiversity assets; hydrological studies and the preparation of a water management strategy; revegetation and protection of remnant vegetation on private property; investigating potential climate change impacts; weed management, plant disease and problem fauna species control; appropriate fire regimes investigated; and the development of a communication plan.

Work in the catchment to date has focused on hydrological and biological investigations to provide the basis for effective management planning. On-ground works have also been undertaken that will contribute towards the management of altered hydrology including:

- a network to monitor surface and groundwater
- containment of a weed population in DNR
- revegetation and fencing in the surface water catchment north-west of DNR
- revegetation of a degraded area in DNR
- planning activities and community consultation.

A framework for monitoring and evaluation has been established to measure progress and performance during implementation of the recovery plan. Progress towards achieving the goal for the catchment will be measured against monitoring targets which are of two types –

management triggers and limits of acceptable change. Limits of acceptable change are the limits within which change to biodiversity assets can be tolerated in the context of the goal and related values. Management triggers lie inside the boundaries of acceptable change and are intended to provide an early alert so that an adaptive management response can be implemented if required. Given the short period over which data are available, both sets of indicators can be expected to change as new knowledge becomes available.

This plan will be implemented through annual operational planning and works by the recovery catchment team. It will include annual reporting on expenditure and outputs, and progress reports addressing the monitoring targets. Major reviews of the recovery plan will also be undertaken periodically.

1 Salinity, biodiversity and the role of recovery catchments

The Drummond Catchment was designated as a natural diversity recovery catchment (NDRC) in 2001 as part of the Natural Diversity Recovery Catchment program. The aim of this program is to focus government and community actions to protect regionally significant, high priority biodiversity assets, especially wetlands, threatened by salinity.

The recovery plan for the Drummond NDRC (DNDRC):

- identifies the priority cultural values of biodiversity assets threatened by salinity in the catchment
- sets goals for biodiversity conservation based on these cultural values
- identifies the most important biodiversity assets that must be managed to achieve the specified values and related goals
- identifies the ecosystem processes that threaten goal achievement and proposes a series of management actions to address these threats
- establishes a framework for monitoring management actions and evaluating progress
- documents the planning and priority-setting processes
- serves as an implementation guide for catchment managers, landholders and the community.

The threat of salinity to biodiversity

The expansion of salinity is changing significant areas of the Western Australian (WA) agricultural landscape. Salinity poses a serious issue for agricultural production and is also a threat to biodiversity, affecting the survival of native species and their communities. The use of the term 'salinity' in this report refers to secondary salinity as opposed to 'primary salinity', which is naturally occurring, such as in salt lakes predating European settlement.

The state government developed the *Western Australian Salinity Action Plan* (Government of Western Australia 1996) in response to the increasing threat of secondary salinity. This plan identified salinity in the south-west of WA as one of the state's most critical environmental problems. The plan was subsequently updated through the publication of *Natural Resource Management in Western Australia, The Salinity Strategy*[1] (State Salinity Council 2000) and *Salinity*: *A New Balance, Government's Response to the Salinity Taskforce report*[2] (Government of Western Australia 2002).[3] In their review of the current and potential extent of salt-affected land, McFarlane et al. (2004) estimated that WA has the largest area of secondary salinity in Australia and was also at the greatest risk of further salinisation over the next 50 years.

McFarlane et al. (2004) estimated that about one million hectares of the state was affected by salinity and this was increasing at 14,000 hectares per year. The area with salinity hazard[4] was estimated to be between 2.9 and 4.4 million hectares. Most of this (about 80 per cent) is on cleared agricultural land but also includes important public assets such as biodiversity, water resources and infrastructure (McFarlane et al. 2004; George et al. 2005). Recent work on groundwater trends in the wheatbelt indicates that groundwater levels, in comparison with the preceding decades, have generally been more stable since 2000, with some areas showing downward trends (George et al. 2008). However, salinisation has continued to 'expand in all regions, especially following episodic floods, such as those that occurred in 1999–2000, 2001 and 2006' (George et al. 2008, p. 3).

The south-west of WA[5] is an important area for biodiversity. The region has been recognised as one of the world's 34 biodiversity hotspots based on the very high terrestrial species endemism combined with a high level of vegetation clearing (that is, 30 per cent or less of the original vegetation remaining) (Mittermeier et al. 2004). The south-west of WA has 5,710 plant species of which about 3,000 (53 per cent) are endemic (Mittermeier et al. 2004).

1. Usually referred to as the *Salinity Strategy.*
2. Usually referred to as the *Response to the Salinity Taskforce Report*
3. Throughout the remainder of this document, these reports are referred to as the *Western Australian Salinity Action Plan, Salinity Strategy* and *Response to the Taskforce Report* respectively
4. Areas at risk from salinity because groundwater is predicted to rise close to the surface.
5. Throughout this document the south-west of WA refers to the area lying to the south and east of a line connecting Kalbarri and Cape Arid east of Esperance.

A key project funded through the *Western Australian Salinity Action Plan* (Government of Western Australia 1996) was the wheatbelt biological survey (1997–2001)[6] which documented biota in the south-west agricultural zone and the extent to which it is threatened by salinity (Keighery et al. 2004). This survey revealed that salinity has already had a significant impact on the native plants and animals of the wheatbelt, particularly those species inhabiting wetlands. It was estimated that 450 plant species and 400 species of fauna could be at risk of global or regional extinction (Keighery et al. 2002a, 2004). Of particular concern is that most wheatbelt wetlands have already been severely degraded and these changes have been largely undocumented.[7] The wheatbelt biological survey substantially increased the knowledge of the impacts of salinity on biodiversity.

Secondary salinity and altered hydrology

As research has progressed and understanding has improved, it is now apparent that secondary salinity is just one of the many complex effects that have arisen from altered hydrology in the Australian landscape. In the south-west, altered hydrology has resulted from changes in the water balance due to the removal of perennial native vegetation (high water users) and its replacement with annual crops and pastures (low water users). Along with the increase in salt-affected areas, other adverse impacts of altered hydrology may include:

- Changes in the area, distribution, frequency and timing of inundation in wetlands. Negative environmental impacts, independent of water quality, may relate to plant health and recruitment, and aquatic invertebrate survival.
- Increased waterlogging, through increases in soil water content, regardless of the quality of the water. Vegetation higher in the landscape and fringing wetland vegetation may also be affected.
- Changes in acidity and alkalinity, including elevated levels of acidity (low pH) or depletion in buffering capacity. While acidity itself can cause decline/mortality of native flora and fauna, metals and other pollutants that are also associated with acidic water can have additional negative environmental effects. It should be noted that, although less common, increases in alkalinity (high pH) can also have undesirable effects.
- Increased erosion can cause the loss of topsoil and produce deeply incised drainage channels. Potential undesirable impacts of increased erosion include poor slope stability and high rates of vegetation mortality in drainage lines due to exposure of roots.
- Increased sedimentation, a by-product of excessive erosion, can result in accelerated rates of sediment deposition downstream. This in turn can cause turbidity and alter flow regimes.
- Increased salinity and other changes in water quality. Increased input of salts may result in undesirable impacts to biota. The nutrients phosphorus and nitrogen may lead to eutrophication and algal blooms. Decreases or depletion in ions, such as potassium, calcium or magnesium, can also cause environmental conditions to become intolerable for some biota.[8] For example, native aquatic snails cannot survive where chemical conditions prevent them from producing shells.

The current, general trend of a drying climate, in turn, is compounding the above impacts by directly affecting catchment water budgets. While some impacts may be reduced under a changed climatic regime, there is currently not enough information to confirm this. For example, if summer rainfall was to increase, salinity and other problems arising from altered hydrology may be exacerbated.

The term 'secondary salinity' implies that salt is the only problem. Therefore, 'altered hydrology' is a more appropriate term, as it encompasses the entire suite of complex processes that has followed anthropogenic modifications to south-west landscapes. Impacts of altered hydrology can threaten the survival of native species, their biological communities and ecosystems. Effective management depends on understanding the physical characteristics of an area, as well as the plant and animal tolerances and thresholds to hydrological and associated changes.

Natural Diversity Recovery Catchment program

The NDRC program is a commitment by the state government arising from the *Western Australian Salinity Action Plan* (Government of Western Australia 1996). The objective of the program is stated as:

[6] The major publication from the wheatbelt biological survey was *A biodiversity survey of the Western Australian agricultural zone* by Keighery et al. (2004). The survey area 'extended from the 600mm annual rainfall isohyet inland to the eastern edge of land clearing which approximately equates with the 300mm isohyet'.
[7] A broad picture of changes due to salinity is provided by the oral history work of Sanders (1991) and the depth and salinity monitoring work by Lane et al. (2009).
[8] Precipitation of gypsum ($CaSO_4$) due to increased input of SO_4 from catchment drainage can deplete a waterbody of calcium and impact on macroinvertebrates and gastropods. Plants are also susceptible to changes in the ionic content of water.

The government will develop and implement a coordinated wetlands and natural diversity recovery program targeting at least six key catchments over the next 10 years to ensure that critical and regionally significant natural areas, particularly wetlands, are protected in perpetuity.

While not specified, the intent was to select catchments threatened by altered hydrology, particularly salinity. Reviews of the state government's salinity programs have reconfirmed the importance of the NDRC program and, where appropriate, have proposed its expansion (State Salinity Council 2000; Frost et al. 2001; Wallace 2001; Government of Western Australia 2002).

The NDRC program provides one focus for government and community actions to manage the impact of salinity on biodiversity in the south-west agricultural region. In designated catchments, it aims to conserve representative biological communities and their related physical diversity, together known as 'natural diversity'.[9] The focus of the program has been on selecting assets that represent the range of biodiversity threatened by salinity. Responsibility for the NDRC program resides with the WA Department of Parks and Wildlife (DPaW).[10]

NDRCs are one of two types of existing recovery catchments, the other being water resource recovery catchments (potable water resources) managed by the Department of Water. There has been useful cross-agency support across these two programs.

Priority setting for salinity actions

To guide resource allocation to protect high value assets threatened by salinity the WA State Salinity Council commissioned the development of the Salinity Investment Framework (SIF) in 2000. This study recognised that it is crucial to have a rigorous framework for ranking salinity investments by governments given the extent and consequences of salinity and the very high cost of management. The recommended approach to priority setting is described in two reports: *Salinity Investment Framework: Interim Report Phase I* (Department of Environment 2003) and *Salinity Investment Framework Phase II* (Sparks et al. 2006). The assets evaluated were: biodiversity, agricultural land, water resources, rural infrastructure and social amenities. The selection of NDRCs precedes the Salinity Investment Framework processes, but the relevant work is picked up in the Investment Framework.

Three NDRCs were established in 1996 under the *Western Australian Salinity Action Plan* (Government of Western Australia 1996). These were Lake Warden, Toolibin Lake and the Muir-Unicup Wetland Complex. A further three NDRCs have been established since the inception of the program: Lake Bryde, Buntine-Marchagee and Drummond.

The first three NDRCs were selected prior to the completion of the wheatbelt biological survey (Keighery et al. 2004). It was judged important to identify and begin to manage areas where high biodiversity values coincided with significant threats from altered hydrology, particularly salinity. The selection of the later NDRCs (Lake Bryde, Buntine-Marchagee and Drummond) was informed by the preliminary results of the wheatbelt biological survey (Keighery et al. 2004).

As an interim measure, a set of criteria was developed for identifying recovery catchments (Appendix 1):

- biodiversity values at risk from altered hydrology
- biogeographic representation
- opportunities for research and development or demonstration
- tenure of land at risk
- representation of hazard
- potential for success (note that local community support was an important element assessed in this regard)
- sociopolitical considerations.

The nomination document *Proposed Drummond Nature Reserve Natural Diversity Recovery Catchment* (Department of Conservation and Land Management 2001) (Appendix 2), cited the following criteria in recommending the catchment for recovery planning:

- Drummond Nature Reserve, and specifically the claypans in the reserve, represent an important biological community predicted to be at risk from altered hydrology
- occurs in a biogeographic zone not represented by other NDRCs—located on the north-east boundary of the Jarrah IBRA Region and the western edge of the Avon Wheatbelt IBRA Region,[11] the vegetation is transitional, containing elements of several systems, many at the edge of their range
- potential to be a demonstration catchment representative of the many small-to-medium-sized reserves that occur on the east of the forest belt from Bolgart to Cranbrook, which have high conservation values (for example wetlands and wandoo woodlands) threatened by salinity
- model for undertaking, evaluating and costing

[9] This document is concerned with the conservation of natural biodiversity rather than domesticated species and other biodiversity arising from human actions.
[10] On 1 July 2013, the Department of Parks and Wildlife was created following the separation of the Department of Environment and Conservation. In July 2006, a reorganisation of some government departments resulted in the Department of Conservation and Land Management becoming part of the new Department of Environment and Conservation. [11] IBRA: Interim Biogeographic Regionalisation for Australia, see http://florabase.dpaw.wa.gov.au/help/ibra/

biodiversity actions for similar reserves where local effects and remedies are considered to be the means to overcome the salinity issues

- requires solutions that seek to achieve sustainable agriculture and increased water use on agricultural lands in the catchment, aspects which are of mutual interest to landholders and DPaW
- important educational values—situated close to Perth, with catchment issues and solutions that are comparatively easy to demonstrate.

The recommendation that the DNDRC be established was endorsed by the Conservation Commission of WA, the State Salinity Council (since disbanded) and the Minister for Environment (WA) in 2001. The catchment was the sixth NDRC to be established and was officially launched in September 2003.

The selection of recovery catchments is now structured around a more quantitative approach. A formal analysis using data generated by the wheatbelt biological survey (Keighery et al. 2004) has been used to determine which other areas of the wheatbelt might best complement the existing NDRCs (Walshe et al. 2004). This information has been combined with the results from the Salinity Investment Framework to select potential recovery catchments for the future.

Planning process

The process used to develop this recovery plan is summarised in Figure 1. While there is a logical and linear sequence to this process, in practice it is iterative and interactive. It also involves input and consultation from the community, particularly (in this case) the DNDRC Advisory Committee and the Avon Nature Conservation Advisory Committee.

The DNDRC Advisory Committee is the main forum to facilitate work with the catchment community. Members represent the following stakeholders:

- catchment group – Land Conservation District Committee of Solomon-Yulgan
- local government – councillors from shires of Toodyay and Victoria Plains
- government agencies – DPaW, Department of Water (DoW) and Department of Agriculture and Food (DAFWA).

The DNDRC Advisory Committee has met seven times between 2003 and 2011 to discuss progress and provide input to the development of the recovery plan. Initially, the advisory committee considered objectives and strategies. The focus then moved to catchment research but also included some 'no-regret' activities.[12]

Planning and on-ground work to date have focused on the following:

- Hydrological assessments, survey work and ongoing monitoring to provide the basis for effective management and planning.
- Decreasing the flow of excess (surface and ground) water affecting biodiversity assets through revegetation. These plantings also expand, buffer and link significant remnant vegetation within the greater DNDRC.
- Protecting remnant vegetation as part of hydrological management.
- Research into biodiversity indicators for evaluating management effectiveness. This has included testing the effectiveness of remote sensing tools for monitoring change in vegetation condition, and trials of ecosystem monitoring techniques for assessing resource condition trends in managed (revegetated) and unmanaged sites (Tongway and Hindley 2004).
- Alternative farming practices aimed at increasing water use in the catchment, including salt-tolerant pastures, oil mallees and sandalwood.
- Building an appropriate culture to support biodiversity conservation.

Within DPaW, a technical advisory group (TAG) has provided planning guidance. This represents senior management, scientists and recovery catchment officers. One of the roles of this committee is to provide technical and management advice on the development and implementation of recovery catchment plans. This includes advising the management team on the planning and feasibility of management actions. A wide range of other stakeholders have also been involved to date (Appendix 3).

The process for review and approval of recovery plans includes internal review by the TAG as well as input from the project management team and the advisory committee. This process is iterative and assists in refining goals and actions, and developing an evaluation and monitoring plan. Community input and support have been sought for this recovery plan through the advisory committee prior to publication and release.

[12] No-regret activities are on-ground works that are required for longer term success, but may or may not be the most urgent in the short to medium term. These provide a sound basis for early on-ground action while investigations and more detailed planning occur. They also provide an important mechanism for engaging the local community.

DPaW District staff at a claypan in Drummond Nature Reserve.
Photo – Ken Wallace.

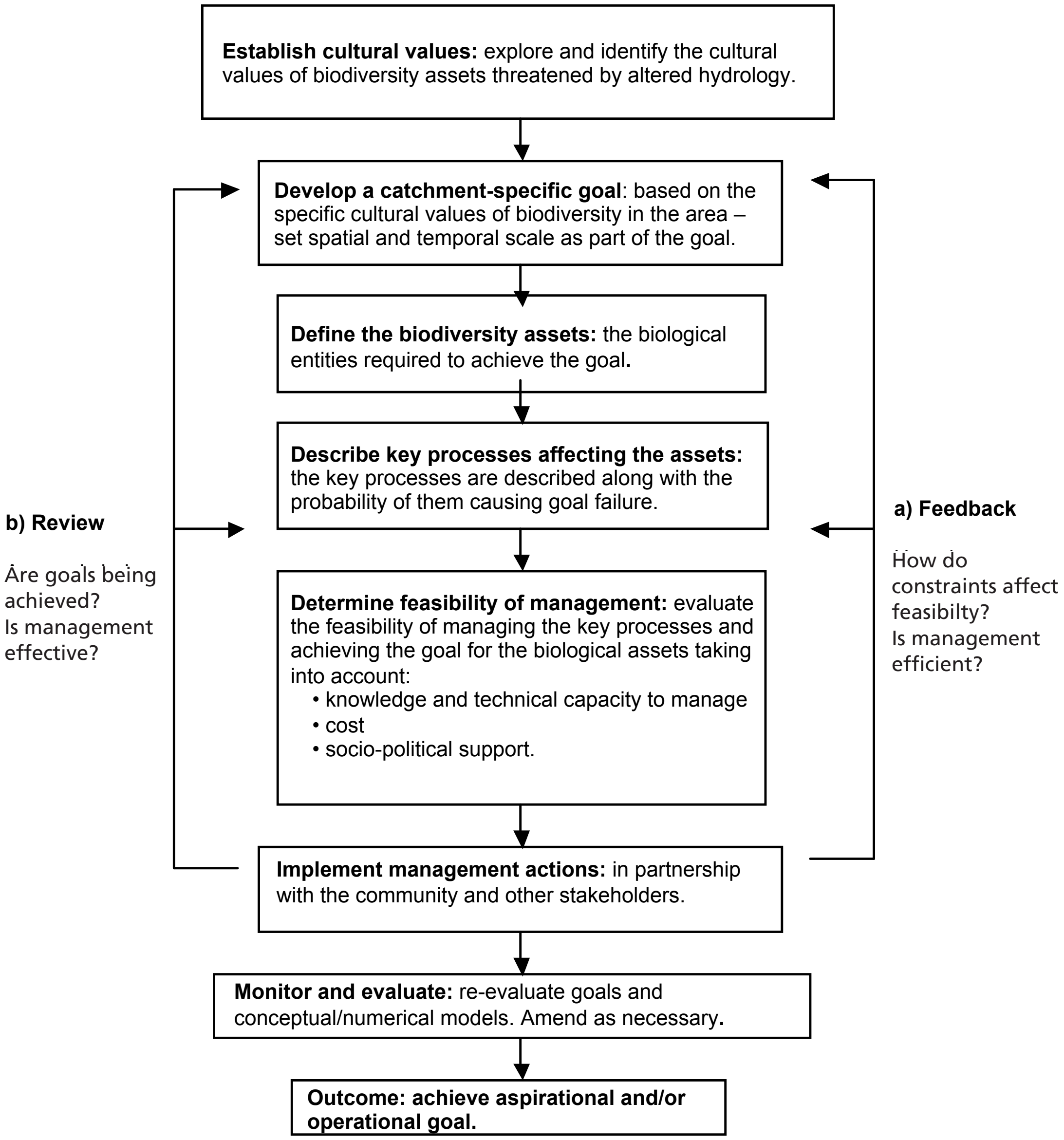


Figure 1 The planning and management process for natural diversity recovery catchments

2 Description of the Drummond NDRC

Planning area

The DNDRC extends across the two shires of Victoria Plains and Toodyay, and the administrative areas are described in Table 1.

Table 1 Overview of the administrative areas of the DNDRC

Local government shires	Victoria Plains Toodyay
DPaW administrative regions	Swan Region, Perth Hills District Wheatbelt Region, Avon-Mortlock District
Land tenure	Freehold – 80% of area, about 58 landholders DPaW-managed land – 6% Bindoon Army Training Area – 11% Other tenure – 3%

Catchment overview

The DNDRC covers an area of 37,866 hectares, approximately 100 kilometres north-east of Perth and about 10 kilometres west of Bolgart (Attachment 1, Appendix 4). The catchment spans about 22 kilometres from north to south and 16 kilometres from east to west, and consists of three subcatchments: Yulgan Brook, Solomon Brook and Mt Anvil Gully. The DNDRC is within the larger catchment of Toodyay Brook, and more widely, the Avon River. The catchment is a long-established farming area with 29 per cent remaining as remnant native vegetation (11,034 hectares) comprising five nature reserves and part of a sixth; parts of the Julimar Conservation Park (proposed) and Bindoon Army Training Area; plus on-farm remnants.[13]

The management focus within the DNDRC is two relatively undisturbed freshwater claypan wetlands situated within DNR, which is 439 hectares and a class 'A' nature reserve (Reserve No. 42808), vested with the Conservation Commission of Western Australia for the purpose of 'conservation of flora and fauna'. It was privately owned and part of a neighbouring farm before it was gazetted in 1993. DNR is located in the north-west corner of the Toodyay Shire, on the watershed between the Solomon Brook and Mt Anvil Gully catchments, in the mid to upper part of those catchments (Department of Conservation and Land Management 2001).

DNR has very high biodiversity values, mainly focused on the two seasonal claypan wetlands (about three hectares each). These claypans are unique to the wheatbelt as they are the last remaining wetlands of their type in uncleared land this far east. They contain one species of declared rare flora (DRF) and seven species of priority flora. Two other DRF species and 10 priority flora species have also been recorded in the reserve. Two of the valley floor vegetation communities—wandoo woodland over dense low sedges community and the freshwater claypan community—are rare in the agricultural zone. The presence of the latter community in DNR defines its eastern limit, as it is more commonly found on the Swan Coastal Plain (Department of Conservation and Land Management 2001).

Social and economic characteristics

At the 2006 Census, the combined population of the shires of Toodyay and Victoria Plains was 5,015 people. The catchment itself is a sparsely populated agricultural area, with less than 380 people[14] and approximately 58 farming properties (Kay 2001). It is a well-established rural community with many second and third generation farmers in the district. Broadacre farming is the dominant industry. Clearing native vegetation for agriculture began in the 1830s but expanded significantly with the completion of the Toodyay-Bolgart Railway in 1909 (Kay 2001). In the north-west of the catchment, clearing was still occurring into the 1990s (Department of Conservation and Land Management 2001). Currently, the main farming enterprises are cereal, legume and oilseed cropping, followed by meat and livestock production.[15]

[13] Calculations by Geographic Information Services Section, DEC, Kensington. April 2009.
[14] Australian Bureau of Statistics. Based on statistics relating to two Census Collector Districts (5040113 and 5041402) within which the catchment is located.
[15] ABS, www.abs.gov.au/ausstats, accessed April 2006.

The towns closest to the catchment, Bolgart to the east and Calingiri to the north, are typical of small townships in the WA agricultural zone. These towns have a range of infrastructure and services, including primary schools, hotels, sporting facilities, general commercial shops, agricultural suppliers and grain bulk-handling facilities. The local government centre is located at Calingiri.

Cultural heritage

The district holds significant cultural heritage relating to both Aboriginal—spanning thousands of years (Ballardong n.d.)—and settler cultures since the early years of the Swan River Colony (Erickson 1971, 1974). There are two Aboriginal language groups relating to the catchment area: the Juat in the western section and the Ballardong in the eastern.[16] Three Aboriginal cultural heritage sites of significance have been identified on private property on the catchment's eastern side. These are registered with the Department of Indigenous Affairs.[17]

Two other heritage sites have been recorded in the catchment. There is an Aboriginal gnamma within DNR and there are settlers' ruins dating back to the 1860s within the Bewmalling Nature Reserve. Old Plains Road was the route used by early settlers to drove flocks of sheep from Toodyay to grazing grounds at the Moore River in the mid to late 1800s (Western Australian National Parks and Reserves Association 1986). DNR is named after the first government botanist, naturalist and explorer, James Drummond (1784–1863) who lived at 'Hawthornden', Toodyay. It is thought that Drummond would have travelled and made botanical collections along Old Plains Road.

Physical characteristics

Climate

The DNDRC experiences a Mediterranean climate, with mild wet winters and hot dry summers. Mean maximum daily temperatures range from 17 degrees Celsius in July to 34 degrees Celsius in January. Evaporation exceeds rainfall for at least 10 months of the year, with June and July the only months when rainfall is consistently likely to exceed evaporation.[18]

Average rainfall across the catchment ranges between 650 millimetres and 400 millimetres per year, generally decreasing from west to east. Bureau of Meteorology rainfall stations are located at Bolgart and a short distance to the west, at Wattening.[19] The average annual totals for both these stations show a slightly declining trend. For Bolgart, the short-term average (1986–2008) is 10 per cent lower than the long-term average (1906–2008) (Table 2). However, the record for Bolgart is incomplete with data missing for the years 1971–82 and 1985. Hence, the short-term average was calculated from 1986–2008.

Table 2 Annual rainfall total averages at Bolgart

Period	Average annual rainfall (mm)
1906–1970	474.5
1986–2008	411.8
1906–2008	458.1

Regional geology, geomorphology and soils

The majority of the DNDRC is underlain by a granitic basement of varying depth. This basement outcrops at the surface regularly across all of the sub-catchments. In places, the granitic basement is intruded by dolerite dykes. There is no evidence of any major palaeochannels in the catchment. The granitic basement has been subjected to a range of geological processes including: glaciation, deep weathering and laterisation resulting in a granitic regolith profile that overlies this basement in many areas. Bedrock has been weathered *in situ* to form a regolith profile which consists of four main lithologies or regolith units: saprolite located immediately above bedrock; the clay-rich pallid zone; patchy discontinuous silcrete; and laterite or ironstone, both of which may be semi-impermeable. The distribution and properties of these units can be very important for both local and regional hydrogeological regimes. In many areas, the regolith profile is capped by more recent Quaternary sediments and soils derived from weathering and reworking of regolith material. Distinct variation in soils is evident across the catchment, varying between gravels, clays and silts with occasional sands.

Hydrology and hydrogeology

The hydrological boundary of the greater DNDRC is defined according to the surface water catchment. The DNDRC comprises three sub-divisions or sub-catchments: the Solomon Brook Catchment, Yulgan Brook Catchment and the Mt Anvil Gully Catchment (Attachment 1, Appendix 4). The catchments' main tributaries drain east-southeast into Toodyay Brook, which in turn flows south to the Avon River. Most stream flow within DNDRC is ephemeral; however, the lower section of Toodyay Brook has minor flows perennially. Groundwater flow direction generally mimics topography and surface water drainage within the DNDRC.

[16] http://www.dia.wa.gov.au/Documents/Maps/maps%20sept09/Tindale.pdf
[17] http://www.dia.wa.gov.au/AHIS/
[18] Based on data from Bureau of Meteorology, using evaporation data for Goomalling (closest station to DNR with data) and comparing it to rainfall data for Bolgart and Wattening, which are further west than Goomalling and have higher annual rainfall.
[19] Bureau of Meteorology (http://www.bom.gov.au/climate/data/weather-data.shtml)

Several main aquifer systems have been identified within DNDRC, including weathered bedrock (deep regolith), alluvial, aeolian sand plain and infill valley basin (Kay 2001; PPK 2002). Deep regolith aquifers occur throughout the upper and middle catchment. These are characterised by brackish to saline groundwater and highly variable hydraulic conductivities, ranging from poor in the shallow pallid zone to good in the saprolite zone, which directly overlies the bedrock. Aeolian sand plain aquifers are common in the upper catchment, as infill of depressions along valley flanks (mainly Solomon and Yulgan catchments) and valley floor settings. These sand plain aquifers are typified by freshwater qualities and high hydraulic conductivities with ephemeral discharge common on the downgradient side. The unconfined alluvial aquifer dominates the valley floors of the middle catchment area. Generally, depth to groundwater is shallow (less than five metres), hydraulic conductivities are good and water quality is variable. The infill valley basin aquifer occurs along a north-south trending line in the middle catchment area, comprising mainly sandy sediments (and some clays); it infills the basement hollows above the main tributaries. These discontinuous aquifers vary between being confined and unconfined across the greater DNDRC. Water quality ranges from fresh to saline; hydraulic conductivities and yields are often high. It should be noted that there is evidence of the possible existence of fractured rock aquifers within the lower reaches of the DNDRC, in particular the Mt. Anvil Catchment. The location of these will be defined by structural control and will be difficult to utilise due to highly variable yields.

DNR is situated in the upper reaches of the DNDRC and straddles the boundary between the Solomon and Mt Anvil catchments. It is dominated by shallow outcrops of bedrock and ironstone intermixed with deep regolith aquifers, infilled valley sand aquifers and sand plain aquifers, all of varying depths. The extent and connectivity of these aquifers are determined to a certain degree by the location of the bedrock highs. Groundwater flow is generally west to east through DNR, although it can be impeded and sometimes diverted in areas of the bedrock highs. The two pristine, fully vegetated freshwater claypans in DNR are situated within topographic depressions in the south-west and north-east corners of the reserve. Both claypans are relatively impermeable and are surrounded by highly conductive, sandy sediments. Localised surface water flows tend to concentrate towards these two claypans during the winter rain events. For a more detailed explanation of DNR's hydrological characteristics, refer to Forbes and Vogwill (2010).

3 Biodiversity values and management goals

Cultural values and biodiversity conservation

DPaW's statutory functions are the key drivers for departmental management of biodiversity and conservation lands and, in a legal sense, circumscribe the operational activities of the department. However, to guide management, it is important to describe the cultural values of biodiversity conservation in the DNDRC. This information is important both for setting goals and describing biodiversity assets. These values explain why biodiversity conservation is considered important in this catchment and for what purposes biodiversity is being conserved.

Individuals and groups within any community have a range of motivations for conserving biodiversity. For effective natural resource planning and management, it is important to clarify the dominant cultural values within the particular situation (Shields et al. 2002; Wallace 2006). The relevant cultural values can then be used, provided they are consistent with the department's legislated functions, to underpin the catchment goals and definition of specific biodiversity assets for conservation, and drive decision-making for management actions. The classification system for cultural values developed by Wallace (2006) has been adapted for this plan.

The DNDRC Advisory Committee met in June 2008 to determine the relative importance of the various cultural values delivered from biodiversity threatened by altered hydrology within the DNDRC. The steps in this process were as follows:

1 All the biodiversity assets considered to be at risk of altered hydrology were described. Note that, depending on the values analysis, not all of these assets may be a priority for management.

2 The eight cultural values (see below) were defined and discussed.

3 Committee members ranked the values anonymously in relation to the biodiversity assets described in (1). The results were combined to rank the values from the collective perspective of the committee. The committee represents key communities of interest, including the state community (through agencies representing biodiversity, water and agriculture) and local communities of interest.

4 The top three ranked values were accepted as the priorities for planning processes. (Appendix 5).

The cultural values identified, in order of priority were:

1 Scientific and educational values—focused on scientific investigations that advance knowledge of salinity management, and the broader contribution to education and training. The advisory committee ranked this value as the most important and identified that the biodiversity assets of the catchment are an educational resource for local land-holders, school groups and the broader (state) community. DNDRC was also identified as a case study for environmental management and as a benchmark for measuring change, including of the historical value of biological communities.

2 System benefits values—from maintaining the catchment and downstream environment. In relation to managing altered hydrology, these potentially include flood mitigation, nutrient stripping and salt storage. The advisory committee ranked this category second, based on the premise that the wetland assets are highly connected to downstream environments. More recent work suggests these benefits are likely to be limited, although there is some hydrological connection with environments downstream. For this reason the value has been retained.

3 Opportunity values—based on the range of potential future opportunities represented in the biodiversity assets. These might include genetic resources or water resources yet to be harvested. The advisory committee identified that conserving the full range of native taxa in the biodiversity assets protected opportunities for future human benefit.

4 Amenity values—including aesthetic values, such as the scenic values of natural landscapes, as well as shade and shelter values. Amenity values help maintain a sense of place.

5 Philosophical/spiritual/intrinsic values—are a strong driver for biodiversity conservation at the state and local level.

6 Recreation values—including opportunities for tourism and recreational use for activities such as bushwalking, picnicking and birdwatching.

7 Consumptive use values—natural resources harvested for non-commercial, domestic use. Potentially, this could include seed collection from the reserve, with appropriate approvals, for off-reserve land or biodiversity conservation work.

8 Productive use values—not relevant here in relation to biodiversity assets.

At a state level, the *Salinity Investment Framework Phase II* (Sparks et al. 2006) recognised that opportunity values, system benefits values and philosophical/spiritual/intrinsic values were the most vulnerable to salinity and therefore of highest importance. Although this differs from the advisory committee's top three ranked values, it is likely that the specific set of biodiversity assets required in each case will overlap significantly. This issue is explored further in the section below dealing with selection of priority biodiversity assets.

The goal of the Drummond NDRC

The goal of the DNDRC is:

To deliver the scientific and educational values, opportunity values and system benefits values derived from the current (2011) composition and structure of biodiversity assets of the DNR threatened by altered hydrology for the next 20 years.

This goal focuses on biodiversity assets that were predicted to be at risk due to altered hydrology at the time of the establishment of the DNDRC. This prediction is explored further in Section 5. The goal is constrained in space and time, setting clear boundaries for asset management and timeframes for monitoring. Spatial and temporal dimensions are also required so that the threatening processes and feasibility of achieving the goal can be assessed. The specific biodiversity assets required to deliver the goal are determined in Section 4.

The spatial scale of the goal is the boundary of the specified broad asset types within DNR. These areas are part of the wider DNDRC (Attachment 1, Appendix 4). This aspect of the goal is in line with *Proposed Drummond Nature Reserve Natural Diversity Recovery Catchment* (Department of Conservation and Land Management 2001). The nomination document focused on DNR and, in particular, the freshwater claypans and other biodiversity assets therein, which were predicted to be at risk from altered hydrology. This plan maintains that focus but recognises that with time it could broaden to include assets within the wider recovery catchment area.

The temporal scale for this document is 20 years. This is a compromise between the long duration of some natural cycles (in some cases over 100 years) and our ability to plan with reasonable certainty. In addition, it is expected that while positive outcomes from recovery works will be achieved in the short term, major achievements will occur over longer timescales, but within the next 20 years.

While the WA Salinity Strategy goal for NDRCs refers to biological and physical diversity, the goal for the DNDRC is directed only at biological values. Actions required to conserve biological assets threatened by salinity are expected to also protect physical diversity. For example, management of erosion and sedimentation will contribute to the protection of both wetland biological communities and wetland geomorphology.

Sustainable land use goal

Projects in recovery catchments provide opportunities to test and develop methods for combating salinity that may be applicable throughout the south-west agricultural region. This was recognised in the review of DPaW salinity programs (Wallace 2001) and in the Toolibin Lake Recovery Plan (Toolibin Lake Recovery Team & Toolibin Lake Technical Advisory Group 1994), where three of the principal goals relate to sustainable land use. This acknowledges that the most efficient way of achieving biodiversity goals is to undertake works on farmland that address hydrological and other threats to conservation values. Ultimately, agricultural solutions need to be economically viable if they are to be adopted.

As such, a secondary goal in recovery catchments, including DNDRC, is:

To contribute to the development of technologies to combat salinity throughout the agricultural region.

Nonetheless, the management priority in NDRCs is always protecting biodiversity assets threatened by salinity. Maintaining biodiversity assets may not be a major focus for many land-holders in the DNDRC, but developing environmentally sensitive technologies that combat salinity and support more sustainable, economically viable agriculture is of mutual interest. For example, limiting the spread of salinity and waterlogging benefits both agricultural industries and biodiversity conservation.

Sustainable land use will be explored through research and development, management, demonstration and monitoring activities. Activities are underway in the catchment to: protect biodiversity, develop technologies to combat salinity, and provide immediate benefits to catchment land-holders. These activities contribute to on-farm water and stock management and include the following:

- A joint DAFWA, DNDRC and Forest Products Commission 'Sustainable Grazing of Saline Lands' trial project 2005. This project aimed to establish perennial pastures on saline land and to stabilise the degradation of remnant woodland.
- Continuing work on developing new commercial industries based on mallee eucalypts in the catchment and elsewhere in the south-west, including planting of oil mallee plantations to act as vegetation buffers for DNR.
- Fencing to protect native vegetation from stock grazing and revegetation of conservation areas.
- Establishing sandalwood plantation demonstration sites.
- Partnership programs between local landholders, DPaW and DoW to trial innovative invasive weed control programs with the aim of returning infested paddocks to productive pastures.

In turn, these activities are expected to contribute to:

- understanding important principles in managing saline lands with similar geomorphology
- developing economically viable and biodiversity beneficial solutions for water management
- increasing agricultural productivity
- delivering the priority cultural values outlined in this recovery plan.

Responsibilities and ownership of goal implementation

It is DPaW's responsibility to implement management actions to achieve the goals of this recovery plan. DPaW has a statutory responsibility for managing biodiversity in WA and is the lead agency in the NDRC program. This is reflected in state government policy such as the WA *Salinity Strategy*. DPaW is accountable, through the Minister for Environment (WA), to the WA community for delivering biodiversity conservation outcomes. The DNDRC Advisory Committee does not have any direct responsibility for implementation of the recovery plan, although it has strong ownership of the goal and management actions described.

Factors affecting ownership and implementation of recovery plan actions include:

- Landholder support of actions on private land. Most of the land (80 per cent) in the DNDRC is private property and many recovery actions will require the cooperation of relevant land-holders. Achieving the goal of the plan will therefore depend on support received from a number of catchment land-holders. Thus, the management actions proposed for farmland will need to satisfy the economic and other goals of land-holders. Management actions that meet the goals of all partners will best integrate land use and recovery catchment activities.
- Land-holder support for biodiversity conservation. The advisory committee indicated that support for the goals of the DNDRC plan relies, at least in part, on continued DPaW investment within the wider recovery catchment (DNDRC Advisory Committee meeting minutes, 26 July 2006). This underlines the importance of maintaining, as far as practicable, activities that benefit both the recovery goal and local land-holders in general. One example of such activity is the DPaW contribution to the management of spiny rush in the catchment, which benefits all catchment managers.

The nomination document acknowledged that local catchment groups had been proactively implementing conservation works for several years (Department of Conservation and Land Management 2001; Drummond NDRC Advisory Committee meeting minutes, 20 February 2003). This local support was an important factor in the selection of this catchment for the NDRC program.

Opportunities for engagement

Management activities undertaken acknowledge local needs and allow landholders to further their aims for economically viable, sustainable land use. Accountability for implementation rests with DPaW, but achieving the goal for the DNDRC requires actions which bring together a diverse set of land-use issues and a number of landholders in a collaborative and focused way.

The DNDRC project provides a unique opportunity for land-holders to:

- access new knowledge relating to management of altered hydrology
- better access funds for on-ground works integrating sustainable agriculture and biodiversity conservation
- contribute to defining and implementing solutions to land degradation
- participate in developing new agricultural land industries that also provide a range of environmental benefits
- conserve catchment biodiversity for the benefit of present and future generations.

4 Biodiversity assets

A biodiversity asset is defined here as a living entity, population of organisms, or assemblage of organisms that is considered important to humans in terms of the priority values described in Section 3.

When the DNDRC was nominated for inclusion in the NDRC program the focus was clearly on the biodiversity values of DNR which were assumed to be at risk due to altered hydrology. This plan maintains that focus. It is recognised, however, that there are other biodiversity values in the wider catchment and where known, these values were outlined in *Proposed Drummond Nature Reserve Natural Diversity Recovery Catchment* (Department of Conservation and Land Management 2001). The main feature of the catchment is that it is located in a transition area between the northern jarrah forest and the Avon Wheatbelt.

DNR is located in a predominantly cleared agricultural landscape. However, on the western catchment boundary, four kilometres from the reserve, there is a large area of forest and woodland. This part of the Bindoon Military Training Area and the proposed Julimar Conservation Park are of considerable conservation value. It has been identified as one of the most significant breeding sites for Carnaby's cockatoo (R. Johnstone, pers. comm.), which is listed as endangered nationally. There are five nature reserves within the catchment and a small portion of a sixth nature reserve (Appendix 6). Remnant vegetation comprises 29 per cent of the catchment: 11 per cent is in the Bindoon Military Training Area, six per cent in DPaW-managed land, 10 per cent on private land and two per cent miscellaneous – a total area of 11,034 hectares.[20] Appendices 7 and 8 provide information on the flora and fauna within DNR and the catchment, and Appendix 9 explains the conservation codes.

Priority biodiversity assets threatened by altered hydrology

To achieve the goal and deliver the priority values of science and education, opportunity and system benefits, it will be necessary to conserve the following:

1. The 2011 composition of native biota threatened by altered hydrology. All types of taxa present must be maintained to achieve the goal but the numbers of each taxon may vary, provided population viability is maintained.
2. The 2011 structure of native biota consistent with (1). Although the current structure (largely mature vegetation) is preferable from the viewpoint of aesthetic values, it is only a management requirement to the extent that it is consistent with achieving (1).

Achieving system benefits values, such as sediment and nutrient control, would normally require extensive biodiversity assets to be managed. However, in the case of DNDRC, the potential downstream impacts are comparatively minor, and maintaining the assets as outlined above is predicted to achieve this value. The linkage between the priority values and assets is outlined in more detail in Table 3.

Even the comparatively small area of priority biodiversity assets that are the focus of management in the DNDRC represent a large number of native taxa (at least 37 native vertebrate fauna species recorded from limited surveys, 111 aquatic invertebrate species and 447 native flora species recorded in DNR, see appendices 7, 8 and 10) – much larger than can be directly managed with current resources. Under these circumstances, management typically focuses on those biodiversity assets that are most susceptible to the primary threatening process, in this case altered hydrology.

[20] Calculations by Geographic Information Services Section, DEC, Kensington. April 2009.

Robin redbreast bush in the claypan wetlands.
Photo – Matt Forbes

In the context of the above goal and discussion, the most important biodiversity assets are the two vegetated claypan wetlands (each about three hectares) with robin redbreast bush (*Melaleuca lateritia*) mid-dense shrublands over herbs (including aquatic and amphibious taxa) on the floor of the claypans, surrounded by a band of scattered flooded gum (*Eucalyptus rudis*) over low sedges (*Baumea rubignosa*) (Keighery et al. 2002b).

Both claypans are confined to distinct sandy depressions with a lens of olive grey clay situated 0.5–2.0 metres below the surface. There are no clear drainage lines entering the claypans suggesting that, together with the rain that lands directly on them, good sub-surface internal drainage through adjacent sandy soils is filling the claypans after rainfall. During winter, the claypans' water levels range from approximately five centimetres to about 50 centimetres, and they dry out in the late spring/early summer (Cale 2005; Forbes & Vogwill 2010). They 'are characterised by temporally overlapping suites of annual taxa that germinate and flower as the wetland dries' (Gibson et al. 2005, p. 288).

The claypans in DNR are the southernmost of a collection of wetlands which extends to the north and east within the boundary of the DNDRC. However, all the other wetlands in this collection are within cleared farmland and even where they have some fringing vegetation they are open to grazing or are otherwise degraded (Western Australian National Parks and Reserves Association 1986). In contrast, DNR wetlands are located within uncleared land and are still in near pristine condition.[21]

The biological importance of these wetlands relates to the following:

- The claypans are examples of a wetland type which was rarely recorded in the wheatbelt biological survey[22] (Keighery et al. 2002b, 2004). 'It is estimated that more than 90 per cent of the original extent of these communities has been cleared for agriculture, and the remaining areas, despite largely occurring in conservation reserves, are threatened by weed invasion and rising saline groundwater' (Gibson et al. 2005, p. 287).
- These claypans support:
    - A large population of *Eleocharis keigheryi* (DRF) and seven priority flora (*Myriophyllum echinatum* P3; *Stylidium longitubum* P3; *Rhodanthe pyrethrum* P3; *Trithuria australis* P4; *Hydrocotyle lemnoides* P4; *Schoenus natans* P4; *Persoonia sulcata* P4) (Appendix 7).

– High aquatic invertebrate species richness including at least one new species of Rotifera, two new species of Ostracoda and several species that are otherwise rare in the inland south-west of Western Australia (Cale 2005, Pinder et al. 2011 see Appendix 10). A total of 151 taxa have been collected from the claypans with 127 taxa at the south-west claypan and 113 taxa from the north-east claypan (Cale 2005, Pinder et al. 2011). On the basis of the high species richness from both

[21] Acknowledgement to the Camerer family (and any previous owners) who retained the area of bush which protected these wetlands, and which is now Drummond Nature Reserve.
[22] Survey area was the agricultural area between the 600mm and approximately 300mm isohyets.

wetlands, they would rank within the top 10 per cent of the 207 wetland and river sites sampled by Pinder et al. (2004) in the wheatbelt biological survey (Cale 2005).

– A priority ecological community—'Claypans with mid-dense shrublands of *Melaleuca lateritia* over herbs'—of which there are only nine other known occurrences extending from Lancelin to Kojonup. The other examples of this wetland type are largely confined to the Swan Coastal Plain and parts of the jarrah forest. In DNR they occur near the eastern margin of the IBRA Jarrah Forest Bioregion and could be considered at their eastern limit (Keighery et al. 2002b). This claypan community is proposed for endorsement as a threatened ecological community via state government processes.

Maintaining these assets is clearly a core requirement for achieving the management goal and delivering the priority values.

Another important biodiversity asset is the wandoo woodland in the north-west corner of DNR. Keighery et al. (2002b, p. 65) described 'trees are dead or suffering from dieback and understory is dead and/or replaced by annual weeds'. High groundwater levels and salinity indicate that this area is affected by altered hydrology due to the clearing of native vegetation to the north and west of DNR. Dieback may also be present but at this stage has not been detected in surveys. The habitat that the woodland provides and the occurrence of *Acacia chapmanii* subsp. *australis* (DRF), contribute to the biodiversity value in the north-west corner of DNR.

Wandoo woodland in DNR. Photo – Matt Forbes.

Table 3 Linking recovery achievements to priority cultural values and related assets

Priority cultural value	In relation to the cultural value, management in DNDRC will deliver the following outputs:	Related assets
Scientific and educational values	Scientific investigations that advance our knowledge of natural resource management, particularly in the context of altered hydrology including climate change. Educational opportunities for local land-holders, school groups and the general community. Although these opportunities will centre on biodiversity, they will also include a wide range of other aspects of natural resource management.	The biodiversity assets required to deliver this range of knowledge and educational opportunities are the current taxonomic composition of native biota associated with the claypans and the wandoo woodland in the north-west corner of DNR. The numbers and structure of these assets should be consistent with maintaining population viability and minimising management input. Loss of even one taxon will reduce the scientific opportunities, and may, depending on the species, threaten educational usage of the area.
System benefits values	Buffer the effects of altered hydrology downstream of DNR to the north-east by reducing the flow of: • sediments • nutrients • salt. During the term of this plan, the level of acceptable downstream impacts will be assessed.	Within most catchments substantial areas of native vegetation and their biota would be required to prevent or minimise the downstream movement of sediments, excess nutrients and excess salt. In the case of Drummond, the assets listed above should be sufficient, but this will be explored during the term of the plan.
Opportunity values	Ensure that the future opportunities for economic development of germplasm, leisure opportunities, and other cultural values presently under-utilised are protected for future generations.	The biodiversity assets described for delivering scientific and educational values will also deliver the outputs required for this value. Fundamentally, the full compositional range of the current biodiversity needs to be maintained to ensure future opportunities are not compromised.

Biodiversity assets requiring hydrological investigation

Other biodiversity assets of DNR that may also be threatened by altered hydrology and therefore require hydrological investigation include the following:

- The only three recorded occurrences of the priority ecological community 'Wandoo woodland over dense low sedges of *Mesomelaena preissii* on clay flats' (Keighery et al. 2002b; Department of Environment and Conservation 2006b). The level of threat from altered hydrology of these occurrences is yet to be ascertained and therefore this is a proposed priority management activity.
- Banksia woodlands of variable composition (including *Banksia attenuata, B. menziesii, B. prionotes* and *B. grandis*) (Keighery et al. 2002b). In a survey of remnant vegetation in the DNDRC, Bennett (2002) reports that 'there were few examples of these communities (that is, banksia species low woodland) so all those in reasonable condition should be conserved'. The level of threat posed by altered hydrology and the condition of these woodlands in the reserve is to be ascertained.
- Marri (*Corymbia calophylla*) while not uncommon, is showing signs of decline (for example, up-slope of the south-western claypan) and this may be a result

of rising groundwater or invasive species (lerps). They are a common overstorey species in the reserve and therefore are important for biodiversity. Whether the observed decline is related to altered hydrology or invasive species needs to be determined.

- Grasstrees (*Xanthorrhoea preissii*) are common in DNR and, like the marri, are showing signs of decline, particularly in the north-west corner. They provide important habitat for a wide variety of fauna (Borsboom 2005) and therefore their potential loss has implications for biodiversity. The process involved in the decline of the grasstree population in the reserve is unknown, and although parrot damage is obviously a factor, it may be an interrelationship of several factors which includes altered hydrology. Grasstrees are a common component of the wandoo woodland in the north-west corner of the reserve.

Summary

To meet the priority values of science and education, opportunity and system benefits, this plan focuses on the biodiversity assets of highest importance threatened by altered hydrology. These assets are:

- the freshwater claypans and their biota
- the wandoo woodland in the north-west corner of DNR and its biota.

However, as the understanding of the hydrology of the reserve is incomplete, it is also necessary to highlight the possible threat to several other assets, namely the priority ecological community 'Wandoo woodland over dense low sedges of *Mesomelaena preissii* on clay flats', the banksia woodland, the marri woodland and the grasstree population, and therefore the need for further hydrological investigation in relation to these communities.

5 Setting management action priorities

The process to determine priorities for management action is broadly based on the approach described for biodiversity assets by the Department of Environment (2003), Wallace et al. (2003), and Sparks et al. (2006). This approach is based on four steps:

1. a biophysical threat analysis, which is an evaluation of the key ecosystem processes that must be managed to protect the biodiversity assets and achieve the management goal (Table 4)
2. assessment of technical capacity and knowledge to manage the assets in the context of the biophysical threats (including an assessment of management costs)
3. assessment of sociopolitical support for implementing the goal
4. confirmation of the goal for assets given the outcomes of the feasibility analysis – for example, goals may need to be amended if it is not currently feasible to achieve them.

Each of these aspects is dealt with below.

Biophysical threat analysis

The focus of the NDRC program is the conservation of biodiversity assets outlined above. However, as stated by Sparks et al. (2006, p. 13) 'while it may be feasible to protect a wetland biodiversity asset from salinity, it may be much more difficult to prevent an invasive weed destroying its key biodiversity elements. In this case, it would make little sense to work on controlling salinity without also being confident that the invasive weed could be managed'. Therefore, a critical part of the planning approach is to analyse the full range of ecosystem processes that threaten goal achievement and evaluate those that must also be managed as a matter of priority.

The analysis technique used here is based on Wallace et al. (2003), Walshe (2005) and Walshe et al. (2007). This technique provides a framework for an expert desktop analysis of the probability that a specified threatening process will prevent goal achievement.

In this document, the methodology focuses on assessing the probability that a specific issue, with and without management intervention, will cause goal failure. The assumptions underlying the assigned probabilities are documented[23] (Table 4). For the most important threatening processes, cause-effect diagrams and related techniques are used to model relationships and better quantify the likelihood of success (see Section 6).

The analysis for DNDRC was conducted by an expert panel. A draft document was completed in February 2004. This was reviewed by the advisory committee in June 2008 and by a DEC in-house group during December 2008 (with subsequent circulation to the committee).

[23] To undertake a quantitative threat analysis, a detailed understanding of spatial and temporal trends of hydrological, physio-chemical and other ecological trends is required. Given the lack of quantitative data in the DNDRC (and this is often the case when dealing with complex systems), an expert assessment was used to estimate the probability of threats leading to goal failure.

Table 4 Probability (%) of specific ecosystem processes causing goal failure in the DNDRC with and without management

Goal: To deliver the scientific and educational values, opportunity values and system benefits values derived from the 2011composition and structure of biodiversity assets threatened by altered hydrology for the next 20 years.

Priority biodiversity assets at risk from altered hydrology required to deliver the above goal: biota of the two freshwater claypans (including peripheral band of '*Eucalyptus rudis* over sedge') [a] & [b]; and the wandoo woodland in the north-west corner [c]; (all located in DNR).

Assets (in DNR) possibly at risk from altered hydrology, requiring investigation to confirm situation: 'Wandoo woodland over sedge' (priority ecological community) [d]; banksia woodland [e]; marri (*Corymbia calophylla*) woodland [f]; grasstrees (*Xanthorrhoea* sp.) [g].

Threat category	Management issue	Probability (%) that threat will cause goal failure, with existing management[1]	Probability (%) that threat will cause goal failure, with extra management[2]	Assumptions underlying initial probability assessment
1.0 Altered biogeochemical processes	1.1 Hydrological processes, including salinity	100	15	South-west freshwater claypan [a] is considered to be at the greatest threat – unmanaged; it is considered that interactions between surface and groundwater (primarily surface water driven) will result in loss of composition and structure. It has 30%–40% of its catchment lying outside the reserve in farmland, and lies within 50m of farmland. The 'probability with management' assumes that surface water can be redirected away from [a], and groundwater may be managed by pumping if required. North-east freshwater claypan [b] is not considered to be at risk from hydrological change because it is buffered by 400m of native vegetation, and only a small proportion of the wetland's catchment lies outside DNR (quite different from the case of [a]). North-east claypan [b] is also protected from sub-surface flows by a bedrock high to its north and west (running NE-SW). The chance of the claypans being permanently inundated is extremely small, and therefore does not require management intervention. The composition of the claypan invertebrate communities is also dependent on source populations of freshwater insects in the surrounding landscape. These may be farm dams or natural wetlands but degradation of source habitats could result in altered community composition in the Drummond claypans. Wandoo woodland (north-west corner) [c] is hydrologically threatened by groundwater and surface water (carrying with it organic matter, dissolved nutrients, nutrient-rich sediments and weed seeds) emanating from farmland to the north and west (north and south of Bulligan Rd and along Old Plains Rd). Without management, this area will lose structure and composition. It is predicted that increased revegetation on private property will prevent hydrological problems being expressed. If revegetation is insufficient, then pumping or drainage may be required.

Threat category	Management issue	Probability (%) that threat will cause goal failure, with existing management[1]	Probability (%) that threat will cause goal failure, with extra management[2]	Assumptions underlying initial probability assessment
(cont'd)				The 'Wandoo woodland over sedge' PEC [d] within DNR has been mapped by DPaW; however, the level of threat is unknown as not all areas of the PEC are covered by monitoring bores. No imminent threat to the patch near bore DDVP7. However, this all needs to be investigated further and more hydrological data are required. Some patches of banksia woodland [e] face a similar threat to [c]. Need to confirm threat and establish biodiversity value of woodland. Marri death [f] for example in vicinity of [a] – processes involved are not understood. Hydrological situation needs to be monitored.
	1.2 Nutrient cycles, including eutrophication	30	15	[a] Threatening process is the movement of organic matter, dissolved nutrients and nutrient-rich sediments (including those containing fertiliser) from adjacent farmland into the wetland in a large surface water run-off event, where they may remain in the water column or accumulate in sub-surface clays. One of the critical characteristics of this wetland, undisturbed, is its low nutrient status. The breakdown of organic matter entering the wetland could result in anoxic conditions with at least a temporary decline in biodiversity while oxygen is low. Increased nutrient loads could cause eutrophication with increased turbidity, anoxic conditions, or toxic blooms (for example cyanobacteria) resulting in major long-term changes to the composition of biological communities. The risk of damaging run-off events is considered to be small. Decreased 'probability with management' assumes that surface water can be redirected away from [a].
	1.3 Carbon cycle and climate variability and change[24]	?	?	High degree of uncertainty. A wetter climate will increase run-off while a drier climate may lead to decreased surface water recharge. Climate variability poses a potential threat to the continued occurrence of threatened species within freshwater claypans. Management might be required to remove excess water under some circumstances, and to harvest freshwater for application under others. Related probabilities have been included above under altered hydrology in relation to the assemblages at risk but see also 'drought' below.
2.0 Impacts of introduced plants and animals	2.1 Environmental weeds	50	10	Threatening processes are the introduction of weeds with surface flows into [a], and kangaroos and introduced weeds in [b]. Final probability assumes surface flows can be diverted from [a], and weed control and kangaroo management are successfully undertaken.

[24] The expert panel assessment did not estimate the probability of goal failure due to climate change. Although acknowledging its importance, the panel did not have adequate data on which to base an assessment. In addition, the panel recognised that key recovery actions to counter salinity, particularly revegetation, would make a contribution to climate change adaptation. However, climate change is clearly a threat that needs to be investigated further in relation to this recovery plan, particularly with regard to maintaining claypan water depths and soil moistures within boundaries consistent with the conservation of endemic biota. At the time of this plan being written there was insufficient information to support any judgment and hence this plan needs to address this knowledge gap.

Threat category	Management issue	Probability (%) that threat will cause goal failure, with existing management[1]	Probability (%) that threat will cause goal failure, with extra management[2]	Assumptions underlying initial probability assessment
(cont'd)	2.2 Feral predators	0	0	Assuming the threat would not cause any more change in the future than it has already.
	2.3 Preventing new introductions of damaging species	1	1	Invasiveness of genetically modified plant species for adjacent agriculture (cropping and pasture) may pose a serious threat compounded by climate change causing further species introduction. Most likely scenario under which target biodiversity assets would be detrimentally affected is if herbicide resistance in crop species leads to difficulty in weed control. This may occur either through the crop plant itself becoming a weed, or by transfer of herbicide resistance from crop plant to a related weed.
	2.4 Herbivory by introduced species	10	5	Research identified herbivory as an issue for *Acacia chapmanii* subsp. *australis* in [c], and suggested grazing may be a wider issue. Recent observations suggest that, at least for the *Acacia chapmanii* site, grazing by kangaroos, and to a lesser extent rabbits, may be a problem (Dufty 2008). Exclusion plots on claypans would identify the extent of the issue for [a] and [b]. However, rabbits still need to be managed through biological controls, poisoning and warren destruction.
	2.5 Competition for food and shelter (other than as above, and includes habitat damage by pigs)	0	0	By maintaining current control, the threat is neutralised.
3.0 Impacts of problem native species	3.1 Parrots	30	5	Based on parrots taking out grasstrees [g] over 50 years (refer to survey data from nearby Wongamine Nature Reserve where estimated 80% lost).[25] Current research indicates exclusion of parrots from small numbers of individual grasstrees using wire netting is possible in key areas, including fringing riparian habitat and in [c] and [d] thereby retaining valuable habitat for a range of fauna.
	3.2 Grazing and trampling by kangaroos	10	5	With regard to [a] and [b], kangaroo resting, grazing and trampling are possibly causing a change in structure. Need to test damage through use of exclusion fencing. If necessary, kangaroo control may need to be implemented.
4.0 Impacts of disease	4.1 Dieback (*Phytophthora* spp.)	5	5	Based on DEC investigations and dieback mapping survey (Van de Sande 2003), presence of (*P. megasperma)* complex confirmed, but no obvious impact on specific assets. *Phytophthora cinnamomi* was not detected. Need to implement hygiene procedures and maintain watching brief.
	4.2 Armillaria	5	5	Based on dieback and Armillaria mapping survey (Van de Sande 2003). Need to implement hygiene procedures and maintain watching brief.

[25] M.Garkaklis, pers. comm.

Threat category	Management issue	Probability (%) that threat will cause goal failure, with existing management[1]	Probability (%) that threat will cause goal failure, with extra management[2]	Assumptions underlying initial probability assessment
5.0 Detrimental regimes of physical disturbance events	5.1 Fire regimes	30	10	Lack of understanding of fire regime and ecology of the PECs [a & b]. Incorporate adaptive trial approach on crucial riparian habitat. Rating largely reflects a lack of knowledge. The same assumptions apply to other PEC [d].
	5.2 Cyclones	0	0	DNR not located in zone vulnerable to severe cyclonic activity.
	5.3 Drought	5	5	Potential threat to *Acacia chapmanii* subsp. *australis;* marri [f] decline may be due to drought; and drought may be an issue in areas where vegetation depends on shallow watertable. Potential for drought impacts on the wetlands [a & b] are incorporated under altered hydrology.
	5.4 Erosion (wind and water, includes sedimentation)	0	0	Assuming non-threat as DNR has overall healthy vegetation cover and does not receive significant runoff.
6.0 Impacts of pollution	6.1 Herbicide/pesticide use and direct impacts	0	0	Assuming buffers provide adequate protection.
	6.2 Pesticide surfactants and impacts	0	0	Assuming buffers provide adequate protection.
	6.3 Oil and other chemical spills	0	0	Adjacent land use presents minimal risk.
7.0 Impacts of competing land uses	7.1 Recreation management	0	0	Isolation of DNR, with no strong recreational attributes and low local population density.
	7.2 Agricultural impacts (other than as already dealt with above)	0	0	As for 7.1.
	7.3 Consumptive uses (legal uses for example seed collecting)	0	0	Activity is well managed with no illegal activity known to be present.
	7.4 Illegal activities	1	1	Illegal collection of rare flora by collectors is possible. Range of illegal activities (firewood collecting, hunting) is minor. Need to monitor.
	7.5 Mines and quarries	0	0	Any mineral attributes are non-commercial.

Threat category	Management issue	Probability (%) that threat will cause goal failure, with existing management[1]	Probability (%) that threat will cause goal failure, with extra management[2]	Assumptions underlying initial probability assessment
	7.6 Utilities including power/water supply, public road maintenance	1	1	Maintenance of power line and adjacent roads can cause disturbance. Increase communication with Western Power.
8.0 A sociocultural environment inconsistent with conserving biodiversity assets threatened by salinity	8.1 Attitudes to saving assets from salinity threats, conservation values and their contribution to human quality of life	20	10	Salinity management has significantly dropped in profile. If funding is reduced, then this would threaten successful management. Better explanation of the values required.
9.0 Insufficient genetic and ecological resources to maintain viable populations	9.1 Destruction of habitat (food, water, shelter, oxygen, access to mates)	10	10	If *Acacia chapmanii* subsp. *australis* population (included in [c]) is of a viable population size consistent with retaining genetic integrity, then unlikely to be goal failure due to this issue. In relation to fauna, the goal is relatively short term (20 years) and the fauna is likely to have stabilised since land clearing in the district. Of the fauna recorded from DNR, the main candidates for possible loss are the rufous treecreeper and perhaps the white-cheeked honeyeater.

Notes:

1. Probability that threat issue will cause goal failure with current management inputs: Spatial and temporal scales fixed as a basis for the probability analysis. The question being asked here is that, without additional management to that currently occurring, what is the probability that the specific threat-issue will result in non-achievement of the goal?

2. Probability that threat issue will cause goal failure with additional management inputs: In comparison with (1) above, the question being asked here is that, if resources are applied, what is the probability that the specific threat-issue will result in non-achievement of the goal?

It is proposed here that probabilities of 20 per cent or less represent a reasonable level of risk.

Threat analysis summary

The key biophysical threats that, without management intervention, are most likely to cause goal failure are altered biogeochemical processes and impacts of introduced plants and animals. The most important management issues in this context that are likely to cause goal failure (with estimated probability of causing goal failure with existing management in brackets) are:

- hydrological processes, including salinity (100 per cent)
- environmental weeds (50 per cent)
- nutrient cycles, including eutrophication (30 per cent)
- detrimental fire regimes (30 per cent)
- attitudes toward saving assets from salinity threats, in particular, inadequate understanding of the contribution by biodiversity assets to human quality of life (20 per cent).

The threat analysis suggests that with additional management the probability of goal failure can be reduced to an acceptable level for all these issues. It should be noted that the probabilities associated with 'carbon cycle and climate variability' are as yet undetermined.

Technical capacity and knowledge

A feasibility analysis of managing biodiversity assets threatened by salinity was undertaken as part of the *Salinity Investment Framework Phase II* (Sparks et al. 2006). A desktop calculation estimated that the costs to government of managing hydrology to protect the existing DNDRC biodiversity for the next 30 years were $8.19 million (URS 2004). This is an annual management cost of about $273,000 per year. The estimate was based on generic information about the catchment and its biophysical characteristics. While this estimate should be treated with caution, given the paucity of data used in its calculation, it does provide an indication of the level of resources required to protect all catchment biodiversity assets. More recent hydrological work suggests that the costs of management over a 30-year timeframe will be substantially less than this calculation, at least for the biodiversity assets within DNR.

Another feasibility analysis will be necessary once the next phase of investigations in DNR is complete (mainly relating to the hydrological characteristics of the freshwater claypans and the underlying aquifers). However, existing technical capacity and knowledge are adequate to manage the main issues threatening the management goal in DNR. With targeted management actions, the overall cost of recovery is almost certainly lower than estimated by the URS (2004) desktop analysis. It should be noted that if the revegetation component of salinity management is financially driven, the costs to governments may be reduced by nearly 50 per cent (Sparks et al. 2006).

Sociopolitical support

Sufficient community support at all levels is required to achieve conservation goals. Although broad community support is required to ensure that there are adequate resources available, it is not simply an issue of funding. Management will not succeed without land-holder support for management actions on their properties. Assessing the sociopolitical support for biodiversity conservation is largely achieved through consultation.

The DNDRC has received support from the local community through the advisory committee. The committee includes local land-holders, local government representatives and agency representatives. It has provided a means for seeking community views and support for proposed catchment management actions. Agreement on the goal for the catchment by the advisory committee is one measure of local community support.

The willingness of land-holders to implement on-ground actions demonstrates that there is broader support for conservation work in the catchment. In 1998, the local farming community formed the Solomon-Yulgan Catchment Group (SYCG) to address land degradation and the loss of biodiversity. The catchment group was very active and successful in its early years, receiving a substantial Natural Heritage Trust grant in 2001 to tackle land degradation issues across the catchment. The SYCG is an important partner in the DNDRC, implementing on-ground actions of mutual benefit to both the recovery catchment project and the SYCG. Local land-holders have responded well to current on-ground works that are part of the DNDRC program. They have, however, indicated through the advisory committee that a continued commitment to resourcing on-ground works within the catchment is important in maintaining general community support.

Given the most recent feasibility analysis, including projected costs, the advisory committee considers that the DNDRC management goal will attract broad sociopolitical support. Therefore, management has proposed to proceed and the management goal has been confirmed.

6 Managing threats to priority biodiversity assets

Approach

The NDRC program allocates resources to manage ecosystem processes to achieve biodiversity conservation goals. For efficiency, effort is highly focused on addressing processes that pose a major threat to goal achievement. This plan focuses on the most significant processes identified in the biophysical threat analysis:

- altered biogeochemical processes (hydrological processes, nutrient cycles and climate variability)
- impact of introduced plants (environmental weeds)
- detrimental regimes of physical disturbance (fire regime)
- a sociocultural environment inconsistent with conserving biodiversity assets that are threatened by altered hydrology.

Outlined below are the proposed management activities required to significantly increase the probability of achieving the goal for the priority biodiversity assets identified in Section 4. With increased knowledge, these actions will be more accurately specified.

Planning terminology

The terms used in this plan draw on the definitions in the *National Framework for Natural Resource Management Standards and Targets* endorsed by the Natural Resource Management Ministerial Council in 2002 (Natural Resource Management Ministerial Council 2003). The terms 'activity' and 'outputs' provide common links into DPaW planning processes.

The hierarchy of terms used in this plan are illustrated in Figure 2 and defined in the Glossary. This is the framework used to develop and implement this plan.

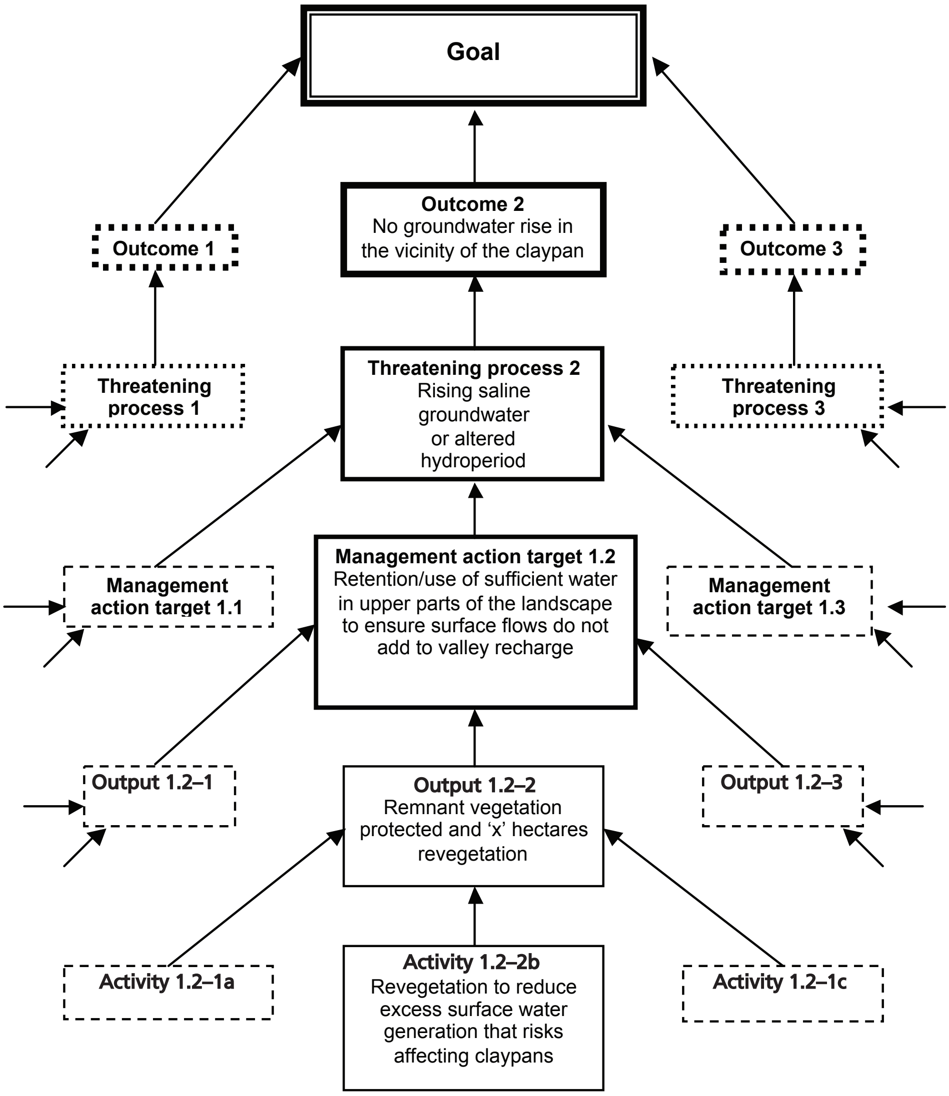


Figure 2 Hierarchy of planning terms used in the recovery plan

Note that multiple outcomes are required to achieve the goal and the figure includes examples for one chain of the hierarchy.

As shown, the arrows indicate the implementation process: the planning process is the reverse – it commences with recognition of values and goals, which leads to identification of the threatening processes and associated activities.

Managing the threats to goal achievement

Altered biogeochemical processes

Anthropogenic activities, such as clearing of native perennial vegetation and water harvesting, may significantly alter natural physiochemical and biogeochemical processes. These changes alter hydrological processes and regimes which can, in turn, have undesirable effects on biodiversity and cultural assets. Such hydrological changes include increased frequency and extent of flooding and inundation, salinisation, acidification, erosion and sedimentation and eutrophication.

Climate change can also alter biogeochemical processes both directly (such as changes in temperature, humidity, rainfall, evaporation) and indirectly (for example by further affecting the already altered hydrology). Therefore, impacts to biogeochemical processes as a result of altered hydrology and climate change are discussed separately.

Altered hydrology

Biodiversity assets in DNR are threatened by altered hydrological processes affecting the occurrence, timing, quantity and quality of water reaching biodiversity assets. The potential impacts of altered hydrology (Section 1) are summarised below in Table 5. To manage these processes it is essential to quantify and understand them and, where possible, to address existing, and prevent future, impacts on biodiversity assets. A conceptual hydrological model for DNR is shown in Figure 3.

Table 5 Summary of threats to biodiversity assets posed by altered hydrology

Quantity surface water (hydrology)	Quantity groundwater (hydrogeology)	Quality waterborne (surface or groundwater)
• waterlogging resulting from slow or restricted surface water movement • erosion (soil, drainage line) • flooding, inundation and associated damage • altered wetland hydroperiod • soil and wetland salinisation	• waterlogging of vegetation root zone from rising groundwater • soil and wetland salinisation • increases in extent or flow rate of seepages • increased recharge, rising groundwater levels	• sedimentation and turbidity • nutrient cycle changes and excess quantities of nutrients • eutrophication • spread of weeds • pesticides • acidification • salinisation • other contamination or deficiency

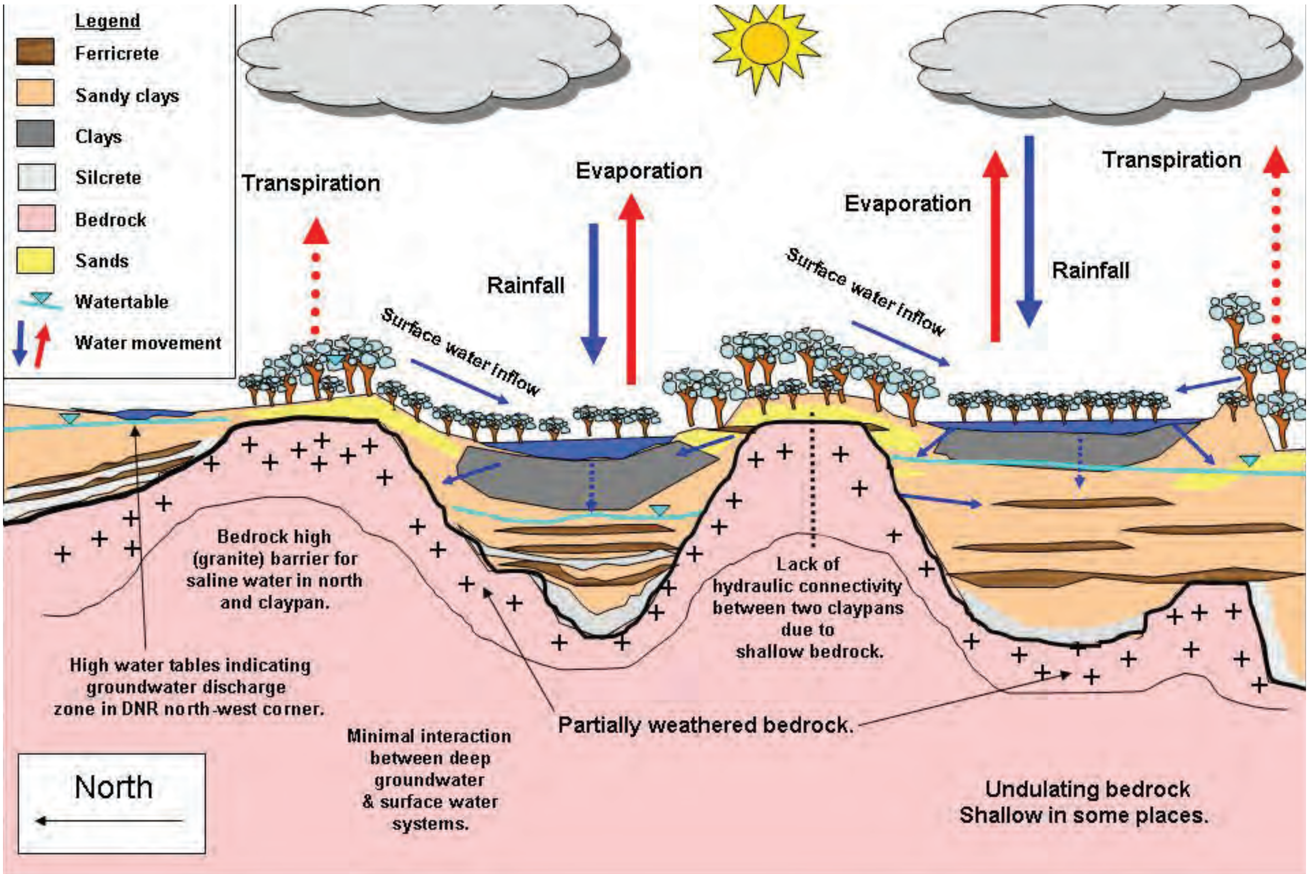


Figure 3 Drummond Nature Reserve conceptual hydrological model

Figure 4 depicts the complex interconnection between surface water and groundwater, with the interaction of water quantity and quality processes that give rise to hydrological threats. The hydrological processes affecting biodiversity assets are described, with linkages between water quantity and quality issues shown as dashed lines. Solid lines indicate cause and effect relationships in the physical processes. For example, land-use change and associated altered hydrology can result in an increase in the spread of weeds and changes in downgradient nutrient loads.

Conceptual, analytical and numerical models are essential to describe and analyse our understanding of the water and salt balances affecting biodiversity assets. Such models also underpin monitoring and evaluation, including the description of hypotheses concerning the interaction of processes and the predicted effectiveness of remedial measures at catchment, sub-catchment or individual asset scales. Water quantity and quality are measured at multiple points in the landscape to quantify the relative contributions and interactions between various hydrological processes. Water volumes and quality form the basis for designing targets for discharge and recharge management.

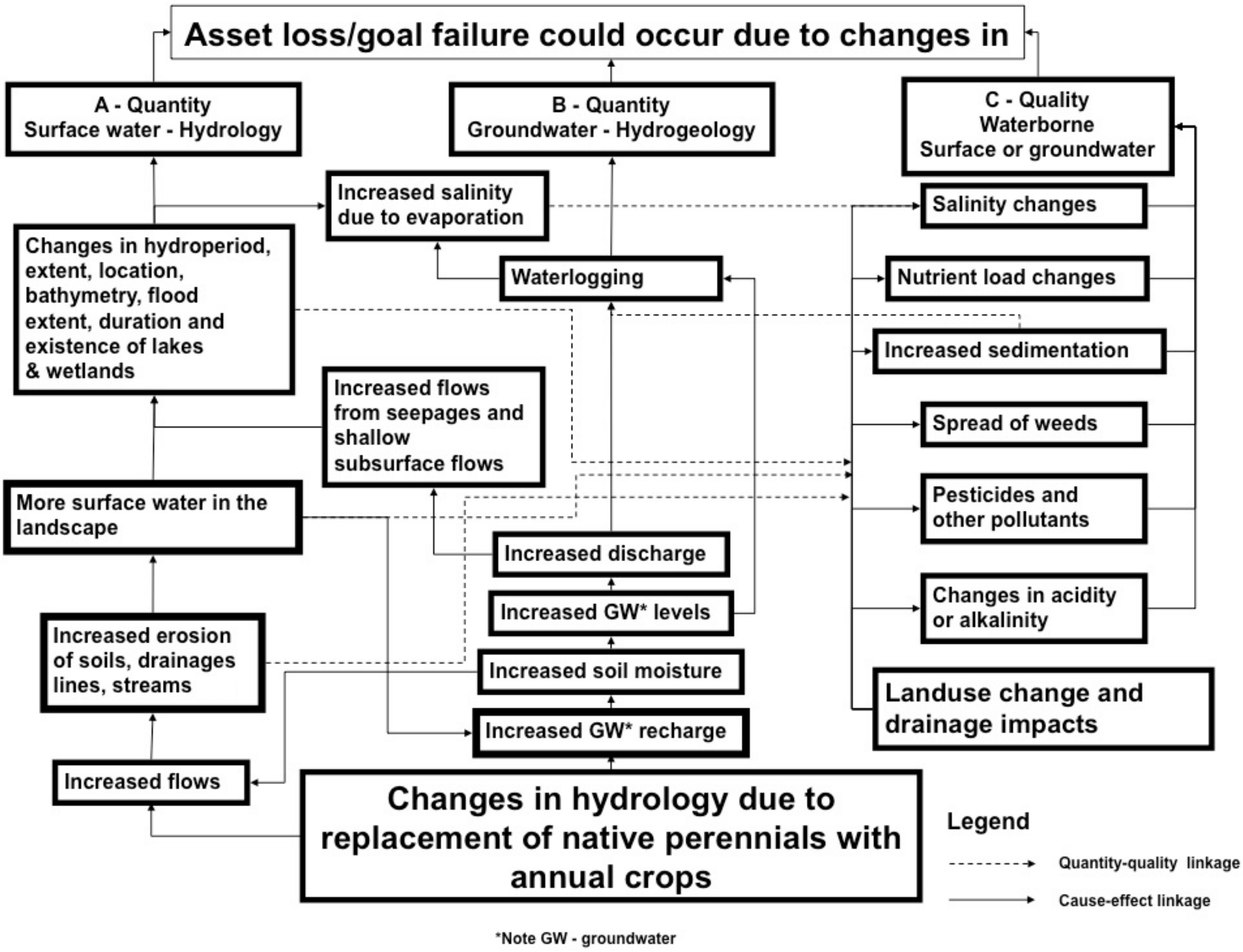
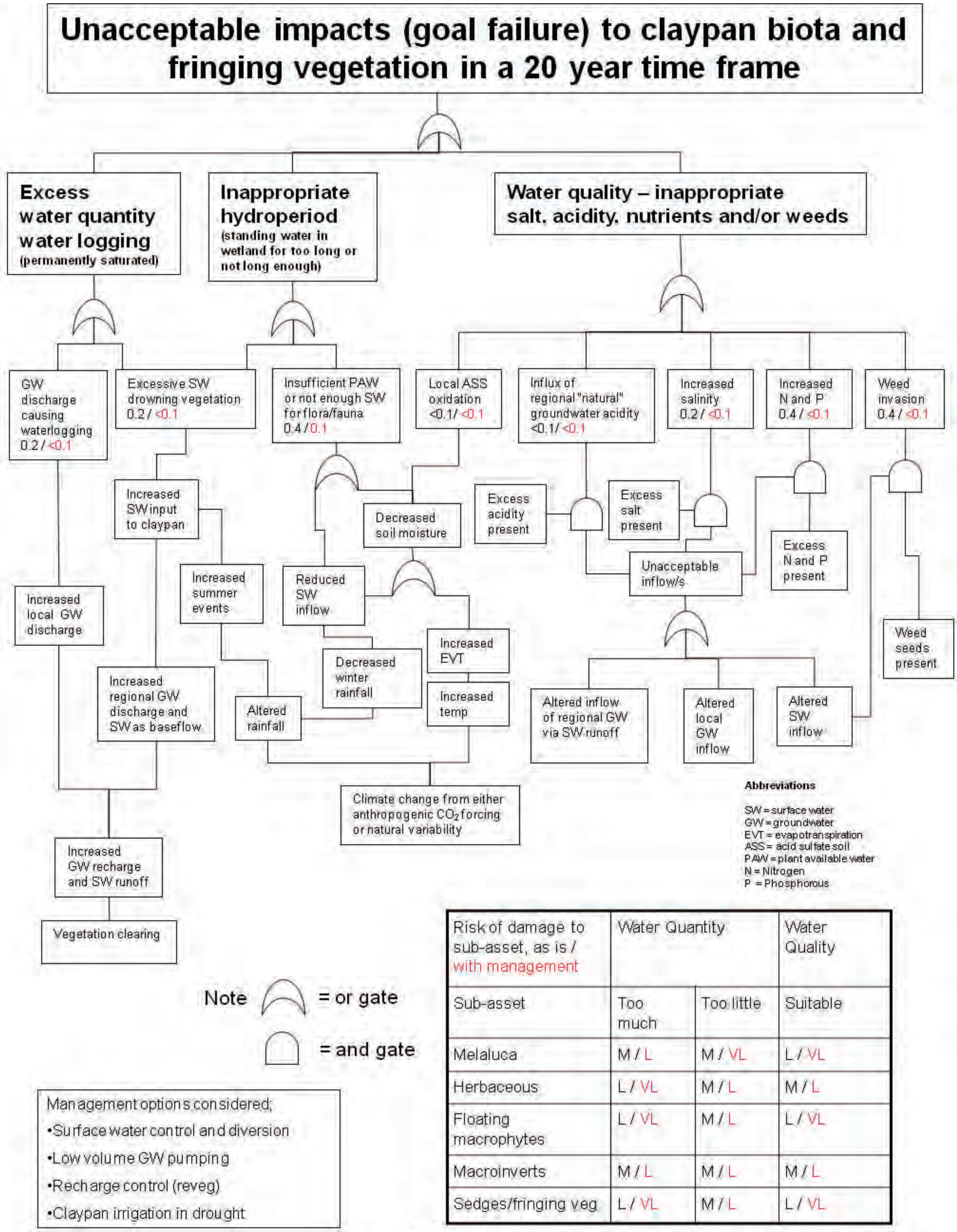


Figure 4 Quantity, quality and cause-effect linkages arising from changes to water balance

Management of waterborne impacts of altered hydrology requires an understanding of water movements in terms of quantity, quality and timing. To plan management it is also essential to know the water requirements (tolerances and thresholds) of the key biodiversity assets. These are known as environmental water requirements (EWR). EWRs are the water requirements necessary to sustain water-dependent ecosystems at a low level of risk (ANZECC & ARMCANZ 1996; 2000a; 2000b). They are a subset of ecological condition indicators, which reflect other characteristics of the environment but are defined based on hydrology (water quantity and/or quality). Once they have been determined, EWRs will be used to develop targets for the management of key biodiversity assets, particularly modelling of altered hydrology (refer to activities relating to tolerances and thresholds in Figure 5).

Long-term data are critical to effective landscape-scale management of biodiversity assets due to the complexity of hydrological interactions and the natural year-to-year variability of the climate. Lane et al. (2004, p. 52) reviewed a number of authors for the length of time required to typify a climate regime, changes therein and interactions with the physical environment, and concluded that 'a period of at least several decades, perhaps more, does seem warranted'.



Risk of damage to sub-asset, as is / with management	Water Quantity		Water Quality
Sub-asset	Too much	Too little	Suitable
Melaluca	M / L	M / VL	L / VL
Herbaceous	L / VL	M / L	M / L
Floating macrophytes	L / VL	M / L	L / VL
Macroinverts	M / L	M / L	M / L
Sedges/fringing veg	L / VL	M / L	L / VL

Note: Threat categories. H = high, M = medium, L = low and VL = very low

Figure 5 Risk of unacceptable impacts to claypan biota and fringing vegetation in a 20-year timeframe

Surface and groundwater threats – water balance and salinity

Hydrogeochemical and hydrogeological investigations undertaken in DNR from 2007 to 2011 have significantly increased our knowledge of groundwater and surface water interactions across the reserve. DNR is underlain by a heterogeneous mixture of surficial sediments including deep regolith ranging from deep clayey sands to saprolite and ferricrete over bedrock with shallow, unweathered granite and granite outcrops. It is likely that much of the north-western section of the reserve is hydrologically separated from the remainder by impervious geological bodies such as granitic basement highs. While knowledge gaps still exist, the picture emerging is that the reserve is separated into several hydrological domains either side of the catchment divide between the Mt Anvil and Solomon sub-catchments, and between bedrock highs. As a result, the issues causing impacts in the north-western section are different to those affecting the southern (including south-west claypan) and eastern (including north-eastern claypan) sections of DNR. However, there is still some possibility of hydrological linkage in shallow sediments in the centre of the reserve.

Bores situated in the north-west corner of the reserve show groundwater levels close to the surface and with varying salinities (Forbes & Vogwill 2010). Sections of the wandoo woodland in this area are degraded, with evidence of salt crystallisation at the soil surface and shallow saline groundwater. Other vegetation to the east is also degraded with shallow non-saline groundwater levels likely the cause. The affected area appears to receive surface and groundwater inflow from cleared agricultural lands to the north and north-west. These lands form a significant proportion of the surface catchment for the northern part of the reserve. At this stage, the detrimental effects of increased groundwater levels and/or high salinity concentrations seem to be limited to this northern area of the reserve by the underlying geology. That is, there appears to be an impervious barrier along the southern and eastern boundaries of the affected area.

A different hydrological regime is observed to the south of this inferred impervious barrier. Here, geochemical analysis of groundwater and surface water indicates that there is unlikely to be any immediate threat from rising groundwater. There is currently a lack of any significant evidence of hydrological connection between the claypans and groundwater. However, this relationship needs to be assessed in more detail over a longer period of time. At this stage, the greatest threat to the claypans, in particular the south-west claypan, appears to be from waterborne threats (weeds and nutrients) transported by altered surface water run-offs.

There is evidence that, since land clearing, large volumes of water have washed across the road into the reserve at the south-west corner[26] (Western Australian National Parks and Reserves Association 1986). This is a potential threat to the integrity of the south-west wetland due to the introduction of weeds, increased nutrient levels, and altered wetland water levels and hydroperiod. Furthermore, the increase in surface water influx could increase groundwater recharge and result in the underlying groundwater system discharging saline water through the south-west claypan (discussed further below).

Excessive surface water flows enter the reserve on the western side near the corner of Bulligan Road and Old Plains Road, and on the northern side on Bulligan Road near the banksia woodland. While low magnitude flows appear to be common during winters with average-to-high rainfall, during high magnitude rainfall events (for example, 60 millimetres in an hour) very large flows are generated. The former are driving vegetation degradation along the north-west margin of the nature reserve and the latter are likely to be the type of flows impacting on the south-west claypan. The nature and consequences of these inflows require further investigation to determine their likely impacts on the reserve's biodiversity.

In contrast to the south-west claypan, the north-east claypan and its catchment are almost entirely contained within the reserve. The claypan itself is about 400 metres from any cleared land and is bounded to the north and west by less permeable granitic bedrock. As a result, it is neither affected by surface water flows originating from outside the reserve nor by the high groundwater levels observed in the north-western section of the reserve. This is reflected in the apparently better condition of the north-east claypan.

Waterborne threats

Biodiversity assets can also be degraded through variations in water and soil chemistry, and by waterborne material. For example, land use and associated hydrological changes have the potential to modify biophysical processes that control the composition of water and soil, including concentrations of carbonate, magnesium, potassium, oxygen, sulfate, and changes to pH (acidity/alkalinity). Potential contaminants include metals, organic compounds, elevated nutrients and sediment levels.

[26] For example, the flood event of April 2008 when about 60mm of rain fell in about one hour. Significant surface water flowed into the south-west corner of the nature reserve, bringing stubble debris with weed seed from adjacent paddocks. A similar event probably occurred in the summer of 2000, the year of the Moora floods, when evidently there was similar heavy rain which caused significant surface water flow across paddocks and flooded roads. Bulligan Road had a big pool of water on it near the banksia woodland. (R. Huston, pers. comm.)

Altered nutrient status of wetlands

A major threat to the south-west claypan is nutrient enrichment or eutrophication. The wetlands are naturally nutrient deficient and any change has the potential to affect ecological processes in them. Measurements of water characteristics in 2004 indicated that total-nitrogen (N) levels in the water column were moderately high, but that total-phosphorus (P) levels were moderate to low. It was concluded that 'increased concentrations of phosphorus should be guarded against as they may give rise (together with the moderately high N) to greater algal growth and the potential for habitat change' (Cale 2005).

Recent hydrogeochemical findings further reinforce this and indicate that there is still a major threat of nutrients being transported into the reserve by surface water (Forbes & Vogwill 2010). In particular, the identification of enriched levels of N within some of the surface and sub-surface waters of the south-west claypan is concerning. These were significantly higher than those seen in the 2008 winter surface water accumulation.

Given the multiple threats, management of large surface inflows into the south-west claypan is a high priority. A numerical hydrological model is required to predict these water inputs to the claypans and to assess both the cost and feasibility of management. Prediction of event regularity and intensity under existing and future climate regimes is needed to gauge the surface water flow thresholds for transporting nutrients into the claypan. The EWRs for the claypan flora and fauna also need to be quantified and incorporated into the model. Tables 6 and 10 detail management actions to address these waterborne threats.

Erosion and sedimentation

Increased run-off and reduced soil cohesion can lead to accelerated rates of erosion from agricultural land during high volume flow events. Heavy or sustained rain has the potential to transport sediment, including sediment-bound nutrients and increase wetland water turbidity.

Introduction of weeds

Waterborne seed from invasive weed species can become established and threaten the integrity of the claypans. The general issue of weeds is dealt with in more detail below.

Acidification

A general pattern has been identified of neutral-to-slightly acidic ground and surface water in DNR, suggesting that acidification is not an issue in the short term. This is more than likely due to the high carbonate buffering capacity that exists in many areas and the lack of sulfide (pyrite) minerals in the claypan sediments. Further investigation of this situation is required but is not a high priority.

Table 6 Management actions to address surface and groundwater threats – altered hydrology and salinity impacts on biodiversity assets

Activities	Outputs	Management action targets
Comprehensively describe (spatially and biologically) the biodiversity assets of DNR threatened by altered hydrology.	1. Survey and report defining location, extent and conservation significance of assemblages present in DNR. 2. Prepare a monitoring protocol including hydrology, vegetation and fauna, in accordance with the then Department of Environment and Conservation (2009a) (30 June 2012).	Adequate knowledge of the biodiversity assets threatened by altered hydrology in DNR (30 June 2012).
Install, monitor and maintain an asset-specific monitoring network for surface flows and groundwater. Determine the spatial distribution and intensity of hydrological threat in relation to the biodiversity assets, and assign management priorities for assets.	3. Monitoring network in place and maintained. 4. Report prepared on the spatial distribution and intensity of hydrological threat, which includes management priorities for assets.	Adequate knowledge of the current hydrology and the factors affecting assets threatened by altered hydrology (30 June 2012)

Activities	Outputs	Management action targets
Determine tolerances and thresholds, that is EWRs, for the communities in the freshwater claypans and the wandoo in the north-west corner, and others if deemed to be threatened by altered hydrology. Derive a numeric hydrological model with sufficient resolution and an acceptable level of certainty to analyse and determine optimal management regime for each asset.	5. EWR report prepared, initially for priority assets, and others if deemed threatened. 6. Numerical model calibration and sensitivity analysis complete.	Understanding of biota habitat requirements and an effective tool for determining feasibility and scale of management required in relation to surface and groundwater threats (30 June 2013).
Devise a water management strategy, based on hydrological modelling, and implement solutions. These may include but not be limited to: • engineering • revegetation • land purchase.	7. Produce a draft water management strategy for DNR.	Reduction in hydrological threat to relevant biodiversity assets (30 June 2013).

Outcome(s): There will be two key outcomes from the above work. Firstly, by 30 June 2013 an adequate hydrological model combined with EWR investigations will have been used to generate improved targeting of management actions to address changes from altered hydrology. Secondly, the interim on-ground actions will have reduced the threat posed by altered hydrology (30 June 2015).

Hydrology and climate change

While not yet fully understood, the potential impacts of climate change on biodiversity are well recognised. Past climate variability and change have already played a key role in shaping ecosystems and the distribution of species across WA (Environmental Protection Authority 2007). Climate change is expected to directly affect biodiversity through changes in temperature, rainfall and extreme events. Indirect effects may include altering the scale and nature of existing threats to biodiversity, such as salinity. This will bring changes to biodiversity assets as well as the values of ecosystems as species adapt or become extinct, emigrate or immigrate, and others become isolated. In areas where there is excess groundwater, a drying climate may ameliorate some hydrological problems, although this may be counteracted by more heavy summer rainfall events.

The Indian Ocean Climate Initiative (IOCI) has provided one estimate of the likely outcomes (Table 7), predicting that all of the south-west of WA, on average, will undergo changes in climate patterns (IOCI 2002; 2005).

Table 7 IOCI climate predictions averaged over the entire south-west (IOCI 2005)

Climate variable	Condition at 2030	Condition at 2050
Mean summer temperature	+0.5° to +2.1°C	Continued increase
Mean winter temperature	+0.5° to +2.0 °C	Continued increase
Mean winter rainfall	-2% to -20%	Continued decrease
Winter potential evaporation	+0% to +10%	Continued increase
Frequency of extreme climate events	Increased but not quantified	Further increased

Impacts of climate change on terrestrial ecosystems are expected to be particularly damaging in the south-west with models predicting temperature increases of several degrees Celsius and a significant reduction in rainfall over this century (IOCI 2005). Recent research shows that the predicted reduction in average annual rainfall will almost entirely result from the loss of rainfall in late autumn and early winter months. Work by Hennessy, Macadam and Whetton (2006) broadly supports these estimates.

Potential implications of climate change for DNR will be assessed through the asset-specific hydrological models. These models will need to be combined with detailed scenarios, climate change projections and climate change impact predictions[27] from other groups such as the Intergovernmental Panel on Climate Change (IPCC) and IOCI. Scenarios and projections of climate change will need to examine the potential impact on catchment biodiversity assets of both declining winter rainfall and increasing high intensity summer rainfall events.

In the broader context of climate variability, to address the potential impact of high and low temperature extremes, average temperature rises and increased evaporation potential, DPaW has commenced research into:

- biodiversity response modelling to investigate the vulnerability of WA's plants and animals to climate change
- developing a climate change biodiversity strategy.

The results of these initiatives and relevant research will be incorporated into the recovery planning process as they become available.

Table 8 Management actions to address the impact of climate change on altered hydrology and biodiversity assets

Activities	Outputs	Management action targets
Determine palaeoclimatic record of the DNR claypans. Run downscaled General Circulation Models (GCMs) and generate catchment scale predictions of the implications of climate variability[28] . Combine these predictions with hydrological models (Table 6).	1. Report prepared on palaeoclimatic record of the DNR claypans and local catchment scale predictions of the implications of climate variability (2013 if data and personnel are available). 2. Report assessing the potential future hydrological threat to DNR biodiversity assets from climate variability (2014 if data are available).	A detailed understanding of the hydrological impacts of possible climate variability on biodiversity assets (2016 if possible).
Integrate results from broader research on the predicted impact of climate variability (including the extent and duration of flooding and drought) on the biodiversity assets of DNR. Specific models for the catchment and assets, and an understanding of past and potential future climate regimes will be used.	3. Report prepared describing the predicted climate variability and the implications for the biodiversity assets of DNR. 4. Develop management responses appropriate to the threats of cyclones, floods and droughts, as analysis is completed, that is artificial maintenance schemes or engineering/geotechnical solutions.	Assets protected (to the extent deemed feasible) from the impacts of climate variability (30 June 2016).

[27] Climate change impact predictions are distinguished from climate change projections to emphasise that climate projections rely on the emission/concentration/radiative forcing scenario used. These are based on a number of assumptions and are therefore subject to considerable uncertainty.
[28] Note that variability includes variations due to natural causes and anthropogenic forcing such as elevated CO_2 emissions.

Environmental weeds, diseases, introduced and problem animals

Environmental weeds can potentially cause local extinction of native plants through direct competition and allelopathy. Introduced animals may threaten population viability of native animals, particularly through grazing (that is, resource competition), inadvertent trampling and predation. Condition decline or mortality due to plant diseases can degrade native plant communities which, in turn, can also impact on their dependent fauna.

The biophysical threat analysis in Section 5 identified that, in general, threat levels are considered to be low relative to other threats, particularly altered hydrology. However, active management is required to prevent new introductions and degradation through the spread of existing weeds, problem animals and disease. Tables 9 and 10 identify the main activities to address these threats.

Environmental weeds

DNR has a vascular plant flora of at least 480 taxa of which 33 are introduced (Appendix 7). The majority of the weeds identified within the reserve are predicted to have minimal impact on the reserve ecosystems. Therefore, expending resources on controlling them is not justified with the exceptions discussed below. Moreover, Keighery et al. (2002b) observed that, 'most of the weeds are currently confined to disturbed areas of the reserve (road edges, firebreaks and drainage lines from roads) and are not widespread through the reserve'. Wild gladiolus (*Gladiolus caryophyllaceus)*, Paterson's curse (*Echium plantagineum*) and blowfly grass and shivery grass (*Briza* spp.) were highlighted by Keighery et al. (2002b) as weeds of current and future concern.

A control program for Paterson's curse has been initiated because it is an invasive, declared plant (P1).[29] A few plants of this species have been found growing in the south-west claypan and growing in greater numbers nearby, reaching into the band of sedges surrounding the claypan. They were found growing in the banksia woodland on Bulligan Road, having been introduced with surface water flow. The control program has contained the spread and reduced the population of this weed and this program needs to continue.

A patch of Paterson's curse near the south-west claypan, prior to control. Photo – Matt Forbes.

[29] Definition. Declared plant (P1): prohibits movement. The movement of plants or their seeds is prohibited within the state. This prohibits the movement of contaminated machinery and produce including livestock and fodder (http://agspsrv95.agric.wa.gov.au/dps/version02/01_plantview.asp?page=6&contentID=48&) (3 Mar 2009).

In the wider catchment, the primary weed threat comes from the sharp rush (*Juncus acutus*), which has infested drainage lines in several areas. Trials are underway to assess the efficacy of sharp rush control using current best practice. A native sedge, *Juncus kraussii,* occurs on Bulligan Road near DNR, and it is at high risk of hybridisation with infesting populations of the introduced sharp rush (K. Brown, pers. comm.).

The management approach for the most serious weed species recorded from DNR is outlined in Table 9. Priority is given to the control of Paterson's curse, sharp rush and perennial veldt grass.

Table 9 Management actions to address the most serious weed species recorded from or near Drummond Nature Reserve

Weed species	Proposed actions	Target	Comments
Paterson's curse (*Echium plantagineum*)	Maintain current control measures (annual spraying) and monitor outcomes Spray existing plants with glyphosate or spot spray in late autumn (when most seed has germinated) with chlorosulfuron plus wetting agent to help prevent further germination (Brown & Brooks 2002)	Eradicate current and new infestations	Declared plant (P1) – see footnote 29 on previous page. A broadleaf annual or biennial, seed spread by water or machinery, can germinate any time of year. Recorded in south-west claypan and in banksia woodland on Bulligan Rd
Wild gladiolus (*Gladioulus caryophyllaceus*)	Wild gladiolus is a significant problem on the eastern boundary of DNR Spot spray metsulfuron methyl just on flowering (Brown & Brooks 2002)	Eradicate current and future infestations	Pink flowered, cormous species
Hesperantha falcata	Map occurrence (flowers only open late afternoon) and control Hand weeding or spot spraying (Brown & Brooks 2002) if district manager judges as current or future risk to assets	Reduce infestation if decided it should be controlled	White flower, cormous, grows in winter-wet locations, but not inundated areas. Seeds well, will out-compete orchids and similar species recorded for claypan (Keighery et al. 2002b)
Blowfly grass and shivery grass (*Briza* spp.)	Map occurrence. Control probably not justified given its ecological impact relative to the potential detrimental impacts of the required control measures. Refer to Brown & Brooks (2002) chapter 3 and case study 3.1	Monitor	Very common bushland weeds whose ecological impacts are uncertain, although reported to compete with native annual species (P. Hussey, pers. comm.)

Weed species	Proposed actions	Target	Comments
Wavy gladiolus (*Gladiolus undulatus*)	On alert	Eradicate if found in reserve	White flower, cormous species, grows in winter-wet locations. No record of this in reserve but is recorded in reserves to the west
Sharp rush (*Juncus acutus*)	Map occurrence on land adjacent to reserve On alert for occurrence within the reserve	Eradicate close to and within the reserve	No record of this in reserve but is recorded in the wider catchment. A weed of drainage lines and winter-wet areas
Perennial veldt grass (*Ehrhata calycina*)	Map occurrence on land adjacent to the reserve and control on road verges. Consult Brown & Brooks (2002) chapter 3 and case study 3.4 for most suitable control measures	Eradicate current occurrence and any future infestations in or threatening the reserve	A tussock-forming grass, reproduces by seed or short rhizome, has potential to change the ecosystem (for example invades bushland, increases fire hazard, monopolises resources). Resprouts after fire. Small infestation recorded on Mount Rd road verge

Weed management will include strategies to reduce the likelihood of future introductions. This will include the control of surface water entering the reserve and addressing the possibility that kangaroos are acting as vectors for weed establishment in the claypans. It will also include a monitoring regime to regularly assess the status of weed populations and to assess the results of control measures.

Plant diseases

Phytophthora sp. (dieback)

Phytophthora cinnamomi or '*Phytophthora* dieback' is considered to be a 'moderate' threat to the native plant communities and their dependent fauna in the catchment (L. Twycross; C. Dunne, pers. comm.). This rating is based on the nature of the predominant soil types (which are less conducive to the disease), annual average rainfall of between 500 millimetres to 600 millimetres[30], and that the dominant plants are resistant to *P. cinnamomi* (that is, marri and wandoo). The threat of *P. cinnamomi* may escalate if summer rainfall events become more frequent with climate variability.

A 2003 survey for *P. cinnamomi* in the reserve found no evidence of the pathogen (Van de Sande 2003) and the Bindoon Army Training Area to the west of DNR is considered free of *P. cinnamomi* (Glevan Dieback Consultancy Services 2008). However, *P. cinnamomi* has infested a large part of the Mavis Jeffrey Nature Reserve, south-west of Toodyay, which emphasises that vigilance is required to actively protect the disease-free status of the catchment.

A survey in 2000 of the banksia woodland on Bulligan Road in DNR by DEC officers, found evidence of a different and less destructive species of *Phytophthora* (*P. megasperma* complex) (Van de Sande 2003, sample VHS8183).

While the dominant overstorey species in the reserve (wandoo and marri) are resistant to *P. cinnamomi*, there are components of the vegetation which are highly susceptible, including 35 taxa in the Proteaceae family. There are several patches of banksia woodland with four different banksia species represented. In addition, the grasstree (*Xanthorrhoea preissii*) is common throughout, including in the wandoo woodland in the north-west corner. Sites in the reserve subject to flooding and on sandy soils are most at risk.

Inadvertent introduction through vectors such as vehicles, or the use of infested plant stock or earth materials, presents a risk. The location of the electricity line and associated service corridor in the northern section of the reserve is also a risk. Dieback hygiene protocols prior to

[30] Less than 400mm rainfall is considered low risk

entering the reserve need to be enforced. Neighbouring farmers should be encouraged to maintain vigilance for *P. cinnamomi* on their land. Surface water movement through the landscape will also facilitate any spread of future infestation and therefore surface water run-off entering the reserve is another risk. The reserve needs a dieback strategy to be compiled and revised as new information and recommendations are available. Basic guidelines on dieback management are provided in *Managing* Phytophthora *Dieback in Bushland: A Guide for Landholder and Community Conservation Groups* (Dieback Working Group & Threatened Species Network 2008) and *Best practice guidelines for the management of* Phytophthora cinnamomi (Department of Conservation and Land Management 2004).

Armillaria luteobubalina

The honey fungus (*A. luteobubalina*) is a native parasite and can infect and kill a range of trees and shrubs, including wandoo, which is known to be susceptible. The pathogen was detected at five sites in DNR: four of the occurrences were in marri woodland or marri/wandoo woodland, and one was in banksia woodland (Van de Sande 2003). The pathogen was not detected near either of the claypans, or in the wandoo in the north-west corner; however, this survey was mainly focused on *Phytophthora* detection. Further attention to the threat posed by this fungus is warranted given the susceptibility of wandoo and the dominance of wandoo in the biodiversity asset in the north-west corner, and in the priority ecological community 'Wandoo woodland over dense low sedges of *Mesomelaena preissii* on clay flats'. Being a native species, there is no simple method for controlling *Armillaria*; therefore, appropriate hygiene practices are essential to prevent the fungus spreading.

Mundulla Yellows

A slow, progressive dieback and yellowing disease found in many eucalypts, Mundulla Yellows is thought to be caused by a virus, viroid or similar agent, although other agents are possible. It has not been recorded in the vicinity of the catchment. However, in the south-west of WA it has been recorded from Northampton to Esperance, including several places in the wheatbelt (M. Stukely, pers. comm.). It occurs largely in areas near roads and towns and also in proximity to intermittently flowing waterways (Paton & Cutten 1999). These areas will require targeted monitoring for potential infection. As a little known and only recently described disease, it has the potential to seriously affect native species, revegetation and eucalypt plantations. The key to management will be identification of the cause. If it is a biotic disease, management will need to be directed towards averting an epidemic. For a solely abiotic disease, a different management strategy will be needed (Hanold et al. 2006).

Introduced and problem animals

Introduced herbivores and predators

Foxes, cats and rabbits are sighted regularly and widely in the catchment. Rabbits seriously impact on vegetation communities by grazing on native plants and limiting their capacity to grow, flower and set seed. Foxes and cats predate on small and medium-sized native mammals, birds and other fauna.

Results from recent management actions to recover *Acacia chapmanii* subsp. *australis* (DRF) in DNR identified herbivory by kangaroos, and possibly rabbits, as a threatening process for the regeneration of this species (P. Dufty; P. Ladd, pers. comm.). Controlling rabbits in areas of emergent *A. chapmanii* is likely to have a positive benefit for conservation of this species. Rabbit control is also good bush management practice and is part of the *Good Neighbour Policy* (Department of Environment and Conservation 2007b).

Problem native species

Native species with an increased abundance and/or altered distribution since European settlement can threaten other native species. In the catchment, problem species include the western grey kangaroo, Australian ringneck parrot and galah.

The main impacts of large numbers of kangaroos include grazing of vegetation, damage to vegetation due to movement and creation of resting sites, and the transport of weeds. Existing native vegetation as well as successful regeneration and revegetation can be impacted. It is possible that kangaroos are having a detrimental impact on the vegetation in the claypans. Australian ringnecks are understood to be responsible for 'grazing' grasstrees (*Xanthorrhoea* sp.) in the reserve, to the extent that some have died. This behaviour has been documented for several areas in WA (Borsboom 2005). The level of threat to grasstrees in DNR from Australian ringnecks needs to be ascertained and investigations into potential deterrents can then be undertaken.

Grasstree damage by Australian ringnecks.
Photo – Matt Forbes.

In addition, the nesting behaviour of the Australian ringneck and the galah can be destructive and aggressive, displacing other, less common species such as Carnaby's cockatoo, which is listed under the WA *Wildlife Conservation Act 1950* as 'Fauna that is rare or is likely to become extinct' and under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* as 'endangered'. The reserve contains breeding habitat for Carnaby's cockatoos and birds have been seen feeding within the reserve.

The mobility of introduced and problem animals in the landscape presents a challenge for management. For example, local eradication of cats and foxes frees up areas for reinvasion from adjacent areas. As such, the frequency, timing and area of application of control measures are key considerations for management. The general principle is that synchronised, large-scale implementation of control measures is more effective than a piecemeal or individual landholder approach. In the catchment, this may require a shire-facilitated approach across different land tenures involving as many landowners and stakeholders as possible. While coordination of such control measures is a major task and is resource intensive, evidence from successful control programs suggests that there are clear benefits of this approach. Specific management actions are detailed in Table 10.

Table 10 Management actions to address impacts of introduced and problem plants and animals and disease

Activities	Outputs	Management action targets
Implement control action for the following species as outlined in Table 9: Paterson's curse, wild gladiolus, sharp rush (if it appears), perennial veldt grass. Review existing weed information, map weed occurrence and distribution, and prepare a plan for weed management within three years to protect the assets.	1. Outputs will be documented annually as area, or number of infestations, managed during the financial year. 2. Plan prepared which reviews existing weed situation, particularly in relation to the assets but also including areas of weed concentration. Plan details ongoing management required to achieve management objectives. (30 June 2012)	Targets identified in Table 9 achieved. Ongoing weed management program refined, adapted and documented.
Review plant disease information (particularly *Phytophthora* spp., *Armillaria* and Mundulla Yellows) and re-survey every three years (update existing report 2009). Enforce decontamination and disease suppression activities where required.	3. Update existing report in 2012 and resurvey every three years. 4. Disease protection plan (for decontamination and suppression) prepared and implemented (30 June 2012).	No new disease occurrences or spread of existing infestations.
Undertake problem species control consistent with *Good Neighbour Policy* (Department of Environment and Conservation 2007b). Investigate whether other problem species are threatening the biodiversity assets specified in this plan, and prepare and implement control programs as required.	5. Rabbit damage consistent with neighbour expectations and plant survival in revegetation sites. 6. Review and action plan, if required.	Damage to key assets minimised.

Regimes of physical disturbance

Physical disturbance events, such as fire, flood and drought, are natural ecosystem processes that may be important to the persistence of some species, for example, those species requiring disturbance to germinate. However, in combination with human factors new fire regimes may degrade biodiversity assets. The impacts of climate change are likely to contribute to changes in these regimes. A brief description of the threats and their management in the reserve is given below and in Table 11.

Fire

Fire is a natural ecosystem process in the reserve; however, biodiversity assets may be threatened by inappropriate fire regimes. Determining the pre-European fire regime, particularly frequency and intensity, is difficult. Additionally, the highly fragmented nature of the native vegetation in the current landscape has created a situation under which natural fire regimes may no longer be appropriate in the context of the management goal. Planning for fire management, including investigations to fill knowledge gaps, is managed at a state and regional level, and is not considered further here.

In the short term, management responses will include installation and maintenance of appropriate firebreaks combined with best practice management of bushfires consistent with existing departmental guidelines. Management actions will also be consistent with relevant shire regulations and the *Bush Fires Act 1954*, and consider opportunities for weed control following bushfire to protect and maintain biodiversity.

Cyclones and floods

Flood events distribute large quantities of water and waterborne materials throughout the system. This may result in severe impacts on biodiversity assets, particularly the claypans, as well as other low-lying areas. At the same time, particular species can be expected to respond positively to flooding.

Localised flooding will be the only issue for DNR, given its position above the valley floor of the catchment. This will be addressed initially by the development of hydrological models and assessment of average recurrence intervals of various magnitude rainfall events under current and potential future climate regimes. Once the models have been built, management options will be developed and implemented as appropriate.

Drought

Since European settlement, there have been serious droughts in WA that have affected the catchment. During drought, wetlands dry out for extended periods and vegetation may collapse due to lack of water, putting biodiversity assets under considerable stress. Droughts have also likely influenced the current invertebrate community composition. Understanding the claypan water regimes during drought times may provide an indication of the resilience of these communities. The management response will depend on the modelling outcomes but may include artificial watering (such as by redirection of surface flows) for areas where drought presents a high risk of goal failure.

Management responses to both drought and flood require development of predictive models and understanding of EWRs. These models and EWRs will be developed as part of the response to the threat of altered hydrology.

Table 11 Management actions to address threats to biodiversity assets – detrimental regimes of physical disturbance

Activities	Outputs	Management action targets
Protect assets from unplanned fires by maintaining firebreaks around DNR (as required) and limiting the extent of bushfires. Investigate and report on appropriate fire regimes for assets (at state level) (2015). Implement prescribed burning and associated monitoring as required to maintain appropriate regimes for each asset. Note that, in the short to medium term, no burning may be required to protect key biodiversity assets threatened by altered hydrology.	1. Firebreaks maintained around DNR to protect assets from unplanned fires and limit the extent of any bushfires. 2. Report prepared on appropriate fire regimes for assets. 3. Appropriate fire regimes for each of the assets is maintained and situation monitored.	Appropriate fire regimes for the assets (30 June 2016).

Impacts of competing land uses

The potential threats to DNR's priority biodiversity assets from competing or incompatible land uses are listed below. They are not of immediate concern but the situation needs to be monitored and, if practicable, action taken to prevent issues arising. Activities that are of current interest include:

- dumping of waste, taking of firewood, hunting, taking of rare flora, collecting seed illegally
- inappropriate recreational activities such as use of off-road vehicles in the reserve
- maintenance of power line and peripheral roads. Communication with Western Power and the shires of Toodyay and Victoria Plains is required to limit disturbance, spread of disease and other negative impacts on the reserve.

Building an appropriate culture

Management success may be hindered by a lack of understanding among stakeholders that biodiversity conservation is an important contributor to human wellbeing. Similarly, the culture in any of the stakeholder groups may be a barrier to successful implementation of this recovery plan. For example, if DPaW officers do not have an appropriate understanding of agricultural needs, this will be a barrier to successful recovery work.

Collectively, all these sociocultural threats to achievement of the goal for the catchment are brought together under the term 'inappropriate culture'. It is emphasised that culture, as used here, is only considered inappropriate when it threatens achievement of the management goal. The corollary of this is that it is necessary to build an appropriate culture for successful implementation of the recovery plan.

In this context, it is important to maintain or improve the current level of two-way communication with catchment land managers and other communities of interest, particularly those represented on the advisory committee.

It is also essential to communicate the importance of biodiversity in the catchment to a state and national audience. This recovery plan is part of this process; however, where appropriate, other opportunities will also be taken to widely communicate the values of catchment biodiversity. A communication plan will be developed to ensure activities in this area are well targeted and cost effective (Table 12). These actions include resource support for the recovery team, management of meetings, production of the catchment newsletter, and staff training.

Table 12 Building an appropriate culture

Activities	Outputs	Management action targets
Develop a communication plan, which assesses stakeholder views and support, and provides a mechanism to achieve feedback on progress in the catchment.	1. A communication plan developed (30 June 2012).	Communication of all aspects of the recovery plan considered relevant to the catchment land-holders and community in general (30 June 2012 and ongoing).

Other threatening processes

A number of other threatening processes are listed in the threat analysis. While it is important to review the threat analysis annually to ensure there are no new important threats, effective management of those listed above is sufficient to provide a high probability of goal achievement. If necessary, actions will be developed to tackle other threats if the current situation changes.

Progress to date

Expenditure and outputs

When the DNDRC was established, the hydrological threats to DNR were poorly understood. Therefore, initial work focused on investigations, revegetation and remnant vegetation protection.

Revegetation has centred on 'no regrets' activities, that is, on-ground works that are required for longer-term success, but may or may not be the most urgent in the short-to-medium term. Revegetation focused on DNR has related to hydrological control, vegetation buffering and the creation of wildlife corridors. Revegetation and remnant vegetation protection activities also occurred across the wider catchment to improve the protection of biodiversity assets throughout the catchment while at the same time engaging the local community.

Significant monitoring and research investigations completed by the project between 2001 and 2011 include:

- Groundwater and salinity investigations in the catchment, involving the establishment of a groundwater monitoring network (bores at 44 sites including nine sites relating to DNR), hydrogeological logs for each site, and collection of other related data (standing water level and water quality) (PPK 2002).
- Survey of the remnant vegetation in the catchment relating to 27 private properties and four nature reserves (Bennett Environmental Consulting Pty Ltd 2002).
- Aquatic invertebrate survey of the two freshwater claypans in DNR in October 2004 (Cale 2005), November 2007 (Avon Baselining Project, Jones et al. 2009) and in 2010 (north-east wetland dry; south-west wetland was very shallow) (*State Salinity Strategy* wetland monitoring program).
- Dieback survey of DNR conducted in May 2003 which aimed to determine the presence/absence of *Phytophthora cinnamomi*, other *Phytophthora* spp. and forest pathogens, and to report on the overall health of the vegetation (Van de Sande 2003).
- Groundwater bore monitoring for water quality baseline (Gecko Environmental 2005).
- EM31 and EM38 survey in the north-west corner of DNR (Geoforce Pty Ltd 2003).
- Groundwater-surface water interactions were investigated, via isotopic, major ion and nutrient analysis, to assess the potential threats to the claypans and their associated rare and endangered flora by altered hydrological processes (Forbes & Vogwill 2010).

Weather station located in the south-west claypan. Photo – Matt Forbes.

An important feature of the work has been the community engagement and contribution in relation to revegetation works, surveys and planning. The recovery catchment officer has communicated details of the project to the local community by means of newsletters (3), attendance at a variety of local meetings (15 groups), and tours of the catchment for a range of groups (8).

Outcomes 2001–2006

The catchment has not been under management for a sufficient period for outcomes in relation to goal achievement to be identified. However, there have been a range of outputs that will make an important contribution to the longer-term achievement of outcomes. These include the following:

- Hydrological investigations to date have focused on installing and maintaining an appropriate network for monitoring surface and groundwater quality. The data generated will contribute to a greater understanding of the hydrology and hydrogeology of the catchment and the risks posed to key biodiversity assets.
- Paterson's curse populations in the vicinity of the south-west claypan and in the north-west corner of DNR have been contained.
- *Phytophthora cinnamomi* was not detected in DNR in. the survey conducted in 2003
- Revegetation with native species (approximately six hectares) was successfully completed on private property within the immediate surface water catchment north-west of DNR. In the same area of the catchment, about 25 hectares of existing remnant vegetation was fenced to prevent stock access. These actions are expected to reduce surface water flow and groundwater recharge to the northern section of the nature reserve. The revegetation and remnant vegetation protection works undertaken to improve hydrological management in the catchment have also contributed to improving the persistence of native terrestrial biota.
- A degraded area in the north-west corner of DNR has been replanted (about 3.5 hectares).
- Planning activities and associated consultation have contributed to conserving the biodiversity assets by providing a focus for community stakeholders and catchment managers. Meetings and consultation have assisted in identifying the key values, formulation of catchment goals as well as asset definition and ranking.
- Engagement of landowners and agency personnel with on-ground works and on field trips has contributed to building a supportive culture for biodiversity conservation in the catchment.

Table 13 Summary of recovery catchment expenditure and outputs against core activities 2001–2006

Activity	Outputs	Expenditure ($)	Expenditure (% of total)
Survey investigations identifying remnant bushland that could be incorporated into the conservation estate, or protected or managed to benefit their biodiversity values and for salinity control	40 surveys	18,122	2
Revegetation to buffer remnant vegetation and provide new habitat (including linkages), plus hydrological control (excluding commercially prospective species)	27 sites 310,000 seedlings 144 hectares 18km fencing 12 landholders	424,853	50
Revegetation using commercially prospective species to buffer remnant vegetation, provide habitat (including linkage) and provide hydrological control	6 sites 69,500 seedlings 22 hectares 7.4km fencing 4 landholders	75,860	9
Improved protection and management of remnant native vegetation on private properties	17 sites 136 hectares 37km fencing 12 landholders	110,181	13

Activity	Outputs	Expenditure ($)	Expenditure (% of total)
Weed and feral animal (rabbit) control	11 sites 14 hectares 1 nature reserve	13,402	2
Monitoring and research/investigations (other than listed for particular project areas above)	9	116,351	14
Management of recovery and related committees, input to catchment planning, liaison with local authorities and all other groups	19 meetings 15 groups dealt with 3 newsletters 4 advisory committee meetings 15 other meetings/talks	83,406	10
Total		**842,175**	**100**

Reproduced from *Draft Ten Year Business Plan: Drummond NDRC* (Department of Environment and Conservation 2009b).

7 Implementation, monitoring and evaluation

This section establishes the implementation process and outlines the framework that will be used for monitoring and evaluating progress towards achieving the DNDRC goal.

In summary, the planning period will involve the implementation of:

- surveys and monitoring to obtain adequate knowledge of the hydrology, flora and fauna, and the threats to biodiversity assets
- EWRs and a numeric hydrological model to understand the biota habitat requirements and guide management
- a draft water management strategy to reduce the hydrological threats to biodiversity assets
- revegetation as planned, to increase water use and better control recharge
- studies and modelling to understand the impacts of climate variability on biodiversity assets and develop appropriate management responses
- operational actions, monitoring and planning to minimise the impacts of weeds, problem animals and disease
- an investigation into appropriate fire regimes for the biodiversity assets
- a communication plan
- implementation of the operational activities outlined below, and any other works, including surface water engineering, that arise from the above studies and as approved by the DPaW Director of Nature Conservation as necessary operations.

Monitoring and evaluation framework

Monitoring progress and evaluating performance will initially focus on the three priority assets which have been defined: the two claypan communities and the wandoo community in the north-west corner of DNR. If additional important assets are assessed to be threatened by altered hydrology, they too will require monitoring and management.

The goal and related targets

The goal for DNDRC is:

To deliver the scientific and educational values, opportunity values and system benefits values derived from the 2011 composition and structure of biodiversity assets of the DNR threatened by altered hydrology for the next 20 years.

The goal outcomes can be assessed in a number of ways including:

a whether the values have been delivered, and to what degree

b whether the 2011 composition and structure of biodiversity assets has been maintained c with what efficiency (a) and (b) have been delivered.

Methods for assessing (a) will be developed within the next five years. With regard to (c), expenditure in relation to activities and quantified outputs will continue to be documented in the current format (Appendix 12). This allows for benchmarking against other similar projects. Therefore, the focus in this document is on (b), assessing whether the 2011 composition and structure of biodiversity assets has been maintained. An assumption is that the delivery of values will be maintained if this asset target is met; however, this assumption needs to be tested in the life of the plan.

The proposed monitoring targets are summarised in Table 14. An assessment template to determine progress against the targets is provided in Appendix 11. These targets are the basis on which the long-term success of management and the need for adaptation will be assessed. The targets are of two types – management triggers and limits of acceptable change.

Limits of acceptable change are the limits within which change to biodiversity assets can be tolerated in the context of the management goal and related values. The concept of acceptable change is widely used to evaluate change in the ecological character of wetlands listed under the Ramsar Convention. In this plan, the stated limits of acceptable change have been based on our current understanding of the natural variability of the claypans and the ecosystem properties required to maintain the current composition and structure of biota.

Management triggers lie inside the boundaries of acceptable change and are intended to provide an early alert so that an adaptive management response can be implemented if required, prior to the limits of acceptable change being reached. This precautionary approach allows an assessment of the level of change occurring and the impacts on biota. The information obtained from such an assessment will improve our understanding of natural variability and assist in refining management triggers and limits of acceptable change.

Given the comparatively short period over which data has been collected, management triggers have been established based on knowledge of past conditions and documented extremes; that is, knowledge that the biota has persisted within these environmental boundaries. Where more information is, or becomes, available limits of acceptable change have also been provided. Given the short period over which data is available, both sets of indicators can be expected to change with new information.

The recovery catchment officer will report annually on the status of asset targets. As part of the planning and management process for natural diversity recovery catchments (Figure 1), a major review of goal achievement will be conducted at five and ten-year intervals. This evaluation activity will also be used to improve decision-making, enhance organisational learning and document achievement of targets for biodiversity assets, and thus progress to goal achievement.

Assumptions used in setting targets

Groundwater and surface water

The underlying assumption for the groundwater and surface water targets is that the situation, up to June 2010[31], is acceptable and should be maintained. Further investigation into the patterns of natural variability of the groundwater and surface water, and the responses of the biota, will assist in refining limits of acceptable change and management triggers.

Management triggers for groundwater and surface water have been proposed in consideration of the available data, that is, from 2008, 2009 and 2010. It should be noted that the rainfall for 2010 (272.20 millimetres) was not sufficient to cause inundation of the claypans with a cohesive waterbody. The 2010 annual rainfall figure was obtained from the Bureau of Meteorology's weather station at Bolgart Bin (November 2009 to April 2010 inclusive) and the then DEC weather station, which was established in the south-west claypan in late April 2010 (May 2010 to October 2010 inclusive). More years of data will provide a better understanding of the rainfall (quantity and timing) required for inundation of the claypans to occur. Management triggers could then be linked to rainfall and appropriate responses undertaken (that is, surface water engineering).

Flora

Taxonomic composition is defined here as the types of taxa, and the number of individuals within each taxa (adapted from Wallace 2007). While some baseline flora information is available (Keighery et al. 2002b), monitoring will be required to accurately define the taxonomic composition of the claypan flora.

Indicator species have been included in the targets to provide a focused approach in identifying change in flora, and because it is not feasible to monitor all taxa in all assets. The indicator species are considered to be the flora most sensitive to change and have been determined based on the information available and current understanding of the claypan vegetation. The indicator species may change as a result of future monitoring.

[31] This date was selected because the winter of 2010 was the driest on record. Degradation of the wetland vegetation is becoming apparent (but this will not necessarily change the biotic composition).

The assumptions used in determining the indicator species include:

- *Melaleuca lateritia* is a perennial shrub that is the dominant species of the claypans and would presumably be the most visible species to be affected by altered hydrology or other threats. Given that it is a deeply rooted perennial species, it may be assumed that it will be the plant most sensitive to changes in groundwater conditions.
- *Eleocharis keigheryi* is a perennial sedge that is dependent upon freshwater and is listed as declared rare flora at a state level and vulnerable at a national level. As this species has been identified as at risk and in need of special protection, it is likely it will be impacted by altered hydrology or other threats, in particular, invasive weeds. The species is taken to represent shallow-rooted perennial plants.
- *Eucalyptus rudis* surrounds the claypans in a scattered band and has shown to be highly susceptible to altered hydrology (that is, *E. rudis* was one of the first species to decline at Toolibin Lake as a result of altered hydrology). *E. rudis* is the deepest-rooted species in close proximity to the claypans.

Management triggers are proposed over a five-year timeframe in recognition that few ecological variables are likely to show significant change in less than five years (Harding & Williams 2010). A 20 per cent reduction in the cover of *M. lateritia* and *E. keigheryi* provides a conservative target to trigger a management response in this early stage and future annual monitoring will allow the target to be refined. *E. rudis* occurs in a scattered band around the claypans; therefore, measuring basal area will provide a better indication of change than measuring cover. Annual species in the claypan flora are not considered to be useful as indicators of change over the short term as they are highly variable from year to year.

Fauna

Aquatic invertebrate communities are dynamic and individual species will come and go from wetlands. Long-term monitoring (annually) of community composition (that is, the species identified within a community) will provide a reliable indicator of change in the character of an invertebrate community. Historical data from 2004 and 2007 will be used to compare future communities through statistical analysis using qualitative and quantitative multivariate techniques. Limited data was collected in 2010 as the north-east wetland was dry and there was very little water in the south-west wetland (Appendix 10). Another measure of change and health of a community is to consider the taxonomic differences between component species (that is, taxonomic distinctness). For example, an invertebrate community composed of species belonging to various families is likely to indicate a more robust community than one composed of the same number of species belonging to one or few families. Future monitoring will provide information in this regard and the targets can be revised if appropriate. It should be recognised that monitoring of invertebrate communities will be dependent upon climatic conditions and the claypans being inundated.

The indicator invertebrate species selected are those characteristic of seasonal claypans in the inland south-west of Western Australia and which were present in DNR in 2004 and 2007. Seven species have been identified in at least three of the four samples, that is, two samples in 2004 and two samples in 2007. During 2004 and 2007, there were five to seven species present per sample and all seven occurred on both dates in one or both wetlands (that is, if one was absent in one claypan, it was present in the other). It should be noted that other species characteristic of south-west claypans may occur occasionally in DNR and the targets may need to be revised when more data are available.

Some rare invertebrate species have been identified in DNR claypans though they are not currently considered suitable species to include in targets. For example, several rotifers are known only from DNR; however, rotifers have short life spans and a rapid turnover in species composition within a hydrological cycle and therefore will not be sufficiently detectable by annual sampling. These rare species should be recorded when they do occur and a management response triggered only when their absence is noted over the long term. It should be noted that knowledge of the distribution of invertebrate species across a region is dependent upon sampling effort and a species that appears to be endemic or rare may be a result of inadequate sampling.

Limited vertebrate surveys have been conducted at DNR and baseline information is required to set management triggers and limits of acceptable change. Monitoring should initially focus on amphibians, which will provide the best indicator of change within the claypans, in consideration that frogs utilise the claypans more than other vertebrates. As with aquatic invertebrates, monitoring of frogs will be dependent upon climatic conditions and it may be useful for the invertebrate monitoring to be coupled with amphibian monitoring.

Table 14 Proposed monitoring targets

Biodiversity assets	Monitoring parameters		Management triggers	Limits of acceptable change
Claypan flora	Groundwater	*Water quality* Monitor: Ca, Mg, Na, K, Cl, Br, SO_4, NH_3, NO_3, TN, TP, EC, pH, alkalinity (HCO_3). Key indicators to identify water quality change include: NaCl, TDS, pH, EC, P and N, foreign matter (for example weeds). *Water quality* Monitor: groundwater depth once a month manually (by dipper). Need to establish a deep bore on the south side.	**South-west claypan** • maintain summer (i.e. is February when the claypan is dry) deep groundwater levels 3m below the soil surface of the claypan to ensure no input of saline groundwater via the capillary fringe. • groundwater only occurs seasonally in the shallow bores – if water becomes permanent this suggests increased inflow and potential threat. **North-east claypan** • groundwater only occurs seasonally in the shallow bores – if water becomes permanent this suggests increased inflow and potential threat.	To be determined when more data is available.
	Flora	*Composition, processes, indicator species, acceptable level of weeds* Monitor: in accordance with endorsed methodologies, remote sensing using VegMachine and hyper-spectrum/multi-spectrum.	Claypan flora indicator species: *Melaleuca lateritia* • no significant change in condition and no more than 20 per cent reduction in cover over a five-year timeframe. *Eleocharis keigheryi* • no more than 20 per cent reduction in cover over a five-year timeframe. *Eucalyptus rudis* • no significant change in condition and no significant reduction in basal area over a five-year timeframe.	Maintain the taxonomic composition of the claypan native flora over the timeframe of the goal (20 years).
Wandoo woodland flora	Groundwater	*Water quality and quantity* Monitor: to be determined. Need to establish several deep groundwater bores.	Maintain depth to groundwater greater than 5m (3m unsaturated zone unaffected by salt, 2m to break the connection between the root zone and the groundwater).	To be determined when processes are understood.

Biodiversity assets	Monitoring parameters		Management triggers	Limits of acceptable change
Claypan fauna	Surface water	*Water quality* Monitor: Ca, Mg, Na, K, Cl, Br, SO_4, NH_3, NO_3, TN, TP, EC, pH, alkalinity (HCO_3). Key indicators to identify water quality change include: NaCl, TDS, pH, EC, P and N, foreign matter (for example weeds). *Water quantity* Monitor: surface water depth continuously by loggers once inundation occurs.	Observed range 18–22mS/m (101–122ppm) Maximum inundation (cohesive waterbody) of six months but four months is more typical. Minimum inundation once every three years. As an interim management trigger, nutrients to stay within default trigger values for south-west Australia wetlands (ANZECC & ARMCANZ 2000a). pH should be between 5.5–8 consistently (averaged over a weekly basis).	To be determined when more data is available (it is expected that up to 60mS/m (314ppm) should not present a problem. Hydroperiod to be determined when there are more years of record. More information is needed to set nutrient targets based on biota. pH to be determined.
	Fauna	*Composition, processes, indicator species, acceptable level of feral fauna* Monitor: in accordance with endorsed methodologies and consistent with previous surveys where possible (for example Cale et al. 2004).	*Claypan invertebrates* Community composition does not differ significantly from historical data over a five-year timeframe. No less than four indicator species should be present in any one wetland on any sampling occasion;[32] no less than six indicator species should be present across both wetlands over a two-year sampling period; all seven indicator species should be present across both wetlands over a five-year sampling period. Indicator species include: • clam shrimp (*Lynceus* sp.) • ostracod (*Bennelongia australis*) • beetle (*Paroster* sp.) • beetle (*Berosus approximans*) • copepod (*Calamoecia attenuata*) • phantom midge (*Promochlonyx australiensis*) • cladoceran (*Latonopsis brehmi*). *Vertebrate fauna* To be determined.	Maintain the community composition of the claypan invertebrates over the timeframe of the goal (20 years). To be determined when more data is available.

[32] A sampling occasion for invertebrates requires the claypans to maintain a minimum surface water depth of 10cm for at least a six-week period. Monitoring may still occur if these conditions are not met; however, the target will not be assessed.

Cultural values

As part of the monitoring and evaluation process, it is vital to assess achievement of the cultural values outlined in Table 3. This should be achieved by activities described in relation to the targets. However, in the case of system benefits, it is necessary to develop additional criteria to assess whether values are being maintained or improved. These criteria will be developed and tested during the first three years of plan implementation, and after appropriate amendment, will be added to the recovery plan and reporting process.

During the next five years, the methods for assessing the cultural values and their achievement will be updated.

Implementation process

Annual operational planning and works

Scheduling of priority actions and the delivery of outputs is given at Table 15. These outputs are grouped according to the biodiversity asset threat categories and will form the basis for annual operational planning by DPaW's Swan Region with advice from the recovery catchment team and technical advisory group, as required. These are relative priorities and may be adjusted as new knowledge is gained. This is part of the planning and management process for NDRCs (Figure 1), which includes a feedback process to regularly assess constraints and how these affect management feasibility.

The 'warning light' approach shown in Table 15 provides an indication of possible barriers to implementation. 'Green lights' are relatively well established tasks or those unlikely to pose significant issues in implementation. 'Amber' and 'red lights' indicate activities that are at risk of running behind schedule. For the most part, these risks relate to activities that are highly dependent on successful completion of other activities or are of a lower priority. The warning system is designed to help operational personnel keep track of susceptible activities and, where necessary, adapt.

The recovery catchment managers will, as part of the standard departmental budget process, prepare an annual works program based on Table 15, that will be recorded in the standard budgeting and expenditure template used in the salinity program (Appendix 12). The proposed budget will be assessed by the manager of DPaW's Natural Resources Branch who will recommend an allocation for endorsement by the director of DPaW's Nature Conservation Division.

Under the direction of the manager of Swan Region allocated recovery funds will be spent on approved works.

Annual reporting process

All expenditure and outputs will be reported in the standard template (Appendix 12), which will be submitted by 31 August of each year for the preceding financial year. In addition, progress against the targets will be outlined annually, with major reviews periodically.

Table 15 Threat categories and timeline for delivery of management outputs

Traffic light approach

Green lights – well established tasks

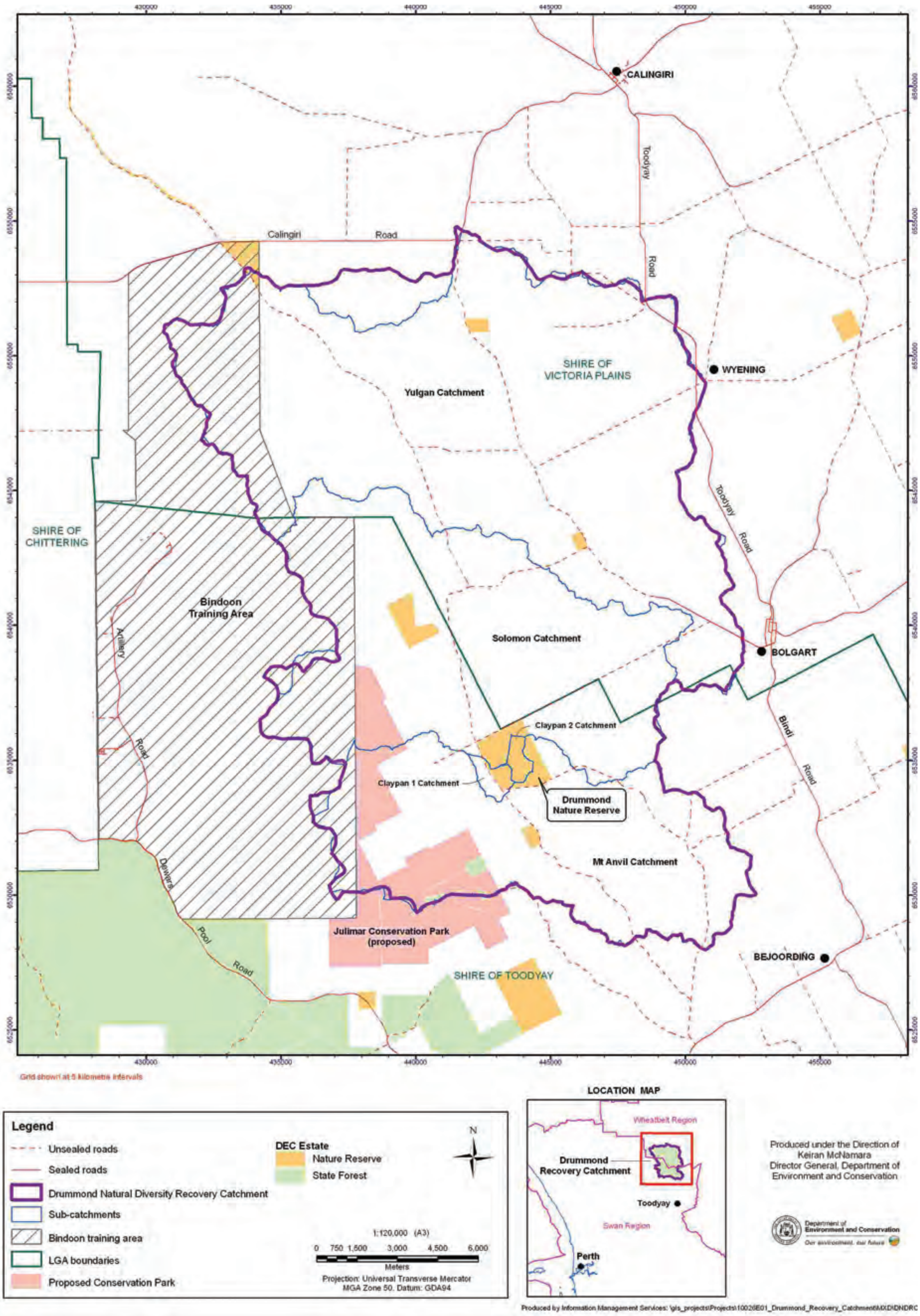
Amber or red lights are at risk of running behind schedule

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Management outputs to address surface and groundwater threats – water balance and salinity impacts on biodiversity assets											
1. Survey and report defining location, extent and conservation significance of assemblages present in DNR.											
2. Prepare a monitoring protocol including hydrology, vegetation and fauna.											
3. Monitoring network in place and maintained.											
4. Report prepared on the spatial distribution and intensity of hydrological threat, which includes management priorities for assets.											
5. EWR report prepared, initially for priority assets, and others if deemed threatened.											
6. Numerical model calibration and sensitivity analysis complete.											
7. Produce a draft water management strategy for DNR.											
8. Produce and implement a plan for revegetation and remnant vegetation protection (on private property) for the area hydrologically relevant to DNR.											
Management outputs to address the impact of climate change on the altered hydrology and biodiversity assets.											
1. Report prepared on palaeoclimatic record of DNR claypans and local catchment scale predictions of the implications of climate variability.											
2. Report assessing the potential future hydrological threat to DNR biodiversity assets from climate variability.											
3. Report prepared describing the predicted climate variability and the implications for the biodiversity assets of DNR.											
4. Develop management responses appropriate to the threats of cyclones, floods and droughts, as analysis is completed, i.e. artificial maintenance schemes or engineering/geotechnical solutions.											

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Management outputs to address impacts of introduced and problem plants and animals, and disease											
1. Outputs will be documented annually as area, or number of infestations, managed during the financial year.	■	■	■	■	■	■	■	■	■	■	■
2. Plan prepared, which reviews existing weed situation, particularly in relation to the assets but also including areas of weed concentration. Plan details ongoing management required to achieve management objectives.	■	■									
3. Update existing plant disease report in 2012 and resurvey every five years.		■					■				
4. Disease protection plan (for decontamination and suppression) prepared and implemented.	■	■									
5. Rabbit damage consistent with neighbour expectations and plant survival in revegetation sites.	■	■	■	■	■	■	■	■	■	■	■
6. Review and action plan, if required.	■	■	■	■	■	■	■	■	■	■	■
Management actions to address threats to biodiversity assets – detrimental regimes of physical disturbance											
1. Firebreaks maintained around DNR to protect assets from unplanned fires and limit the extent of any bushfires.	■	■	■	■	■	■	■	■	■	■	■
2. Report prepared on appropriate fire regimes for assets.	■	■	■	■	■	■					
3. Appropriate fire regimes for each of the assets is maintained and situation monitored.	■	■	■	■	■	■	■	■	■	■	■
Building an appropriate culture											
1. A communication plan developed.	■	■									

Attachment 1

The spatial scale of the Drummond NDRC goal



Acronyms

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
DAFWA	Department of Agriculture and Food Western Australia
DEC	Department of Environment and Conservation
DNDRC	Drummond Natural Diversity Recovery Catchment
DNR	Drummond Nature Reserve
DPaW	Department of Parks and Wildlife
DoW	Department of Water
DYRIM	dynamic river model
EWR	environmental water requirement
GCM	general circulation model
IBRA	interim biogeographic regionalisation for Australia
IOCI	Indian Ocean Climate Initiative
IPCC	Intergovernmental Panel on Climate Change
LASCAM	large-scale catchment model
LISFLOOD	a two-dimensional hydrodynamic model specifically designed to simulate floodplain inundation in a computationally efficient manner over complex topography
NDRC	natural diversity recovery catchment
PEC	priority ecological community
SIF	salinity investment framework
SYCG	Solomon-Yulgan Catchment Group
TAG	technical advisory group

Glossary

activity

A specific task or grouping of tasks which use up resources to produce an output (Department of Environment and Conservation 2007a).

aeolian

Deposited or formed by wind (Macquarie University 2003).

algal bloom

Sudden growth of algae in an aquatic ecosystem, which may be a naturally occurring cycle or may be induced by nutrient enrichment (Department of Environment and Conservation 2007a).

allelopathy

The adverse effect which one plant has on another, caused by the release of chemicals into the soil that suppress the growth of nearby plants (Macquarie University 2003).

alluvial

Unconsolidated terrestrial sediment that has been deposited by flowing water (Speed & Strelein 2004).

ameliorate

To make or become better; improve (Department of Environment and Conservation 2006a).

animal

i) any living or dead member of the kingdom Animalia (other than a human being)

ii) any viable or non-viable progeny, larvae, embryo, egg or sperm of an animal or other part, product or genetic material of an animal from which another animal could be produced

iii) any part of an animal

iv) the carcass of an animal (Department of Environment and Conservation 2006a).

anthropogenic

Of, relating to, or resulting from the influence of human beings (Department of Environment and Conservation 2006a).

aquatic

Living or growing in, on, or near water (usually taken to mean freshwater, as opposed to marine) (Department of Environment and Conservation 2006a).

aquifer

A geological formation or group of formations able to receive, store and transmit significant quantities of water (Department of Environment and Conservation 2007a).

bedrock

The solid unweathered rock (typically ferrous igneous granite or mafic igneous dolerite in the wheatbelt), or parent material which underlies the loose material (regolith), such as soil, sand, clay or gravel (Department of Environment and Conservation 2007a).

biodiversity

The variability among living organisms and the ecosystems and ecological complexes of which those organisms are a part. Includes:

i) diversity within native species and between native species

ii) diversity of ecosystems

iii) diversity of other biodiversity components (Department of Environment and Conservation 2006a).

biodiversity asset

Threatened taxa and ecological communities, significant ecosystems or taxa (Department of Environment and Conservation 2006a).

biogeographic regions

Interim Biogeographic Regionalisation for Australia (IBRA) is a framework for conservation planning and sustainable resource management within a bioregional context. IBRA regions represent a landscape-based approach to classifying the land surface from a range of continental data on environmental attributes, including climate and geomorphology (Department of Environment and Conservation 2006a).

biota

All life, including plants, animals and fungi (Department of Environment and Conservation 2006a).

buffer

In the context of this recovery plan, a buffer is a form of physical barrier, which is used to protect environmentally sensitive biota from threat. For example, a band of remnant vegetation around a wetland may reduce weed incursion, surface water flows, and chemical drift from surrounding land uses (Department of Environment and Conservation 2007a).

catchment

Area of land drained by a river and its tributaries (Department of Environment and Conservation 2006a).

condition

The presence of all appropriate elements and occurrence of all processes at appropriate rates in relation to a specified goal. For example, vegetation in good condition would be expected to have all expected species present and be reproducing at the rate expected under natural conditions (Department of Environment and Conservation 2007a).

conservation

The protection, maintenance, management, restoration and enhancement of the natural environment (Department of Environment and Conservation 2006a).

dieback

A symptom of disease in trees and other vegetation in which the foliage progressively dies from the extremities; commonly referred to with respect to native forests or woodlands. (See *Phytophthora* dieback and *Phytophthora cinnamomi*) (Department of Environment and Conservation 2006a).

dolerite

Fine-grained mafic igneous rock rich in iron and magnesium that occurs as intruded vertical dykes throughout the Yilgarn Craton (Speed & Strelein 2004).

dyke

A planar body of intrusive rock that cuts through the surrounding rock (Speed & Strelein 2004).

ecological community

A natural assemblage of organisms that occurs in a particular type of habitat (Department of Environment and Conservation 2006a).

ecosystem

A dynamic complex of ecological communities and their abiotic environment interacting as a functional unit (Department of Environment and Conservation 2006a).

endemic

Species naturally restricted to a specified region or locality (Department of Environment and Conservation 2006a).

erosion

The process by which the surface of the Earth is worn away by the action of water, glaciers, winds, waves, etc. (Macquarie University 2003).

eutrophication

The enrichment of water by nutrients, such as compounds of nitrogen or phosphorus. It causes an accelerated growth of algae and higher forms of plant life. These consume more oxygen often leading to an oxygen deficit, which can have a major detrimental effect on fish and other aquatic organisms (Department of Environment and Conservation 2007a).

fauna

Animals found in a specific area (Department of Environment and Conservation 2006a).

feral species

A domesticated species that has become wild; for example donkey, camel, horse, pig and goat (Department of Environment and Conservation 2006a).

flora

Plants found in a specific area (Department of Environment and Conservation 2006a).

geomorphology

The scientific study of the landforms on the Earth's surface and of the processes that have fashioned them (Department of Environment and Conservation 2007a).

germplasm

The genetic material, especially its specific molecular and chemical constitution that compromises the inherited qualities of an organism (Department of Environment and Conservation 2007a).

granite

A coarse-grained intrusive igneous rock composed of quartz, feldspar and micas (Speed & Strelein 2004).

groundwater

Water within the saturated zone below the ground (Speed & Strelein 2004).

habitat

The biophysical medium:

i) occupied (continuously, periodically or occasionally) by an organism or group of organisms, or

ii) once occupied (continuously, periodically or occasionally) by an organism or group of organisms, and into which organisms of that kind have the potential to be reintroduced (Department of Environment and Conservation 2006a).

hydraulic conductivity

A measure of the ability of a material to transmit fluid (Speed & Strelein 2004).

hydrogeology

The scientific study of the occurrence and flow of groundwater (Department of Environment and Conservation 2007a).

hydrology

The study of the hydrologic (water) cycle. While it involves aspects of geology, oceanography and meteorology, it emphasises the study of bodies of surface water on land and how they change over time (Department of Environment and Conservation 2007a).

hydroperiod

Cyclical changes to the amount or stage of water. Changes to a hydroperiod may result in increased/decreased time periods of inundation (Department of Environment and Conservation 2007a).

in situ

In its original place (Speed & Strelein 2004).

introduced species

A species occurring in an area outside its historically known natural range as a result of intentional or accidental dispersal by human activities (including exotic organisms and genetically modified organisms) (Department of Environment and Conservation 2006a).

inundation

The process by which the land surface becomes flooded or covered with water. Note that extended periods of inundation may lead to waterlogging (Department of Environment and Conservation 2007a).

invasive species

Species introduced deliberately or unintentionally outside their natural habitats where they have the ability to establish themselves, invade, outcompete natives and take over the new environment (Department of Environment and Conservation 2006a).

invertebrate

Any animal without a backbone (vertebral column) such as insects, squid, snails and worms (Department of Environment and Conservation 2006a).

landscape

A mosaic where the mix of local ecological communities and ecosystems or land uses is repeated in a similar form over a kilometre-wide area. In agricultural areas, a landscape unit that is repeated with a similar pattern of land use, including natural habitats. From a biodiversity perspective, the distances over which significant species occur should govern the upper size limit of a landscape for biodiversity planning (Department of Environment and Conservation 2006a).

macroinvertebrate

Invertebrates (lacking a backbone), which can be seen with the naked eye (Department of Environment and Conservation 2007a).

management action targets

Short-term targets (one to five years), relating mainly to management actions or capacity building. Examples of management action targets include: X hectares of recharge zones within the region to be revegetated by year Y or X km of riparian zone to be fenced and managed for conservation (Natural Resource Management Ministerial Council 2003).

monitoring

The regular gathering and preliminary analysis of information needed for day-to-day management or evaluation. Monitoring activities provide indicative information to track and review the performance of policies, strategies and programs at regular intervals to inform management decision-making. This indicative information must directly relate to the expected outcomes and outputs of the policy, strategy or program. Monitoring provides information on what is occurring and what the program, policy or strategy is achieving (Natural Resource Management Ministerial Council 2003).

monitoring and evaluation framework

A monitoring and evaluation framework structures monitoring and evaluation activities to provide accurate, cost effective and timely performance information for management decision-making. Monitoring and evaluation activities use many of the same data sources, and complement one another in covering the full range of issues affecting the performance of an activity. Because of the differences between the two activities, each requires different management structures and processes (Natural Resource Management Ministerial Council 2003).

native species

A species that is indigenous to Western Australia (Department of Environment and Conservation 2006a).

natural diversity recovery catchment

An area established as part of the Natural Diversity Recovery Catchment program under the State Salinity Strategy to help recover and protect significant natural areas, particularly wetlands, from salinity and waterlogging. Selection is based on a number of criteria, including representative of nature conservation values and the likelihood of recovering and protecting areas from salinity (Department of Environment and Conservation 2006a).

natural resource management

Management of land, water, air and biodiversity resources of the state for the benefit of existing and future generations, and for the maintenance of life support capability of the biosphere. Includes use of natural resources by extractive and mining industries (Department of Environment and Conservation 2006a).

organism

Includes:

i) part of an organism

ii) the reproductive material of an organism

iii) an organism that has died (Department of Environment and Conservation 2006a).

outputs

A specific deliverable or product, which is the result of activity (Department of Environment and Conservation 2007a).

palaeochannel

An ancient fluvial, incised drainage valley that has been in-filled with sediments (Department of Environment and Conservation 2007a).

palaeoclimatic

The study of past climates from the traces left in the geological record (Department of Environment and Conservation 2007a).

pallid

White or pale (Speed & Strelein 2004).

perennial

In relation to vegetation that typically lives for more than two growing seasons. All trees and shrubs are perennial (Department of Environment and Conservation 2007a).

Phytophthora cinnamomi

A soil-borne organism (often referred to as a fungus) belonging to the class Oomycetes or 'water moulds', known to cause root-rot disease in Australian flora species (see dieback) (Department of Environment and Conservation 2006a).

***Phytophthora* dieback**

Death or modification of native vegetation caused by *Phytophthora cinnamomi* (Department of Environment and Conservation 2006a).

plant

i) any living or dead member of the kingdom Plantae

ii) a seed or spore, whether it is viable or non-viable

iii) a part, product or genetic material of a plant from which another plant could be produced

iv) any other part of a plant, that is, not referred to in (ii) or (iii) above; for example, a 'non-reproductive' part (Department of Environment and Conservation 2006a).

Quaternary

The most recent geological period (Macquarie University 2003).

recharge

The downward movement of water that is added to the groundwater system (Department of Environment and Conservation 2007a).

recovery plans

Documents that set out the research and management actions necessary to stop the decline, and support the recovery, of listed threatened species or threatened ecological communities. The aim of a recovery plan is to maximise the long-term survival in the wild of a threatened species or ecological community. Recovery plans are appropriate for species or ecological communities where sufficient information is available to prescribe recovery actions with confidence (Department of Environment and Conservation 2006a).

regolith

The mantle of solid material on top of basement, including soil, alluvium, and material weathered in situ from basement (Speed & Strelein 2004).

saprolite

A soft, earthy and clay-rich, thoroughly decomposed regolith formed in situ by chemical weathering of igneous or metamorphic rocks (Speed & Strelein 2004).

sedimentation

Process of deposition, at or near the Earth's surface, of material derived from pre-existing rock, biogenic sources or precipitated by chemical processes (Department of Environment and Conservation 2007a).

silcrete

A zone rendered hard (indurated) by secondary cementation with amorphous silica (Speed & Strelein 2004).

species

A group of organisms that either:

i) interbreeds to produce fertile offspring

ii) possesses common characteristics derived from a common gene pool, and includes a sub-species (Department of Environment and Conservation 2006a).

species richness

The number of species within a specified area (Department of Environment and Conservation 2006a).

stakeholder

A person, group of people, organisation or government with a share or interest in an issue (Department of Environment and Conservation 2006a).

surficial

Pertaining to or lying on the surface of the Earth. Surficial geology is the study of surficial deposits including soils.

sustainability

Meeting the needs of current and future generations through an integration of environmental protection, social advancement and economic prosperity (Department of Environment and Conservation 2006a).

taxon (taxa pl.)

A group or category, at any level, in a system for classifying organisms (Department of Environment and Conservation 2006a).

threatened ecological community

An ecological community that is threatened by destruction and is formally listed as vulnerable, endangered, critically endangered or presumed destroyed (Department of Environment and Conservation 2006a).

threatening process

A biophysical process which can impact on biodiversity assets and prevent achievement of a specific conservation goal (Department of Environment and Conservation 2007a).

viroid

An infectious particle, similar to but smaller than a virus, that consists solely of a strand of RNA (ribonucleic acid) and is capable of causing disease (Department of Environment and Conservation 2007a).

water balance

Accounting for all water inputs and all water outputs within a system (Department of Environment and Conservation 2007a).

weathered

The breakdown of rocks and minerals at and below the Earth's surface by the action of physical and chemical processes (Department of Environment and Conservation 2007a).

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