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NQ DRY TROPICS

Collinson's Lagoon

System Management Plan

Version1

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> List of abbreviations

BBIFMAC	Burdekin Bowen Integrated Floodplain Management Advisory Committee
BHWSS	Burdekin Haughton Water Supply Scheme
BMP	Best Management Practices
BOD	Biological Oxygen Demand
BSC	Burdekin Shire Council
CAP	Conservation Action Planning
DIWA	Directory of Important Wetlands in Australia
EVNT	Endangered, Vulnerable and Near Threatened
DO	Dissolved Oxygen
ICM	Integrated Catchment Management
JCU	James Cook University
LBW	Lower Burdekin Water
NRM	Natural Resource Management
RMA	Riparian Management Agreement
SMP	System Management Plan
TSS	Total Suspended Solids

> Executive summary

Econcern was contracted by NQ Dry Tropics in late 2021 to develop System Management Plans (SMPs) for five high value wetland systems located on the Lower Burdekin River floodplain, approximately 50km south of Townsville, North Queensland. The development of these SMPs forms part of the Restoring the Bowling Green Bay Ramsar Wetlands project, funded by the Australian Government's National Landcare Program. These SMPs aim to improve environmental management outcomes in floodplain tributary and distributary creek systems that comprise the Cape Bowling Green Bay Ramsar wetland catchment. This current round of SMP development follows the initial SMP prepared by Econcern for the Lower Burdekin floodplain's Sheep Station Creek catchment in 2020 (Econcern 2021). This catchment was the first focus because it had the longest history of environmental management investment of any Lower Burdekin wetland system. This history has provided much learning and delivered a range of innovative management outcomes. Many of the management issues identified in the Sheep Station SMP are generic to the broader Lower Burdekin floodplain and, in the interest of document brevity, this initial SMP is referenced substantially in subsequent SMPs, including this document. However, as detailed in this SMP for Collinson's Lagoon system, there are a range of distinct environmental management challenges associated with the unique landscape, hydrological setting, and development history of any individual wetland system. These factors need to be recognised in any prudent extension of wetland management planning strategies from one system to adjoining areas.

The main part of the Collinson's Lagoon system is 1.3km long and up to 120m wide, and occurs within a prior channel of Sheep Station Creek, which is an overbank distributary of the Burdekin River. The floodplain catchment of 9400ha is 23km long and drains to a confluence with East Barratta Creek. Most of the catchment is irrigated cane land, including the upper catchment within the Burdekin Haughton Water Supply Scheme (BHWSS) area. The drainage network consists of scheme tailwater drains, large constructed drains through remnant floodplain habitat, excavated modified stream channel, lagoons and coastal drainage depressions. The northern, lower catchment is used for beef cattle grazing. The system's hydrology is highly modified by irrigation scheme tailwater inflows. It has state significant biodiversity values, including ecologically significant wetlands, a corridor network of remnant floodplain and riparian habitat, 'of concern regional ecosystems', and Endangered, Vulnerable and Near Threatened (EVNT) fauna records. The most significant ongoing threats to the condition of the Collinson's Lagoon system are altered hydrology, associated aquatic weed infestation, a hot fire regime associated with ungrazed exotic pasture grasses, and woody weeds.

This management plan has been developed for natural resource managers and stakeholders associated with natural resource management on the Lower Burdekin floodplain. These include riparian landholders, mostly cane farmers; BHWSS operator Sunwater; local government (Burdekin Shire Council); Traditional Owners (represented by Gudjuda Reference Group Aboriginal Corporation); and the broader community, including community-based interest and natural resource management (NRM) groups such as Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC), Lower Burdekin Landcare, and NQ Dry Tropics.

Over the past two decades these stakeholders have been involved in a range of innovative environmental management initiatives that have improved the condition of floodplain wetland systems in the region. Actions have included the use of weed harvesters and excavators to remove neglected aquatic weed infestations, the development of cost-shared weed control programs instituted through Riparian Management Agreements (RMAs), and multiple riparian revegetation programs. At the time, these initiatives were truly innovative in the sense they had not been done before in the seasonal dry tropics, or – in the case of RMAs – Australia. Environmental management in the Collinson's Lagoon system has included an RMA that has funded ongoing aquatic weed control, returning it from a state of 'weed choked' and near ecological collapse, to open ecosystem health. These management efforts have involved weed harvesters, raking excavators, boat, and helicopter-based spraying programs. The main lagoon's remnant habitat has been fenced and control-grazed for a decade to reduce hot fire risks, and a woody weed control program has also improved the condition. Further, Sunwater maintains an excavated channel flow path through a modified stream channel in the southwest of the main lagoon's remnant habitat complex.

This plan was prepared following site field work and consultation with landholders and other management stakeholders between November and December 2021, and in February 2022. Through this field work, a literature review, and targeted stakeholder engagement, it was possible to identify system asset values, threats to these assets, and management strategies and nominated works to address threats. The condition of riparian zone vegetation was also mapped and a management planning map covering the system was prepared. This management plan examines the management needs of the wetland system under 10 issue areas covering:

1. Altered hydrology;
2. Aquatic weeds;
3. Water quality;
4. Fish passage barriers;
5. Lack of riparian vegetation;
6. Woody weeds;
7. Fire regime;
8. Grazing regime;
9. Critical habitat loss, and
10. Climate stress.

While each issue is examined separately in terms of management needs and opportunities, the relationship and interaction between issues is also identified where relevant to support integrated management recommendations and solutions. Implementation of this plan's recommendations depends entirely on voluntary adoption by relevant management stakeholders and the availability of sufficient resources to facilitate them.

> Background

Cape Bowling Green Bay Ramsar wetland

Ramsar wetlands are recognised as wetlands of international importance and listed under the Ramsar convention. These are wetlands that are representative, rare or unique, or are important for conserving biological diversity. Australia currently has 65 Ramsar wetlands covering some 8.3 million hectares. Five are in Queensland, including the coastal Cape Bowling Green Bay in the Lower Burdekin. As a signatory to the Ramsar convention, the Australian Government has a legal responsibility to ensure for the wise use and conservation of Ramsar wetlands. To this end, NQ Dry Tropics has been funded by the Australian Government's National Landcare Program to restore high value wetland systems in the catchment of the Cape Bowling Green Bay Ramsar wetland. To approach this task strategically, an SMP was initially developed for an individual floodplain distributary stream that drains to the Ramsar site: Sheep Station Creek (Econcern 2021). Examining environmental management arrangements for this one entire creek catchment generated a useful SMP template that has since been applied, with some site-specific adjustment, to adjoining floodplain tributaries and distributaries comprising the Cape Bowling Green Bay catchment. This SMP has been developed for Collinson's Lagoon system.

Lower Burdekin floodplain – identifying assets and threats

This wetland SMP uses terminology and methodology aligned with Conservation Action Planning (CAP), more broadly applied by NQ Dry Tropics within its natural resource management region. In essence, a CAP seeks to identify the 'assets' within a given planning region, identify 'threats' to these assets, and develop strategies which may serve to reduce the threats to assets. Assets fall within a range of non-mutually exclusive categories including:

- Environmental;
- Economic;
- Social, and
- Cultural assets.

In seeking to serve the improved environmental management of the catchment of the coastal Ramsar wetland, this SMP is primarily focussed on environmental assets. However, the greater dimension of environmental assets needs to be considered and promoted in presenting the case for their conservation. For example, a healthy wetland system has recognised environmental value. Where this same wetland provides for nature-based recreation such as birdwatching or fishing, it also holds social value. If fish populations supported by the wetland include commercially-targeted species, it also holds economic value. If the site is of significance to Traditional Owners, or the history of non-Indigenous Australians, it also has cultural value.

While some asset values are complementary, they can also sometimes be in competition. For example, the developed irrigation water supply systems of the Lower Burdekin floodplain are very important economic assets that have delivered employment and economic benefit to the regional community. They have, however, often come at a cost to the health of wetland systems impacted by the consequent modification of floodplain hydrological regimes that has accompanied irrigation development. Other examples of value conflict can occur where appreciation of the recreational values of a wetland, for instance, four-wheel driving, may conflict with the conservation of sensitive biodiversity, or where a pasture species favoured as an asset for pastoral production acts as an invasive weed in wetland habitats. Ultimately, it is for society's social, political, and legal systems to determine which values are managed within a regional landscape. This SMP seeks to identify best management practice for identified environmental assets, while recognising that such management aspirations need to operate within a broader economic, social, and cultural context.

System Management Plan – scope and purpose

This SMP has been commissioned by NQ Dry Tropics to provide a blueprint for improved environmental management of the targeted wetland system. In doing so, it aims to support improved management and protection of the environmental assets of the Cape Bowling Green Bay Ramsar wetland on the coastal margin of the targeted system. The SMP's scope includes the ecological assets of the targeted wetland system, and the biophysical condition, processes and management arrangements within the system's catchment area that may ultimately impact wetland condition.

This SMP aims to provide a 'go to' document for investment in the management of high value Burdekin floodplain wetlands. Recognising the vagaries of environmental management funding and the consequent often reactive nature of program investment, it provides a proactive planning tool that can direct management funding when it becomes available toward already defined priorities. It also acts as a prospectus for those seeking to pursue funding applications or sponsor environmental management. Further, this SMP seeks to document historical wetland management gains, the implementation issues surrounding them, and provide recommendations on how to better address outstanding environmental management challenges facing the contemporary wetland system.

The SMP's intended audience is the range of natural resource management stakeholders associated with the Lower Burdekin floodplain. These include riparian landholders, most of which are cane farmers; BHWSS operator Sunwater; local government (Burdekin Shire Council); catchment heavy industry (such as Wilmar); Traditional Owners (represented by Gudjuda Reference Group Aboriginal Corporation); and the broader community, including community-based interest and NRM groups such as BBIFMAC, Lower Burdekin Landcare, and NQ Dry Tropics.

Over the past two decades these stakeholders have been involved in innovative management initiatives that have improved the condition of wetlands that were considered highly degraded in the early 2000s back to relatively healthy, though modified, aquatic ecosystems today (Econcern 2021). Innovative management approaches implemented have included using weed harvesters and excavators to remove neglected aquatic weed infestations; developing a cost-shared aquatic weed control programs instituted through RMAs; fish passage provision around instream infrastructure, and reach-scale riparian revegetation programs. At the time, these initiatives were truly innovative in the sense that they were novel approaches for the seasonal dry tropics, or – in the case of RMAs – were Australian-firsts.

Implementation of this plan's recommendations depends entirely on their voluntary adoption by landholders and other relevant management stakeholders and the availability of sufficient funding and material resources to facilitate it.

Collinson's Lagoon system overview

Location and geomorphic setting

The Collinson's Lagoon system is located approximately 11km west of the township of Ayr, and 73km south of Townsville in the Lower Burdekin region. The system has about 9400ha of contributing catchment area, which is mainly floodplain that has been levelled and intensively developed into irrigated cane land. The contributing catchment is nested within the larger Barratta Creek sub-catchment of the defined Haughton River basin in an area that functionally forms part of the Burdekin River floodplain during floodplain-inundating high flows. The main named lagoon is 1.3km long and up to 120m wide and represents a prior channel and current high flow distributary channel of the adjoining Sheep Station Creek system, which is itself a distributary of the Burdekin River. Two other prior channels of Sheep Station Creek drain to the lower system from near the Ayr Airport and the Pioneer Sugar Mill, and form the easternmost sub-catchments of the system. Within the overall system there are up to 10 other lagoons or definable waterbodies, including back levee swamps, 'blocked valley basins', and oxbows hosted within a range of channel settings.

Figure 1. Collinson's Lagoon catchment (highlighted in white) relative to the Cape Bowling Green Bay Ramsar wetland site (green line), and relative to Brandon and the Burdekin River (right).

There is about 8km of modified stream channel, extending upstream from a confluence at the downstream end of the main lagoon, and a further 6.2km of coastal drainage depressions hosting shallow lagoons. This extends downstream from the main lagoon through Lochinvar Station to a confluence with the East Barratta Creek channel, which is on marine plains just upstream of tidal influence. Upstream of the modified stream tributary, there is a further 6.8km of large (20m wide) constructed areal tailwater drainage channel through remnant floodplain vegetation. This area historically contained drainage depressions and 'floodout' wetlands characterised by gilgai or 'melon hole' landforms. Upstream of the large constructed areal drains, there is a further 6.5km of tailwater drain mainstem to the contributing catchment boundary, draining irrigated farmland.

Hydrology – natural and modified

Like all wetlands in the seasonal dry tropics, the natural hydrology of the system was highly seasonal and related to the timing and magnitude of the annual wet season. The dominant influence on the dry season hydrology of the contemporary Collinson's Lagoon system is aseasonal inflows of supply channel overflow and irrigation tailwater from the BHWSS area and adjoining farmland. These inflows override the historically seasonal characteristics of the system and are a major driver of its water quality and other related factors impacting its condition, such as aquatic weed infestation. Wet season hydrology remains an important contributor to site geomorphology and habitat resetting. It includes floodplain catchment runoff, which has been increased by levelling for farm development, and constructed high-capacity drains that transect floodplain drainage depressions, historically acting as runoff detention areas. During large floodplain inundation events overbank distributary flood breakouts from the Burdekin River distributed via Sheep Station Creek, or further upstream breakout points, are also conveyed through the system. During high flood flows, or even low base flows, backflows can also enter the lower system from the East Barratta Creek confluence. Much of the system's catchment is also underlain by shallow sand-bedded alluvial aquifers of varying confinement that interact with surface water features, such as lagoons, and significant areas of this groundwater system have been subject to irrigation-driven groundwater rise in recent decades.

Land use, tenure, and remnant vegetation

Most of the system and its catchment is freehold land. Other tenures include the main lagoon system from Bruce Highway upstream to Rose Road, which is Crown watercourse; and the western tributary branch of the main lagoon system, which is leasehold. Sunwater-managed drainage easements also extend along the modified stream channel reach through freehold land south from Rose Road to Sayers Road, and separate easements cover major tributary branches of the easternmost sub-catchments of the system. Land use within the system's catchment is dominated by irrigated sugarcane agriculture. The north-western downstream portion of the catchment falls within Lochinvar Station and is used for beef cattle grazing. Remnant vegetation on Sunwater land has been nominally retained for nature conservation, and some is also leased for grazing. The highest integrity remnant vegetation within the system occurs within the BHWSS on Sunwater leasehold land and within the freehold/leasehold component of the main Collinson's Lagoon remnant habitat complex. The former includes high value floodplain vegetation (open woodland and rare swamp forest on gilgai soils), and the latter encompasses closed paperbark forest. Most remnant riparian vegetation adjoining the main lagoon system and within the complex of remnant native vegetation on freehold land between Sayers Road and Rose Road is partially cleared or otherwise disturbed. Highly disturbed riparian and coastal floodplain remnants also occur along the grazed drainage depressions and lagoons through Lochinvar Station. Native aquatic plant (macrophyte) community integrity is greatest within the system's main lagoon, which is off the direct flow path of aseasonal flows. This higher integrity is also found in more readily-grazed waterbodies within Lochinvar Station, and small seasonal waterbodies within Sunwater-owned floodplain remnants.

Key assets and values

The Collinson's Lagoon system has high ecological values due to it being a large, connected, floodplain remnant habitat complex that drains to a large coastal wetland system. It has high bird and fish habitat values, including a playing a role as a nursery for first-year class barramundi. The system also supports good populations of barramundi, two species of crocodile, and several turtle and waterbird species. Collinson's Lagoon also retains rare floodplain vegetation types and wetland assemblages that are otherwise poorly represented in the post-settlement landscape, for example, closed paperbark swamp forest on gilgai soils and open grassland seasonal swamps. The system also forms part of a regionally important cross-floodplain (Haughton – Burdekin River) wildlife corridor linkage. Further, its woodland and forest assemblages provide habitat for a range of disturbance-sensitive species, including arboreal mammals, owls and raptors, and other fauna including reptiles and macropods. Past sightings of koala are recorded for the catchment. Several of its lagoons and palustrine wetlands off the main drainage system retain good native aquatic plant (macrophyte) assemblages, and water quality conditions are more representative of natural conditions. The entire system is also an interface between intensive production landscapes and the receiving Cape Bowling Green Bay National Park and Ramsar wetland site, with the Collinson's Lagoon complex providing a range of ecosystem services, including water quantity (detention) and quality treatment functions, primary production, and biotic connections.

Historical and current management

The Collinson's Lagoon system has been included in a range of past and ongoing environmental management initiatives. Riparian Management Agreements (RMAs) were established between riparian landholders, Burdekin Shire Council (BSC), NQ Dry Tropics and Sunwater to fund sustained aquatic weed control on the main lagoon system. These efforts were successful in returning these waterbodies from a 'weed choked' state, near ecological collapse, to open ecosystem health. Previous management has used weed harvesters and weed raking excavators with boat and helicopter-based weed spraying programs, primarily to target water hyacinth and also for the aquatic grass hymenachne. The riparian zone and remnant habitat associated with the main lagoon system has been fenced and has been subject to controlled grazing for over a decade to reduce the hot fire risk associated with ungrazed exotic pasture grasses. These grazing actions, along with woody weed (chinee apple) control programs, has resulted in improved condition of the remnant riparian forest. Sunwater also maintains an excavated channel flow path for BHWSS tailwater flows through the modified stream channel within the freehold drainage easement in the south-west of the main lagoon's remnant habitat complex.

Ongoing threats, management challenges

The most significant ongoing threats to the condition of the Collinson's Lagoon system is altered hydrology, associated aquatic weed infestation, a hot fire regime associated with ungrazed exotic pasture grasses and woody weeds. The primary driver of altered hydrology is aseasonal inflows of irrigation scheme tailwater, including supply channel overflows, from the Sunwater-operated BHWSS in the upper catchment. Impacts include a loss of seasonality via reduced dry season water level drawdown, and the associated proliferation of floating aquatic weeds and aquatic grasses, like hymenachne, para, aleman, that impact native aquatic plant communities and water quality. Water quality impacts associated with BHWSS inflows and weed proliferation include sustained turbidity, elevated nutrients, organic loading, and dissolved oxygen depletion. Salinity levels in the lower coastal wetland complex are also suppressed by sustained freshwater inflows, which impacts brackish aquatic plant communities and habitat values. Other hydrological impacts are associated with the constructed drainage network that has alienated natural wetland detention areas and delivers runoff and contaminant loads more directly to the lower system. Aquatic weed infestations, both floating and aquatic grasses, occur throughout the system in response to its modified hydrology. These weeds generate secondary fish passage barriers by creating anoxic (oxygen depleted) reaches that are only passable during high flow events. Aquatic weed infestations also reduce flow through the system and increase sedimentation in affected basins. This condition creates blocked flow path flood risks, which are exacerbated where mobilised aquatic weed mats accumulate against riparian vegetation and built infrastructure; the latter sometimes resulting in infrastructural damage.

Where lagoon riparian zones and floodplain vegetation is ungrazed, hot fire risks continue to be realised, degrading the condition, and diminishing the extent of remnant overstory vegetation. Where unshaded lagoon margins result, water quality is further impacted by elevated temperatures that reduce the water's dissolved oxygen carrying capacity. Woody weed infestation is also an ongoing management challenge both within riparian zones, in the case of rubber vine, parkinsonia, neem, and remnant floodplain vegetation, with chinee apple infestation. Clearing and other methods of woody weed control presents risks to the condition of remnant floodplain vegetation, and – along with other condition impacts, like hot fires and land use intensification – presents longer term risks to its viability as wildlife habitat and functional corridors. Over the longer term, irrigation-driven groundwater rise is another emerging threat to riparian and remnant vegetation which could ultimately result in soil waterlogging and salinisation in areas of the system's catchment. Proposals to draw-down groundwater levels using dewatering bores (Sunwater pers. comm.) also present a new suite of potential water quality and hydrological impact risks.

> Methods – assessment and reporting

Stakeholder consultation

Stakeholder consultation for the preparation of this management plan was undertaken during November to December 2021 and February 2022 and involved:

- on-site consultation with riparian landholders distributed through the wetland system;
- meetings with representatives from community organisations involved in project work within the targeted wetland system, including Lower Burdekin Landcare, BBIFMAC and NQ Dry Tropics;
- consultative meeting with Sunwater;
- meeting with BSC managers and operational staff involved in overseeing the aquatic weed control program service delivery; and
- informal engagement with researchers from research and development (R&D) providers that have worked across the Lower Burdekin floodplain, primarily at TropWater, James Cook University (JCU).

For each interviewed landholder, engagement involved non-structured questioning about impressions of the environmental status of the creek; opinion of the adequacy of existing management arrangements; suggestions for additional or improved management approaches, and willingness and/or nominated preferences for conducting various on-ground environmental management works on the landholders' riparian landholdings. The latter are captured as 'nominated works' in Appendix 1 and presented on catchment management plan sheets (Appendix 2).

Literature review

Literature reviewed for preparation of this plan was sourced from 'grey literature' associated with previous NRM management plans, strategies, and consultant reports from the Lower Burdekin, plus formal scientific journal papers covering topics usually directly related to the Lower Burdekin floodplain study area. A range of information was also sourced online from Queensland Government agency sites including Queensland Globe (https://qldglobe.information.qld.gov.au/), Wetland Info (https://wetlandinfo.des.qld.gov.au/wetlands/), and DES regional ecosystem descriptions (https://apps.des.qld.gov.au/regional-ecosystems/).

Field work

Most field work was conducted in conjunction with landholders. Once site access permission was granted by landholders, some sites were subsequently revisited to gain additional information. Information was collected primarily by noted observation and digital images and included details about: riparian vegetation condition, weed infestation status, evidence of fire history, status of revegetation sites, potential fish passage barriers, water infrastructure, habitat values, incidental records of flora or fauna, observations of land degradation, and potential works sites. During the field work, a drone was also used to get aerial imagery of the high conservation value forested wetlands on gilgai soils within the BHWSS remnant habitat corridor network (Photo 53 and 54), and of the excavator-maintained creek channel reaches in the drainage easement downstream of Sayers Road (Photo 37 and 38). This imagery was useful for examining the hydrological impacts associated with circumventing the forested wetlands with a large tailwater drain (RB1), and for considering the potential for revegetation to reduce the need for grass weed excavation within the drainage easement.

Management planning mapping

Maps of riparian vegetation condition were produced to inform environmental management planning for the wetland system (Appendix 2). These were generated by using a computer-based geographic information system (ArcGIS) to draw lines (polygons) around features on digital aerial images that depicted different classes of riparian vegetation condition. Eleven classes of riparian condition were defined including overstorey vegetation, grasses, and within channel aquatic classes. These are below and in Appendix 2:

1. Remnant vegetation.
2. Degraded remnant.
3. Revegetated.
4. Exotic trees.
5. Grassland.
6. Exotic grasses.
7. Cumbungi.
8. Open water.
9. Native aquatic plant-covered water.
10. Floating aquatic weed-covered water.
11. Water with emergent aquatic plants.

Mapping system reaches into these riparian condition classes provides a basis for:

- examining the overall and relative ecological condition of the wetland system;
- identifying system-scale drivers of ecological degradation;
- developing generic management recommendations for reaches dominated by condition types;
- defining strategic priorities for restoration and protective management; and
- a timeline baseline to compare with future creek condition states.

In addition to riparian vegetation condition, GPS-reference points collected in the field for reach asset values, management issues and nominated works are also displayed on the management plan maps (Appendix 2).

> Summary system assets, threats, and nominated management strategies/works

System assets, threat management issues, and nominated works compiled during the development of this SMP are tabulated in Appendix 1 and presented on management planning maps (Appendix 2). They are described and summarised below.

Assets

These are ecological values associated with the wetland and/or adjoining riparian ecosystem that are significant at scales beyond this site alone. They are underpinned by criteria such as productivity, biological diversity, habitat connectivity, representativeness, and habitat provision that serve fish and wildlife populations and nature conservation objectives at reach, catchment, regional, state or even national scales.

The main ecological asset values identified for the Collinson's Lagoon system include:

- Large area of intact remnant floodplain, woodland and wetland vegetation retained within a habitat corridor and node network of the BHWSS area that links across the floodplain from the Haughton to Burdekin rivers. This area contains matters of state environmental significance, for example, an 'of concern' regional ecosystem and habitat for EVNT wildlife species, has records for listed vulnerable bird species, and good populations of arboreal mammals and macropods, reptiles, and amphibians.

- A series of deep-water perennial lagoons that host relatively diverse fish populations including migratory species such as barramundi, crocodiles, waterbird, and woodland birds. This includes a large lagoon which retains native water lily communities and clear water quality.

- High value remnant riparian and floodplain vegetation remnants that have high diversity and structural complexity that provides habitat for a diversity of aquatic and terrestrial fauna including crocodiles, freshwater turtles, other reptiles, migratory fish and passerines, and other woodland birds, owls, raptors, and bats.

- A diverse range of bird habitats and populations covering numerous group types, from woodland and grassland species to migratory passerines, owls, raptors, waterbirds, and waterfowl.

- A bunded coastal drainage depression wetland complex that contains wetlands of state significance, provides fishery nursery habitat, and supports vulnerable estuarine crocodiles.

- An interface wetland system between intensive production and protected landscapes, including the Ramsar wetland. The system provides a range of ecosystem services to the downstream receiving environment, including water quality processing, primary production and flows of materials and biota.

- A high-profile aesthetic wetland adjoining national road corridor Bruce Highway, which contains state land and provides opportunities for management demonstration sites and public use and appreciation.

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Threats/management issues

System management issues include aquatic and riparian zone threat management concerns that are characteristic of a wetland reach or specific to it. They also include threat management issues that occur at more than one site within the wetland system, and are well demonstrated by a particular reach example. Some identified threat management issues have impacts that affect the wetland ecosystem at a catchment scale.

The main system management issues for the Collinson's Lagoon system include:

- Aseasonal inflows of irrigation scheme (BHWSS) tailwater that has generated both altered hydrology and impacted the water quality of the receiving Collinson's Lagoon system. Water quality is compromised via turbidity and nutrient loading, and by maintaining artificially high-water levels, which promotes floating and aquatic grass weed growth and generates aseasonal seepage into coastal drainage depressions downstream of the Bruce Highway.

- Cyclical infestations of floating and aquatic grass weeds that represent a symptom of the altered hydrology and water quality of the system. These form channel-blocking weed chokes and, under current control approaches, perpetuate water quality (low dissolved oxygen, high nutrients) and weed infestation risks.

- Poor riparian vegetation condition or extent along entire reaches or sub-catchment drainage systems, often in conjunction with dense cumbungi bullrush infestations.

- Riparian vegetation-damaging hot fire regimes associated with burns conducted late in the dry season in habitat settings with large fire fuel loads, generated by an ungrazed exotic pasture grass understory.

- An extensive woody weed infestation (chinee apple) through the middle reaches of the main system and eastern sub-catchment.

- Incremental land use intensification that results in the loss of remnant habitat condition and connectivity.

Nominated works

This is a non-exhaustive list of wetland system asset threat management strategies or works that were identified over the course of project field work, or subsequently during desktop-based assessment. They are proposals only and implementation is subject to landholder endorsement, funding resourcing, appropriate agency approvals where required, and further landholder and management stakeholder engagement.

Nominated works for the Collinson's Lagoon system include:

- Prevent or reduce aseasonal inflows of BHWSS tailwater to and through the system to reinstate the seasonal hydrological character (dry season water level drawdown) to the lagoons and lower coastal system. Also, help mitigate hydrology and water quality impacts associated with aseasonal inflows. Management options include:
    - Reduce the supply channel overflow volumes;
    - Reduce tailwater volumes from individual farms, and
    - Promote off-stream reuse of tailwater volumes.
- Conduct a major riparian revegetation program for the entire bank margin of the large lagoon, western drainage channel, and depositional reach of the drainage easement lagoon within the main Collinson's Lagoon system.
- Trial a large woody debris and snag placement program along a section of the bank in the main Collinson's Lagoon, and monitor its use by wetland fauna, including birds, reptiles, and fish to assess the merit of potential broader adoption.
- Extend the controlled grazing program associated with the main Collinson's Lagoon system to additional lagoon frontage areas, for instance, the central land peninsula and western seasonal wetland basin. Include a high-water refuge for cattle within the fenced area.
- Trial a catchment-based line of control 'partial-eradication' approach for targeted floating aquatic weed species (water hyacinth, water lettuce) within the RMA area of the lagoon system.
- Reinstate weed harvester and excavator-mounted rake clearing of surface weed mats and chokes on an annual to biannual frequency. This will help to clear created fish passage barriers, and reduce associated water quality risks and floating aquatic weed reinfestation refuges.
- Investigate and develop an enhanced 'water quality treatment train' design and operational procedures for Wilmar's stormwater settlement pond within the Pioneer Mill sub-catchment of the eastern catchment.
- Undertake selective woody weed control and protective management arrangements for high value riparian and floodplain remnant habitats on private land within the system's mid reaches.
- Develop and implement an environmental management plan addressing woody weed control, controlled grazing, and burning for the wetland and woodland habitat remnant within the eastern Pioneer Mill sub catchment.
- Develop and implement an integrated habitat rehabilitation program involving cumbungi excavation, controlled grazing and burning, and regeneration and revegetation for riparian areas within the distributary channel of the Hoey Road sub-catchment within the eastern catchment.
- Trial alternative in-channel vegetation management within a section of BHWSS tailwater drain for delivering improved water quality and wetland functional value outcomes.
- Apply enhanced integrated management efforts to treating exotic aquatic grass margins on lagoons, including enhanced and more seasonally-targeted application of controlled grazing; a commitment to the integrated use of spraying and burning; and strategic revegetation of lagoon margins with shade-generating tree canopies.
- Establish wallaby fencing between remnant vegetation areas harbouring large wallaby populations and adjoining cane production areas subject to high levels of wallaby grazing.
- Develop suitable site-scale riparian and fish habitat 'refuge' works to implement within the grazing production landscape of the lower system's bunded drainage depression wetland complex.
- Conduct an integrated wet season fish movement and water quality monitoring program to gain better understanding of fish passage connectivity and the significance of potential habitat and water quality constraints.
- Develop a greater capacity for using controlled burning for habitat and weed management within the system, including conducting burns within the distributary channel of the Hoey Road sub-catchment;

the main Collinson's Lagoon habitat remnants; and within BHWSS remnant floodplain vegetation corridors.

- Develop the capacity to conduct terrestrial fauna surveys through the system's remnant habitat areas, and employ wildlife ecologists, undergraduate students, or citizen scientists where suitable.
- Engage private landholders in protective management arrangements for high value habitat remnants within the context of a regional wildlife corridor and nature conservation strategy.
- Engage management stakeholders to establish formal nature conservation management arrangements for the retained remnant floodplain habitat corridor and node network within the BHWSS.

> System management plan, key threats to assets and recommended management strategies

Wetland system catchments are perhaps one of the most readily-identified examples of an integrated system. In other words, changes in the condition of one component of the system influences and impacts the status of other components. When considering the management of a wetland system, the Integrated Catchment Management (ICM) approach developed in Queensland in the 1990s (DPI 1993) still offers one of the most useful frameworks for considering how management initiatives across a range of issues serve to deliver benefits for the system as a whole.

Based on consultation with management stakeholders, a literature review and field investigations, the following 10 threat management issues are identified as important to the ecological health of the Collinson's Lagoon system. These are:

1. Altered hydrology;
2. Aquatic weeds;
3. Water quality;
4. Fish passage barriers;
5. Lack of riparian vegetation;
6. Woody weeds;
7. Fire regime;
8. Grazing regime;
9. Critical habitat loss, and
10. Climate stress.

While each issue is examined separately in terms of threat management needs and opportunities, the relationship and interaction between issues is also identified where relevant to support integrated management recommendations and solutions. One example of a threat that operates across nearly all other threat management issues is the emerging impact of climate change, which has a demonstrated capacity to exacerbate existing environmental stress.

Altered hydrology

Types and impacts

The natural hydrology and associated ecology of wetlands within the seasonal dry tropics, including those of the Lower Burdekin floodplain, is highly seasonal and related to the timing and magnitude of the annual wet season. The key drivers and stimuli for biophysical processes that determine the ecological character of the Lower Burdekin's natural floodplain wetlands include elements such as annual inundation in response to wet season rainfall, connection to floodplain distributary channel flows, the subsequent cessation of flow, waterhole isolation, and water level drawdown through the dry season, sometimes to complete drying. These seasonal events provide for germination of aquatic plants; reproduction, movement, and recruitment of fish populations; nesting, and breeding of waterfowl; flushing of organic matter, scouring, and habitat resetting within drainage channels; seasonal changes in water quality, and processing and assimilation of catchment nutrient loads.

In the contemporary, modified floodplain system, the hydrology of most freshwater wetlands, including most stream networks, is influenced by irrigated farm and/or irrigation scheme development within contributing catchment areas. Irrigation tailwater, including supply channel overflow from Sunwater's owned and operated BHWSS or individual farms, drain to low lying areas that host wetlands. Often, in the case of the BHWSS, this is via large, constructed drains. Within both the Burdekin Delta and floodplain, distributary stream channels are used by both Sunwater and Lower Burdekin Water (LBW) operations to convey water pumped from main rivers (Haughton, Burdekin) to deliver surface water for irrigators and to recharge shallow groundwater aquifers. Across large areas of the BHWSS, irrigation-driven groundwater rise has also occurred (Figure 1) to the extent that some water tables now discharge to surface drainage networks. Elevated groundwater is also suspected of directly impacting the condition of native vegetation, including riparian zones in some areas of the floodplain.

Photo 1. Sunwater tailwater drain (RB1, RB1/0) sources of aseasonal inflows to Collinson's Lagoon system. Note water colour upstream (clear black offline from tailwater) versus downstream (turbid brown online to tailwater) lagoons.

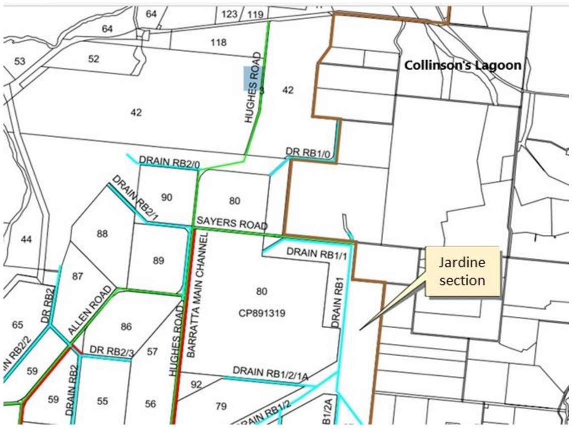


Photo 2. Sunwater BHWSS infrastructure, Collinson's Lagoon catchment.

The collective impact of irrigation tailwater, supply channel overflow, pumped flows, and elevated groundwater discharge is that historically-seasonal floodplain stream systems such as Ironbark, Barratta, Collinson's, Sheep Station, Plantation, Kalamia, and Saltwater creeks, and many smaller unnamed distributary streams, are now perennial or semi-perennial. This means they maintain connective flows, or seepage, between wetland waterbodies that were historically isolated, or even dried during the dry season. These aseasonal inflows contribute to a reduction in dry season drawdown of lagoon water levels and altered water quality (higher turbidity and nutrient loading). This altered hydrology and water quality has generated major changes to wetland aquatic plant communities, increasing the abundance of fringing exotic aquatic grasses and floating weeds; decreasing the abundance of native water lilies, submerged aquatic plants (where turbidity is high), sedges, and other emergent aquatic plants; and impacting associated habitat values for wetland fauna, including birds, reptiles, and fish. The colonisation of historically drying, but now saturated, distributary channels by impenetrable stands of cumbungi bullrush has also impacted system water quality, fish passage, and hydraulic capacity, in addition to habitat values. A positive habitat impact associated with increased stream perennially has been the development of denser and more diverse riparian overstory vegetation zones along some previously seasonal creek systems. Some stakeholders have expressed concerns that this also represents a flow capacity impact, though comparisons with unshaded, weed-filled channels have not been tested.

Another forms of altered hydrology impacting the Burdekin floodplain and coastal wetlands include damming and bunding of stream channels and floodplain drainage depressions. These are usually established to form watering points and/or ponded pasture forage, for grazing stock. In near-coastal areas such structures also inadvertently, or intentionally, exclude tidal ingress, the latter sometimes being employed by water managers as a saltwater intrusion prevention groundwater management tool. Where these structures are established on seasonal drainages in tidally-influenced areas, estuarine and brackish vegetation (mangroves, samphire flats, bulkuru sedge) upstream of the bunds is replaced with freshwater vegetation, and downstream areas risk becoming hypersaline. Where inflows to bunded areas remain seasonal, the habitat quality of wetlands that establish within them can be good. Where such areas are subject to sustained aseasonal inflows and reduced seasonality, they usually become dominated by exotic aquatic grasses, floating weeds and/or cumbungi. Independent of bunding or damming, sustained aseasonal flows of freshwater into estuarine areas such as the Barratta Creek estuary is changing their salinity regime, water quality, primary productivity, and fish habitat value as weeds such as hymenachne advance into areas previously characterised as tidal (Burrows *et al* 2012).

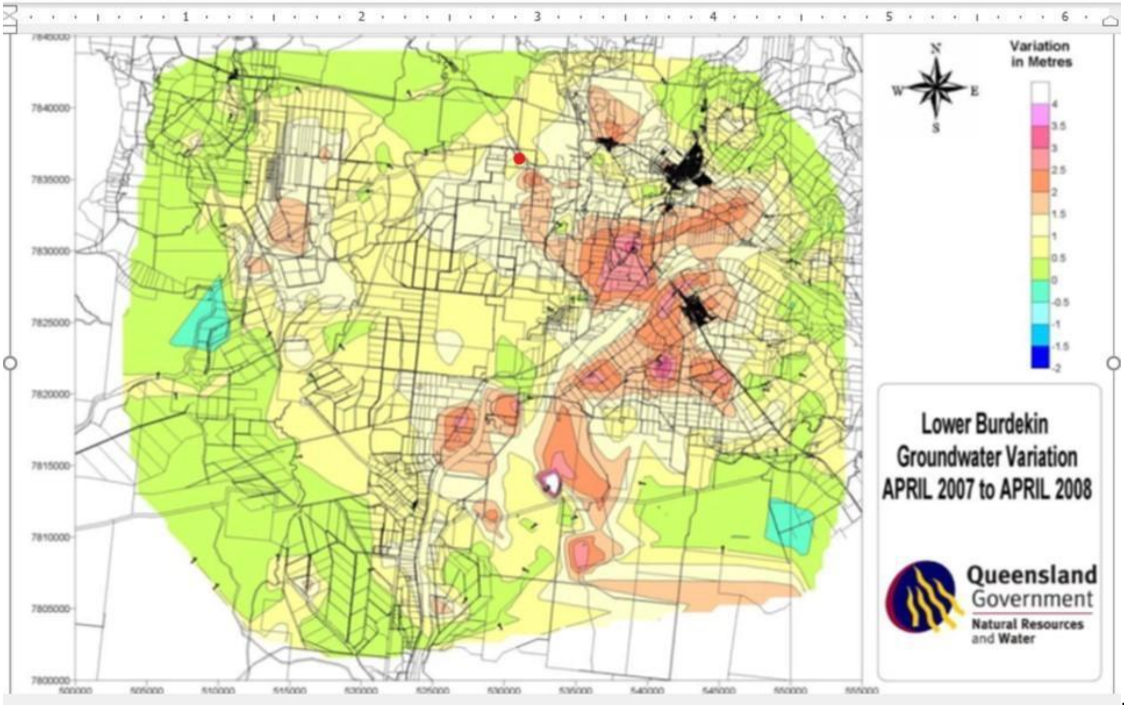


Figure 2. Main Collinson's Lagoon (red dot) within the area of Lower Burdekin floodplain experiencing groundwater rise.

Development of much of the floodplain to agriculture has also altered its runoff hydrology. Whereas the natural floodplain was comprised of diffuse drainage networks, including depressions, distributary channels and isolated basins; the developed floodplain has been filled, levelled, and served by constructed drainage systems, which – in the case of the BHWSS – can be large high flow capacity systems (Figure 3, Photo 13). While a result is less detention of runoff on the floodplain, in peakier flow events conveyance to receiving natural drainages and wetland systems is more rapid. As such, these peakier, higher velocity flows have a greater capacity to transport contaminant loads (sediment, nutrients) and erode channels, both natural and constructed.

The upper catchment Burdekin Falls Dam represents another basin-scale alteration of hydrology that also impacts floodplain wetlands. This dam acts as a detention area during high rainfall events across the basin, serving to reduce the height and frequency of Lower Burdekin flood peaks that previously would have broken out of the river channel into floodplain distributaries, scouring and resetting habitat conditions for channel-hosted wetlands. Riverbank levees constructed to prevent such outbreaks and protect farmland have also reduced the occurrence of these ecologically important flows. Another impact consequence of the Burdekin Falls Dam capturing turbid flood events is that, while river baseflows historically drained to clear, now water reticulated through irrigation scheme areas remains turbid for most, if not all, the calendar year. This sets in train a host of water quality associated impacts for a river and floodplain system that naturally had high clarity water outside of the annual wet season.

System specifics

Where discussion relates to values or management issues listed in Appendix 1, or mapped in Appendix 2, the designated value or management issue (V, M) number is referenced.

Nearly all the generic altered hydrology issues described for the Burdekin floodplain as a whole (above) apply to the Collinson's Lagoon system, although it should be noted that the system does not convey pumped regulated flows. For most of the system that is downstream of the BHWSS, the hydrology is dominated by inflows (Photo 3) of scheme irrigation tailwater and supply channel overflow from its upper catchment (M1). These aseasonal inflows contribute to near-perennial flows through the system downstream to receiving coastal areas. This changed condition results in major reductions in dry season water level drawdown, or drying, in lagoons and swamps, and connecting channels and drainage depressions throughout the system.

The altered hydrology has generated major changes (Photo 5, 6) for the system. These have impacted aquatic plant communities, with an increase in aquatic weeds and decrease in native communities; water quality, with higher turbidity and nutrients; fish passage connectivity due to barriers created by weed chokes; and degraded habitat values for wetland fauna. While flow volumes are not individually as large, irrigated farmland in the system's eastern catchment outside the BHWSS also delivers irrigation tailwater.

Photo 3. Historically the Collinson's Lagoon system only experienced inflows during the wet season and it existed as a chain of isolated waterholes connected only by poorly-defined, dry drainage depressions through the dry season. Irrigation scheme (BHWSS) tailwater now maintains near-perennial inflows to the system via excavated and constructed drain channels.

Photo 4. Independent of the BHWSS tailwater, individual irrigated cane farms also contribute collectively to significant inflows of irrigation tailwater to the system's drainage network and wetlands.

Inflows (Photo 4,12) to floodplain wetlands (M20) and distributary channels (M25) generates water quality decline and aquatic weed growth in open wetlands, and sustained wetness in receiving drainage channels. This promotes the dominance of cumbungi (bull rush) and para grass at the expense of historically seasonal, open water, and native aquatic plant-dominated wetland habitats (Photo 9,10).

Photo 5. One of the consequences aseasonal inflows causing reduced hydrological seasonality and limited water level drawdown in the main lagoon system is the inability for grazing cattle to readily access exotic aquatic pastures. This necessitates chemical-based control (above), which generates low dissolved oxygen and eutrophication water quality impacts associated with dead grass biomass decomposition.

Photo 6. Aerial view of the central section of the main lagoon system under sustained aseasonal inflows and elevated water levels. This illustrates the dominance of lagoon margins by exotic aquatic grasses hymenachne, para, and aleman, and the formation of multi-species weed chokes within the mid channel (M17).

Within the hydrologically-modified lagoon system, exotic aquatic grasses (Photo 5, 6) have proliferated to dominate the water edge zone extending both up bank and out onto the water's surface (M17). Under seasonally-variable water levels, this zone hosted a suite of 'variable water level zone habitats'. This included bare, exposed banks and a range of rooted floating (like water lilies) and submerged and emergent native aquatic plants that provided important habitat, feeding and nesting resources for wetland fauna, including fish, amphibians, and birds. Within the main Collinson's Lagoon, which is located off the direct tailwater inflow conduit, water quality (turbidity) and hydrological impacts are not as pronounced (Photo 1), allowing some of these aquatic plant communities, like water lilies, to persist (M19).

Table 1. Summary of altered hydrology impact risks to Collinson's Lagoon system

Source of hydrological impact	Parts of system/sites/values (V) affected	Nature of impacts/associated management issues (M)	Management/works (W) options
Aseasonal inflows irrigation scheme (BHWSS) tailwater	Main stem drainage lines and hosted wetlands downstream of Sunwater drains RB 1 and RB1/0 (Photo 1, 2). (V1) (V2) (V3) (V5) (V8) (V9) (V12) (V15)	• Reduced/loss of hydrological seasonality, i.e., reduced water level drawdown, drying. • Promotion of aquatic grass weed margins and cumbungi infestation along drainage lines. • Loss of seasonal water level zone habitats (incl. bare banks) and native aquatic plants. • Promotion of floating aquatic weeds and dense submerged aquatic plant beds. • Increased nutrient and suspended sediment loading. • Weed/submerged plant growth-related decline in water quality, particularly dissolved oxygen sustained or cycling below critical thresholds. Also manifests as fish passage barriers. (M1) (M16) (M17) (M19) (M23) (M24)	• Reduce volume of tailwater generated (recycle tailwater, better supply channel scheduling). • Reuse tailwater from drains. • Divert tailwater flows. • Control outlets/gates to vary receiving system water levels to emulate seasonality. (W1) (W24) (W25)
Farm tailwater	Drain to BHWSS tailwater drains (above) and independently to wetlands, including some not receiving BHWSS scheme tailwater. (V1) (V3) (V5) (V7) (V8) (V9) (V11) (V12) (V13)	• Increased nutrient loading. • Loss of seasonal drying. • Promotion of aquatic floating and grass weeds and cumbungi infestation along drainage lines. • Decline in water quality, particularly dissolved oxygen. (M20) (M25)	• Reduce volume of tailwater generated (improved irrigation methods/scheduling). • Reuse/recycle tailwater. • Divert/detain tailwater flows from natural wetlands. (W19)
Floodplain levelling and draining	All downstream floodplain affected during large rainfall runoff and/or inundation events. (V3) (V4) (V5) (V6) (V8) (V9) (V11) (V13)	• Higher rates of runoff, higher flood peaks downstream. • Greater capacity for transportation of contaminant loads (sediment, nutrients). • Greater erosive force on natural and constructed channels and infrastructure. (M5) (M8) (M11)	• Incorporate detention basins/runoff detention function on farm, within drainage network, and within drain. • Retain undeveloped areas of floodplain with detention capacity and route drainage via the undeveloped areas of floodplain. (W17) (W18)
Drains circumventing/ bypassing wetlands	Wetlands bypassed /circumvented by drains and floodplain areas downstream of wetlands.	• Higher rates of runoff, higher flood peaks downstream. • Greater capacity for transportation of contaminant loads (sediment, nutrients). • Altered hydrology, seasonal inundation timing, and duration for wetlands.	• Retrofit drains to include high flow outflow conduits to alienated wetlands.

Source of hydrological impact	Parts of system/sites/values (V) affected	Nature of impacts/associated management issues (M)	Management/works (W) options
	(V3) (V4) (V5) (V6)	• Loss of dependent ecology and catchment function/water quality processing role of wetlands. (M5) (M8)	• Levee-off wetland basin margin rims truncated by constructed drains to enable detainment of inflows. (W18)
Bunding coastal drainage depressions*	Coastal plain wetlands, e.g., downstream of highway, Lochinvar. (V9)	*Bunded drainage depressions in lower Collinson's Lagoon system are also impacted by aseasonal inflows of BHWSS tailwater. • Reduced/loss of hydrological seasonality, i.e., reduced water level drawdown, drying. • Reduced/loss of seasonal salinity influences and associated brackish aquatic plant communities, like bulkuru sedge. • Promotion of aquatic grass weed margins and cumbungi infestation along drainage lines. • Loss of seasonal water level zone habitats (incl. bare banks) and native aquatic plants. • Promotion of floating aquatic weeds and dense submerged aquatic plant beds. • Increased nutrient and suspended sediment loading. • Weed/submerged plant growth-related decline in water quality, particularly dissolved oxygen sustained or cycling below critical thresholds. Also manifests as fish passage barriers. (M16) (M17) (M23) (M24)	• Reduce volume BHWSS tailwater inflows generated (see above). • Reuse tailwater from drains. • Divert tailwater away. • Control outlets/gates to seasonally vary water levels within bunded reaches and/or to allow drying and/ or seasonal ingress of tidal water to establish brackish condition.
Burdekin Falls Dam	All of floodplain (All values to some extent) (V1) (V3) (V4) (V5) (V6) (V7) (V8) (V9) (V11) (V13)	• Reduced occurrence of Burdekin River breakout flows across floodplain and down distributary channel systems. • Reduced geomorphic (channel form) and habitat resetting by scouring flows. • Reduced frequency of connected water quality freshening flows from top of system to estuary.	• No real options for Collinson's Lagoon system. In other systems within leveed floodplain distributaries and/or supplied with regulated inflows, like Sheep Station Creek, some options are levee reduction or regulated flows during wet season.
Groundwater rise	Significant proportion of Collinson's Lagoon catchment (V1) (V2) (V3) (V4) (V5) (V6) (V7) (V8) (V9) (V11) (V12) (V13) (V15)	Impact on natural systems within Collinson's Lagoon system is yet to be documented, although there are already concerns for some production areas in the system's catchment. Potential impacts for natural systems include: • Soil salinisation, waterlogging-induced dieback of remnant vegetation, elevated salinity of surface waters, reduced seasonal drawdown of waterbodies, and reduced instream biodiversity.	• Reduce sources of groundwater accession, including unlined drains, water standing on permeable soils, and elevated water levels (hydraulic head) in lagoon basins. • Retire areas from irrigation use. • Groundwater dewatering by drainage/bore pumping.

Source of hydrological impact	Parts of system/sites/values (V) affected	Nature of impacts/associated management issues (M)	Management/works (W) options
Groundwater dewatering	Not yet operational, but proposed within the catchment (Sunwater pers. Comm.). (V2) (V3) (V5) (V8) (V9) (V12) (V15)	• Potentially similar suite of impacts to aseasonal tailwater flows (above) with additional risks of salt loading and/or elevated nitrate levels. • NB: Elevated salinity could potentially mitigate some other impacts, including reducing the invasive potential of aquatic floating/grass weeds, and reducing turbidity due to flocculation.	• Reduce groundwater rise (above). • Divert flows around sensitive receiving environments. • Manage salinity levels with conjunctive mixing channel water. • Use control outlets/gates to vary receiving system water levels to emulate seasonality.
Channel head cutting	Not yet found to be occurring, but could pose a risk to the main lagoon system. (V1) (V2)	Risk identified by landholders. • Potential for concentrated high outflows through old and current highway crossings at the bottom of the lagoon to head-cut upstream towards the bottom of the lagoon basin (Photo 7). Could result in lowered Full Supply Level (FSL) within main lagoon basin. (M22)	• Rock armour outlet to secure against head cutting (W9). • Investigate opportunity for controlled outlet level control structure at this site.

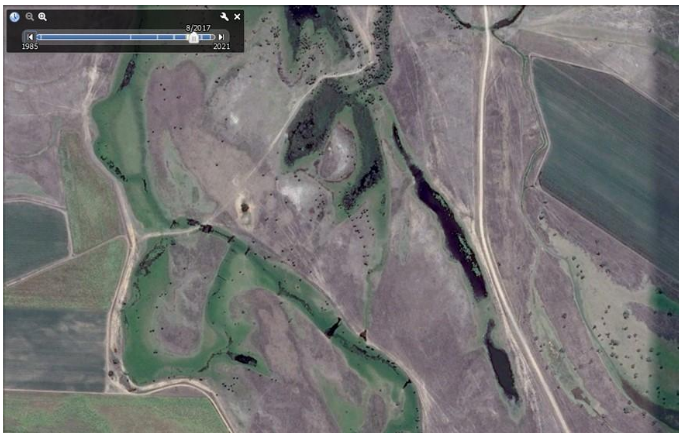


Photo 7. August 2017 aerial image of bunded coastal drainage depressions in Lochinvar Station. Wetness of individual waterbodies, seasonal period, and year affects the access of grazing cattle to exotic aquatic grass-dominated wetlands. NB: grazed open seasonal wetland not receiving aseasonal flows (right) versus grass-dominated flow fed channels (left).

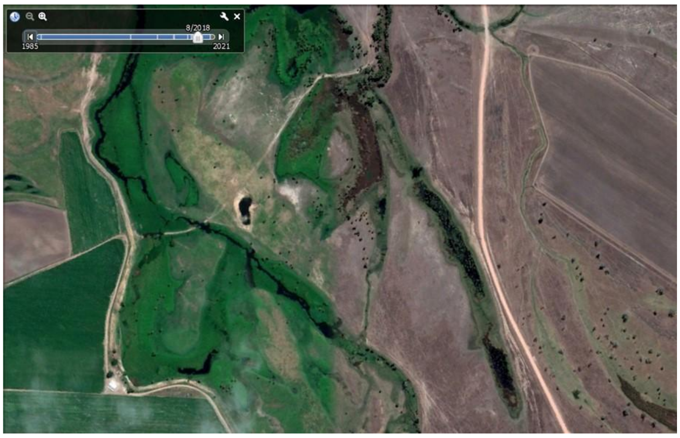


Photo 8. August 2018 aerial image of the same site. During wetter years/higher inflows, open water channels persist in central basin areas too deep for grass growth (top left), though grass-dominated shallow inundated areas are broader. The ‘seasonal’ basin (right) is not as grazed open because water levels are flow-supplemented and higher.

The hydrological modification of the system extends downstream of the Bruce Highway into bunded coastal drainage depressions within Lochinvar Station (Photos 7, 8). Historically, lower system drainage depression reaches within Lochinvar Station had a highly seasonal character (M24) and included a range of wetlands from perennial lagoons to shallow vegetation-dominated swamps. Native aquatic plant communities across this range of wetlands were diverse, including emergent sedge and spike rush communities, rooted floating beds of water lilies and pond lilies, and submerged and emergent species found in the shallow and seasonally-drying margins. This range of native aquatic plants provided important habitat, feeding and nesting resources for wetland fauna, including birds, fish, and amphibians. Here, as elsewhere in the upper system, exotic aquatic grasses, like hymenachne and para, dominate the shallow water edge and bank zone (M23) to the demise of native aquatic plant communities and bare bank habitat that previously occupied the seasonal water level zone. In some wetlands where higher salinity levels or retained seasonality still promotes native aquatic plants, greater habitat and faunal diversity is still observed.

While cattle grazing provides an extensive non-chemical control method for these aquatic grasses, the effectiveness of grazing-based control is limited by the cattle’s access to these pastures. Cattle access is mitigated by seasonal water levels and wetness, and is reduced in wetter years or periods of higher inflows. Management approaches able to reduce aseasonal inflows to the system and/or support dry season lowering of water levels would serve to vastly increase the effectiveness of grazing-based control, while allowing these grasses to be used while their dominance and impact is reduced within aquatic habitats of the lower system.

Photo 9. Aerial view of highway wetland in Photo 10 (right). Perennial channel wetness and seepage driven by farm irrigation tailwater inflows to historically seasonal floodplain distributaries are typical of the system’s eastern catchment outside Sunwater’s BHWSS area. These channels are characterised by cumbungi, ungrazed para grass, and lack open water habitats.

Photo 10. A view from the highway into the cumbungi and para grass-choked distributary channel (Photo 9). While overstorey riparian vegetation provides some habitat values for birds and other fauna, the wetland habitat values of these channels are limited.

Photo 11. Floodplain wetlands isolated from inflows of irrigation tailwater (top right) are a rare nature conservation asset on the Burdekin floodplain and have a different weed and water quality status to those receiving aseasonal flows (Photo 12).

Photo 12. The routing of irrigation tailwater to floodplain wetlands ultimately leads to condition decline in terms of cumbungi and exotic aquatic grass infestation (above), and associated habitat loss and water quality degradation.

Under pre-development conditions, the upper floodplain catchment of the Collinson's Lagoon area was defined by defuse drainage depressions that drained to natural basins and flow detention areas including the 'Green Swamp' (Photo 7), and a broad closed paperbark forest on gilgai/melonhole landforms upstream of Sayers Road (Figure 3). With the development of the BHWSS, large constructed tailwater drains now cut through areas that previously had only diffuse drainage systems. Where these drains bypass natural wetland detention areas, they are lower than the original wetland basins and serve to isolate the wetlands from inflows except under large inundating flood conditions (M5). When these wetlands get inundated by flood events, the adjoining drains drain them quicker than their pre-development topography allowed (Figure 3). The result of the interface between the historical floodplain and constructed drainage system is that catchment runoff rates are much greater, conveying higher flow velocities and flood peaks, along with associated elevated sediment/nutrient loads, to the lower catchment. At the same time, remnant wetland basins are isolated and prevented from providing flow detention and associated load processing functions.

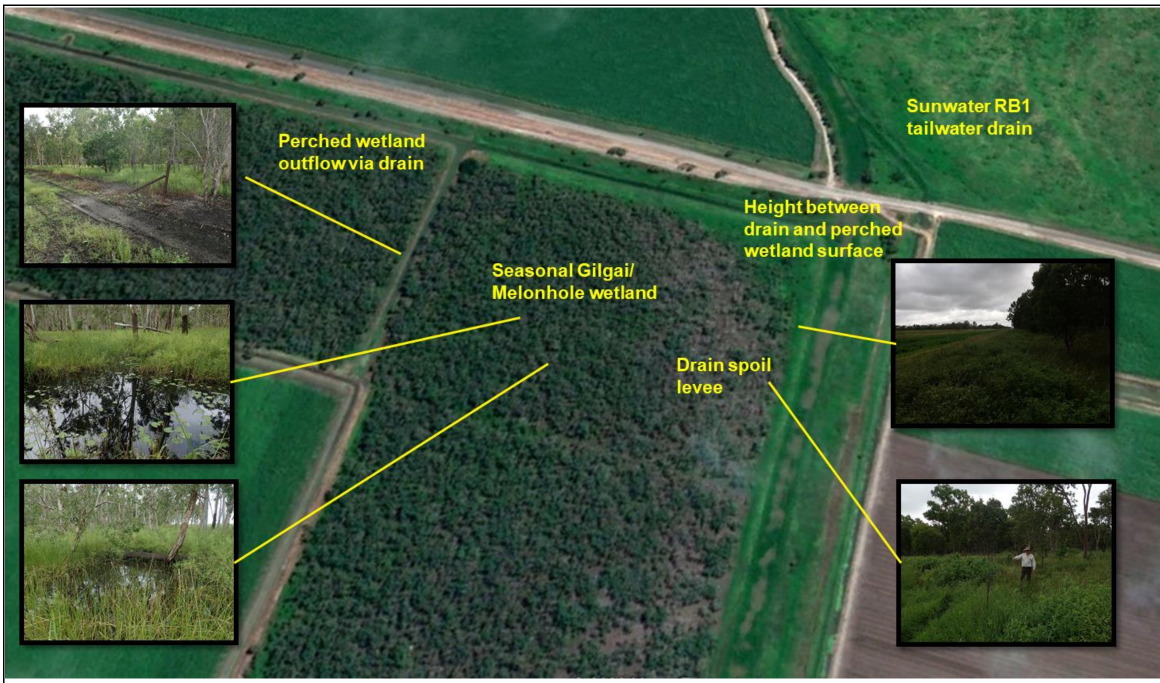


Figure 3. A rare *Melaleuca dealbata* seasonal forested wetland on gilgai/melonhole landforms. This remnant was historically a low-lying area of impeded drainage. It represents the last example of a previously extensive vegetation type on the floodplain and has been left 'perched' relative to the adjoining constructed tailwater drain RB1. High flow inflows to the wetland are impeded by a drain excavation spoil levee left adjoining RB1. Water inflows or rainfall to the system is also now drained by outlets to its drain perimeter.

A hydrological risk nominated by a concerned landholder relates to where the old Bruce Highway crosses the Collinson's drainage system (Photo 14). Here the diffuse broad channel of the lagoon system narrows into a more incised channel that conveys water into the downstream Lochinvar Station wetland channels. During high flows, conveyed water has eroded the transition point between channel forms and risks generating head cutting that could progress upstream toward the main lagoon basin. If this process was to continue, there is a possibility of lagoon water levels being reset to a lower level that would reduce the aerial extent of the upstream wetland system (M22).

Photo 13. 'Green Swamp' is a state significant natural treeless wetland that historically acted as a detention basin in an area of impeded floodplain drainage and provided bird and other wetland fauna habitat through the wet season. Constructed drains RB1/2A (left) and RB1 (right) now alienate it from inflows in all but flood events.

Photo 14. Local landholders who have observed the evolution of the main lagoon's outflow channel to the highway are concerned that concentrated high flows through the old or current highway crossings could generate head-cutting erosion with risks to the lagoon's water level setting.

Understanding the extent of altered hydrology within the Collinson's Lagoon system is critical to developing management recommendations to deliver protection or improvements to wetland ecological condition and values. The Collinson's Lagoon system has been highly modified in terms of its hydrological character. The drivers of this modification have been the extensive development of irrigated agriculture within its contributing catchment area, including the BHWSS, which is served by floodplain-scale drainage infrastructure. This development has provided enormous economic and social benefits to the regional community, albeit at a cost to environmental values.

While there is limited community support for 'un-modifying' existing land and water resource use, there are opportunities to work within this modified system to identify ways to improve its ecological function to serve ecosystem health and protect the ecological values desired by the community. Understanding the historical ecological and hydrological condition of the system is important to identify natural system features that can be reinstated or emulated. Or, conversely, to recognise where the modified system has departed from any semblance of the natural system to the extent that future health prospects may be stronger with novel ecosystem and habitat outcomes.

This consideration is central to wetland system management planning across most of the Burdekin floodplain. Essentially, the system has been modified from being seasonally dry to perennially wet. The challenge for wetland managers is to identify where 'seasonally dry(ing)' can be reinstated, or alternatively how 'perennially wet' can be made ecologically healthy and valuable.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Engage with irrigation scheme (BHWSS) operator Sunwater and other management stakeholder representatives, particularly water users and riparian landholders, to reduce the volume of aseasonal flows of scheme tailwater into Collinson's Lagoon system, including coastal drainage depression reaches (W1). This will help to reinstate seasonal flow conditions and drawdown lagoon and channel water levels, and address associated seasonal water quality conditions and aquatic plant communities (W24). Actions include:
    a. Improve and modernise (telemetric) flow allocation/scheduling to reduce channel overflow, and to avoid or minimise the channel overflow contribution to downstream tailwater flows.
    b. Reuse tailwater in the upper catchment to reduce flow volumes in two Sunwater drainage channels (RB1, and RB1/0) feeding to Collinson's Lagoon system via zero cost incentives. Also, establish recycle pit infrastructure to reuse aseasonal flows in coastal drainage depressions of Lochinvar Station for off-stream pasture production. Reinstate main channel and bunded reach dry season drawdown to increase the grazing effectiveness of aquatic

grass pastures along the main channel network. This will create open water habitat, open channel conduits for fish passage, and more niche opportunities for native aquatic plant communities in subsequent wet season inundation/flow events (W24).

   c. Conduct senior management level negotiations with the Department of Resources, as the responsible government department, to approve a Lower Burdekin floodplain ‘Area Management Plan’. This approach would encompass waiving overland flow and water course water access/licencing fees where target volumes can be supplied by excess aseasonal flows emanating from farm irrigation and BHWSS area tailwater (W25).

2. Engage with landholders of Lochinvar Station to implement adaptive water and habitat management to reinstate greater hydrological seasonality, aquatic plant habitat diversity, open water habitats, and improved fish passage connectivity within Lochinvar Station wetlands while maintaining, or increasing, pastoral productivity. Actions include:

   - Establish off-stream pasture production systems;
   - Divert flows between adjoining channel to generate seasonal isolation/drying, and
   - Conduct riparian revegetation/channel excavation to create fish habitat refugia (see *Lack of riparian vegetation*, *Fish passage barriers* sections).

3. Engage with Sunwater and local irrigator stakeholder representatives to have access to current monitoring data to improve understanding about the relationship between groundwater and lagoon system water levels and the connectivity between the two. Also, the potential to manage surface drainage and flows as part of managing groundwater rise and seasonal hydrology, including surface water management planning.
4. Improve the runoff hydrology of the BHWSS area, including how detention functions. Detention areas could be retrofitted within channels and areas adjoining the drainage network to reduce the drainage modulus and associated peak flows, and minimise contaminant transport to downstream-receiving wetlands, such as the Collinson’s Lagoon system (W18). This could include reinstating inflows, inundation, and the flow detention function to ‘perched’ seasonal wetlands that have been circumvented by constructed tailwater drains. Remove barriers restricting high flow inflows and levee-off topographic lows points that convey outflows from perched wetlands back to areal drainage channels (Photo 13, Figure 3).
5. Assess the head cut erosion risk associated with the lagoon outlet flow site at old Bruce Highway crossing. If the risk is substantiated, engage geomorphic expertise, the Department of Main Roads, and other relevant agencies to progress resourcing, proposal development and permit approvals for stabilisation works (W9).
6. Examine the topographic relief/height differentiation between the lagoon outlet level sill and the channel downstream of the highway crossing to assess the potential for controlled outlet level infrastructure. This would artificially drain the main lagoon level to a dry season drawdown analogue capable of facilitating cattle grazing access to fringing aquatic grass margins.
7. Engage sugar producers to examine irrigation management in the system’s eastern catchment. The aim is to reduce tailwater flow volumes to receiving floodplain distributary drainage channels. Engagement to consider:

   - irrigation practices management;
   - potential role/incentives for tailwater recycling;
   - diversion of tailwater from receiving natural systems, and
   - groundwater connectivity issues.

Aquatic weeds

Types and impacts

Aquatic weeds are commonly cited as the most significant cause of ecological impact within Lower Burdekin floodplain wetland systems (Waltham *et al* 2020, Tait 2013, Perna *et al* 2012, Veitch *et al* 2007, Tait & Perna 2001). They create blockages to flow and fish passage; outcompete native aquatic vegetation; generate high fire fuel loads in seasonally dry riparian vegetation (in the case of aquatic grasses); and cause collapses in instream dissolved oxygen levels via organic loading and covering open water surfaces, consequently impacting fish and other fauna habitat availability and quality. While these impacts are attributed to weeds, it should be recognised that observed weed infestation levels are often a symptom of other ecological impact drivers that promote weed proliferation. For instance, altered hydrology due to aseasonal inflows from irrigation areas, which increases aquatic habitat availability and reduces water level seasonality; and increased availability of nutrients associated with catchment land use and runoff, regulated inflows, and irrigation tailwater. Given the ongoing use of the Lower Burdekin floodplain's land and water resources for irrigated agriculture, these drivers of weed proliferation will, to some degree, remain part of most modified ecosystems. Effective weed management needs to be ongoing if wetland ecological values are to be retained or improved. Considering the costs associated with aquatic weed management, there is a strong impetus for control practices to be as effective as possible, and for innovative developments that support continuous improvement in management approaches.

A large range of aquatic weed species are recorded from the Lower Burdekin floodplain, with most of these recorded for the Collinson's Lagoon system (Table 1). Aquatic weeds include floating, submerged, and fringing emergent growth forms including aquatic grasses. There are also several emerging aquatic weed risk species identified in the *Burdekin Shire Biosecurity Plan* (BSC 2020) that have been more recently recorded in the shire or adjoining regions (Table 2). While exotic species are more commonly recognised as 'weeds', several native aquatic plants (Table 1) have also become weedy in nature under the modified ecosystem conditions of the developed floodplain. Some native species, like cumbungi bull rushes, are now responsible for major ecological and economic impacts. The impacts generated by aquatic weeds vary between species, although some impacts are common to most and often a suite of aquatic weed species are involved in impact-generating infestations (Table 1).

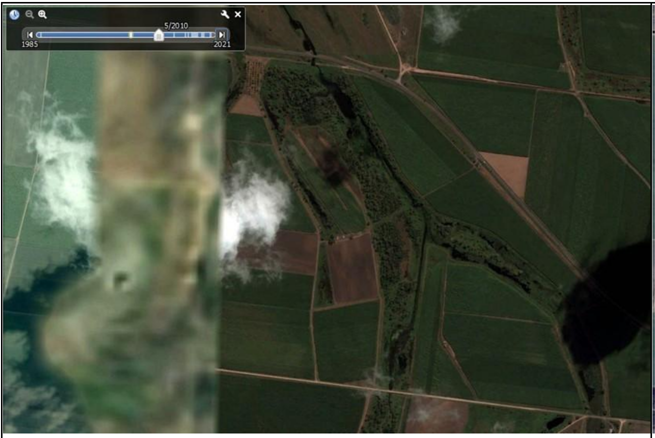
Photo 15. A historical 1964 aerial photograph of the Collinson's Lagoon system adjoining the Bruce Highway. Greater hydrological seasonality and seasonal burning were a feature of the landscape at that time. Riparian vegetation was more open structured; permanent lagoons (left) were clear-watered and fringed by water lilies, and seasonal basins (right) were dominated by aquatic-bedded and emergent aquatic plants, including native aquatic grasses and spike rushes.

Photo 16. Fringing exotic aquatic grasses such as hymenachne (background) remain a weed management challenge for the Collinson's Lagoon system. Chemically-sprayed water margins (dead grass background) are soon replaced by actively growing margins (foreground), while dead grass contributes to water quality degradation. Higher grazing pressure, lowered water levels, and broader and/or more frequent spraying interventions could potentially contribute to better control outcomes.

System specifics

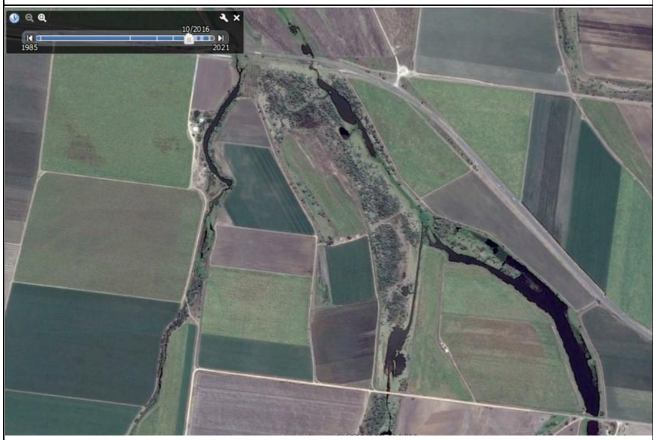
Management history and approaches

Historical aerial photographs (Photo 15) of the Collinson's Lagoon system – taken in the 1960s, prior to hydrological modification – illustrate a highly seasonal system that naturally dried to small extents of perennial groundwater-connected waterholes during the dry season. Dry season water quality was clear, and aquatic plant communities were dominated by beds of fringing water lilies and submerged aquatic plants in perennial waterholes, and emergent sedge and spike rush communities in shallow seasonal wetlands and margins. Development of irrigated farming over the following decades culminated in the Burdekin River Irrigation Area BRIA (now BHWSS) being established in the late 1980s. This development lifted Burdekin River water into floodplain systems, further modifying receiving wetlands via inflows of irrigation tailwater and associated transported nutrient loads. Floating aquatic weed species, including water hyacinth, salvinia and water lettuce, began appearing in the Lower Burdekin region through the 1970s and these species were established in most systems by the 1980s. Several invasive aquatic grasses, like hymenachne and aleman grass, were also introduced to the region by the then Department of Primary Industries as 'ponded pastures' through the 1990s. In conjunction with agricultural land use intensification and the resulting alienation of grazing land uses from Lower Burdekin riparian and wetland areas, these grasses and other long-established exotic aquatic grass species, such as para grass, established extensive infestations through open wetland basins and wet channels.

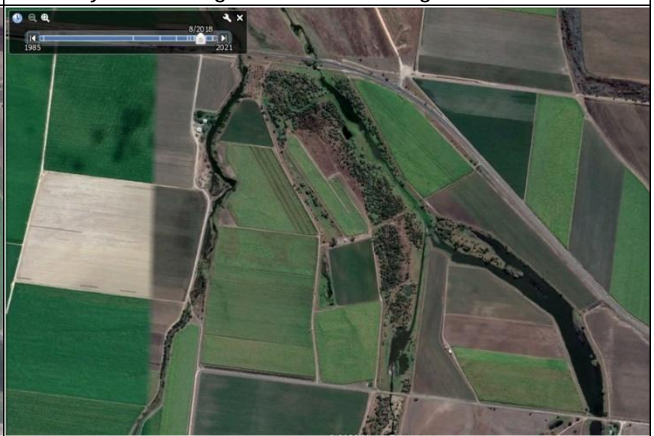


5/2010. Water hyacinth mats are extensive throughout the system. Grass margins of lagoons and channels are grazed back.

10/2013. Native water lilies are in the main lagoon, open channel throughout. Grazing-controlled grass margins. Water hyacinth refugial mats in main lagoon backwater.

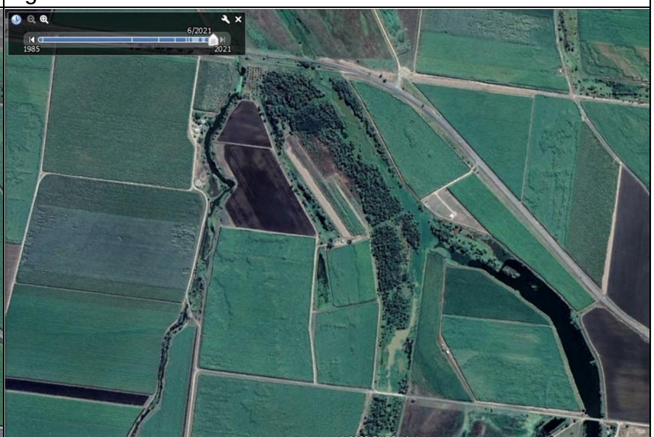


10/2016. Central weed choke formed, grazed open channels and lagoon margins elsewhere. Water hyacinth refugial mats in main lagoon backwater.



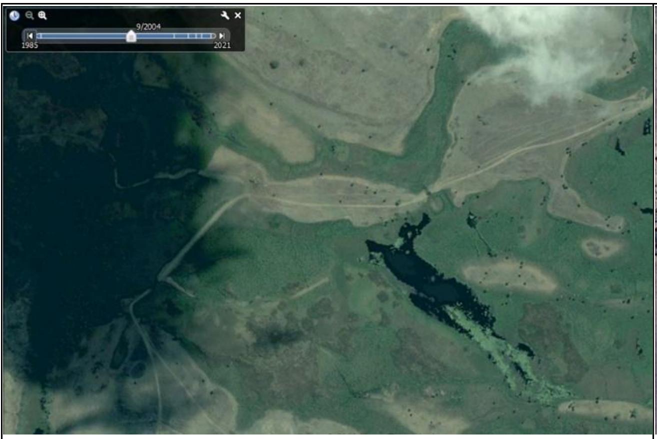
8/2018. Central weed choke formed, grass margins encroaching on lower lagoon, open channels, and lagoon margins elsewhere. Water hyacinth refugial mats in main lagoon backwater.

7/2019. Central weed-choke extensive, grass margins encroaching on lower and upper west branch lagoons, and onto channels. Water hyacinth refugial mats in main lagoon backwater.

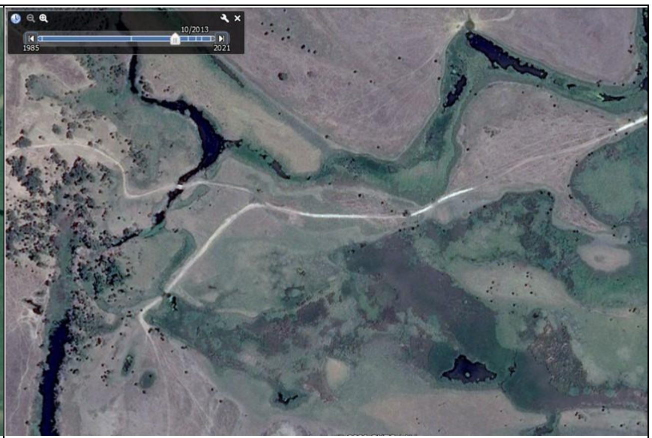


6/2021. Central weed-choke extensive, grass margins encroaching on lower and upper west branch lagoons, and onto channels. Large water hyacinth refugial mats in main lagoon backwater and blocked confluence channel.

Figure 4. Aerial images of Collinson's Lagoon system's main lagoon's aquatic floating and grass weed status 2010-2021.



9/2004. Extensive para grass coverage, one open basin with native water lilies.



10/2013. Para grass coverage reduced by grazing pressure >1 open water body, central basin covered in floating aquatic weed water hyacinth.

10/2016. Para grass coverage reduced by grazing pressure, only main channel open water body, central basin covered in floating aquatic weed water hyacinth.

4/2018. Early in the growing season, para and hymenachne coverage is extensive, water hyacinth still dominating most open waterbodies.

7/2019. Grazed open water bodies in main basin, water hyacinth reduced (absent?) in extent, native water lilies on open water body margins.

6/2021. More than 1 grazed open water bodies, water hyacinth reduced (absent?) in extent, lilies absent from open water body margins.

Figure 5. Aerial images of aquatic floating and grass weed status 2004-2021 in Lochinvar Station bunded wetlands of the lower Collinson's Lagoon system.

Aquatic grass margins often act to anchor floating aquatic weed mats, and then use them as a floating substrate to colonise mid channel areas. This results in impenetrable aquatic weed chokes and surface-covering weed mats with concomitant degradation of water quality and loss of wetland habitat values for birds, fish, reptiles, and other biota. By the early 2000s, much of the main Collinson's Lagoon system was impacted by channel-choking and surface-covering aquatic grass and floating weed mats. This status remained relatively unchanged, except for in higher rainfall years when a large wet season flood spate successfully flushed weeds out of the system.

Figure 6. Collinson's Lagoon controlled grazing trial site signage (top), ungrazed site totally covered in exotic aquatic pastures 2007 (centre), and same site post-controlled grazing trial 2013 (bottom).

Building upon the experience gained from managing severe aquatic weed infestations elsewhere in the Lower Burdekin, BSC – with funding support from NQ Dry Tropics – identified the site as a target for the council's mechanical weed harvester operations in 2008. This weed harvester, along with LBW's excavator-mounted rakes, successfully removed the neglected surface-covering weed mats and chokes from the system. The water quality conditions and the freshwater fish community recovered exceptionally following this management intervention (Loong *et al* 2009, Burrow and Davis 2009). The next step was to ensure the condition established by the weed harvester was maintained, so BSC's land protection officer engaged riparian landholders in a Riparian Management Agreement (RMA). The RMA provided a means for landholders and other stakeholders to share the cost of a boat-based, chemical -spaying (glyphosate) control program. This targeted the main weed species of concern, including water hyacinth, water lettuce, salvinia, hymenachne and para grass. Sunwater was also a cost-sharing partner in the RMA program. Initially involving around five landholders, this RMA has operated for over 15 years. It originally conducted up to three spraying interventions per year, which were delivered by both private contractor and council operators in the main Collinson's Lagoon system, including the often-separated lower lagoon adjacent the highway and the western branch lagoon immediate downstream of Rose Road.

A parallel controlled grazing-based aquatic grass weed control program was implemented in 2010, two years after the initial weed harvester operation. Initial results from this trial were exceptional (Figure 6). Despite these successes, control outcomes in more recent years have been less comprehensive and warrant further program development and management consideration (see *Grazing regime* section).

Photo 17. Main lagoon and western channel confluence weed choke of floating water hyacinth, bound by aquatic grass weeds (para, aleman). Chokes are not accessible for the boat-based spray unit. They represent a water quality barrier to fish movement, and a reinfestation source for water hyacinth controlled in the broader accessible system.

Photo 18. Eastern backwater of the main Collinson's Lagoon. This site is generally inaccessible to the boat spray unit and acts as a perennial refuge for water hyacinth reinfestation sources. System backwaters and weed chokes (left) represent a justifiable case for periodic physical weed removal interventions using a weed harvester and excavator.

Over the years, NQ Dry Tropics has provided additional resources to support aerial spraying when channel weed chokes have made reaches inaccessible for boat-based operations. NQ Dry Tropics has also successfully trialled the use of drone-based spraying at the site as a cheaper alternative to a helicopter. These trials have proven successful in terms of cost and the ability to access weed infestations near trees and powerlines. Another successful innovation at this site was the registered use of grass-specific herbicide Verdict to target aleman grass, which had proven resistant to standard glyphosate. Glyphosate had also been observed to kill non-target vegetation, like tree seedlings, and was ineffective at transferring through water to targeted stems; whereas Verdict overcomes both these shortcomings.

A separate aquatic weed management trial funded by the Commonwealth Government through Wetland Care Australia was conducted within Lochinvar Station wetlands in the lower system between 2013 and 2015. The Delivering Bio-Diversity Dividends for the Barratta Creek Catchment project specifically examined the viability to control water hyacinth via aerial (helicopter) spraying operations. Water quality impacts of this trial were also monitored (Waltham and Fixler 2017). Results indicated that spraying could control edge infestations of the weed without significant impact to water quality, but control of large surface-covering aquatic weeds mats (~80%) that had accumulated following poor wet season flushing resulted in severe degradation of water dissolved oxygen levels below critical thresholds required for fish survival. Water temperature monitoring also revealed that fish in the large treeless wetlands of Lochinvar Station often face surface water temperatures above their critical maxima. Their ability to find refuge in deeper water is limited by low dissolved oxygen levels, which is exacerbated when spray-controlled weed biomass is added to the water column (Waltham and Fixler 2017).

Outstanding weed management issues and opportunities

The Collinson's Lagoon RMA has generally been a success in maintaining the three component lagoons as open waterbodies, with these comprising the large lagoon bisected by Rose Road, the small western branch lagoon downstream of Rose Road, and the medium-sized lagoon upstream of the Bruce Highway (Figure 4). Early in the operation of the RMA, water hyacinth mats were allowed to increase beyond a controllable extent for the boat-based spraying operation (Figure 4), meaning the more costly weed harvester intervention was needed. Since that time, control interventions have kept the lagoons free of surface-covering mats, although aerial spraying has been periodically employed to tackle weed chokes that are inaccessible to boat operators.

Photo 19. Spaying of aquatic grass margins forms part of the RMA-supported aquatic weed control program for the main Collinson's Lagoon. The only section not sprayed along this bank is that under the remnant paperbark tree where shading has naturally excluded grass margins; a pertinent insight into more sustainable grass margin control.

Photo 20. Water-covering closed Cumbungi stands within a floodplain distributary channel of the system's eastern sun catchment that drains Wilmar land. This native bulrush's extensive weedy infestation has been promoted by perennial seepage and a lack of seasonal drying generated by aseasonal irrigation tailwater flows to the system. Management of this native weed remains a challenge, but integrated use of physical removal, fire and grazing may present opportunities (see *Fire regime* and *Grazing regime* sections).

Several ongoing weed and weed control impact issues warrant further management consideration:

1. **Reinfestation potential of water hyacinth.** While water hyacinth has been relatively comprehensively controlled in the past decade, it retains a perennial reinfestation risk. Examining aerial images throughout the RMA operational period (Figure 4), or conducting site-based investigations (Photo 18), will usually reveal residual water hyacinth mats within the system. Sometimes they are bound up in channel weed chokes and inaccessible to boat-based operators, while other times they are cryptically located in system backwaters, or upper catchment refuges. Water hyacinth is known for its exponential growth capacity. Small residual infestations under the right seasonal conditions can readily grow into a lagoon-choking surface mat. Greater vigilance and more frequent intervention in the location and control of residual weed sources within the system, potentially using aerial drone monitoring and spraying capacity, could translate into lower overall control investment requirements, particularly in labour and chemical volumes.

2. **Channel-blocking weed chokes.** Throughout the operational history of the RMA (Figure 4), there have been many periods when combined aquatic grass and floating weed mats block channel flow paths, impeding flow and creating a poor water quality fish passage barrier. Chemical-based control of these weed chokes also serves to further degrade water quality in terms of dissolved oxygen and elevated nutrients (Loong *et al* 2009). In the main Collinson's Lagoon, these blockages form on a shallow reach of the lagoon basin. Sometimes a channel is excavated through these blocked areas. In drier periods, late dry season grazing of the lagoon margin appears to maintain a connective channel (Figure 4). Sustained heavy grazing pressure late in the dry season and/or targeted chemical control immediately following channel excavation could help to maintain an open channel. The greatest outcome for controlling weed chokes would be achieved via the hydrological management of lagoon water levels to facilitate bank drying.

3. **Exotic aquatic pastures dominating lagoon margins and shallow channels.** The bank and shallow water zone of the entire main lagoon system remain dominated by exotic aquatic grasses including para, hymenachne and aleman. In shallow reaches, or where floating weed mats are available as a growth substrate, they extend across channel areas to form channel weed chokes (above). The grasses are targeted as part of the RMA-supported weed control program. The decomposition of controlled grasses contributes to nutrient loading and dissolved oxygen degradation water quality impacts (Loong *et al* 2009). Also, grasses readily reinfest following control operations. In essence, while existing control approaches prevent the targeted grasses from covering the entire lagoon basin as they did in the past (Figure 6), maintaining infestation levels at a 'manageable' status; this status remains less than ideal from a wetland habitat perspective. As such, further management innovation is required to achieve an improved outcome. As noted above, a capacity for hydrological management of lagoon water levels to facilitate bank drying would offer the greatest control prospects. Meanwhile, other tools provided by dedicated late dry season grazing regimes, and possibly integrated use of fire (see *Grazing regime* and *Fire regime* sections), could provide management gains. Applying chemical control following grazing activities that have reduced the extent of grass margins could also present opportunities to limit chemical volumes used for control. In turn,

this would minimise the water quality risks associated with chemical control, and the wet season regrowth potential of grass margins (M17).

4. **Water quality impacts of killed weed biomass.** As noted in preceding points (above), chemical-based control of aquatic weeds presents ongoing water quality risks to the system due to the biological oxygen demand (BOD) and organic nutrient release associated with decomposing dead weed biomass in the water column. While chemical control remains an invaluable tool for aquatic weed management, there needs to be more assessment and integrated use of other potential weed control tools. Some of these actions include controlled grazing, the use of fire ('cool' burns), and establishing riparian vegetation shade canopy. Timing control interventions more strategically, for example more frequent but smaller scale, is worthy of investigating via a cost benefit assessment. Namely, there could be merit in trialling control interventions 'before they are needed', for instance, prior to aquatic grass margins extending onto lagoon waterbodies, or before aquatic weed mats become visible. Effective control could be delivered with lower chemical volumes and less killed weed biomass would be added to the waterbody. Extending the width of control from the water margin up unto dry bank edges (Photo 16) could also help to reduce the biomass of grass weed that establishes over the water surface and reduce the reinfestation potential. Where manageable, burning sprayed weeds could also reduce the volume of biomass decomposing within the water column. As noted above, following up other control interventions, like late dry season grazing, and/or channel excavation with a spraying intervention, could substantially extend the time before reinfestation.

5. **Alternatives to chemical control.** This point is to clearly reiterate that there are alternatives to chemical-based weed control, and they need to be employed more regularly and subjected to greater trial and innovation rather than be supplanted by established chemical tools. For example, controlled grazing has been applied to the Collinson's Lagoon system for over a decade and has proven successful in reducing hot fire risks to riparian vegetation. It has not yet, however, fulfilled anywhere near its potential capacity for aquatic grass margin control (see *Grazing regime* section), despite its apparent early effectiveness (Figure 6). Though it is reiterated that the hydrological management of lagoon water levels to facilitate water level lowering and bank drying would offer the greatest control prospects for many of the weed control issues faced.

6. **Drainage depressions of the lower system.** Examining the status of aquatic weeds within the coastal drainage depressions of the lower system within Lochinvar Station (Figure 5) reveals that this area has undergone a parallel, though potentially delayed, weed history sequence to the upper system within the main Collinson's Lagoon reaches. Research conducted within the site highlighted the system water quality merits of regular weed control interventions as opposed to the emergence of neglect surface-covering weed mats (Waltham and Fixler 2017). Recent aerial images (Figure 5) suggest that water hyacinth infestation has been flushed and/or controlled from the system. Remaining infestations of para and hymenachne are valued by the grazing operation as forage resources. Working within the status quo of sustaining exotic aquatic pasture resources, there could still be opportunities at a site or reach scale to implement grass 'weed' control interventions that deliver habitat and water quality benefits to the system (see *Lack of riparian vegetation, Fish passage barriers,* and *Grazing regime* sections).

7. **Cumbungi infested drainage lines of the eastern catchment.** This is a particular aquatic weed infestation issue largely restricted to this sub catchment (M25). Grazing, burning and integrated riparian rehabilitation approaches would appear to offer the greatest prospect for controlling these native bullrush infestations. These options are developed in the *Lack of riparian vegetation, Fire regime* and *Grazing regime* sections).

8. **Weed control status of BHWSS tailwater drains.** There are risks for downstream floodplain and infrastructure from large constructed tailwater drains within the BHWSS that convey water throughout most of the year, as they present conditions suited for the proliferation of aquatic weeds, including grasses, and submerged, emergent and floating species. Weed control interventions within these drains are not sufficient to prevent weed establishment, with large biomasses of floating mats of aquatic weeds establishing in these drainage systems periodically. When there are rainfall-driven high flow events, these weed mats are transported downstream to receiving stream channels and/or lagoon basins. They can form channel-blocking dams where they accumulate on riparian vegetation or bridge infrastructure. This poses both flooding risks to adjoining areas, and impact risks to the stream channel and built infrastructure (M8).

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Continue and enhance the RMA program to reduce aquatic weeks at Collinson's Lagoon. BSC to communicate with landholders adjoining the western lagoon system and creek channel upstream from

Rose Road to seek interest in joining the RMA-supported program, thereby extending it to these areas.

2. Stakeholders to schedule seasonally-stratified inspections, including trialling aerial drone monitoring of the Collinson's Lagoon system's weed infestation status. Identify opportunities for proactive and preventative weed spraying interventions that target weeds ahead of 'control problems', namely, before substantial edge infestations of aquatic grasses or extensive mats of floating weeds form. Strategically timed intervention potentials include:
   I. following the cessation of late dry season grazing;
   II. immediately after any channel-opening excavator clearing or weed harvesting operations, and
   III. immediately following wet season high flow spates and flushes of the system.
3. Implement a catchment-based line of control 'partial-eradication' approach for floating aquatic weed species, like water hyacinth and water lettuce. For example, within the lagoon system and tributary creek and constructed channel system, plan to follow a high-flow flushing event to eradicate floating weed reinfestation sources from the top of the catchment downstream, with two or more closely repeated control events. Given the accessible size of the system, drones could be employed for identifying post-flood flow weed refuges, and for chemical control and monitoring.
4. Move from favouring chemical control towards physically removing persistent weed chokes and floating weed refuges via a weed harvester, excavator (including amphibious), and weed conveyor as an annual/biannual part of the weed management program.
5. Actively monitor controlled grazing condition outcomes to guide the weed management program operator, grazing stakeholder engagement, and inform management decision making. This action includes integrating other control methods and focussing on targeting grazing pressure (see *Grazing regime* section).
6. Trial proactive and innovative aquatic weed and in-channel vegetation management arrangements for large tailwater drains within the BHWSS. These actions should be delivered within the scope of mitigating impacts to downstream receiving environments in terms of flood, and other hydrological and water quality risks.
7. Incorporate the use of grass selective herbicide after late dry season grazing pressure has ceased. This will help beneficial native herbaceous perennials to dominate the wetland margins.

Table 2. Aquatic weeds of Lower Burdekin wetland systems

Common name (* = native)	Genus species	Growth form, habit, and main impacts	WONS	Queensland *Biosecurity Act 2014* category	Priority target weeds of BSC's *Aquatic Weed Management Plan 2020-2025*	Management methods and notes
Water hyacinth	*Eichhornia crassipes*	Floating species. Forms rafts that get colonised by other emergent and surface scrambling species. particularly aquatic grasses. Large infestations cover the water surface of lagoons and channels and create anoxic (no dissolved oxygen) reaches and fish passage barriers. Blocks channel flows, increases flood risks and creates mosquito breeding habitat.		3	X	Physical (weed harvester, rake excavator), registered chemicals and biological (weevils). Raft concentration (i.e., culvert gates) and catchment isolation methods are potentially useful. Nutrient removal via harvesting.
Water lettuce	*Pistia stratiotes*	Floating species. Floating plant with similar habit as water hyacinth. Contributes to mixed species floating weed mats.		3	X	Physical (weed harvester), biological (weevil) and registered chemicals. Nutrient removal via harvesting.
Salvinia	*Salvinia molesta*	Floating species. Prefers still water. Covers and shades the water surface and contributes organic loading, decreasing dissolved oxygen levels.	X	3	X	Registered chemicals and biological (weevil). Nutrient removal via harvesting.
*Azolla	*Azolla spp*	Floating species. Prefers still waters. Floating plant with similar habit and potential impact to salvinia. Indicative eutrophication.		Not categorised		Physical – water quality management – indicative of high nutrients.
Para grass	*Urochloa mutica*	Emergent aquatic grass. Occurs in dense monocultural stands in moist drainage depressions and riparian vegetation understorey. Extends onto and binds floating weed mats. Shades shallows, excludes native aquatic plants, block channels, suppresses native vegetation recruitment, introduces high fire fuel loads into riparian zones, contributes high organic loading, depletes dissolved oxygen levels.		Not categorised		Physical (rake excavator), registered chemicals and grazing. Implementation of effective grazing systems including the use of water level drawdown is key to the management of this species.
Hymenachne	*Hymenachne amplexicaulis*	Emergent aquatic grass. Occurs on a bank edge zone and grows into water ~2m deep. Extends onto and binds floating weed mats. Similar suite of impacts to para grass but extends into deeper water and not as far up bank onto levees.	X	3	X	Physical (rake excavator), registered chemicals and grazing. Use of haloxyfop down to the water line will protect the natural recruitment of native macrophytes and trees.
Aleman grass	*Echinochloa polystachya*	Emergent aquatic grass. Occurs on a bank edge zone and grows into water ~2m deep. Extends onto and binds floating weed mats. Blocks channels. Outcompetes native aquatic plants on bank edge and shallows zones.		Not categorised		Physical (rake excavator), registered chemicals and grazing. Use of haloxyfop down to the water line will protect the natural recruitment of native macrophytes and trees.
*Rice grass	*Leersia hexandra*	Emergent aquatic grass. Extends onto and binds floating weed mats, forms major infestation in deeper waters of lower catchment bunded drainages.		Not categorised		Physical (rake excavator and/or weed harvester), registered chemicals and grazing. The effectiveness of the weed harvester on this species has not yet been assessed. Good waterfowl habitat.
*'Water green'	*Ipomoea aquatica*	Emergent/floating aquatic vine. Occasionally extends onto and binds floating weed mats.		Not categorised		Physical – not generally a significant problem unless part of the weed mat. Good habitat.

*Cumbungi	*Typha domingensis*	Emergent bull rush. Occurs in the water edge zone in most of the catchment but forms major infestations in lower catchment bunded drainages. Blocks channels, creates anoxic reaches/fish passage barriers due to high biological oxygen demand (BOD) of accumulated organic material. Decreases native plant diversity and waterbird habitat.		Not categorised		Registered chemicals, potentially water level manipulation and physical (burning, harvesting), i.e., removal of root stock with an excavator. Prevention of tailwater inflows/draining to create seasonal drying has been demonstrated to be very successful.
*Hornwort	Ceratophyllum *demersum*	Submerged aquatic. Forms dense non-rooted submerged beds. Causes depletion in dissolved oxygen values below levels lethal for aquatic organisms/fish during summer night-time respiration and/or turbid wet season inflows.		Not categorised		Physical – weed harvester, shading, water level manipulation, pump foot valve protection. Good habitat.
Cabomba	*Cabomba caroliniana*	Submerged aquatic. Cabomba is an aggressive perennial that can form dense canopies below the water surface. Infestations displace native plants and animals, affect water quality, and impede recreational water users.	X	3	X	Only recorded from Healey's Lagoon. Mechanical control – hand-pull small infestations, taking care to remove the entire plant to prevent re-infestation. Use harvesters on larger areas for temporary control. Herbicide control – Carfentrazone is currently the only herbicide registered for control of cabomba.
*Giant lotus	*Nelumbo nucifera*	Emergent lily bed. Mainly recorded from more seasonal sub catchment wetland reaches. Emergent plant of bank edge grows in water ~2m. Can block channels, and creates a foundation for accumulation of floating weed mats.		Not categorised		Registered chemicals, potentially water level manipulation and physical (harvesting, cutting). Good habitat.
*Umbrella sedge	*Cyperus exaltatus*	Emergent sedge aggressive secondary coloniser on floating 'platforms' weeds. Occurs throughout the creek system in the water edge zone, but forms extensive occurrences in moist margins and depressions of lower catchment-bunded drainages.		Not categorised		Registered chemicals, potentially water level manipulation and physical (harvesting, cutting) – not a major problem. Good habitat.
*Smart weed	*Persicaria decipiens*	Emergent plant that occurs in moist drainage depressions and riparian vegetation zones and extends onto and binds floating weed mats. Forms mono cultural stands usually in response to grazing pressure.		Not categorised		Registered chemicals, physical – not generally a significant problem unless part of weed mat. Good habitat.

Table 3. Emerging aquatic weed risk species of the Collinson's Lagoon system

Common name	Genus species	Growth form, habit, and main impacts	WONS	*Queensland Biosecurity Act 2014* category	Management methods and notes
Arrowhead 	*Limnocharis flava*	An anchored aquatic plant with erect stems that grows in saturated, fertile, and muddy conditions as a perennial plant in areas with sufficient moisture. Can also be annual where moisture is seasonal. Plants grow up to 1m above the waterline. Colonises shallow wetlands and margins of deeper waterways. Blocks channel flows, traps silt, increases flood risks, creates mosquito breeding habitat, reduces access to waterways and displaces native plants and animals. Has been recorded in the Townsville local government area.		2, 3, 4 & 5	No herbicides are registered to specifically control limnocharis and there are no known biological control agents. *Queensland Biosecurity Act 2014* requires that new infestations must: • be reported to Biosecurity Queensland on **13 25 23;** • be identified and removed by approved officers, and • have locations recorded prior to removal. Classed as very high risk in *Burdekin Shire Council Biosecurity Plan* (BSC 2020).
Sagittaria 	*Sagittaria platyphylla*	Emergent aquatic perennial up to 1.5m tall. Grows in irrigation channels, drains, creeks, rivers, lagoons, dams, and wetlands. Establishment favoured by slow moving or static shallow water. Forms floating mats, blocking irrigation ditches, shallow dams, and waterways. Invades and degrades natural wetlands. Competes with native water plants. Has been recorded in the Townsville local government area.	X	3	No herbicides are registered to specifically control sagittaria. Off-label use permits PER80934 allow for the use of glyphosate as a foliar spray. Control is best carried out when water levels are low. Hygiene and containment measures need to be applied to prevent further spread downstream. Mechanical control – place all removed plant material in a sealed plastic bag, leave in sunlight to decompose, then dispose of at council-approved landfill. Alternatively, leave material in the sun to dry, then burn. Classed as very high risk in *Burdekin Shire Council Biosecurity Plan* (BSC 2020).
Water mimosa 	*Neptunia oleracea*	Floating perennial weed that attaches to a bank at the water's edge. Stems to 1.5m long, grow out over water and form spongy, fibrous covering between nodes. Grows on land in damp soil or on water as thick floating mats. Commonly found in and around freshwater pools, swamps, and canals. It is a nitrogen-fixing legume that releases nitrogen into water bodies. This can lead to increased algal blooms and encourage growth of other weeds. Restricts water flow and increases water loss through evapotranspiration. Smothers water surface, shading out native aquatic plants, leads to deoxygenated water and impacts fish populations and creates mosquito habitat. Has been recorded at Saltwater Creek in the Burdekin local government area.		2, 3, 4 & 5	No herbicides are registered for control and there are no known biological control agents. Mechanical control – Remove all plant matter from infested water bodies and pull plants out of surrounding banks, making sure to remove the attached root system. Dispose of plant parts in an appropriate waste facility or rubbish bin. Water mimosa is a restricted invasive plant under the *Queensland Biosecurity Act 2014.* • All sightings must be reported to **Biosecurity Queensland** within 24 hours of the sighting. • It must not be given away, sold, or released into the environment without a permit.

		Has been subject to sale and distribution through Asian communities and gardeners.			Classed as very high risk in *Burdekin Shire Council Biosecurity Plan* (BSC 2020).

Water quality

What are the issues and state of knowledge?

Water quality in seasonal Lower Burdekin floodplain wetlands is naturally variable through the year. Under natural pre-development conditions, water quality in distributary stream systems and their hosted wetlands transitioned from turbid floodplain-inundating flows in the wet season, settling and clearing into the non-flow period of the early dry season, and then interacting with groundwater that maintained perennial lagoons during the water level drawdown period of the late dry season (Perna *et al* 2012). Seasonal 're-setting' of water quality would then follow with wet season rainfall leading to local catchment run-in, then flow initiation, and – in larger events – Burdekin or Haughton River overbank flushes down distributary systems (Davis *et al* 2017). In seasonal drying wetlands, water quality generally progressed through to the clearing phase, and then into a critical period with higher temperature and turbidity and lower dissolved oxygen, prior to drying.

In the contemporary, modified floodplain system, wetland water quality is largely driven by the condition of sourced Burdekin or Haughton River water supplying irrigators via regulated creek flows; aseasonal inflows of farm irrigation tailwater (BHWSS) channel overflow; the condition of creek reaches, particularly their weed infestation status, and by the quality and contaminant load of surface and groundwater inflows from their catchment.

Some of the processes and key drivers of water quality associated with predevelopment hydrological conditions no longer occur as frequently, in the natural seasonal period, or at all. For example, flow cessation, dry season water level drawdown, groundwater domination of inflows, Burdekin/Haughton River overbank flood flow flushing and scouring (Perna *et al* 2012). However, even under the contemporary modified regime, wetland water quality still undergoes major seasonal variation with the early summer wet season, including pre-flushing flow or flood inundation, being identified as the period of greatest water quality stress for hydrologically modified systems (Burrows *et al* 2006, Veitch, *et al* 2007).

Photo 21. The RMA-supported aquatic weed control program has helped to avoid chronic water quality degradation from surface-covering floating weed mats over the past 15 years. Yet there are still water quality challenges for areas in the lower main lagoon system adjoining the highway. These risks are from the ongoing spray-based control of aquatic grass margins in the form of low dissolved oxygen and high nutrients.

Photo 22. An algal bloom indicative of high nutrient availability at the main lagoon system's outflow at the old highway crossing. Water quality monitoring at this site has recorded nutrient levels several times higher than recommended by Queensland Water Quality Guidelines (QWQG) for the maintenance of aquatic ecosystem health, including ammonia levels approaching toxic thresholds for fish (Table 4 – Zone C).

Very few sites within the Lower Burdekin floodplain have been the subject of regular water quality monitoring programs, and those conducted by industry groups or government agencies are often subject to privacy non-disclosure provisions. Therefore, our state of knowledge is mainly informed by studies examining water quality issues more generally across the floodplain. Also, it focuses on selected drainages, and has been part of specific fish habitat and weed management investigations (Burrows *et al* 2006, Davis *et al* 2013, 2014, 2017, Veitch *et al* 2007, Loong *et al* 2005, Perna 2005, Pearson *et al* 2003, Hunter *et al* 1998, Hunter *et al* 1996, Keating *et al* 1995).

Data collected in the Lower Burdekin and broader GBR catchment is available at:
https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/modelling-and-monitoring

https://qgsp.maps.arcgis.com/apps/MapSeries/index.html?appid=9d1aad1e2b444ec6a1890e4032284147

Fortunately, some site-specific water quality investigations have been conducted within the Collinson's Lagoon system (Table 4). These include monitoring following weed harvesting and subsequent spraying operations within three defined zones of the main lagoon system (Loong *et al* 2009), and over several years of spray-based weed control efforts in the lower system within Lochinvar Station (Waltham and Fixler 2017).

Water quality risks to aquatic ecosystem health identified for the Collinson's Lagoon are consistent with those recognised more broadly for the Lower Burdekin floodplain, including downstream receiving environments, such as the Cape Bowling Green Bay Ramsar wetland and the GBR World Heritage Area. These issues include:

- low dissolved oxygen (DO);
- high turbidity/total suspended solids (TSS);
- elevated nutrient levels;
- agri-chemical residues, and
- salinity.

Generalised water quality issues identified for different reaches of the Collinson's Lagoon system are presented in Table 5. The drivers/likely causes, potential impacts, and data and management notes for these issues are summarised in Table 6. Specific considerations for this system management plan are discussed below.

Photo 23. Pioneer Sugar Mill's industrial land use in the upper easternmost catchment of Collinson's Lagoon system. Stormwater from the mill grounds, including bagasse and mill mud storage areas (Photo 24) – which potentially has high biological oxygen demand (BOD) – drains to a system confluence within the Lochinvar Station reach (Photo 20, 88, 89).

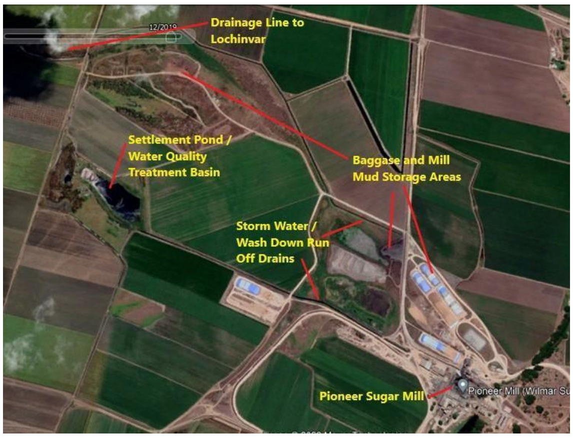


Photo 24. Pioneer Sugar Mill layout in the upper easternmost catchment of the Collinson's Lagoon system. The main stormwater drain is routed via a settlement pond (Figure 7) that provides some water quality treatment capacity. There is no other active management of wetland ecosystem function or habitat value risks in this part of the catchment.

WQ parameter	units	QWQG	WQ Zone A	WQ Zone B	WQ Zone C
True Colour	TCU		15	16	22
Total Nitrogen (TN)	µg N/L	350	683	2637	1146
Total Filterable N	µg N/L		570	626	1066
Ammonia	µg N/L	10	1	2	510
Nitrite	µg N/L		1	2	2
Nitrate	µg N/L		6	12	5
NO_X	µg N/L	10	7	14	7
Total Phosphorus (TP)	µg P/L	10	68	372	221
Total Filterable P	µg P/L		42	39	219
Filterable Reactive P	µg P/L	5	32	26	178
Particulate N (PN)	µg N/L		113	2011	80
PN proportion of TN			0.165	0.763	0.07
Dissolved Organic N (DON)	µg N/L		562	610	549
NO_X proportion of TN			0.01	0.005	0.006
Particulate P	µg P/L		26	333	2
Dissolved Organic P (DOP)	µg P/L		10	13	41
TN:TP Ratio			22.211	15.675	11.467
DIN:DIP Ratio			0.553	1.361	6.423

Table 4. Recorded water quality nutrient levels from three water quality zones within the main Collinson's Lagoon system (Loong *et al* 2009). Unhighlighted red values are Queensland Water Quality Guidelines (QWQG), and yellow-highlighted red values are recorded site exceedances.

System specifics

Where discussion relates to management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (M or W) number is referenced.

Under its natural pre-development condition, the Collinson's Lagoon system's water quality was seasonally variable, as described for a typical floodplain waterbody above. Catchment run-in and/or inundating floodplain flows filled the system with turbid water during the wet season. Following wet season flows, suspended solids settled, and the water cleared, typically to a dark tannin-stained colour (Photo 15). Nutrient loads delivered to the system with wet season run-in were processed and taken up by riparian vegetation, and instream and fringing aquatic plant and associated microbial communities. During dry season water level drawdown, some aquatic plant biomass would be removed from the water column by being stranded on exposed banks. The perennial nature of a subset of lagoons upstream and downstream of the highway would also suggest groundwater connectivity had an influence on natural water quality (Perna *et al* 2012).

During the development of the Burdekin River Irrigation Area (BRIA) in the early 1990s, irrigation scheme tailwater drains were routed into the headwaters of the Collinson's Lagoon system (Photo 1). These tailwater drains convey catchment runoff, farm irrigation tailwater, and supply channel overflow from the BHWSS area. As identified in the *Altered hydrology* section, inflow volumes from the BHWSS tailwater drainage scheme to the system are substantial and 'aseasonally' extend into the dry season period, which historically was a time of clearing water quality and receding water levels. Due to the usually turbid nature of Burdekin River source water, tailwater discharging from the BHWSS is typically turbid (Photo 25, 26). Depending on the proportion that is farm irrigation runoff versus supply channel overflow, it contains varying elevated loads of nutrients (M20). Even where nutrient loads are not highly concentrated in scheme tailwater, the throughput volume received by the Collinson's Lagoon system has nutrient loading much higher than the system would have received naturally. Downstream of BHWSS inflows, local farming catchments also contribute irrigation tailwater to the system (Photo 4) and potential nutrient and agri-chemical residue contaminant loads. These can also enter the system via groundwater connectivity.

Turbidity is itself a water quality impact for a system with ecology and dependent biotic communities adapted to clear water throughout the dry season, including visual predator fish and filter feeding aquatic insects. However, under modified hydrological conditions, sustained turbidity can mitigate the low dissolved oxygen level risks associated with clear water and excessive submerged plant growth (Photo 27, 29).

Prolific growth of floating and aquatic grass weeds, or dense cumbungi stands; channel weed chokes with water surface and edge-covering weed mats (Photo 16, 17; Figure 5); and algal blooms and associated high 'biological oxygen demand' (BOD) organic loading, all create low dissolved oxygen level water quality impacts. These impacts affect ecosystem health, fish passage, and habitat suitability. Chemical control of aquatic weeds can exacerbate dissolved oxygen impacts and nutrient load drivers of aquatic weed infestation, as sprayed weed biomass with high BOD sinks, decomposes, and returns organic nutrients to the water column (Photo 28).

The largest 'main' lagoon within the Collinson's Lagoon system is in a sub-catchment off the main channel that conveys irrigation scheme tailwater (Photo 26). Depending upon flow heights and weed chokes at the confluence of the main lagoon with the main drainage channel, it usually retains clear water (M19) relative to typical tailwater flows (Photo 25). This has positive consequences for its native aquatic plant community, but presents risks for its dissolved oxygen status (Photo 27, 28).

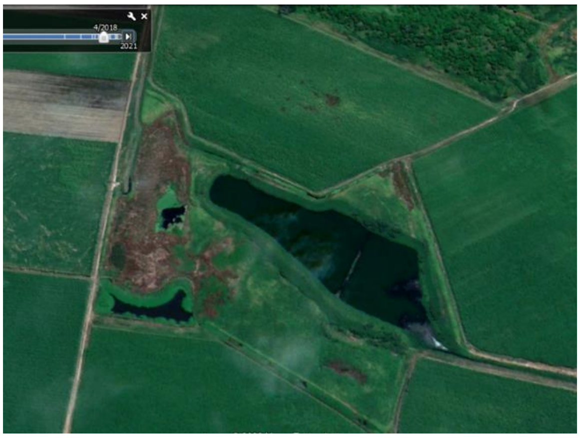
Photo 25. BHWSS RB1/1 tailwater drain (foreground) with a typically high level of turbidity.

Photo 26. Contrast in water turbidity apparent between the dark clearwater of main Collinson's Lagoon (top right) partially isolated from BHWSS tailwater inflows, and turbid lagoons and waterholes on main tailwater inflow channel (left).

Oct - 2013. Pond overgrown and inflow channel occluded by para grass growth; circumventing drain excavated. Open water in cumbungi polishing area (left). Blackwater in outflow channel.

Feb - 2016. Summer algal bloom indicative of high nutrient availability, also within a smaller pond (left). Internal partitions within the pond are visible.

Aug - 2017. Dark blackwater indicative of high organic loading with a high BOD.



Apr - 2018. Cumbungi died off (brown left) from the preceding dry season. Water in the exit drain is less dark/lower load than the tail of the pond.

Jul - 2019. Turbid water potentially indicative of a recent run-in event or alternatively an algal bloom. Darker water inflow at the head of the pond. Water in the exit drain is the same as the tail of pond.

Dec - 2019. Dry season lower water level. Surface encrustations (precipitates) on exposed substrate at tail of pond. Secondary pond dry. Cumbungi died back.

Figure 7. Water quality and condition status of the Pioneer Mill settlement pond within the easternmost upper catchment of the Collinson’s Lagoon system 2013-2019. Preliminary examination of the settlement pond’s operation and the management of the receiving wetland system suggests that there is considerable scope for improving design and management to reduce water quality risks to downstream wetland ecosystems (M27, M30).

Photo 27. A consequence of the greater water clarity of the main Collinson's Lagoon (Photo 26) is the retention of native water lilies, and the proliferation of native submerged aquatic plants (between lilies). Night-time respiration of this submerged plant biomass crashes dissolved oxygen below levels critical to fish and aquatic ecosystem health.

Photo 28. Surface algal growth throughout the main Collinson's Lagoon is indicative of elevated nutrients. Potential sources include tailwater inflows, connected groundwater, and nutrients released from sprayed, decomposed aquatic weeds. The open waterbody in the central lagoon is critical for maintaining dissolved oxygen above critical ecosystem thresholds.

Photo 29. Turbid water conditions within the western lagoon system downstream of drain RB1/0. Although this site sometimes clears along with clearer BHWSS-sourced river water in the late dry season, generally high turbidity limits instream native plants establishing. It also reduces dissolved oxygen cycling risks associated with clear water (Photo 27).

Photo 30. Near natural water quality within a 'perched' wetland within a BHWSS habitat remnant. Wetlands isolated from tailwater inflows that retain near-natural water quality and seasonality are a rare habitat resource on the contemporary floodplain and worthy of biodiversity conservation investment efforts.

Photo 29. Pioneer Mill bagasse storage areas in the upper eastern catchment of the Collinson's Lagoon system. Runoff from these areas has a potentially high biological oxygen demand (BOD).

Photo 30. A rare section of open water within the lower eastern catchment. This part of the system is dominated by dense cumbungi stands and other aquatic weeds; has limited through flow; high organic loading, and anoxic water. Improved wetland condition in this sub-catchment could deliver water quality benefits for the downstream receiving system.

Table 5. Generalised water quality issues for Collinson's Lagoon system reaches

Reach section	**Water quality issues/observed reach conditions**
BHWSS tailwater drains upstream of Sayers Road.	Sustained high turbidity (colloid levels) and elevated nutrients. Periodic aquatic weed (grass and floating) infestation, controlled by spraying. Can create anoxic, low dissolved oxygen conditions.
Excavated creek channel upstream of Rose Road.	Generally, reflects BHWSS tailwater drain inflow water quality (above). Open waterbody and flow usually maintained by excavators. Likely low dissolved oxygen level issues associated with periodic channel blocking and sustained edge infestation of aquatic grasses. When open channels are maintained, low DO risks are not high due to limited submerged plant biomass.
Main lagoon system – large lagoon Zone A (central open waterbody).	Open, generally clear (tannin-stained) water with good air-water surface interactions and mixing. Deep, lacks submerged aquatic plants. Lower depths can drop below critical DO levels. Nutrient levels exceed Queensland water quality guidelines.
Main lagoon system – large lagoon Zone B (submerged aquatic plant-dominated margins).	Covered in water lilies with open areas in between dominated by dense stands of submerged native aquatic plants. Generally clear (tannin-stained) water with limited air-water surface interactions and mixing. Water is stratified, lower depths can stay below critical DO levels, while upper levels cycle below critical DO levels, due to night time respiration demand of submerged plants. Nutrient levels exceed Queensland water quality guidelines. Algal growth is common on the surface.
Main lagoon system – smaller lagoons on main drainage line Zone C (aquatic grass-dominated margins).	Covered in dense covering stands of exotic aquatic grasses, often with a proportion dead due to spray-based control activities. Generally turbid water with limited air-water surface interactions and mixing. Limited stratification, all depths can stay below critical DO levels. Nutrient levels exceed Queensland water quality guidelines. Anaerobic decomposition can generate high ammonia levels. Algal blooms on the surface can be generated in adjoining or downstream areas due to nutrient availability.
Western drainage line waterholes and lagoons downstream of RB1/0.	Generally, reflects BHWSS tailwater drain inflow water quality (above). Open waterbody and flow usually maintained by excavators. Likely low dissolved oxygen level issues associated with periodic channel blocking and sustained edge infestation of aquatic grasses. When open channels are maintained, low DO risks are not high due to limited submerged plant biomass.
Eastern catchment cumbungi-dominated distributary channels.	Generally, closed waterbodies covered in dense stands of cumbungi. Open areas with cumbungi are usually covered in other floating aquatic weed species. Water clear, very dark, apparent high organic loads, unmonitored, but likely low dissolved oxygen levels. Nutrient status unmonitored, but algal blooms would suggest high availability on top of the system. Nutrient processing in the lower system is unknown. Anoxic conditions could generate ammonia. If not too anoxic, nitrate stripping could be operating.
Bunded coastal drainage depressions (Lochinvar).	Large open (no tree cover) wetland basins with deeper basin sections periodically subject to floating aquatic weed infestations, and shallow margins are exotic aquatic grass dominated. Organic loading (including from weed control) and high water temperatures generate low DO risks. When open water is present, DO levels cycle above critical low thresholds. Warm shallows, and exotic grass/floating aquatic weed mat-dominated, sections have critical low DO with no cool/high DO refugia. In open deeper areas with water surface, wind and air interactions provide only higher DO refugia. High nutrient availability, algal blooms can occur.

Studies of water quality in the main Collinson's Lagoon system identified that the central open waterbody (Zone A) experiences air-water surface interactions and mixing that is critical to maintaining dissolved oxygen levels above critical ecosystem thresholds required by fish and other biota (Loong *et al* 2009). This highlights the importance of the ongoing floating aquatic weed control program. Other water quality zones also suffered severe dissolved oxygen levels. Namely, Zone B was open, but dominated by submerged aquatic plants and had day-night cycling DO levels tipping below critical thresholds; while Zone C was characterised by broad, dead, sprayed aquatic grass fringes, and had dissolved oxygen levels that stayed below critical ecosystem thresholds and had near-toxic levels of ammonia. These findings underpin the need to better control the extent of aquatic grass infestation of lagoon margins and, ideally, to employ other methods of control besides chemical spraying (see *Aquatic Weeds* section).

An area of the broader system where water quality monitoring data is not readily available, yet water quality risks are apparent, is the upper eastern catchment. The Pioneer Sugar Mill in the eastern-most portion of the catchment represents an industrial land use which is shared with the adjoining Sheep Station Creek catchment (Econcern 2021). Stormwater runoff from the mill's grounds, which include bagasse and mill mud storage areas (Photos 23, 24, 29), present a likelihood of high BOD organic loads (M27). Wetland condition within the receiving system is characterised by dense cumbungi stands, limited open water, high organic loading, and apparently anoxic water (Photo 30). A settlement pond/treatment wetland is incorporated in the drainage network draining the mill runoff area (Photo 24). Aerial photo interpretation of its operation through time (Figure 7), would suggest that there are limitations in its configuration and operation. Limitations include cell divisions being inundated by high flow levels, and a bypass channel periodically circumventing a cumbungi bull rush tailwater polishing cell (M30). Water quality conditions observed lower in the receiving system (Photo 88, 89) also suggest that high organic nutrient loads may still be getting exported to the downstream system, which encompasses wetlands that are matters of state environmental significance and – further downstream – the internationally-significant Cape Bowling Green Bay Ramsar wetland. Investment in improving the functional design and treatment capacity of the Pioneer Mill settlement pond/treatment wetland and the condition of the receiving wetland system; including creating more open water, through-flow, and less anoxic conditions; could deliver water quality and other ecosystem health benefits for the downstream receiving system.

The large tailwater drains of the BHWSS present another opportunity for water quality treatment within a drainage system. Currently these drains are periodically cleared of their aquatic plant growth (primarily aquatic grass weeds) by chemical spray-based control and returned to a 'clean' drain condition. Intervening periods between drain weed control can see dense grass mats and anoxic water quality condition establish. These same weed mats can present downstream flooding risks if mobilised in a high flow spate. Given the capacity of these tailwater drains, there could be an opportunity to establish native aquatic plant vegetation such as spike rush communities within them without significantly impacting the hydraulic capacity of the drain. Such vegetation could provide water quality benefits in terms of nitrate stripping and some suspended sediment attenuation.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Implement *Altered hydrology* section recommendations to reduce the principal driver of water quality degradation within the system.
2. Engage system management stakeholders to pursue *Aquatic weed* section recommendations to reduce the secondary driver of water quality degradation.
3. Engage system management stakeholders to pursue *Lack of riparian vegetation, Fire regime* and *Grazing regime* section recommendations to increase the resilience of the system to secondary water quality impacts. Also, communicate the underlying elevated nutrient driver of aquatic weed infestations to cane producers, and the need to reduce off-farm export of nutrients and tailwater. Specific topics include discussing on-farm Best Management Practices for fertiliser use and irrigation, tailwater recycling, wetland treatment trains, and runoff detention management.
4. Engage with BHWSS drainage system managers to change the dominant vegetation from exotic aquatic grass stands to a mixed, open water, native spike rush/bullrush community to treat water quality in situ by reducing nitrates and attenuating colloids. This could reduce downstream water quality impacts, including the problematic export of flow-blocking weed mats downstream during flood spates (M17).
5. Engage with Wilmar owners of the eastern catchment drainage network to reconfigure the existing settlement pond into a wetland treatment train that can avoid downstream exports of contaminant loads and water quality impacts (W21).
6. Engage with Wilmar owners of the eastern catchment drainage network to develop a water quality monitoring investigation of the cumbungi-dominated receiving reaches of the lower system. These results would inform wetland condition management to lower system water quality risks. It could be delivered as part of an integrated habitat restoration program for the eastern catchment distributary drainages (see *Lack of riparian vegetation* and *Grazing regime* sections).

Table 6. Lower Burdekin floodplain water quality issues

Issue	Drivers/likely causes	Potential impacts	Data and management notes
Low dissolved oxygen	• Aquatic weed infested waterway reaches are promoted by near-perennial regulated flows/sustained water levels and high nutrient availability. • Biological Oxygen Demand (BOD) associated with bacterial decomposition of organic material produced or trapped by aquatic weeds, including grass margins inundated by higher wet season water levels. • Night-time or turbid inflow-promoted respiration of submerged aquatic plants and attached periphyton. • Prevention of instream photosynthesis/oxygen production by turbidity/weed shading. • Prevention of aeration of the water surface due to weed covering. • High BOD of organic loads in catchment run in during wet season. • Deoxygenated groundwater inflows • Lack of river overbank flooding flushes in the wet season. • Lack of riparian shading/higher water temperatures.	• Fish kills. • Anoxic stream reaches that function as fish passage barriers. • Deoxygenated 'blackwater' flows to downstream receiving environments, including upper reaches of estuaries. • Reductions in instream productivity, biodiversity (including aquatic macroinvertebrates) and fishery resources. • Increased solubility and mobilisation of nutrients in sediments.	Issue well documented by site specific and regional catchment studies (Perna 2003, 2004, 2005, Loong *et al* 2005, 2006, Burrows *et al* 2006, Veitch and Tait 2007). <u>Management needs/opportunities</u> • Reduced aquatic weed and submerged plant biomass. • Greater riparian shading. • Reduced instream nutrient availability. • Reduced BOD/organic loading in catchment run in. • Targeted monitoring to increase understanding of specific issues, including: ○ Impact of aseasonal flow cessation and water, clarification on DO levels through lagoon system ○ role of BOD load in catchment run in on DO status, ○ DO levels through and downstream of weed-choked (including cumbungi) channel areas, including under different flow conditions up to and including wet season flows of different magnitude.
Turbidity	• Mean annual total suspended solid (TSS) loads underpinning turbidity have increased, on average, six-fold in GBR catchment rivers since European settlement. • Burdekin Falls Dam receives turbid wet season flood flows and has minimal colloidal settlement. • Irrigation supplies pumped from Burdekin River flows supplied from persistently turbid Burdekin Falls Dam. • Catchment soil erosion and sediment loads carried in local catchment surface runoff influences turbidity levels during wet season.	• Multiple times the natural run-in loading of receiving water bodies with attached nutrients. • Reduced instream primary productivity. • Reduced submerged water plant diversity and density. • Reduced success of visual predator fish and impacts to sensitive aquatic invertebrates (for example, filter feeders).	Issue well documented at a regional scale with few catchment studies (Perna 2003, 2004, Davis *et al* 2014, 2017). <u>Management needs/opportunities</u> • Few management options exist for turbidity imported with Burdekin River water for BHWSS. • Management of BHWSS in-drain vegetation condition, including promoting native emergent macrophyte communities (spike rush), could provide increased attenuation of fine colloid and suspended sediment loads.
Nutrient loading	• Nutrient load attached to colloids in irrigation supplies pumped from turbid Burdekin River.	• Eutrophication (nutrient pollution) of waterway.	DES is currently establishing real-time monitoring stations on regional creek systems. Regional and site monitoring has recorded Burdekin Wetland concentration exceedances well

Issue	Drivers/likely causes	Potential impacts	Data and management notes
	• Catchment land and water use practices that result in off-farm/property losses (including via groundwater flows) of nutrients, for example, on farm fertiliser use, irrigation tailwater, and post-harvest runoff of high BOD sugar. • Organic nutrients released from decomposing aquatic weed and submerged plant biomass, for example, following weed spraying and during elevated wet season flows. • Wet season local catchment run-in of sediment and attached and dissolved nutrient loads. • Mobilisation of nutrient loads accumulated in bottom sediments (particularly when water becomes anoxic).	• Promotion of aquatic weed/submerged plant growth and associated impacts. • Algal blooms, dissolved oxygen crashes, and fish kills. • Export of elevated nutrient loads to downstream-receiving environments, for example, Ramsar wetland and GBR lagoon.	above ecosystem health guidelines (Perna 2003, 2004, Loong *et al* 2005, 2009, Davis *et al* 2013. 2014, 2017). <u>Management needs/opportunities</u> • Improve on-farm/property practices, for example, fertiliser application rates and practices and irrigation scheduling and volumes. • Remove and/or control of aquatic weed and submerged plant biomass. • Promote riparian vegetation buffers and emergent aquatic plant stream margins with nitrate stripping/uptake functions. • Design farm drainage systems to provide nutrient interception and processing capacity including riparian and aquatic vegetation, detention and recycling basins and controlled rates of runoff/discharge.
Agri-chemical residues	• On-farm use and practices that lead to off-farm losses, including inadequate chemical storage and application methods; timing, especially in relation to rain and irrigation events, and conditions; and wash down and irrigation practices. • Off-farm movement via irrigation tailwater, groundwater accession and rainfall runoff. • On-stream use for aquatic weed control.	• Direct lethal effects on periphyton and phytoplankton. • Long-term, low-dose pesticide exposure can produce effects in freshwater organisms after several generations affecting growth, metamorphosis, locomotor activity, antipredator behaviours, immune capacity, infections, and gonadal condition. • Sublethal effects on endocrine systems of fish and endocrine disruption in amphibians. • Export of pesticide residue loads to downstream receiving environments. For example, Ramsar wetlands and GBR lagoon present impact risks to mangroves, seagrass, algal endosymbionts in corals and benthic microalgae.	Issue documented regionally, including in adjoining drainages, regional groundwater and at Burdekin farm drainages. Previous monitoring of floodplain creek systems has recorded concentration exceedances above ecosystem health guidelines for both low and event flows. Research indicates mixed pesticide residues produce impacts equivalent to higher concentration (Davis *et al* 2013, 2017, Hunter *et al* 1998, Hunter *et al* 1996, Keating *et al* 1995). <u>Management needs/opportunities</u> • Improved on-farm/property practices, for example, pesticide application rates and use timing in relation to rain and irrigation events; irrigation methods, and applied volumes. • Increase use of recycle pits and treatment wetlands. • Real time monitoring and reporting at paddock/sub-catchment scale to tie results to practices. • Design farm drainage systems to provide contaminant load interception and processing capacity, including riparian and aquatic vegetation, detention and recycling basins and controlled rates of runoff/discharge.
Salinity	• Rising saline groundwater contaminating adjoining aquifers and/or discharging to surface water features.	• Physiological stress or death of freshwater biota or exposed terrestrial vegetation.	Emerging management issue for BHWSS and near coastal areas. <u>Management needs/opportunities</u> • Reduce accession surface water to groundwater.

Issue	Drivers/likely causes	Potential impacts	Data and management notes
	• Marine saltwater intrusion into coastal freshwater wetlands or aquifers promoted by high(er) sea levels or drawn-down freshwater aquifers.		• Manage groundwater rise, potentially including dewatering bores and conjunctive use/discharge. • Bunding saltwater intrusion pathways and maintenance of hydraulic head for coastal freshwater aquifers. • Accommodate landward migration of coastal wetland mosaic.

Fish passage barriers

Fish movement needs

The Lower Burdekin floodplain’s native freshwater fish community (Table 7) needs to make a range of movements to fulfill life history cycles, and to distribute to suitable floodplain distributary creek and wetland habitats (Veitch *et al* 2007, Carter and Tait 2010).

The main classes of life cycle movement are:

- Resident – can complete life history at resident site.
- Potamodromous – needs to move within catchment to different freshwater habitats, for example, from pools to running riffles, gravel beds, or off-stream floodplain swamps.
- Amphidromous – young recruit from marine environments, but adults breed in lower freshwater.
- Anadromous – lives in both fresh and marine environments, but moves to freshwater to breed.
- Catadromous – lives in both fresh and marine environments, but moves to marine to breed.

Even resident species capable of breeding and recruiting juveniles without needing to move to different areas or habitats will still naturally undertake intra-catchment movements to distribute their population and colonise new areas. Potamodromous species are compelled to undertake intra-catchment movements within the wetland system to access required breeding and/or nursery habitats, for example, floodplain wetlands or flowing riffle reaches. Diadromous species are those that need to move between fresh and marine environments to reproduce and include the latter three of the life cycle types (listed above). Most diadromous species in tropical Queensland, including the iconic barramundi, are catadromous; meaning they spawn as adults in marine waters and, as juveniles, recruit back to freshwater habitats. In evolutionary time, all species – regardless of their life history cycle – need to be able to move within their range to maintain healthy gene flow between populations.

System specifics

Natural connectivity patterns

The timing of fish movement activity is very much influenced by the opportunistic framework provided by the wet season conditions under which they evolved, although there is some component of movement behaviour that is opportunistic, like attraction to flows. Historically, the distributary drainage systems of the Burdekin floodplain, such as those hosting Collinson’s Lagoon, flowed seasonally during the wet season and transitioned to a chain of isolated lagoons in the dry season. Fish passage connectivity was only provided when catchment runoff, floodplain inundation and/or Burdekin River channel flood outbreaks generated flow events.

Photo 31. An aquatic grass (para) and floating aquatic weed mat choke on lower Collinson’s Lagoon near the confluence with the western channel. Anoxic (low oxygen) water quality conditions around such features present fish passage barriers.

Photo 32. Exotic aquatic grass (para, hymenachne, aleman) dominating open drainage depression reaches in the lower system within Lochinvar Station. Both low dissolved oxygen and temperature maximums in these reaches exceed thresholds suitable to fish for seasonal periods.

These connective flows provided opportunities for resident species to recolonise seasonal habitats, and gave other life history types opportunities to access habitats required for successful breeding. In the case of catadromous species like barramundi, this involved movement of adults to estuary mouths to breed and the return movement of juveniles from coastal nursery swamps, such as those within the lowermost reaches of East Barratta and Lochinvar, to the main upstream lagoons.

Types of barriers

Seasonal hydrology, including waterhole water level draw drawdown and channel drying, was important for maintaining fish passage connectivity on the historical floodplain system. The drying out of distributary channels accompanied by grazing, and/or seasonal burning of standing grass biomass during the dry season, left open, bare channels ahead of the annual wet season's connective flows. Even within perennial waterholes, drawdown of water levels usually resulted in the stranding of much submerged and emergent aquatic plant biomass on lagoon banks. It would then dry, sometimes being burned in dry season fires, or alternatively form an organic layer on the soil surface, where it would decompose and be incorporated into the soil. When these lagoons were subsequently inundated by wet season flood flows, desiccated organic material was readily flushed downstream. The biomass of aquatic plants that had been retained through the dry season was small, relative to the full basin volume of inundated lagoons, and unlikely to pose a significant risk to water-dissolved oxygen levels via the BOD of decomposing material.

In the contemporary hydrologically modified floodplain, including the Collinson's Lagoon system, many of these conditions are no longer met. Floodplain distributary channels retain dry season connective flows, or seepage, that supports a large biomass of standing exotic aquatic grasses and/or cumbungi bulrushes. Lagoons remain near full supply level, supporting a massive standing biomass of submerged aquatic plants (where incident sunlight is present) and/or dense exotic grass margins. When this waterlogged system is inundated by turbid wet season flood flows, the large standing biomass of exotic grasses and submerged aquatic plants respire, then die, and decompose. The BOD of this process can be sufficient to create anoxic (no oxygen) reaches that act as water quality fish passage barriers to most species, other than those specifically adapted to low dissolved oxygen conditions. Such barriers only break down when the size of the flood flow is sufficient to overwhelm the BOD of decomposing material and/or to flush decomposing organic material through the system. Monitoring of the Lower Burdekin floodplain distributary creek systems' water quality and fish communities suggests that, for many systems, the magnitude of average annual wet season flows is insufficient to achieve fish passage water quality suitable connective flows. Further, for some modified systems, like Sheep Station Creek, connective flows of sufficient water quality to facilitate fish passage for the full suite of migratory fish species have not occurred for decades (Econcern 2021).

No significant physical barriers to fish passage have been identified within the Collinson's Lagoon system. While earth bunds do impound lower drainage depression reaches within Lochinvar Station (Photo 7, 8), they have low gradient walls, are inundated by elevated flows, and are readily passable by fish. However, available water quality and fish population monitoring data for Collinson's Lagoon indicate that there are water quality-related constraints to fish movement through the system, with a depauperate fish community recorded in some years as a result (Loong *et al* 2009). Sixteen freshwater fish species; including the iconic barramundi, three other estuarine breeding migratory species, and two exotics (Table 7); are recorded in the Collinson's Lagoon system. This condition is comparable or better than other Lower Burdekin Lagoon systems (Burrows and Davis 2009). However, prior to clearing floating aquatic weed mats from the system via an aquatic weed harvester in 2008, and a larger connective wet season flood in early 2009; only five to six species were recorded from the system. Two were estuarine breeding migrants that are adapted to withstand low dissolved oxygen, namely, empire gudgeon and tarpon (Loong *et al* 2009).

Water quality investigations around the time of the fish surveys indicated that decomposing para grass margins at the downstream end of the lagoon were generating low dissolved oxygen levels and almost toxic levels of ammonia, which would certainly present a water quality fish passage barrier (Loong *et al* 2009). Investigations of water quality conditions in relation to floating aquatic weed infestation levels and associated control efforts within Lochinvar's lower drainage depression reaches have also revealed temperature (thermal) maxima that regularly exceed threshold requirements for a range of species. Also, dissolved oxygen levels that were below critical thresholds for a range of species, particularly following spray-based control of extensive floating weed mats. Independent of floating weed mats and control impacts, extensive beds of aquatic grasses throughout these reaches are also known to create low dissolved oxygen water quality conditions that present fish passage barriers (Veitch and Burrows 2006, Burrows *et al* 2012).

The causes of these water quality fish passage barriers are multifaceted and include altered hydrology, elevated nutrients, weed infestation, and riparian vegetation condition (see *Altered hydrology, Water quality, Aquatic weeds, Lack of riparian vegetation*, *Grazing regime, Fire regime* sections). Management improvements to fish passage connectivity need to be integrated across these other issue management areas, where management opportunities have already been covered. These include:

- Reinstate hydrological seasonality to the system (water level drawdown, channel drying) (see *Altered hydrology* section).
- Prevent surface-covering aquatic floating and grass weed chokes establishing (see *Aquatic weeds* section).

- Reduce the elevated loads of nutrients entering the system (see *Water quality* section).
- Revegetate channel margins with shade canopy-forming riparian vegetation to exclude aquatic grasses from bank margins, reduce submerged aquatic plant biomass, cool water temperature, and increase water dissolved oxygen carrying capacity, and create dedicated fish refugia (see *Lack of riparian vegetation* section).
- Use a dedicated grazing regime, with or without an integrated fire regime, to reduce the dominance and cover of exotic aquatic grass species from wetland and channel margins (see *Grazing regime* and *Fire regime* sections).
- Focus system management efforts to deliver open drainage depression channels and aquatic grass-free lagoon margin conditions ahead of the annual wet season connective flow period.

Altered hydrology is likely to remain a feature of the system. Water quality fish passage barriers may continue to form in association with aseasonal flows and weed infestation outside the wet season. Year-round fish passage was not a natural feature of the system. Taking management actions to deliver system conditions to enable fish passage through the connective flows of the wet season may be an achievable goal. While all existing water quality and fish community data has been collected outside the wet season period, targeted monitoring of higher flow water quality conditions and fish movement patterns could more specifically inform management intended to secure fish passage in the modified system.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Engage system management stakeholders in the pursuit of *Altered hydrology, Aquatic weeds, Water quality, Lack of riparian vegetation, Fire regime and Grazing regime* section recommendations as a pathway towards improving the system's fish passage connectivity.

Table 7. Life cycle movement requirements of fish recorded from floodplain freshwater wetland systems (#exotic)

Name	Genus and species	Life cycle movement	Recorded Collinson's *Burrows & Davis 2009, Loong *et al* 2009
Tarpon	*Megalops cyprinoides*	Catadromous	*
Long-finned eel	*Anguilla reinhardtii*	Catadromous	*
Bony bream	*Nematalosa erebi*	Resident	*
Salmon catfish	*Arius graeffei*	Anadromous/ Potamodromous	
Rendahl's tandan	*Porochilus rendahli*	Potamodromous	*
Butter jew	*Neosilurus ater*	Potamodromous	*
Hyrtl's tandan	*Neosilurus hyrtlii*	Potamodromous	*
Snub-nosed gar	*Arrhamphus sclerolepis*	Resident	
Long-tom	*Strongylura kreffti*	Resident	
Fly-speckled hardyhead	*Craterocephalus stercusmuscarum*	Resident	*
Eastern rainbow fish	*Melaanotaenia splendida*	Resident	*
Barramundi	*Lates calcarifer*	Catadromous	*
Jungle perch	*Kuhlia rupestris*	Catadromous	
Agassiz's glassfish	*Ambassis agassizii*	Resident	
Sailfin glass perch	*Ambassis agrammus*	Resident	*
Spangled perch	*Leiopotherapon unicolour*	Potamodromous	*
Striped grunter	*Amniataba perchoides*	Resident	
Mouth almighty	*Glossamia aprion*	Resident	
Mangrove jack	*Lutjanus argentimaculatus*	Catadromous	
Archer fish	*Toxotes chatareus*	Resident	
Scat	*Scatophagus argus*	Catadromous	
Bully mullet	*Mugil cephalus*	Catadromous	
Giant herring	*Elops hawaiensis*	Catadromous	
Milkfish	*Chanos chanos*	Catadromous	
Silver biddy	*Gerres filamentosus*	Catadromous	
Empire gudgeon	*Hypseleotris compressa*	Catadromous	*
Midgley's Carp Gudgeon	*Hypseleotris bucephala (* Formerly *H. midgleyi)*	Resident	
Purple-spotted gudgeon	*Mogurnda adspersa*	Potamodromous	*
Snakehead gudgeon	*Giurus margaretacea*	Catadromous	
Sleepy cod	*Oxyeleotris lineolatus*	Resident	*
Big-headed gudgeon	*Philypnodon grandiceps*	Potamodromous	
Flathead goby	*Glossogobius giurus*	Amphidromous	
Speckled goby	*Redigobius bikolanus*	Amphidromous	
#Mosquito fish	*Gambusia holbrooki*	Resident	*
#Three-spot gourami	*Trichogaster trichopterus*	Resident	*
#Tilapia	*Oreochromis mossambicus*	Resident	

Lack of riparian vegetation

What is it and why is it important?

The riparian zone is the interface between land and a watercourse or wetland. Riparian zone vegetation is an important component of the landscape because it supports a range of biophysical functions and values. These functions include:

- bank erosion protection;
- maintaining channel stability and form;
- nutrient uptake;
- interception of sediment loads;
- provision leaf litter food sources and structural habitat, including root undercuts/snags for aquatic ecosystems;
- shading and cooling the water's edge and preventing dense submerged aquatic plant growth, thereby increasing the water's dissolved oxygen carrying capacity;
- excluding sun-loving aquatic and levee grasses, thereby helping to maintain open water habitat and channels, reduce wildfire fuel loads and risk, and decrease pest rodent harbourage habitat.
- provide wildlife corridors and refuge habitats, including for predators of adjoining cane land pests; and
- flood protection by reducing catchment runoff rates and slowing the velocity of channel breakout flows.

In intensively developed landscapes like the Lower Burdekin, the riparian zone assumes additional importance because it is often the most significant area of remnant natural habitat. Given its location at the interface between terrestrial and aquatic ecosystems, the riparian zone is important to both. The quality of instream aquatic habitats is often determined, to some degree, by the condition of the riparian zone (Figure 8). Due to these high ecological and catchment functional values, areas lacking riparian vegetation can present threats to the function and value of the aquatic ecosystem. Therefore, rehabilitation of the riparian zone is a priority focus for nature conservation and catchment management project investment.

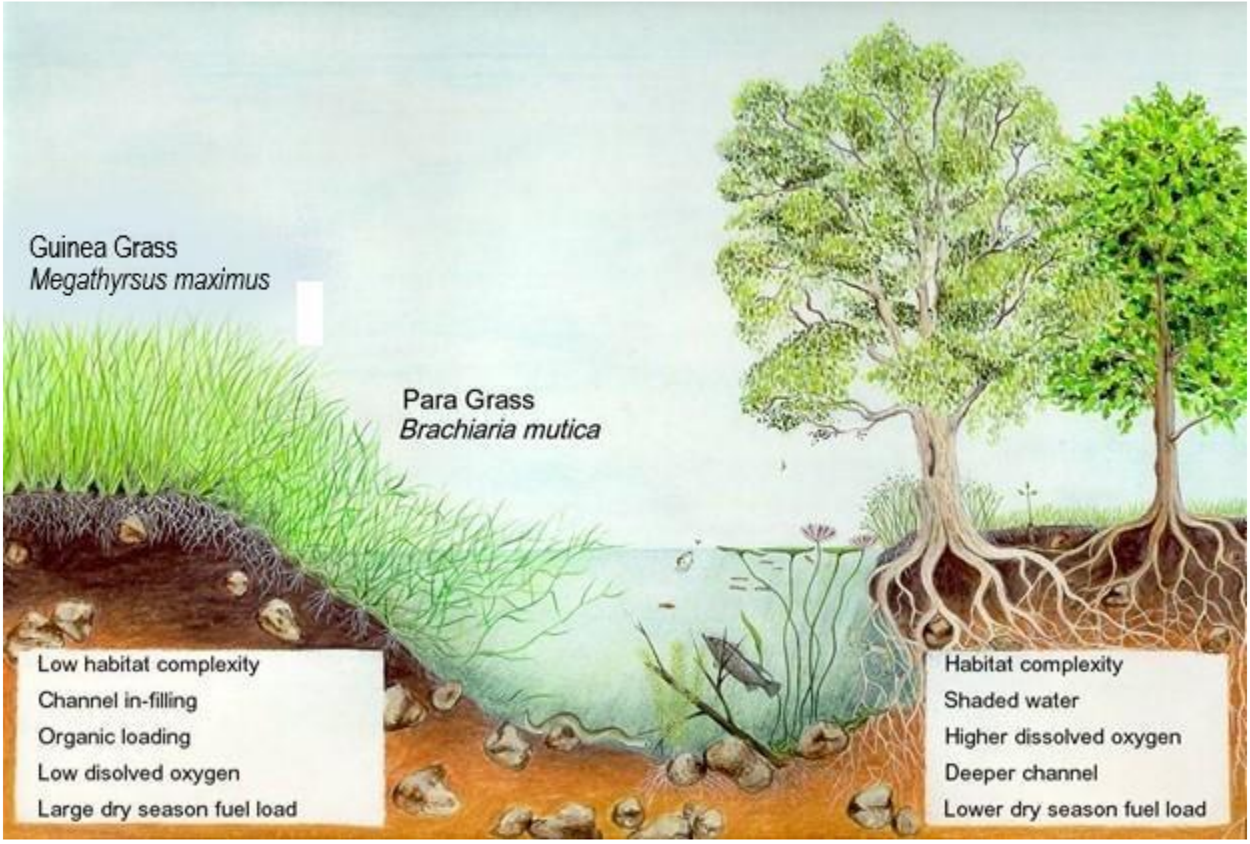


Figure 8. Contrasting ecosystem function and features of an exotic pasture dominated (left) versus native vegetation-dominated (right) riparian zone (Illustration by Lois Genis).

Status of Burdekin floodplain riparian zones

In developed landscapes of the Lower Burdekin, the condition of the riparian zone has often been impacted by a range of land and water resource use pressures, some historical and some current. These include clearing of vegetation; altered stream flows; altered water levels or soil moisture; elevated nutrients; weed invasion; uncontrolled fire; inappropriate stock grazing and trampling; bank erosion; channelisation land filling, and rubbish dumping.

Table 8. Riparian zone rehabilitation approaches for different existing condition contexts

Existing condition context	Potential rehabilitation strategy	Notes
1. Areas of remnant vegetation.	Protect from clearing, monitor, and control weeds, implement fire management suited to vegetation type. **Extensive revegetation**.	Total fire exclusion is appropriate for fire-sensitive and/or closed canopy riparian forests.
2. Areas of degraded remnant vegetation.	If in ungrazed landscape, control/spay out exotic pasture grasses with grass selective herbicides. If in a grazed landscape, manage stock grazing and trampling pressure to keep exotic understory pastures subdominant, allow natural seedling recruitment, and avoid accumulation of large fire fuel loads. Monitor and protect natural regeneration, conduct 'in-fill' planting revegetation (plus stock protection, weed control and watering maintenance) if required for denuded sections. Implement fire management suited to vegetation type. **Extensive revegetation with 'fill in' intensive revegetation.**	Often includes some areas devoid of remnant native vegetation that may require more intensive rehabilitation approaches, for example, as per 3.
3. Areas with no remnant native vegetation, for example, reaches dominated by exotic grasses.	In grazed landscapes stock exclusion fencing is required to support intensive revegetation efforts. Control/spay out weeds, prepare a site for revegetation (holes, mulch, irrigation/watering), plant and maintain (stock protection, weed control, watering) and protect from fire at least until vegetation is established at ~24 months. **Intensive revegetation.**	Initial site preparation may include use of controlled burn to open site access. Direct seeding with fire-stimulated germination species (wattles) prior to burn, or ash bed germinating species (eucalypts, melaleucas) post-burn can add additional recruitment where seasonal/soil moisture conditions suit. Potential erosion risks of high rainfall or flows should be considered if site spray out or burning is planned.
4. Areas of remnant/degraded remnant vegetation with a high exotic pasture grass fire fuel load and associated hot fire risk.	If the site is large enough/suitable, implement controlled grazing (or other means of grass weed control) and fire management suited to vegetation type. Control woody weeds, monitor and protect natural regeneration. **Extensive revegetation with 'fill in' intensive revegetation.**	If the site includes areas devoid of remnant native vegetation consider fencing configurations that create protected grazing exclusion areas to allow more intensive rehabilitation approaches, as per 3. For small sites unsuited to grazing, for example, narrow riparian corridors, fire exclusion and alternate grass weed control preferable.
5. Areas of remnant/degraded remnant vegetation with sustained high grazing pressure.	If possible, implement grazing spelling and monitor/protect natural regeneration. Alternatively, establish grazing exclusion fencing around areas of degraded remnant and rehabilitate as per 2, or fence off areas lacking native vegetation and rehabilitate as per 3. **Extensive revegetation with 'fill in' intensive revegetation.**	Extended spelling that allows accumulation of a fire fuel load and controlled burning suited to the vegetation type can promote recruitment of fire-germinated species whose abundance has been reduced under a sustained grazing regime.

Depending upon the condition of the riparian zone, different rehabilitation strategies may be appropriate (Table 8,10). Where riparian vegetation has been lost completely or partially, revegetation is often a desired rehabilitation strategy. Both intensive and/or extensive revegetation methods may be applied for riparian zone rehabilitation, and these have been described in extensive detail; along with the identification of riparian zone rehabilitation objectives, operational planning, and suitable species selection; in the Sheep Station Creek SMP (Econcern 2021).

System specifics

Mapping of wetland system riparian vegetation condition undertaken for this project (Appendix 2) shows the Collinson's Lagoon system's riparian zone is characterised by non-contiguous, degraded, remnant vegetation that is interspersed with exotic grass-dominated sections. It also has entire reaches and sub-catchments that lack remnant riparian vegetation and are dominated only by exotic grasses and other weeds, including invasive stands of the native bullrush cumbungi. A summary of generalised riparian vegetation condition for definable reaches (Figure 9) within the Collinson's Lagoon system is provided in Table 9. Where discussion relates to management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (M or W) number is referenced.

Photo 33. 1964 aerial image of the upstream end of the Lochinvar Station reach of the lower Collinson's Lagoon system (Reach 11, Figure 9). Floodplain vegetation, including riparian communities, fringe seasonal drainage depressions and waterholes.

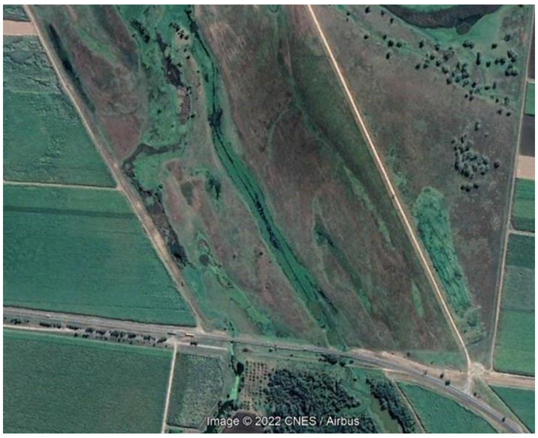


Photo 34. Contemporary image of the same aerial view as left. Riparian vegetation has been lost to clearing, fire and suppressed regeneration due to grazing. Drainage lines are dominated by exotic aquatic grasses and channel water quality conditions include thermal and low dissolved oxygen stress for fish life.

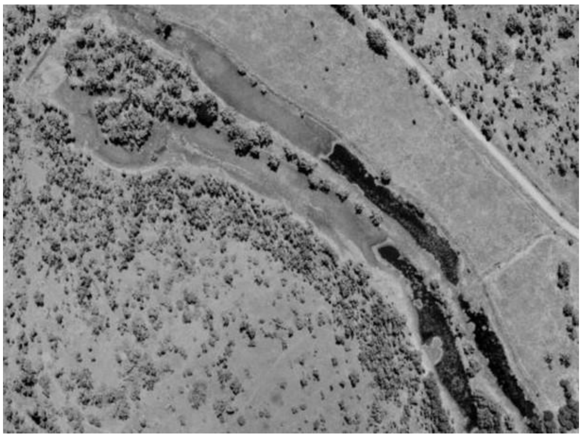


Photo 35. 1964 aerial image of the main large lagoon within the Collinson's Lagoon system (Reach 5, Figure 9). Riparian vegetation has already been cleared on the northern bank. Note dense riparian vegetation on the central land peninsula and southern bank.

Photo 36. Contemporary image of the same aerial view as left. All fringing riparian vegetation on the main lagoon's perimeter bank has been cleared and the land peninsula vegetation thinned by hot fire impacts.

Figure 9. Collinson's Lagoon system reach break up for generalised riparian vegetation condition descriptions.

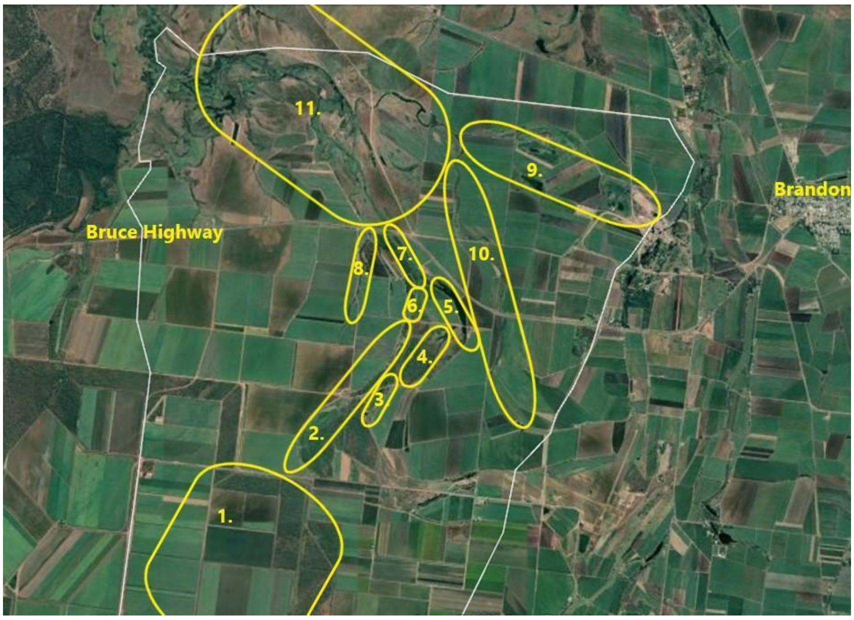


Table 9. Generalised riparian vegetation condition issues for Collinson's Lagoon system reaches

Reach section	Riparian vegetation/observed reach conditions
1. BHWSS tailwater drains upstream of Sayers Road.	Constructed drain through remnant floodplain vegetation. No retained or developed riparian vegetation zone (Photo 53, 54).
2. Excavated creek channel (drainage easement) upstream of Rose Road.	Variable condition, patches of high value remnant riparian vegetation, linked by non-continuous single tree wide degraded remnant riparian vegetation (Photo 37, 38). Woody weed infestation is prevalent. Degraded remnant sections have dense exotic grass understory that extends into water margins. Channel maintained by excavator.
3. Remnant floodplain waterhole drainage to main drain.	Variable condition, patches of high value remnant vegetation on isolated waterholes (Photo 11, 55) and at confluence with main drain. Intervening areas cleared to single tree wide degraded remnant riparian vegetation. Woody weeds are prevalent.
4. Remnant floodplain waterhole drainage to main lagoon.	Variable condition, patches of high value remnant riparian vegetation on isolated waterholes (Photo 56), linkages to main lagoon cleared to isolated degraded riparian patches. Woody weed infestation is prevalent. Excavated drain through eastern channel.
5. Main lagoon system – large lagoon truncated by Rose Road.	Perimeter banks cleared of riparian vegetation, only isolated individual trees (Photo 41, 42) and small length (~100m) of riparian revegetation (Photo 39). Internal land peninsula retains riparian vegetation, including dense refugial stand; the remainder is hot fire damaged (Photo 36, 65, 81).
6. Main lagoon system – smaller lagoon downstream of Rose Road.	The riparian zone is largely dominated by exotic aquatic grass margins, which extend into the lagoon basin (Photo 43, 44, 45, 46).
7. Main lagoon system – smaller lagoon upstream of Bruce Highway.	Most frontages of lagoon in good condition remnant riparian vegetation although broad bands of exotic aquatic grasses dominate the water edge and historic 'variable water level zone' (Photo 16, 21). Cleared area lacking riparian vegetation occurs on the upstream eastern bank.
8. Main lagoon system – western drainage line and lagoons.	Predominantly non-contiguous degraded riparian remnant with intervening areas and an understory dominated by exotic grasses, particularly para grass. Also, significant areas of water frontage and backwater basins with dense cumbungi stands. Long length (~300m) of well-developed good condition riparian revegetation upstream of Good Road (Photo 51, 52).
9. Eastern catchment Pioneer Mill sub-catchment.	Few sparse isolated individual riparian trees, with isolated patches degraded remnant vegetation, set back from active channel. Upper catchment excavated channel. Most riparian zones are broad band exotic aquatic grasses (Photo 47, 48), with dense cumbungi margins, or channel blocking stands. Some reaches with woody or herbaceous weeds.
10. Eastern catchment Hoey Road sub-catchment.	Lower reach trends toward (9) above. Upper reach has patchy, though contiguous, stands of degraded fringing riparian remnant vegetation, including areas with native grass understory (Photo 49, 50). Saturated channel dominated by cumbungi stands and/or para grass.

11. Bunded coastal drainage depression wetlands (Lochinvar).	Riparian vegetation largely cleared and now characterised by isolated individual trees, particularly fire-hardy livistona palms, which occur in stands in some areas. Few isolated patches of degraded riparian remnant. Some deeper remnant lagoons have a non-contiguous, patchy, margin of single tree-width riparian overstorey trees (Photo 34; Figure 5).

Examining the condition of riparian vegetation across the Collinson's Lagoon system's catchment (above) reveals reach specific conditions, needs and opportunities for improving riparian vegetation and the ecosystem functions it supports. Some management proposals have been endorsed by relevant landholders and some are speculative and subject to landholder engagement and endorsement. These are summarised for defined reach sections (Figure 9) below:

Fill in revegetation to shade grass margins to reduce extent of required excavator-based control (Reach 2)

A Sunwater drainage easement runs through this reach and an excavator is used periodically to remove aquatic grass chokes to maintain a channel and water flow (M9). Operating an excavator though this reach needs the streambank to be clear of woody riparian vegetation. Ironically, the resulting open sunlit channel creates conditions highly suited to the reinfestation of the stream channel by aquatic grasses. Alternatively, dense shade canopy-forming riparian vegetation could provide a means of shading out and controlling fringing aquatic grasses along the stream channel, which has been demonstrated in other Lower Burdekin systems like Sheep Station Creek (Econcern 2021). Integrating revegetation efforts focused on creating a dense shade-forming riparian vegetation canopy with maintaining strategic excavator access along this reach could deliver a channel with better habitat values and less maintenance requirements (Photo 37, 38).

Photo 37. Upstream view of excavated creek channel in drainage easement upstream of Rose Road (Reach 2, Figure 9). Riparian vegetation includes good condition remnant (left bank) and degraded remnant (right bank) with a broad band of aquatic grass understory.

Photo 38. Downstream view of the same reach as Photo 37. Channel occluded by aquatic grasses, and requires excavation. Revegetation with dense canopy-forming riparian tree species (e.g., Leichardts) could assist in open channel maintenance (M9, M10).

Photo 39. A small ~100m length of the main Collinson's Lagoon (Reach 5, Figure 9) bank that has been revegetated with dense shade canopy-forming and aquatic grass excluding Leichardt trees (M18).

Photo 40. Understory of Leichardt tree on bank of main Collinson's Lagoon showing a reduced margin of para grass onto water's edge, and reduced biomass (and dry season fire fuel load) beneath the tree.

Revegetation of the main Collinson's Lagoon riparian zone (Reach 5)

This large lagoon is one of the system's higher value assets. It has been the site of considerable past management investment, primarily in weed control. It retains aquatic plant communities, including water lilies representative of the Lower Burdekin pre-development landscape. It has a range of ongoing management challenges associated with water quality, hot fires, weed control, and fish passage barriers. Revegetation of the entire bank margin and ultimately entire riparian zone of the lagoon with shade-generating riparian vegetation would serve to address a number of these challenges and significantly improve its ecosystem health (M18). Revegetation would deliver less fire fuel loads on high banks, less grass margins on the water's edge, reduced submerged aquatic plant biomass, cooler water temperatures, and a higher dissolved oxygen status. Integrated use of chemical spraying, fire management, and controlled grazing where suitable, could enhance the regeneration of remnant riparian vegetation on site. However, given the existing degraded status of the lagoon's riparian zone, revegetation is going to depend primarily on staged intensive revegetation techniques, like planted nursery tube stock (Photo 39, 40, 41, 42).

Photo 41. Revegetation of Collinson's Lagoon's riparian zone would offer multiple ecosystem management benefits, including terrestrial and instream habitat provision, grass weed control (via shading), improved dissolved oxygen status (via water cooling and submerged plant exclusion), reduced wildfire risk (via grass understory exclusion), nutrient uptake, and less pest rodent harbourage (M18).

Photo 42. A two-kilometre perimeter of para grass-dominated lagoon bank is available for revegetation around the Collinson's Lagoon system's main large lagoon. Staged revegetation, including integrated use of chemical spraying, grazing, and burning to prepare bank sections for planting and to promote natural regeneration, would help deliver a viable outcome at this scale (M18).

Photo 43. These paperbark saplings have recruited in an area where the dominant exotic grass groundcover had been stripped back by a high flow event. Spraying, grazing, and controlled burning could create enhanced regeneration opportunities for riparian vegetation in exotic grass-dominated bank margins.

Photo 44. These young Leichardt trees have also managed to germinate in an area where the dominant hymenachne cover had been rolled back by a high flow. Applying management techniques to encourage natural regeneration of riparian vegetation can be more cost effective than planting nursery-raised tube stock.

Integrated control of exotic grass margins of lagoons receiving aseasonal tailwater flows (Reaches 6 and 7)

All the lagoons within the main Collinson's Lagoon system that receive aseasonal inflows of tailwater have exotic aquatic grass-dominated margins that limit habitat values and create water quality impacts. The primary way to address this condition issue is reinstating natural hydrological seasonality and water level drawdown (see *Altered hydrology* section). In the absence of that management capacity, the greatest aquatic grass control options are the integrated use of grazing, fire, and chemical spraying (see *Fire regime, Grazing regime* and *Aquatic weed* sections). Planting dense shade canopy-forming riparian trees could also provide reductions of grass weed margins on banks adjoining deeper water, and warrant a dedicated trial site (Photo 16, 21, 43, 44, 45, 46).

Channel-forming, grass-shading revegetation of deposition wetland basin downstream of Rose Road (Reach 6)

This sediment depositional environment within a lagoon basin presents ongoing aquatic grass weed colonisation and flow blockage issues (M11). Planting a formed channel margin with dense shade canopy-forming riparian tree species would serve to concentrate high flow scour and maintain the channel. It would also exclude blocking grass growth via shade exclusion (Photo 45, 46).

Photo 45. This smaller lagoon downstream of Rose Road on the main drainage line (Reach 6, Figure 9) represents a sediment depositional zone. Colonisation of sediment beds by aquatic grasses serves to further occlude flows (M11).

Photo 46. Revegetation of channel and lagoon basin margins (visible in Photo 45) with inundation-tolerant shade-casting riparian trees, like Leichardts and paperbarks, would help maintain concentrated (M11) channel flow and scour and exclude grass margins.

Shading of excavated drains with riparian vegetation for maintenance cost and habitat benefits (Reach 9)

The flow capacity of the constructed channel network draining the Pioneer Mill sub-catchment is periodically maintained by clearing aquatic weeds by excavator, which includes aquatic grasses and floating weed mats. To operate an excavator though this reach, channel banks are kept clear of woody riparian vegetation. Ironically, the resulting open sunlit channel creates conditions that are highly suited to the reinfestation of the channel by aquatic grasses. Integrating revegetation efforts, like establishing dense shade canopy-forming riparian tree species such as Leichardt Trees on western banks, with excavator access (M29), could potentially reduce the need for an excavator to maintain the channel. At the same time, this action would provide habitat benefits, as has been achieved on other floodplain steams in the Lower Burdekin, like Sheep Station Creek (Photo 48).

Photo 47. Riparian vegetation within the Pioneer Mill sub-catchment of the eastern catchment (Reach 9, Figure 9) is characterised by channel-blocking stands of cumbungi and aquatic and woody weeds.

Photo 48. This channel at the top of the Pioneer Mill sub-catchment is periodically maintained by excavators. Establishing suitable shade-casting riparian vegetation could exclude channel grass growth, reduce maintenance costs, and provide habitat value in a reach with poor ecological values (M29).

Integrated habitat regeneration trials for drainage lines of eastern catchment (Reaches 9 and 10)

The riparian zones of the eastern catchment are highly modified by altered hydrology, hot fires, and weed infestation like cumbungi bullrush. While most of the catchment is highly degraded, remnant riparian vegetation within the Hoey Road sub-catchment provides a basis for creating much higher habitat values within this drainage system. Trialling an integrated approach which includes the physical excavation of cumbungi, controlled grazing, controlled burning, promoted natural regeneration, and 'fill in' revegetation could deliver sustainable wetland habitat outcomes (see *Grazing regime* and *Fire regime* sections). Successful learnings within the Hoey Road sub-catchment could possibly then be applied within the more degraded Pioneer Mill sub-catchment (Photo 47, 48, 49, 50).

Photo 49. Patches of degraded riparian vegetation remnant are semi-contiguously distributed through the Hoey Road sub-catchment of the eastern catchment (Reach 10, Figure 9). An integrated habitat restoration program employing cumbungi excavation, targeted spraying, grazing, burning, and strategic revegetation and regeneration, could deliver sustainable high value wetland habitats through this reach.

Photo 50. Hot fires are a feature of the current management regime within the Hoey Road sub-catchment of the eastern catchment. Although they are implicated in impacts to remnant vegetation condition; observed benefits in terms of exotic grass and cumbungi control and open water habitat creation, point to the merit of including controlled cooler burning in the reach's management regime.

Revegetation of the eastern bank of the western drainage line of the main lagoon system (Reach 8)

This system has been the site of past revegetation success. Landholder investment in site environmental management has been ongoing. The adjoining landholder has given initial support to extending revegetation to the opposite bank and lower reaches of the system. This system links to the larger remnant habitat complex of the main Collinson's Lagoon system, meaning improvements will add value to an existing floodplain habitat remnant. Much of the site has been damaged by past hot fires. Remnant riparian vegetation on site supports promoted regeneration techniques via fire and weed management. 'Fill in' intensive revegetation is also required. Excavation of dense cumbungi margins and stands through the reach would also improve riparian habitat outcomes (Photo 51, 52).

Photo 51. About 300m of successfully-established bank revegetation on the western bank (right above) of the western drainage line (Reach 8, Figure 9), leading to the main Collinson's Lagoon system. The adjoining landholder is supportive of establishing an equivalent on the lower eastern bank.

Photo 52. Lower eastern bank (right) of the western drainage line (Reach 8, Figure 9). Landholder support for revegetation will reduce wildfire risks and rodent harbourage, and increase habitat values and ecosystem function. Intensive management (slashing, spraying) of the western bank (left) could also be relaxed with dense riparian canopy planting.

Management of instream vegetation in BHWSS tailwater drains for improved wetland function (Reach 1)

Tailwater drains within the BHWSS form the upper catchment of the Collinson's Lagoon system. They are essentially a long linear wetland. Their existing ecological values and function is limited. They are usually dominated by exotic aquatic grasses, and weed rafts exported from these drains in high flows create downstream flood risks. While these drains lack true riparian vegetation, dedicated management of in-drain vegetation condition, away from aquatic grass weeds and toward emergent native aquatic plants, could deliver potential water quality, habitat, and flow capacity benefits.

Photo 53. Sunwater drain (RB1) within the BHWSS (Reach 1, Figure 9). These drains form the upper catchment of the Collinson's Lagoon system. They are essentially a long linear wetland. Their existing ecological values and function is limited. Grass weed rafts exported from these drains in high flows create downstream flood risks.

Photo 54. Sunwater drain (RB1) bisecting an area of melon hole/Gilgai floodplain wetland. While these drains lack true riparian vegetation, dedicated management of in-drain vegetation condition – away from aquatic grass weeds and toward emergent native aquatic plants – could deliver potential water quality, habitat, and flow capacity benefits.

Protective management and woody weed control of remnant floodplain wetland habitats (Reaches 3 and 4)

These floodplain wetland habitat remnants on freehold land are largely isolated from the main sources of aseasonal tailwater inflows, and retain natural water quality and hydrology and high value remnant riparian and floodplain vegetation. Currently these sites are heavily infested with woody weeds and are not grazed, which exposes them to hot fire risks. While non-selective woody weed control could impact riparian vegetation condition, an investment in selective woody weed control and engaging the landholder in other protective management measures would serve biodiversity conservation within the broader system (Photo 55, 56).

Photo 55. Although impacted by woody weeds, this floodplain drainage line (lower image) retains remnant riparian vegetation and clear, natural water quality relative to the turbid flows in the tailwater-receiving, adjoining main drainage line (top) (Reach 3, Figure 9). These floodplain wetlands and their associated remnant vegetation represent high value habitat assets.

Photo 56. These two floodplain drainage lines upstream of Rose Road (Reach 4, Figure 9) have been partially cleared of their riparian vegetation, but retain valuable remnant vegetation in associated with the main waterholes. They are a worthy focus for management on account of their habitat value and representation of vegetation types that are poorly conserved in the post-development landscape.

Create shaded, open, deeper water fish habitat refugia in bunded coastal drainage depressions (Reach 11)

The lower coastal drainage depression reaches of the Collinson's Lagoon system have undergone extensive clearing and loss of their riparian vegetation communities through their development history (Photo 33, 34; Figure 5). While these reaches within the Lochinvar Station retain numerous wetlands, they are largely treeless, or have only sparse and isolated fringing riparian vegetation. Water quality investigations of these areas in conjunction with weed management trials (Waltham and Fixler 2017), found critical water quality conditions in terms of elevated temperatures and poor dissolved oxygen levels and carrying capacity. These types of stresses are likely to increase in future years under predicted climate change scenarios (see *Climate stress* section). While the landholder of these areas appreciates the pastoral production potential of exotic pasture-dominated waterways, it could be possible to target strategic riparian rehabilitation efforts into the reach without significantly impacting production values. One possibility would be to identify deeper more perennial water holes within the reach and to use promoted regeneration and/or intensive revegetation to create dense riparian vegetation canopy cover around these sites. This would exclude surface-covering aquatic grasses and maintain cooler water with greater dissolved oxygen carrying capacity.

Figure 10. Land tenure surrounding the main Collinson's Lagoon system. Blue = freehold, brown = leasehold, light blue = drainage easement, and clear = state land.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Identify resourcing opportunities and engage riparian landholders of the main lagoon within the Collinson's Lagoon system (Reach 5) to deliver a staged riparian revegetation program for the entire bank margin and riparian zone of Collinson's Lagoon, recognising that much of the bank margin and riparian zone occurs on state land (Figure 10). The revegetation program should pursue natural regeneration approaches where appropriate, like the integrated use of chemical spraying, controlled grazing and burning, and also develop the capacity for extensive planting of nursery-raised tube stock using local providence seed where possible. Target objectives for the revegetation program should include shading-based exclusion of water edge exotic grass margins and submerged aquatic plant biomass; shading of bank levees to reduce dry season fire fuel loads; reduced pest rodent harbourage habitat, and creation of high value riparian habitats (W3).
2. Identify resourcing opportunities and engage with riparian landholders of western drainage channel to main Collinson's Lagoon system (Reach 8) to deliver an integrated riparian revegetation program, using both natural regeneration and intensive tube stock planting approaches. This includes the scope for excavating cumbungi-dominated margins and depressions. The initial focus should be on the eastern bank where landholder support has been indicated, with the aim to extend revegetation outcomes to the upstream extent of the reach (W10, W11).
3. Engage with Sunwater as managers of the drainage easement and the leasehold landowner of the small lagoon downstream of Rose Road (Reach 6) to revegetate the margins of the excavated flow path and adjoining lagoon bank margins. This should be with dense shade canopy-forming riparian tree species, like Leichardt and paperbark trees, to promote channel scouring and maintenance under high flows, and to shade and exclude channel-blocking aquatic grass growth (W12).
4. Engage with riparian landholders and Sunwater, as the managers of the drainage easement between Rose and Sayers roads, to discuss supporting drainage easement stakeholders with integrated management options for the drainage channel. Pending the response, an option includes incorporating canopy shade-forming riparian vegetation 'fill in', alongside accommodating excavator access needs, to maintain an open water channel while increasing habitat values and ecosystem function (W15).
5. Engage with Wilmar and other riparian landholders of the system's eastern catchment and seek funding resources and support to implement an 'Integrated Habitat Regeneration Program' along a trial reach within the sub-catchment. This would incorporate excavator-based reinstatement of open water habitat in cumbungi-dominated sections; fencing and controlled grazing; controlled burning; promoted natural regeneration, and 'fill in' riparian revegetation (W20).
6. Engage with Wilmar and seek support to trial riparian revegetation of one or two excavated channel bank margins within the Pioneer Mill sub-catchment of the eastern catchment. These dense shade canopy-forming riparian tree species would be a complimentary, or alternative, method to the excavator-based maintenance of grass-free drainage channels (W23)
7. Engage with system management stakeholders to pursue integrated control methods to reduce the extent of exotic aquatic grass margins on the banks of lagoons within the main Collinson's Lagoon system, including further trialling of bankside revegetation with dense canopy shade-generating species (see *Aquatic Weed*, *Grazing regime* and *Fire regime* sections).
8. Engage with Sunwater managers of the BHWSS tailwater drainage network and seek resourcing opportunities to conduct management trials within selected reaches of the drainage system. The aim is to change dominant vegetation from exotic aquatic grass stands to a mixed, open water, native spike rush/bullrush community to treat water quality in situ by reducing nitrates and attenuating colloids. This could reduce downstream water quality impacts and the export of flow-blocking weed mats downstream during flood spates (M17).
9. Engage with system management stakeholders to pursue riparian vegetation condition improvement recommendations within the *Woody weeds* section. Particularly support for resourcing sensitive woody weed control for riparian habitat remnants along the main drainage line, and within isolated floodplain drainage lines between Rose and Sayers roads (W13, W14).
10. Engage with landholders of Lochinvar Station around the range of recommendations (see *Altered hydrology*, *Grazing regime* sections) for lower reaches included in this SMP. Specifically canvas interest and incentive requirements that could support engagement to implement dedicated riparian zone regeneration/intensive revegetation efforts. These actions would help create shaded, open, deeper water fish habitat refugia within the wetland complex of Lochinvar's bunded coastal drainage depressions.

Table 10. Mapped riparian vegetation condition class – ecological value, management issues and identified revegetation needs and opportunities

Exotic grasses
• Has low ecological value, presents hot fire risks to remnant native trees and adjoining cane farms and harbours rodent crop pests. • Can provide suitable cover and bank stability for excavator-maintained channel reaches. • Growth of aquatic grass species (para, aleman, hymenachne) onto water bodies blocks water flow and creates floating aquatic weed mats. This reduces water dissolved oxygen and creates biological oxygen demand (BOD) when grass decomposes in water, particularly when inundated by elevated flows/water levels, creating anoxic 'blackwater'. • Fire risks can be reduced by fuel load reduction with controlled grazing where site conditions allow. • Where no remnant native trees are present, revegetation is dependent on more intensive methods, for instance, seedling planting. • Establishing a shade-generating overstorey tree canopy that controls grass density and reduces bank-side anchor points for aquatic grass species provides a catchment-scale revegetation target.
Remnant vegetation
• Has high ecological value, including providing habitat for fauna uncommon in developed landscapes. • Mapped units can include significant areas of exotic grass and degraded remnant classes. • Conditions can trend positively or negatively depending on operating pressures, for example, weeds, grazing regime, fire regime, physical disturbance, and hydrological change. • Controlled grazing of exotic grass understorey can reduce fire fuel loads and associated hot fire risks and, with spelling, promote natural regeneration. • Exclusion of fire, or a controlled burning regime, can promote increased canopy development and suppression of understorey fuel loads and promote natural regeneration. • Provides baseline comparison sites, target species lists and seed sources for regeneration of equivalent reach areas. • Provides nucleus areas for strategic regeneration of adjoining riparian areas. • 'Fill in' planting can be used to increase mid and overstorey canopy development, though promoting natural regeneration is more appropriate where integrity is high. • Priority management focus for remnant vegetation is protection and represents a more cost-effective investment than revegetation.
Degraded remnant
• Ecological value is variable depending on landscape context but can provide important habitat resources, including feeding and nesting sites within a modified landscape. • Mapped units usually include significant areas of exotic grass and may include exotic trees/woody weeds. • Conditions can trend positively or negatively depending on operating pressures including weeds, grazing regime, fire regime, physical disturbance, and hydrological change. • Controlled grazing of exotic grass understorey can reduce fire fuel loads and associated hot fire risks and with spelling promote natural regeneration. • Exclusion of fire or a controlled burning regime can promote increased canopy development and suppression of understorey fuel loads and promote natural regeneration. • Remnant trees provide the opportunity to use more extensive revegetation approaches, for instance, the promotion of natural regeneration via seedling recruitment and growth • 'Fill in' planting/intensive revegetation can be used to target denuded areas along with promoting natural regeneration within remnant stands.

- Integrated mix of intensive and extensive revegetation approaches is an appropriate management focus and provides a catchment scale revegetation target.

Revegetated

- Observed ecological value is generally high, particularly where the area includes mature remnant stands or individual trees of the original vegetation community are included.
- Primary management focus is protection and maintenance, particularly in relation to reinfestation by grass weeds and associated hot/uncontrolled burn risks.
- Some sites warrant 'fill in' intensive revegetation to address areas denuded by uncontrolled burns and/or die-off of short-lived pioneer species.
- Opportunity to increase habitat values by dedicated understorey/ground cover planting and introducing physical habitat features, like logs and artificial nest hollows.

Exotic trees

- Ecological value is limited in monoculture plantings (orchards) but can be higher when mixed with remnant native species. Can provide some nesting and feeding habitat resources and a range of useful functional values, for example, stabilising stream banks and shading out aquatic grass weeds, and Hornwort around pump intakes.
- Where mixed with native tree species, selected control and clearing and 'in fill' revegetation can be used to regenerate sites toward native vegetation dominance.

Grassland

- 'Catch all' class for grassland areas that are not the 'exotic grasses' class associated with the immediate riparian zone (above). When this includes native grasslands, it can have high habitat values for grassland-dependent species, particularly granivorous birds.
- Riparian areas that represent cleared areas are appropriate for intensive revegetation, particularly adjoining lagoons subject to aquatic grass weed infestation.

Woody weeds

Types and impacts

Woody weeds threatening the condition of Lower Burdekin wetland systems include exotic trees and vines that infest riparian zones and catchment areas to the detriment of native habitat values, catchment processes and production values. The key species recorded in the Lower Burdekin are listed in Table 11 (below). Although some woody weeds are utilised as shelter or food habitat resources by native fauna, their occurrence within native vegetation communities results in the competitive exclusion of native plants. Native fauna have evolved and developed direct or indirectly dependent relationships with these native flora. For example, while canopy-dwelling birds may inhabit an exotic tree canopy, it will generally not support the same populations of native insect food sources that a native tree canopy will. The greatest scope for impact occurs where weeds have the invasive capability to dominate a regional ecosystem setting to the exclusion of native biodiversity, and/or change native vegetation structure and/or function. For example, severe infestations of rubber vine can create 'vine towers' that completely smother and collapse host trees, destroying the vegetation structure (closed canopies) required by dependent species, and opening the vegetation community to further weed infestation, such as sun-loving grasses.

Where vegetation structure gets completely altered by woody weed infestation, secondary impacts may be generated. For example, a rubber vine tower causing canopy collapse opens-up fire-sensitive riparian vegetation to secondary weedy grass infestation, which leads to its exposure to fire impacts. Dense canopy-forming woody weed species, such as chinee apple, can form closed-canopy infestations that shade out understorey grass in formerly open woodland areas. This reduces pastoral productivity and exposes understorey areas to increased soil erosion in the event of heavy rainfall or floodplain overland flows.

Not all species are declared weeds under the *Queensland Biosecurity Act 2014*. Control methods vary from various forms of chemical spraying, including basal cut and foliage spraying; the use of bio controls, like rubber vine rust fungus (*Maravalia cryptostegiae*); and the use of fire. Heavy machinery is also often used for clearing more dense infestations where access for other forms of control is limited, or control by other methods is cost exorbitant. Where heavy machinery is employed, the risks to remnant vegetation stands mixed within woody weed infestations need to be managed to avoid impact to remnant habitat values.

Photo 57. Woody weed infestation within the high value riparian forest remnant adjoining the main Collinson's Lagoon system. This infestation is currently under a NQ Dry Tropics control contract.

Photo 58. Dense leucaena infestation growing within exotic pasture grasses in an eastern catchment tributary of the Lochinvar Wetlands. Extending adjoining grazing land use into these areas would control both.

In recent decades there has been substantial investment by NQ Dry Tropics to control woody weed infestations at Lower Burdekin wetland systems sites, including two nationally significant wetlands: Serpentine Lagoon and Woodhouse Lagoon. Other sites include Churches Lagoon (on Sheep Station Creek) and at Collinson's Lagoon, adjoining the Bruce Highway. An observed reduction in rubber vine infestation levels has also been noted over the past two decades at some sites, including Barratta Creek, where rust fungus successfully established during a series of wetter years.

Levels of woody weed infestation vary between systems but, overall, the extent of infestation across the greater floodplain remains significant. Investment in further control needs to be informed by strategic priorities to make effective use of limited resources. Intervening in low level infestations, including at upper catchment sites before they spread downstream and/or become more extensive, represents prudent investment. Public investment in the resources required to tackle large extensive infestations can only be justified where there are high value wetland assets at stake and/or a production dividend that promotes landholder engagement and co-investment.

System specifics

Where discussion relates to management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (M or W) number is referenced.

Observed levels of woody weed infestation through the Collinson's Lagoon system are variable with some drainage reaches and adjoining frontages extensively and heavily infested, and other branches of the drainage system having only scattered patch infestations of several individual plants. The primary species of concern are chinee apple, rubber vine, parkinsonia, and Leucaena; although scattered occurrences of other species, including lantana, castor oil plant, rain tree, and tamarind, were also recorded.

From a wetland management investment perspective, most of the denser infestations on floodplain sites are primarily the responsibility of private landowners. They pose limited impact risk to wetland system values other than when they provide a source of seed to active drainages, or pose a condition degradation risk to remnant floodplain vegetation with biodiversity conservation values.

The following areas of the Collinson's Lagoon system are nominated as sites where investment in woody weed control could deliver a wetland system environmental management dividend:

- **In the riparian and floodplain woodland remnants associated with the main Collinson's Lagoon system (currently the site of active control, Photo 57).** Over the past decade, investment in woody weed control within this habitat remnant has reduced the abundance of woody weeds, including chinee apple, leucaena and parkinsonia. Ongoing control efforts are required to maintain these condition gains. Residual areas that are not effectively targeted by control hasten reinfestation. Wetted channels have restricted woody weed control access during recent management efforts. Seeking weed control access during dry season periods, or by using vehicles capable of access, would improve woody weed control outcomes at this site (M14).

- **Along the Sunwater drainage easement over the modified (excavated) drainage depression/creek channel between Sayers and Rose roads (Photo 59, 63).** Within this drainage easement section of the system, the most significant remnant native vegetation providing wildlife habitat and corridor connectivity is remnant and regenerating riparian vegetation along the excavator-modified stream channel. This riparian corridor has low, but increasing, levels of woody weed (chinee apple, parkinsonia) and rubber vine infestations. In the longer term these weeds and/or methods used to control them could impact upon the riparian habitat values (M10).

- **The floodplain wetland and woodland remnant vegetation areas between Sayers and Rose roads (Photo 64).** Remnant vegetation and undeveloped land associated with the Collinson's Lagoon system north of Sayers Road has high levels of woody weed infestation, primarily chinee apple, but also other species such as parkinsonia. Cost effective methods used to control these weeds include clearing using heavy machinery. Remnant native vegetation distributed amongst woody weed stands can be inadvertently cleared during such control methods. Demarcating higher value remnant vegetation areas for more targeted control efforts could support better nature conservation outcomes (M7, M21).

- **The south-north flowing distributary of the eastern catchment (Hoey Road sub-catchment) that runs into Wilmar land (Photo 60).** This distributary system has relatively isolated chinee apple infestations, though is otherwise relatively woody weed free. Low level infestations represent prudent control investments, which could be conducted as part of a proposed integrated habitat regeneration program for this system (W20).

- **The remnant habitat complex of woodland and wetland representative of the Ayr land system on Wilmar land, located on the eastern catchment (Pioneer Mill sub-catchment) distributary flowing east-west toward Lochinvar** Station **(Photo 61, 62).** Remnant vegetation adjoining bagasse storage areas within this tributary drainage are highly impacted by woody weeds, ungrazed exotic pasture infestation, and associated hot fires. Despite their poor condition they still retain a range of nature conservation values, including mature trees, relatively high species diversity, and associated fauna habitat values. They also represent the only significant stands of native vegetation within this tributary stem and, as such, are locally important. Dedicated management of the woody weeds and hot fire risks associated with these areas would serve to improve their condition and biodiversity conservation value (M28).

- **The remnant habitat corridors and nodes retained within the BHWSS area.** Despite being 'reserved' nominally for nature conservation, this area has never been bought under any formal nature conservation tenure or management arrangements and is subject to longer term decline due to a lack of effective, fire, woody weed, and grazing management (M2).

Photo 59. Chinee apple and rubber vine infestation within an active stream reach of the upper Collinson's Lagoon system, upstream of Rose Road. Riparian woody weed infestations present seed sources for lower reaches.

Photo 60. Isolated chinee apple infestation within an otherwise relatively woody weed-free distributary channel in the eastern catchment. Low level infestations represent prudent control investments.

Photo 61. This remnant habitat complex of woodland and wetland representative of the Ayr land system is degraded by an extensive infestation of woody weeds, yet still retains biodiversity values.

Photo 62. This patch of woodland and wetland is the most significant area of remnant habitat within the system's eastern sub-catchment and warrants investment in woody weed control.

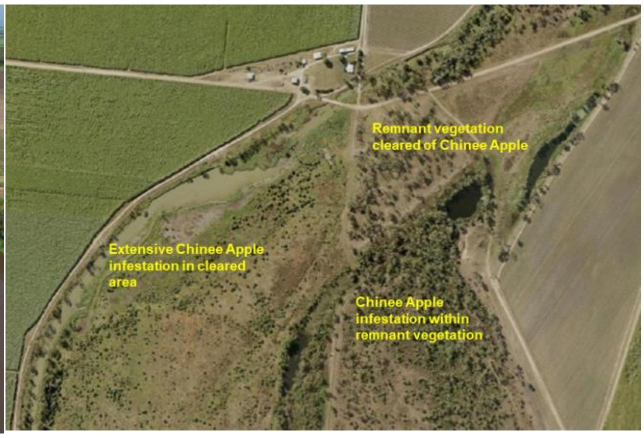


Photo 63. Extensive, dense infestation of chinee apple on previously-cleared lagoon frontage/floodplain area.

Photo 64. Cost-effective control of chinee apple infestations in high value remnant vegetation areas, such as these remnant floodplain wetlands, presents challenges for protecting habitat values.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Comprehensive control of all residual reinfestation potential weeds refuges (W8).
2. Engage with landholders to establish agreements for remnant vegetation in return for resourcing a habitat-sensitive woody weed and rubber vine control program, for example, using small machinery, or personnel-based options. This would secure the high habitat values of the riparian vegetation corridor between Rose and Sayers roads (W13-W14).
3. Engage with Wilmar to assess support to development a resourced site Environmental Management Plan (EMP) for the eastern catchment remnant woodland and wetland habitat complex representative of the Ayr land system. The focus could be on woody weed control, controlled grazing, and fire regime management to deliver improved biodiversity conservation outcomes (W22). See also *Critical wildlife habitat* section.
4. Engage with Wilmar and lessee landholders to seek interest and support for implementing an integrated habitat regeneration program along the length of the eastern catchment's south-north distributary system's riparian corridor (Hoey Road sub-catchment). Actions include installing fencing and conducting controlled grazing; fire regime management; woody weed control; riparian revegetation, and using an excavator to reinstate open water habitat in cumbungi-dominated reaches (W20). See also *Lack of Riparian vegetation* and *Fire Regime* sections.
5. Establish formal nature conservation management arrangements for the retained remnant floodplain habitat corridor and node network within the BHWSS. This would include woody weed control (W16). See also *Critical wildlife habitat* section.

Table 11. Woody weeds of management concern on the Lower Burdekin floodplain

Common name	Species	Growth habit	Comments/nature of impacts	Biosecurity status/control methods
Chinee apple	*Ziziphus mauritiana*	Large shrub or small spreading tree up to 8m tall and 10m in canopy diameter.	Forms dense impenetrable ground cover and native midstory excluding infestations.	Chinee apple | Business Queensland
Parkinsonia	*Parkinsonia aculeata*	Small, hairless tree up to 10m tall.	Forms dense impenetrable ground cover and native midstory excluding, infestations	Parkinsonia | Business Queensland
Prickly acacia	*Vachellia nilotica*	Thorny shrub or small tree up to 5-10m tall.	Forms thickets in open grassland /woodland, reduces ground covers	Prickly acacia | Business Queensland
Yellow oleander	*Cascabela thevetia*	A large tree that can grow up to 10m high.	Outcompetes native canopy species. Poisonous to stock and humans.	Captain Cook tree or yellow oleander (daf.qld.gov.au)
Golden shower tree	*Cassia fistula*	A spreading tree that is semi-deciduous usually grows less than 10m tall, but has the capability of reaching up to 20m in height.	A weed of riparian vegetation, open woodlands, wetland margins, roadsides, coastal environs, and offshore islands.	golden shower tree | Weed Identification – Brisbane City Council
Castor oil plant	*Ricinus communis*	A tall, branching, annual or perennial shrub that grows to 3m.	Invades floodplains, riverbanks, may form thickets. Seeds, and to a lesser extent, the leaves are toxic to livestock and humans.	Castor oil plant | Business Queensland
Neem	*Azadirachta indica*	Fast-growing evergreen generally 15-20m tall, with crown diameter up to 20m.	Outcompetes native canopy species.	Neem tree | Business Queensland
Devil's fig	*Solanum torvum*	An upright shrub or small tree usually growing 0.8-3m tall.	A weed of closed forests, forest margins, waterways (i.e., riparian areas), plantation crops, roadsides, pastures, disturbed sites, and waste areas.	Devil's fig | Weed Identification – Brisbane City Council
Leucaena	*Leucaena leucocephala*	Shrub up to 6m tall.	Forms thickets in riparian zones and alluvial plains, stalls native regeneration and excludes ground covers.	Leucaena | Business Queensland
Java plum	*Syzygium cumini*	Tropical evergreen tree that can reach heights of up to 30m.	Outcompetes native canopy species.	Environmental weed
Tamarind	*Tamarindus indica*	Moderate to large evergreen tree, up to 24m in height, and 7m in girth.	Outcompetes native canopy species.	Environmental weed
Rain tree	*Samanea saman*	Large to massive, evergreen, spreading, umbrella-shaped and symmetrical trees that grow to 60m tall with a crown up to 80m broad.	Spread into native forests, and outcompetes native canopy species, particularly along stream margins and in disturbed areas.	Rain tree (daf.qld.gov.au)
Rubber vine	*Cryptostegia grandiflora*	Climbing vine up to 30m tall in trees, untidy shrub up to 1-2m tall.	Forms dense impenetrable groundcover-excluding, canopy-dominating/collapsing infestations.	Rubber vine | Business Queensland
Lantana	*Lantana camara*	Heavily-branched shrub growing in clumps, thickets, or vines.	Forms dense impenetrable groundcover-excluding infestation that can extend to the midstory.	Lantana | Business Queensland
Elephant ear vine	*Argyreia nervosa*	Perennial woody vine climbing up to 10m high.	Forms canopy-dominating/collapsing infestations.	Elephant ear vine | Business Queensland

Siam weed	*Chromolaena odorata*	Dense, tangling bush up to 2-3m tall, scrambles up trees to 20m.	Forms canopy dominating/collapsing infestations.	Siam weed | Business Queensland

Fire regime

Need

Inappropriate burning has long been recognised as a primary cause of deteriorating riparian vegetation condition in the Lower Burdekin region (BBIFMAC 1999). Fire impacts both sapling recruitment and mature trees. Field work undertaken for the preparation of this management plan identified that burning, particularly in the late dry season, continues to impact Lower Burdekin riparian vegetation condition, including throughout much of the Collinson's Lagoon system (Photo 65, 69).

Most native vegetation within the region has some adaptation to fire, which is a natural feature of ecosystems within the seasonal dry tropics. However, most native vegetation has evolved within a certain set of 'fire regime' parameters (see insert box below). If the fire regime experienced is more intense, or frequent, than its adapted capacity, it will result in mortality of trees and saplings and corresponding declines in vegetation structure, species diversity, and associated habitat values.

For native vegetation, fire is not only a destructive force but also a regenerative one. Many types of riparian trees, particularly wattles (*Acacia spp*.) and others, like casuarina and grevillea, have seeds whose germination is promoted by fire. Other riparian species, like melaleuca and eucalyptus, have seed that is released from capsules by fire and readily germinates in an ash bed soil layer and/or groundcover openings created by burning. A range of weed species, including rubber vine and para grass, are fire sensitive, and controlled burning can provide a riparian restoration tool, along with a fire risk mitigation role.

Fire regime – describes the pattern of burning experienced by a site, or suited to a particular vegetation community, and is commonly characterised in terms of:

- frequency (interval period between fires);
- seasonality (time of year);
- intensity (determined by burn conditions, including time of day, wind, soil moisture, fuel load), and
- extent (amount of habitat type or site burnt per event or year).

Without management attention to the fire regime experienced by the creek's riparian zone, valuable remnant habitat areas will continue to decline in condition, and ecological gains made by revegetation of the creek's riparian zone can be lost.

Photo 65. Riparian vegetation condition created by a hot fire regime on ungrazed banks of the main Collinson's Lagoon. Of note are fire-scarred and adapted livistona palms, burnt remnant trunks of killed paperbark trees, absent sapling recruitment, and an ungrazed large fire fuel load of para grass.

Photo 66. Diverse well-structured riparian vegetation on the banks of Collinson's Lagoon that has been protected from hot fire risk by controlled grazing. Fire-adapted native trees and grasses, including blady grass (right) and salt couch (left), and fire-sensitive exotic pastures (hymenachne, para, water's edge) justify a controlled burning management regime.

Causes/constraints

There are several factors contributing to the often-destructive fire regime experienced by riparian zones within the Lower Burdekin region (Tait 2011). These factors may also be considered as constraints to implementing an appropriate fire regime. They include:

Large fuel loads – Amongst many Lower Burdekin wetland riparian zones, habitat remnants are ungrazed. This factor, combined with invasive exotic grasses, like guinea grass/green panic, para grass, and elephant grass, commonly result in large annual fire fuel loads within habitat remnants. These exotic grasses produce greater standing biomass than native grass species and have a long growing season due to seasonally-extended soil moisture promoted by regulated stream flows and/or irrigation tailwater.

Annual fire exposure – The Lower Burdekin remains one of the few sugar-growing regions in Australia where burning is employed pre-harvest to remove cane trash. Most remnant habitat areas on the floodplain occur near cane fields. Consequently, most are exposed to one or more close proximity annual burning events in surrounding cane fields. This presents a high likelihood of remnant habitat areas also experiencing an annual fire frequency, particularly where cultural practices have long favoured 'cleaning' up pest harbourages and fire fuel loads in remnant habitat areas during or after cane field burning.

Risks to cane crops promote late dry burning – Most cane farmers are unwilling to consider utilising fire as part of surrounding landscape management until cane crops have been harvested to avoid the risk of uncontrolled fire impacting cane fields. At a regional level, cane harvesting is not completed until late in the dry season when conditions tend to promote 'hot' fires. This means that any intentional burning of habitat remnants after cane has been harvested is often damaging to vegetation structure, composition and ecological values, and there are fewer opportunities to conduct beneficial 'cool' or less intense 'controlled burns'.

Photo 67. A cumbungi-dominated distributary generated by aseasonal flows in the eastern catchment that drains Wilmar land toward Lochinvar Station. The intensity of uncontrolled fire in dry cumbungi stands will kill even tall fire-adapted livistona palms.

Photo 68. A cumbungi-dominated distributary created by aseasonal seepage in the system's eastern catchment that drains north from the Bruce Highway toward Lochinvar Station. Dead, large, old paperbark and eucalypt riparian trees could not withstand the intensity of hot fire from a dried cumbungi understory.

Landscape setting

Appropriate fire regime guidelines suited to the native vegetation types that occur on the Burdekin floodplain have been defined by state government agencies (see Econcern 2021). However, these guidelines assume that fire management is occurring in extensive natural landscapes. The Lower Burdekin floodplain is dominated by irrigated agriculture. Remnant natural habitat tends to occur as isolated 'islands' and non-continuous, narrow riparian corridors surrounded by a 'sea' of developed landscape. In this context, natural landscape fire management approaches that depend on patchy burning of the surrounding landscape mosaic cannot be utilised; particularly when most of the surrounding landscape is developed crop land. Limiting the extent of a vegetation type or remnant patch that is burnt in any one event or year is also challenging where it only occurs in small patches surrounded by a landscape that is burnt annually.

Implementing an appropriate (including no) fire regime

The appropriate fire regime for floodplain vegetation remnants will vary with vegetation type and landscape setting. Importantly, sometimes the most appropriate fire regime for some riparian habitat remnants can be total fire exclusion. This applies particularly where the remnants occur on stream or lagoon banks with a high moisture regime; include fire-sensitive species; and/or are comprised of narrow riparian corridors with limited fuel loads; and are not separated sufficiently from adjoining cane farms to avoid being an uncontrolled fire risk. It is important to recognise that, given changed hydrological conditions towards more perennial water supply across the Burdekin floodplain, there are now many more riparian settings that will support a closed canopy riparian forest, as opposed to the more open riparian woodland that may have historically occupied a site. Given the capacity of closed forest to shade out an exotic grass weed understory, which has fire fuel load generating and bank-infesting potential, there is often environmental management benefit in allowing such forest to develop through intentional fire exclusion.

Regional guidelines

Regionally-applicable guidelines for the implementation of appropriate controlled burning practices and fire regimes for Lower Burdekin wetland vegetation remnants within different farming landscape contexts were developed for the Sheep Station Creek SMP (Econcern 2021). Burdekin land managers interested in the use of fire as an ecological management tool are referred to that document for more detailed information.

System specifics

Where discussion relates to management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (M or W) number is referenced.

Fire very much remains a key driver and impact of riparian vegetation condition within the Collinson's Lagoon system, including its contributing catchment areas. As with most condition impacts, they manifest through interactions with other condition drivers, such as hydrology, weed infestation, and the grazing regime. Field investigations identified a diverse suite of fire regime management issues, needs and opportunities. These are summarised for different components and areas of the system below:

1. **Ungrazed frontages of the main Collinson's Lagoon system.** These areas have a very degraded sparse/open riparian vegetation condition (Photo 65, 81). While some of their condition may be attributed to historical clearing, much is due to a sustained hot fire regime associated with large fire fuel loads generated by ungrazed para and guinea grass; the death of mature trees, and the subsequent lack of successful sapling recruitment. Throughout the Lower Burdekin, this process has been demonstrated to 'clear' riparian vegetation communities (Econcern 2021, 2022). Extension of controlled grazing to all suitable broader frontages of the lagoon system, particularly those adjoining existing grazing sites, would reduce these hot fire impacts. Where grazing is not suitable or possible, other means to reduce fire fuel loads and hot fire risks should be employed, for instance, riparian canopy shading of understory grasses (Photo 71, 72).

Photo 69. Hot fire regime-generated riparian vegetation condition of the lower western branch of the Collinson's Lagoon system (V8).

Photo 70. A burnt distributary reach (Dec 2021) in the system's eastern catchment that drains north from the Bruce Highway toward Lochinvar Station wetland. Although this fire appears to have been hotter than ideal, the dominance of native (versus exotic) grasses and groundcovers in regenerating vegetation illustrates the biodiversity benefits of incorporating burning in riparian open forest management.

Photo 71. Dense planting of shade-generating riparian trees, such as these Leichardts (left) on the bank of the main Collinson's Lagoon system, provides a means to reduce fire fuel loads and associated hot fire risks in riparian zones; particularly when combined with controlled grazing.

Photo 72. Although the shade canopy of this young Leichardt tree is not yet fully developed, it is already serving to reduce the extent of both bank and water edge-infesting para grass. It also reduces hot fire risks on the bank, and minimises habitat and water quality impacts in the water edge zone.

2. **Grazed frontages of the main Collinson's Lagoon system.** For the past decade, much of the intact riparian forest remnant adjoining the main Collinson's Lagoon system has been fenced and put under a controlled grazing regime to reduce fire fuel loads and associated hot fire risks. This program has proved relatively successful with fires excluded from the remnant vegetation over this time, and improvements in remnant vegetation condition noted. However, given the fire dependency of the vegetation types included in the controlled grazing area, there is merit in identifying opportunities to conduct controlled 'cool' burns in these areas. If conducted following grazing and under appropriate seasonal and day conditions, fuel loads should be reduced sufficiently to limit the intensity of the fire to one that promotes, rather than diminishes, biodiversity and habitat values (M15). Any capacity to reinstate dry season drawdown of lagoon water levels would increase the role that fire could play in reducing the dominance of bank margins by exotic aquatic grasses (M16).
3. **Irregularly burnt distributary channels of the eastern catchment.** As identified in the *Altered hydrology* section, sustained tailwater flows and seepage into the distributary channels in the eastern sub-catchments of the system have promoted impenetrable cumbungi stands along most reaches. During extended dry season periods these channels and cumbungi stands are sometimes dry enough to carry a fire. When burnt, the oil content of cumbungi foliage supports an intense fire, which generally kills any native overstory vegetation in close proximity. While regular burning (below) appears to reduce the abundance of cumbungi, it comes at a cost to remnant native overstory vegetation. With appropriate protective measures for remnant vegetation stands, fire could potentially play a role in limiting its infestation density within these distributary channels. Alternatively, less intense, controlled fire could play a condition maintenance role if cumbungi stands are initially removed by other means (excavation), and full loads are managed by grazing and/or vegetation canopy establishment (see *Lack of riparian vegetation* section).
4. **Regularly burnt distributary channels of the eastern catchment.** Field site visits and past aerial imagery interpretation reveals that reaches of the eastern catchment distributary (Hoey Road sub-catchment), that drains north from the Bruce Highway toward Lochinvar Station (Photo 73, 74), are burnt on a relatively regular basis. This includes burning some of the reach most years in cooler winter months, or in the late dry season (M26). While the intensity of these burns in ungrazed reaches is thought to be greater than ideal to maintain native overstory vegetation, some positive outcomes of this burning regime were noted. A much greater diversity of native wetland grasses were observed in these reaches (Photo 74), suggesting regular fire promotes native grass biodiversity at the expense of fire-sensitive para grass and other exotic aquatic pastures. Also noted was the lower density of cumbungi stands along these regularly burnt reaches, which abruptly changed at the management regime boundary (Photo 73). This suggests that controlled burning can play a role in the control of cumbungi infestation, though the challenge is managing and avoiding the impacts associated with the intense 'hot' burns that it can generate. Ultimately, further developing the regular burning prescription for these reaches could deliver beneficial habitat condition outcomes, made possible by including grazing, or seasonal timing commitments, to limit the intensity of controlled burns. These reaches are proposed as a focus area for integrative habitat restoration initiatives (W20).

Photo 73. A regularly-burnt distributary reach in the system's eastern catchment that drains north from the Bruce Highway toward Lochinvar. Breaks in cumbungi infestation at this site's northern boundary point to the control capacity of burning, albeit via intense fires.

Photo 74. A December 2021 image of the same reach (left Photo 73), highlighting one of the benefits of regular burning: moving grass community composition away from fire-sensitive exotic para grass toward native wetland

species, including spiny mud grass (*Pseudoraphis spinescens)* and rice grass (*Leersia hexandria).*

5. **Woody weed-degraded woodland/wetland habitat remnant within eastern catchment (V10).** This habitat remnant has identified biodiversity conservation value due to its representation of the extensively developed Ayr land system; the juxtaposition of both wetland and woodland habitats; and due to the scarcity of other remnant habitat within the broader sub-catchment area. In the past, it has been subject to burns (uncontrolled or intentional) that have burnt the entire remnant (Photo 77), which has not served conservation of the site's fauna. The area could warrant a site management plan to restore its condition and protect nature conservation values. Controlled burning, along with grazing-based management of fire fuel loads, would likely form part of site management. Also, developing physical means, like fire breaks, or methods (seasonal, day timing), that limited the extent of the site burnt during any controlled burn would be beneficial for maintaining its ecological values.

Photo 75. A dry season controlled burn through an ungrazed hymenachne stand, over wet ground, at a wetland management trial site on the Barratta Creek floodplain. Most exotic ponded pasture species are fire-sensitive and burning can provide useful control.

Photo 76. Under post-fire grazing pressure, the same Barratta floodplain wetland developed a groundcover of native nardoo and had water lilies established in shallow margins, while the ungrazed control site (background) returned to full para grass cover.

Photo 77. A valuable woodland and wetland remnant habitat complex (V10) in the system's eastern sub-catchment that has been subject to an extensive burn. To protect biodiversity in isolated habitat remnants, controlled burns should ideally only burn a fire-breaked subsection of the remnant in any one event.

Photo 78. Few primary producer communities would have as much experience conducting planned burns as Lower Burdekin sugar farmers. The extension challenge for biodiversity conservation managers is to engage that experience for nature conservation outcomes. This guinea grass-dominated riparian zone on Sheep Station Creek has been grazed to reduce the fuel load to enable a 'cool' controlled burn.

6. **Habitat corridors of BHWSS area.** The high values of the large areas of remnant floodplain vegetation retained within habitat corridors of the BHWSS are described elsewhere (see *Critical wildlife habitat* section). While these areas predominantly retain native grass communities, fuel load accumulation and late season burning does still pose a threat to maintaining their ecological value. Controlled burning as part of dedicated fire regime management needs to form part of the

management arrangements implemented for these areas, ideally as part of formal nature conservation commitments (M2).

7. **Exotic pasture-dominated drainage depressions of the lower system.** The domination of the lower system's drainage depressions by exotic aquatic pastures, like hymenachne and para grass to the detriment of fish and bird habitat values, has been described elsewhere within this SMP: see the *Altered hydrology, Aquatic weeds,* and *Grazing regime* sections. Currently, the asset values of these grasses as forage resources limits the inclination of the landholder to control their extent. If a negotiated, incentivised commitment could be obtained for improving the habitat value of selected sites or dedicated channels within this area, fire could potentially be employed to help deliver this improvement. Experience gained elsewhere on the Barratta floodplain has demonstrated that controlled burning, in conjunction with targeted grazing pressure, can deliver good bird and fish habitat outcomes from exotic aquatic pasture-dominated wetlands (Tait 2011) (Photo 75, 76).

Looking forward, landholders concerned about wildfire risk with interests in fire regime and fuel load management also need to be cognisant of altering landscape fire behavioural conditions and risk scenarios that could emerge in association with emerging climate stress (see *Climate stress* section).

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Conduct a fire regime/controlled burning communication and an extension program targeting riparian landholders, local fire wardens, and RFS members via shed meetings, field days, other appropriate forums, and via published material. Key topics for communication include:
    a. Ecological impact (particularly on remnant overstory vegetation) of hot fire regimes and their association with an ungrazed exotic grass understory.
    b. The role of controlled grazing in reducing fire fuel loads and supporting cooler burns.
    c. The fire sensitivity of exotic aquatic grasses, like hymenachne and para. Also, the capacity for an integrated use of controlled burning and grazing, ideally with seasonal or managed draw-down of water levels, to reduce the abundance of these grasses at a system scale.
    d. The appropriateness of fire exclusion as a 'burning regime' for riparian zones with, or that can support, a closed vegetation canopy.
    e. The role of establishing riparian revegetation/canopy as a grass exclusion and fire risk reduction strategy.
    f. The need to manage fire fuel loads and associated hot fire risks where they adjoin fire-sensitive remnant habitat assets.
    g. The fuel load, seasonal, day timing conditions, and burn conduction methods that support 'cooler' fire outcomes.
    h. The additional benefits of reducing exotic grass density/fuel loads in riparian areas adjoining farmland, for instance, reducing rodent harbourage habitat.
2. Engage relevant stakeholders in implementing the recommendations from the *Grazing regime* section as a pathway towards improving the system's fire regime. In particular, providing support for the reintroduction or expansion of areas of controlled grazing to lagoon frontages and distributary drainage lines.
3. Engage with relevant stakeholders, including the current controlled grazing lessee, riparian landholders, and local fire warden to develop and implement a controlled burning/fire risk management strategy for the remnant habitat complex surrounding the main Collinson's Lagoon, with a focus on:
    a. Reintroducing cool burns to suitable areas of the grazed remnant habitat as a means of maintaining some fire-mediated open woodland areas and fire dependent plant species.
    b. Introducing (potentially controlled hot) fire to exotic aquatic pasture-dominated lagoon margins, preferably in conjunction with dry season or manipulated low water levels (see *Altered hydrology* section). This is a non-chemical way to reduce para, hymenachne and aleman grass dominance of waterway margins, and promote native aquatic plant species.
    c. Extending the existing fenced controlled grazing area of Collinson's Lagoon to the lagoon 'peninsula' (Photo 36, 65; Figure 11). This would reduce the hot/wildfire risk currently associated with large fire fuel loads generated by ungrazed para and guinea grass (W2) (see *Grazing regime* section).
    d. Identifying hot fire risk reduction strategies for residual remnant habitat areas surrounding the lagoon, potentially including slashing and fire break maintenance, and revegetation with dense shade canopy-forming riparian vegetation (see *Lack of riparian vegetation* section).
4. Engage with Wilmar as landholders of the sole remaining woodland-wetland habitat remnant within the system's eastern sub-catchment and explore their interest in developing an environmental management plan for the site, including improved fire regime management (W22).

5. Engage with landholders, including Wilmar, adjoining the distributary reach in the system’s eastern sub-catchment (Photo 73) that drains south-north from the Bruce Highway (Hoey Road sub-catchment) toward Lochinvar. Seek interest in establishing an integrated habitat regeneration demonstration reach, including fire regime management (W20) (see *Lack of riparian vegetation* section).
6. Form a multi-stakeholder working group to move towards establishing formal nature conservation management arrangements, including a managed fire regime and controlled burning program for BHWSS remnant habitat corridors and nodes (M2) (see *Critical wildlife habitat* section).

DRAFT

Grazing regime

Why is it a useful tool?

For most Australian landscapes, the conventional wisdom about nature conservation-based management is that the impact of grazing animals should be kept out of disturbance-sensitive riparian and wetland areas. In contemporary riparian and wetland habitats of the Lower Burdekin floodplain, this convention is turned on its head because one of the greatest sources of wetland and riparian habitat threat is invasive exotic pasture species that can become dominant in the absence of grazing. These pasture species include a suite of aquatic grasses, such as para, hymenachne, aleman, and other species that occupy better-drained levee soils, like guinea grass.

Collectively, these grasses generate a range of impacts within wetlands and the riparian zone (Figure 7) of floodplain wetland systems, including:

- Out-competing native vegetation, including groundcovers and sapling recruitment;
- Creating large dry season fire fuel loads that support ‘hot’ fires;
- Smothering open water and shading out native submerged and emergent edge aquatic plants;
- Degrading water dissolved oxygen levels by organic loading, reduced instream photosynthesis and less water surface – air interaction;
- Impacting fish and waterbird nesting, feeding and egg laying habitats, including dry season-exposed banks used by waterfowl;
- Socio-economic impacts, including creating mosquito breeding habitat, crop weeds, and water channel blockages.

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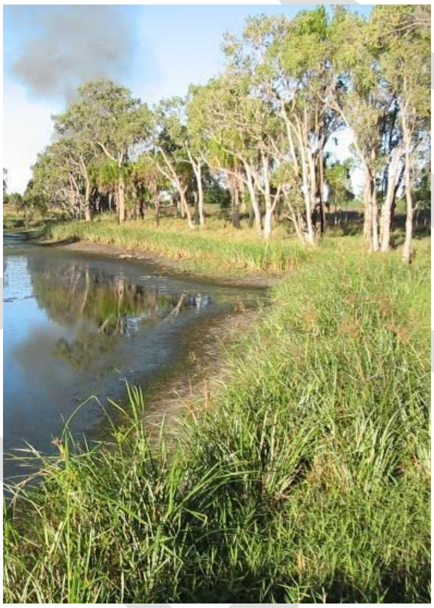

Photo 79. An example of a great controlled grazing outcome on a wetland that retains some dry season seasonality within the Sheep Station Creek system (Castelanelli's Lagoon). Para grass margins (and fire fuel load) have been controlled and replaced with an edge of native emergent sedges.

Photo 80. Retained native grass species in the understory of the controlled grazing area on Collinson’s Lagoon (blady grass foreground; salt couch background/foreground). This is indicative of the biodiversity conservation benefits achieved by using grazing as a riparian vegetation management tool in the Lower Burdekin. Control of hymenachne margins in shallow water (backdrop) remains a management target.

It is within the context of the impacts caused by exotic pasture grasses that grazing, and the lesser disturbance of grazing animals, can be beneficial to the condition and value of riparian and wetland habitats. Ultimately, application of grazing as a habitat management tool requires an appreciation of its impact risks concerning native flora and fauna, bank compaction, and soil erosion; seeking to minimise these, while maximising the benefits of reducing exotic pasture dominance. Guidelines for the use of controlled grazing as a riparian and wetland habitat management tool have been developed for the Lower Burdekin region based on a research project involving a range of monitored management trials conducted over a decade ago (Tait 2011).Those guidelines provide a basis for this management plan's recommendations, yet interested readers should refer to that document and the SMP developed for Sheep Station Creek (Econcern 2021) for a more comprehensive treatment of the issue.

Controlled grazing is not a suitable management approach for all sites and is not needed where other methods can be preferentially, or more effectively, applied to control grass weeds, for example, establishing riparian vegetation canopy shading. However, controlled grazing is a useful management tool because it can be used at a landscape scale and fills an important role where other methods may have limitations, such as chemical and mechanical control, or tree canopy shading established by revegetation. Importantly, all these methods are not mutually exclusive, and the best riparian zone rehabilitation outcome may be achieved by an integrated or sequential application of more than one approach.

In terms of site suitability constraints, the main reasons why controlled grazing may not be suitable at some sites include:

- steep banks/erosion prone soils;
- incompatible adjoining land uses;
- species vulnerable to grazing disturbance and/or good condition or grazing-sensitive habitats; and
- site too small, or shape/configuration has high fencing costs, lacks high water stock refuge, or presents ineffective fencing security.

In contrast to controlled grazing, uncontrolled grazing and associated stock trampling, bank erosion and pugging of wetland and riparian areas, can also present a threat to wetland system ecological values. These threats are particularly relevant concerns where wetland systems fall predominantly within grazing land use areas but also need to be avoided where grazing is applied in a controlled context with agricultural land use areas.

Photo 81. Extension of the controlled grazing area to include this fire-impacted riparian vegetation community of the main Collinson's Lagoon peninsula (Figure 11) would serve to remove the hot fire risk and improve condition.

Photo 82. Lowering of water levels and/or extension of grazing later into the dry season could enable hymenachne to be grazed out of shallow channels (Figure 11), creating more open water habitat for native water lilies (centre background) and other native biota.

System specifics

Where discussion relates to management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (M or W) number is referenced.

While the entire Collinson's Lagoon system was historically used for grazing, current grazing land use is limited to small leasehold areas within floodplain habitat remnants of the BHWSS; a controlled grazing program established in 2010 on some of the riparian habitat frontages of the main Collinson's Lagoon (Figure 11); and the more extensive commercial grazing enterprise on Lochinvar Station on the lower system's coastal drainage depressions. Freehold remnant habitat areas between Rose and Sayers roads also have a recent history of grazing land use but, at the time of writing, are not being used for this purpose.

From a wetland system management perspective, grazing regime issues of interest are those associated with producing sustainable wetland habitats, rather than maintaining cattle carrying capacity, or sustainable pasture resources. While these issues may not always be mutually exclusive, they often are. When seeking to use grazing as an invasive pasture grass control method, grazing regimes intended to sustain and promote these pastures are the antithesis of what is being sought. This dichotomy is evident in early DPI guidelines that describe grazing regimes to sustain pasture species, with these grasses now recognised as invasive environmental weeds. These insights can provide guidance about achieving opposite outcomes via pursuing converse approaches.

The two primary reasons for utilising grazing as a wetland management tool on the Lower Burdekin floodplain are:

1. Reduce the dominance of exotic pasture grasses, particularly aquatic species hymenachne, para and aleman, in favour of native vegetation and recruitment processes.
2. Reduce dry season fire fuel loads and associated hot fire risks, particularly associated with pyrophytic (fire-loving) grasses like guinea grass, or seasonally drying aquatic grasses like para grass.

As noted in preceding sections *Aquatic weeds* and *Fire regime*, the introduction of grazing to an expanded area of wetland habitat that is being impacted by pasture grass infestation and associated hot fire impacts is the most crucial action for grazing regime management. There are also opportunities for existing grazing regimes to be altered towards improved wetland condition outcomes, particularly if greater seasonal water level drawdown could be reinstated to the system (see *Altered hydrology* section). Five areas of Collinson's Lagoon system are nominated for grazing regime management consideration:

Photo 83. Aquatic grass margins are a target for grazing-based control. Heavy grazing pressure during lower (late dry season) water levels, when pasture is accessible to stock, could reduce the need for spray-based control, as conducted prior to this image being taken.

Photo 84. The aquatic plant and associated habitat values of this long seasonal wetland basin on the western margin of the existing controlled grazing area (Figure 11) would benefit from controlled grazing.

1. Improving the effectiveness of the existing controlled grazing program on Collinson's Lagoon.
The NQ Dry Tropics-supported controlled grazing program on the main Collinson's Lagoon system (Figure 11) has been in operation for approximately a decade. It has been successful in its primary objective of reducing hot fire impacts within the area under grazing control, although such impacts have continued to occur outside the control area (Photo 81). It has been less successful in reducing the abundance and dominance of exotic aquatic pastures on the lagoon's margins, despite early successes (Photo 5,16; Figure 6).

Two reasons nominated for this are (1) lagoon water levels are being sustained by aseasonal inflows (rather than drawing down) into the dry season, limiting the accessibility of aquatic grass margins to grazing cattle (see *Altered hydrology* section), and (2) a relatively short grazing season being employed by the grazier. Reinstating greater water level seasonality would address the first issue (see Altered hydrology section). While the second reason could be addressed by extending the applied grazing period further into the late dry season, the short grazing season employed by the grazier is a consequence of site and cattle accessibility constraints. Early in the post-wet grazing season, high water levels limit cattle access across channels and around lagoon banks. Late in the dry season there is a risk of a storm associated with a high flow event, inundating the system, presenting risks to stock, and making it difficult to extract cattle from the site to safe high flood refuge, which does not exist within the currently fenced area. One such event has already been experienced by the grazier. Consequently, they now choose to introduce cattle to the site later in the season and to remove them earlier in the dry season.

These limitations have consequences for the effectiveness of grazing as an exotic aquatic grass control method. High grazing pressure late in the dry season, and sustained grazing pressure (no spelling) through the wet season are two grazing approaches that successfully help reduce aquatic pasture species dominance in wetlands (Tait 2011). This is not occurring under the existing grazing strategy. A solution would be to extend the fenced area to include a high ground flood refuge. Discussion with an adjoining landholder has indicated that this could potentially be accommodated on an adjoining area of fallow cane production land no longer being used due to wallaby impacts (M13). Opportunities to incorporate a high flood refuge into the controlled grazing site and extend the applied grazing season could deliver improved pasture grass control outcomes. The integrated use of fire could also be potentially beneficial to this end (see *Fire regime* section). Any implementation of an expanded fenced area should also consider bringing additional lagoon and wetland frontages into the controlled grazed areas. Some opportunities are illustrated in Figure 11.

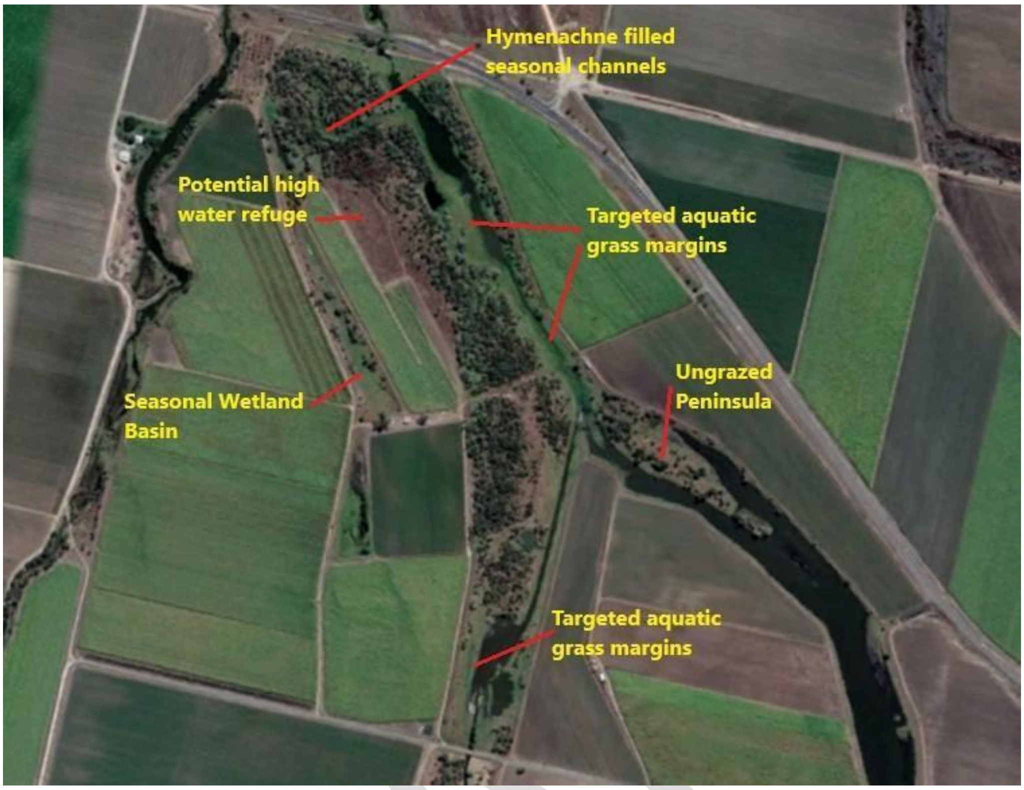

Figure 11. Focal areas for improving the effectiveness and extent of Collinson's Lagoon controlled grazing management outcomes.

Photo 85. Use of this fallow production area to provide a high-water refuge for cattle grazing the adjoining wetland would allow the applied grazing period to start earlier in the post-wet season and extend later into the dry season without risk to stock.

Photo 86. Remnant habitat and non-agricultural production areas located between Rose and Sayer's roads have a recent history of grazing use. Reinstatement of grazing in this area would assist in protecting riparian habitat values from hot fire risk.

2. Introducing controlled grazing to the distributary channels of the eastern catchment. The poor condition of distributary drainage channels in the system's eastern sub-catchment has been described in the *Altered hydrology*, *Lack of riparian vegetation* and *Fire regime* sections, including sustained waterlogging, cumbungi, aquatic grass and other aquatic weed infestation, and a hot fire regime. Examining the regular hot fire regime experienced by some upper reaches of these distributaries indicated that there were some native biodiversity and weed control benefits (Photo 73, 74) associated with the regular burning, albeit at a cost of fire damage riparian overstory vegetation. This observation suggested that controlled grazing, if introduced, could play a mitigative role against the negative impacts of the existing fire regime, and could make habitat outcomes more positive. Observations within the lower reaches of these distributary systems, where they enter Lochinvar Station, highlighted distinct fence line contrasts (Photo 88, 89) in weed infestation status between the grazed and ungrazed reaches, with the latter having poorer wetland habitat values. Both lines of field evidence suggest that introduction of controlled grazing to these reaches, and/or expansion of grazing upstream from existing grazing enterprises downstream, could deliver wetland system benefits.

Photo 87. Seasonal wetland basin within Lochinvar Station in 2003 illustrating native aquatic grasses, emergent and bedded native aquatic plants, and large and diverse waterbird populations.

3. Developing integrated (hydrology, fire) and targeted grazing regimes for wetland condition outcomes in coastal drainage depressions. Anecdotal comparisons with bird habitats and populations observed in the lower coastal drainage depression reaches of the system in past decades (Photo 87) suggest that contemporary conditions of reduced seasonality and greater dominance of exotic pastures in this part of the system have diminished habitat values. Investigations of water quality and fish passage issues surrounding weed control and exotic pasture infestation within the lower system (Waltham and Fixler 2017, Burrows et al 2012) also suggest that its current condition limits fish habitat values and passage connectivity opportunities. Dedicated grazing regime-based management of exotic aquatic pastures can improve both bird and fish habitat values (Tait 2011).

Lower system drainage depressions within Lochinvar Station are already subject to sustained grazing pressure. Aerial photo interpretation (Photo 7, 8) identifies how it interacts with seasonally and annually-variable hydrological conditions, like aseasonal flows, water levels, to produce different outcomes in the level of aquatic grass infestation of drainage channels and wetland waterbodies. Lochinvar Station's landholder has indicated that they value the forage value of exotic species like hymenachne and para grass within their grazing operation, and are not motivated to control these pastures other than by their existing grazing practices. Existing practices can include high grazing pressure in the late dry season, which helps to achieve a desirable environmental outcome of short, cropped exotic grass cover, and an open channel/open basin condition. This is important going into the wet season inundation and connective flow period when most fish migration occurs and when native aquatic plant communities re-establish.

Photo 88. Fence-line comparison between grazed Lochinvar Station (right) and an ungrazed tributary channel of the eastern Wilmar land catchment. Although disturbed, the grazed open wetland basin on Lochinvar's side of the fence has higher ecosystem services.

Photo 89. Aerial image of the fence-line site (Photo 88, left), illustrating the open waterbody in Lochinvar Station versus the closed cumbungi-filled wetland upstream (right), which also has a riparian vegetation community of dense leucaena and an ungrazed para and guinea grass groundcover.

Photo 90. Grazed open wetland basin on Lochinvar Station's side of the fence, versus a weed-choked ungrazed wetland upstream of the fence (background). Groundcover on the grazed wetland includes native grasses and fringing emergent sedges, both habitat resources for waterbirds.

Photo 91. Grazed open wetland basin on Lochinvar Station. The absence of exotic aquatic pasture dominance on this heavily grazed wetland will support the presence of open water habitat into the wet season inundation period and the establishment of native emergent and bedded aquatic plants.

Given landholder attitudes, proposals to reduce the abundance or dominance of exotic aquatic pastures within these lower reaches are largely hypothetical. However, there is the prospect that – in conjunction with sufficient incentives – modifying the existing production system in a way that maintains or increases production values, while serving enhanced environmental values and function, could be further considered. It is in this context that such options are explored further here. The concept of extracting aseasonal flows for off stream irrigated pasture production and/or channel flow isolation was identified in the *Altered hydrology* section as options for increasing the effectiveness of grazing-based control of exotic aquatic grasses on drainage lines where wetness presents a grazing access limitation. System-scale reduction in dry season aseasonal flows emanating from the upper catchment would also affect a similar outcome.

Beyond this level of intervention, dedicated reach or site-scale habitat management investments, could be trialled for these coastal drainage depression reaches, as proposed for riparian overstory revegetation (see *Lack of riparian vegetation* section). For grazing-based management, this could take the form of dedicated areas that are hydrologically isolated from the broader system, like back swamps; and/or have the capacity (fencing configuration), to be subject to higher levels of stocking; and/or provide opportunities for introducing controlled burns into the management mix. Integrated use of controlled burning in conjunction with applied grazing pressure has been demonstrated elsewhere on the Barratta floodplain (Photo 76) to significantly reduce the abundance of exotic pasture cover in favour of native aquatic plant communities with greater bird habitat values (Tait 2011).

4. Woody weed degraded woodland/wetland habitat remnant within eastern catchment (V10). This habitat remnant has identified biodiversity conservation value on account of its representation of the extensively developed Ayr land system; the juxtaposition of both wetland and woodland habitats; and due to the scarcity of other remnant habitat within the broader sub-catchment area. The area could warrant a site management plan to restore its condition and protect nature conservation values (M28). In the past, the site has been subject to fires (uncontrolled or intentional) that have burnt the entire remnant (Photo 77). Grazing-based management of fire fuel loads would need to form part of site management (see *Fire regime* section).

5. Developing targeted grazing regimes for floodplain habitat condition outcomes in remnant habitat corridors of the BHWSS. The high values of the large areas of remnant floodplain vegetation retained within habitat corridors of the BHWSS are described elsewhere (see *Critical wildlife habitat* section). While these areas predominantly retain native grass communities, which represents one of their key habitat values; fuel load accumulation and late season burning poses a threat to maintaining their ecological values. In the absence of grazing, exotic pasture species like guinea and para grass are also invading higher fertility and/or wetter areas. To serve nature conservation management for much of this area, an applied grazing regime is required. This would deliver broad acre control of exotic pasture infestation and provide fuel load management options to serve the controlled burning that is also required, ideally as part of formal nature conservation commitments (M2, M3).

Photo 92. Despite regular hot fires, and partially because of them, this eastern catchment distributary exhibits a predominance of native grasses and a suite of (hot fire-impacted) remnant vegetation. Grazing-based mitigation of fire intensity at this site would serve further native vegetation regeneration.

Photo 93. The diversity of aquatic plant margins and other habitat values of these groundwater window waterholes within an eastern catchment distributary (same as photo left) would benefit from applied grazing pressure to reduce exotic aquatic pasture dominance.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced.

1. Engage with all relevant stakeholders to improve management outcomes for the remnant riparian habitat of the main lagoon system (Figure 11). Actions include:
   a. Extend fenced-controlled grazing area onto lagoon peninsula to reduce hot/wildfire risk and aquatic grass dominance of lagoon margins (W2).
   b. Seek the support of the adjoining cane farming landholder on the western margin of the site to include high water level flood refuge for grazing stock in a fenced-controlled area to enable extension of grazing season into, and out of, the wet season (W4).
   c. If a suitable high-water refuge for cattle can be established, extend the applied grazing period later into the dry season to exploit enhanced grass margin grazing access. Also, initiate the grazing period earlier in the post-wet season, and consider maintaining some site grazing pressure throughout the wet season, to limit exotic pasture growth dominance through the growing season.
   d. Seek support of adjoining cane farming landholder on western margin of site to extend the fenced-controlled grazing area to include the seasonal wetland basins associated with the western margin of the remnant habitat area for habitat and production benefits, for instance, open water habitat, reduced hot/wildfire risk and rodent harbourage (W5).
   e. Integrate controlled burns with grazing-based management of site habitat condition with a targeted focus on fire-dependent components of the riparian woodland, and on the fire-sensitive exotic aquatic grass margins of the lagoon basins and channels.
2. Provide incentives, for instance, support for fencing infrastructure, and engage with landholders of distributary reaches within the system's eastern catchment, including Wilmar. Canvas interest in establishing management works sites as part of an integrated habitat regeneration program along selected suitable reaches. This would include fencing and controlled grazing, fire regime management, woody weed control, riparian revegetation, and excavator reinstatement of open water habitat in cumbungi-dominated reaches (see *Lack of riparian vegetation* section). For the application of grazing pressure, consider opportunities via negotiated landholder support to introduce stock from the existing downstream-connected Lochinvar Station.
3. Engage with landholders of Lochinvar Station around the range of recommendations (see *Altered hydrology* and *Lack of riparian vegetation* sections) for the lower reaches included in this SMP. Specifically canvas interest and incentive requirements that could foster their engagement. If supported, pursue a dedicated grazing regime and other integrated management initiatives to serve improved habitat outcomes in the lower system's coastal drainage depressions.
4. Engage with Wilmar as the landholder of the lone woodland-wetland 'Ayr land system' habitat remnant (V10) within the easternmost sub-catchment. Explore resourcing opportunities to provide fencing infrastructure, or other incentives, to gain Wilmar's support for bringing the site under a biodiversity conservation-focused environmental management plan that addresses its fire regime management needs via controlled grazing, and also addresses woody weed management issues.

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5. Form a multi-stakeholder working group to move towards establishing formal nature conservation management arrangements, including a managed grazing regime integrated with a controlled burning program for BHWSS remnant habitat corridors and nodes (M2) (see *Critical wildlife habitat* section).

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Critical wildlife habitat

Under the *Queensland Nature Conservation Act 1992* critical habitat is defined as:

> (1) habitat that is essential for the conservation of a viable population of protected wildlife or community of native wildlife, whether special management considerations and protection are required, and
>
> (2) may include an area of land that is considered essential for the conservation of protected wildlife, even though the area is not presently occupied by the wildlife.

Beyond this statutory definition applied to threatened wildlife species listed under state or federal legislation, the concept of critical habitat can be considered more generally as habitat types or features that are essential to the maintenance of specific wildlife species or groups within a particular landscape or area (QNC act 1992).

Conserving and improving the wildlife biodiversity that occurs within the Lower Burdekin floodplain is supported by most stakeholders. Understanding what constitutes critical habitat is important for effective wildlife conservation. Since European settlement in the Lower Burdekin, there has been a reduction in the diversity and population sizes of a range of wildlife species previously occurring in the region, which has coincided with the development of pastoral and agricultural land uses. For example, few younger generation residents know koalas were once common in blue gum forests on the levees of the Burdekin River and were recorded from the Collinson's Lagoon system catchment as recently as the 1980s (DES 2021).

During the author's own lived experience in the region from the 1960s to the present, there are several wildlife species that are anecdotally reported to have become rare, or even extinct from areas within the region. These include northern quolls, otherwise known as 'native cats', which occurred in the Mount Kelly area until at least the early 1970s. Spectacled hare wallabies, known as 'pademelons' by Burdekin locals, were once common in coastal floodplain areas until the 1980s, and are now only recorded in rangeland areas on the margin of agricultural production areas. Further, large, diverse (multi species) finch populations now reduced in species number and population size, and frill neck lizards – once commonly-encountered in habitat remnants – are now a notable record. While the loss of wildlife species can be attributed to a general reduction in available habitat area, habitat fragmentation and feral predators, the loss of critical habitat is often a key cause, even where areas of remnant habitat remain.

Photo 94. The endangered koala *(Phascolarctos cinereus)* was recorded within the Collinson's Lagoon system's catchment within the past 35 years (DES 2021).

Photo 95. The spectacled hare wallaby (*Lagorchestes conspicillatus)* were known from the upper Collinson's Lagoon system until the mid-1980s. This image is from the adjoining Sheep Station Creek catchment in the 1970s.

The intention of identifying this ecological asset type, and threats to it, is to engender a greater appreciation of what sorts of features can constitute 'critical habitat' in riparian and other habitat remnants of Lower Burdekin floodplain landscapes, and how this knowledge can feed into landscape management decisions that support the conservation of wildlife. A non-exhaustive list of critical habitat features that are significant on the floodplain, along with their associated values and management implications, are presented in Table 12.

Some of the main implications of management issues surrounding critical habitat include:

- **Fire regime –** The impact of burning regimes and exotic grass fuel loads on vegetation condition has been widely covered elsewhere in this report. It is important to recognise that uncontrolled burns, particularly hot fires, also impact a range of critical habitat features, including tree hollows, woody debris and shed tree bark.

- **Cultural practices –** Some of the practices that lead to a loss of critical habitat are not from required production activities, but rather are long-held cultural values, including an attraction to parkland clearing, 'cleaning up the farm', and removing problem trees. Greater educational extension to landholders on the value of critical habitat features and the wildlife they support could assist in changing some of these practices.

- **Habitat rehabilitation beyond over storey trees –** In recent decades the concept of habitat rehabilitation has generally become synonymous with tree planting, particularly overstorey trees. Greater recognition of the importance of critical habitats should lead to including a broader range of activities under habitat rehabilitation, such as revegetating mid-storey and groundcovers, and establishing physical habitats such as logs, woody debris, and nesting hollows/boxes.

- **Recognising regional landscape ecology –** A landholder's perspective on the importance of habitat features or their management needs is often constrained to their own property boundaries. Awareness of the broader landscape ecology, including recognising the regional importance of site-specific features, can inform better management. For instance, contributions of tree stands to functional wildlife corridors, and/or choosing to maintain certain habitat features on a property due to their regional uniqueness and importance.

Photo 96. The near-threatened northern quoll (*Dasyurus hallucatus)* occurred near Kelly's Hill, adjoining the upper catchment of the Collinson's Lagoon system, until the early 1970s.

Photo 97. The squirrel glider (*Petaurus norfolcensis)* is a larger animal than the more common sugar glider and was recorded in upper catchment areas of the Collinson's Lagoon system as recently as the 1990s, and within the adjoining Sheep Station Creek system in 2021. It is highly dependent on remnant vegetation corridor connectivity.

Photo 98. The vulnerable southern squatter pigeon (*Geophaps scripta)*, listed under both the *Queensland Nature Conservation Act* and the federal *EPBC Act*, is known from the remnant habitat corridors of the BHWSS in the upper Collinson's Lagoon system (image ian@birdway.com.au).

Photo 99. The endangered black-throated finch (southern) (*Poephila cincta cincta)* is known from remnant floodplain habitats of the broader Collinson's Lagoon system, specifically from retained habitat corridors of the Sunwater-managed BHWSS.

System specifics

Where discussion relates to values, management issues or nominated works listed in Appendix 1 or mapped in Appendix 2, the designated (V, M or W) number is referenced.

Examining Table 12 (below), all listed critical habitat features other than 'closed rainforest' are identified to be of relevance to biodiversity conservation management within the Collinson's Lagoon system. Even the closed rainforest critical habitat feature has analogues in the denser fire-sensitive riparian vegetation communities of the main Collinson's Lagoon remnant habitat complex, and in the revegetated closed forest section of the western drainage line (Photo 51). The following are nominated as the primary critical habitat management concerns for the Collinson's Lagoon system:

- Fringing 'riparian' communities – large reach lengths and some entire sub-catchment areas of the Collinson's Lagoon system have little to no riparian vegetation.

- Aquatic plants of seasonal water level zone – aseasonal inflows of irrigation scheme tailwater have severely reduced the seasonality of the system, promoted the proliferation of floating and grass aquatic weeds, and concomitant loss of native aquatic plant communities.

- Bare lagoon banks – closely related to the preceding point, this concern is associated with dry season water level drawdown and a key waterfowl habitat.

- Remnant vegetation corridors/landscape linkages – the broader landscape context of the system's remnant habitat and their proximity and connectivity among them is a major concern and this is a key determinant of biodiversity conservation outcomes.

- Logs/woody debris – these are absent from the main and smaller lagoons and waterholes due to a history of riparian vegetation loss and burning.

- Flow-connected coastal drainage depressions – essential for successful migration of estuarine breeding fish such as barramundi to the upper catchment, yet are threatened by aquatic weeds and the water quality status in the lower system.

The key management needs for most of these features have been covered in preceding sections of this SMP, particularly those sections addressing:

- seasonal hydrology reinstatement (*Altered hydrology* section);
- reducing impacts of aquatic and woody weeds (*Aquatic weeds* and *Woody weeds* sections);
- poor reach condition fish passage barriers (*Fish passage barriers* section);
- improving the extent, condition, and structural diversity of riparian and adjoining frontage vegetation (*Lack of riparian vegetation, Fire regime* and *Grazing regime* sections); and
- the causes of high fire fuel loads and associated hot fire regime impacts (*Fire regime* and *Grazing regime* sections).

The issue of instream snags and woody debris has not been considered earlier. A specific recommendation to increase the availability of this critical habitat within the main Collinson's Lagoon is made below.

The status of remnant vegetation corridors and landscape linkages, and the landscape ecology context of the site, is a more significant biodiversity conservation management planning consideration that needs further development. The impetus for developing SMPs for wetland systems across the Burdekin floodplain is that they sit within the catchment of the Ramsar wetland. The wellbeing of these wetland systems contributes to the health of the Ramsar wetland; a biophysically connected, receiving environment at the bottom of the floodplain drainage system (see *Background* section). Biophysical connections at a local catchment and site scale also need to inform SMPs to serve 'critical habitat' and biodiversity conservation outcomes. Examining the location of the Collinson's Lagoon system within the broader remnant vegetation landscape of the Lower Burdekin floodplain (Photo 100, 101) reveals two important contextual landscape features:

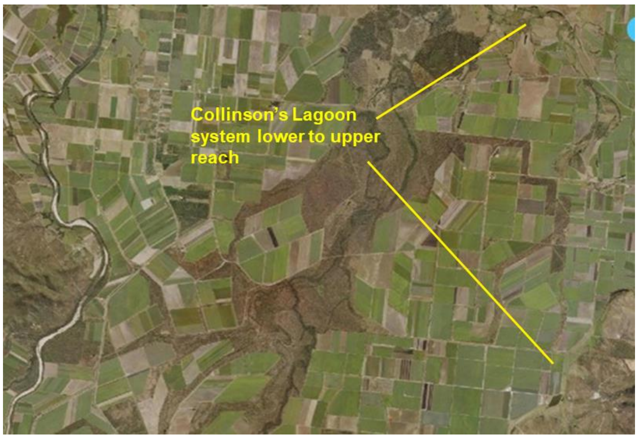

Photo 100. **Photo 100.** Location of the Collinson’s Lagoon system within the broader remnant vegetation landscape of the Lower Burdekin floodplain.

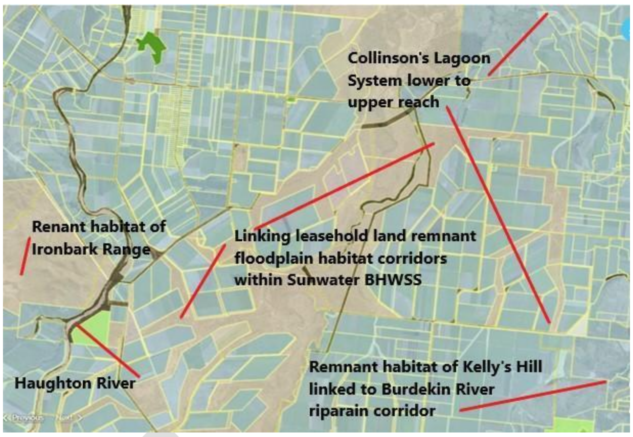

Photo 101. The land tenure context of the Collinson’s Lagoon system illustrates the overlap with a network of retained state land corridors within the BHWSS. These link from the Haughton River in the west across the floodplain, almost to Kelly’s Hill in the east.

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1. The Collinson’s Lagoon systems and retained remnant vegetation areas provide a habitat corridor between extensive areas of retained floodplain woodland within the BHWSS in the south, and with an extensive area of coastal plain grassland and woodland associated with the Lochinvar Station and Cape Bowling Green Bay National Park in the north.
2. The southern upper catchment portion of the Collinson’s Lagoon system is located within a regionally-connected floodplain scale remnant habitat corridor network that has western linkages all the way to the Haughton River and eastwards almost to Kelly’s Hill.

During the development of the BHWSS, thousands of hectares of remnant floodplain habitat were set aside for nature conservation purposes (V3), including a significant part of the Collinson’s Lagoon system’s upper catchment. Despite being ‘reserved’, this area has never been brought under any formal nature conservation tenure or management arrangements. Although it has very high nature conservation values, including listed threatened species (Photo 98, 99), the area’s condition is subject to longer term decline due to a lack of effective fire, woody weed, and grazing management (M2). As noted earlier, wallaby populations within the reserved area and wildfire risks to adjoining cane farms also create management conflict with adjoining land users. In the absence of visible management, the area also suffers from inappropriate management practices such as waste dumping, vegetation clearing, and hot fire regime burns.

The value of the retained habitat corridor network is poorly recognised in state-based mapping of regional habitat corridors and, consequently, has not been employed in regulatory decision making around vegetation management, or actively promoted to adjoining private landholders. Consequently, important regional habitat connectivity themes have been undermined. For example, the retained BHWSS remnant vegetation corridors in the Collinson’s Lagoon catchment include a designed corridor that runs east from the Barratta Creek system to the Collinson’s Lagoon drainage line, and then south upstream toward Mount Kelly following along the main drainage system feeding Collinson’s Lagoon. At the terminus of this corridor near the Mount Kelly lowlands, the extent and condition of remnant vegetation is poor within the leasehold Sunwater land that hosts the corridor, and within the adjoining freehold land that links to remnant habitat on Mount Kelly. The lack of native vegetation in this critical corridor linkage area undermines its functional viability for many species of disturbance-sensitive wildlife that could otherwise utilise it (M4).

Addressing the biodiversity conservation management needs of the BHWSS habitat corridor areas is beyond the scope of this individual SMP, though the strategic merits of having a floodplain-scale SMP would serve the outcomes of Collinson’s Lagoon and other SMPs, like Didgeridoo Lagoon. This integrated approach and the associated outcomes would serve downstream receiving environments, including the Ramsar wetland. This is explored further in the *Innovative management* section.

Beyond the leasehold land tenure BHWSS habitat corridors, other important remnant habitats and corridor connection opportunities identified within the system occur on freehold land and require the engagement and support of private landholders to secure biodiversity conservation outcomes. Remnant vegetation and undeveloped land associated with the Collinson’s Lagoon system extending north from Sayers Road to the coastal Cape Bowling Green Bay National Park occurs on freehold land. Collectively, these areas could provide south-north wildlife corridor connectivity between retained floodplain habitats and the coastal plain adjoining the national park. The viability of such a corridor would be vastly improved if landholders were supportive of retaining and regenerating native vegetation within a designated corridor area (M6).

Included within this nominated corridor area are stands of remnant floodplain woodland and wetland riparian vegetation between Sayers and Rose roads that have high nature conservation values (Photo 55, 56). These areas also have high levels of woody weed infestation, primarily chinee apple, and other species such as parkinsonia that limit their productive use for grazing. Cost effective methods used to control these weeds include clearing using heavy machinery. Remnant native vegetation is often inadvertently cleared during such control methods. Demarcation of higher value remnant vegetation as areas for more targeted control could support better nature conservation outcomes and may offer an incentive for negotiated protective management outcomes if funded by community NRM sources (M21).

The nature conservation value of remnant habitat areas is often relative to what is available. In the context of extensive natural areas, a small, degraded remnant would have low values. In the context of an extensively developed landscape, even small, degraded areas can represent a bastion of biodiversity conservation opportunity. Within the highly-modified Pioneer Mill sub-catchment, of the eastern catchment of the Collinson's Lagoon system, only one remnant woodland-wetland habitat complex remains (V10). Although heavily disturbed by woody and grass weeds and having a hot fire history, the site retains nature conservation values that could be improved by management investment. If managed, this site would provide a nucleus to further progress broader catchment habitat management initiatives (W22).

One of the disincentives for cane farmers to support the retention and protection of remnant natural habitat is that it can promote wildlife species that act as pests to adjoining cane lands. The remnant paperbark forests and riparian woodlands associated with the main Collinson's Lagoon system support a large population of agile wallabies that have created ongoing pressure on adjoining cane lands, particularly via grazing pressure on young cane plants. The main impacted adjoining landholder has tried a range of control methods with limited success, and has since retired one cane block adjoining the remnant habitat area that had become non-viable due to wallaby impact. The introduction of cattle grazing into the habitat remnant has provided some improvement on wallaby numbers by reducing the availability of refuge areas. Ultimately there is a case for supportive management arrangements, including possibly establishing dedicated wallaby fencing, where the public benefit of protecting biodiversity is reciprocated by public investment in managing wildlife crop pests (M12, W6).

No formal terrestrial fauna surveys have been conducted in the catchment or broader floodplain region since those associated with the development of the BHWSS (ACTFR 1994), or earlier seminal regional surveys of the 1970s (Lavery and Johnson 1974). To address Australia's biodiversity conservation crisis needs habitat loss and fragmentation to be halted and reversed, and that the status of wildlife resources targeted by management efforts is monitored and understood.

Recommendations

Note: where recommendations correspond to nominated works (W) in Appendix 1 and 2, the listed works number is referenced. As identified above, most identified critical habitat management needs have been addressed by recommendations in preceding plan sections. Some specific critical habitat recommendations are presented below.

1. Engage system management stakeholders to pursue and implement the recommendations in the *Altered hydrology, Aquatic weeds, Fish passage barriers*, *Lack of riparian vegetation, Woody weeds*, *Fire regime* and *Grazing regime* sections of the SMP as the primary pathways towards improving critical habitat conservation outcomes within the Collinson's Lagoon system.
2. Engage Sunwater; state government agencies including DES; BSC; Gudjuda Reference Group; and other relevant community stakeholders to develop a supported and funded proposal to establish formal nature conservation management arrangements for the retained remnant floodplain habitat corridor and node network within the BHWSS. This includes appropriate tenure designation, weeds, feral and fire management programs, and public access infrastructure and management (W16).
    a. In support of this recommendation, NQ Dry Tropics engage with Sunwater and private landholders located between the upstream extent of Sunwater's tailwater drain RB1 and its associated retained remnant vegetation corridor, and the adjoining remnant habitat areas of Mount Kelly. Seek resources and support for establishing promoted regeneration and/or intensive revegetation initiatives to re-establish wildlife corridor connectivity between the Barratta Creek floodplain and Mount Kelly, and the adjoining Burdekin River riparian corridor (W19).
3. Engage with landholders and other management stakeholders of the Collinson's Lagoon system to create a regional wildlife habitat corridor from retained floodplain habitat areas of the BHWSS in the south, through floodplain habitat remnants between Sayers and Rose road, and retained coastal plain habitat areas of the Lochinvar Station to the Cape Bowling Green Bay National Park in the north.
    a. In support of this recommendation, NQ Dry Tropics extension officers engage with private landholders of high value woodland and wetland habitat remnants located between Sayers and Rose roads. The objective is to assess opportunities for incentives, possibly including woody weed control support, to secure protective management outcomes (W13, W14).
4. Support community investment in wallaby-proof fencing between remnant habitat on the western margin of the main Collinson's Lagoon remnant habitat complex and adjoining cane production areas in recognition of the public benefit of biodiversity conservation served by site management and the associated pest impacts to cane production (W6).

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5. Engage with Wilmar as the landowners of the remnant wetland-woodland habitat remnant within the Pioneer Mill sub-catchment (V10) to develop a site environmental management plan (EMP). This would be focused on woody weed control, controlled grazing, and fire regime management to deliver improved habitat outcomes in both the wetland and woodland (W22).
6. Engage with managers of state land/watercourse in the main Collinson's Lagoon riparian zone (Figure 10) and lagoon frontage landholders. Obtain funds to conduct re-snagging and large woody debris roost habitat establishment in a trial section of the historically-seasonal water level zone of the lagoon margins. Monitor subsequent use by wetland fauna to assess merits of pursuing this action more broadly around the lagoon margins.

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Table 12. Examples of 'critical habitat' within the Lower Burdekin floodplain and implications for management

Critical habitat	Why important	Wildlife groups that benefit	Management implications/opportunities
Tree hollows	Provide nesting and nursery sites that are protected from the elements and predators.	Arboreal mammals (gliders, possums), microbats, hollow nesting birds.	Fire management to avoid uncontrolled burning loss of old trees. Avoidance of old tree clearing. Establishing artificial nest boxes can benefit dependent species.
Fringing 'riparian' communities	Has greater structural complexity, diversity, and associated feeding (fruit, nectar) and nesting resources than surrounding woodlands (or agricultural landscapes).	Migratory passerines, (songbirds), honey eaters, parrots, raptors.	Rehabilitation of riparian forests in agricultural landscapes will support populations of dependent species reduced during development habitat losses.
Riparian – Ecotone margins	Greater diversity of habitat and food resources available, as includes both riparian and adjoining woodland vegetation.	Arboreal mammals (gliders, possums), nectivorous birds, raptors.	Clearing the margin of riparian zones often results in loss of ecotone woodland component in retained vegetation. An ecotone is essentially the boundary between different vegetation assemblages or ecosystem types. Natural recruitment is possible where there are remnant trees. Best opportunities are in broader development set-back corridors.
Mid/understorey trees	Provides a broader range of food resources (wattle gum, broad leaf tea tree nectar, associated insects) than what is provided by overstorey canopy trees alone.	Arboreal mammals (gliders, possums), nectivorous birds, insectivorous bats.	Need to challenge commonly desired parkland clearing aesthetic of 'cleaning up' 'useless scrub' trees, often mid-storey vegetation (like broad leaf tea tree). Need to include in targeted revegetation species.
Aquatic plants of seasonal water level zone	Include important food and nesting resources for waterfowl, prey sheltering, egg laying, cover habitat for fish and aestivation habitat for turtles	Waterfowl, waterbirds, fish, aquatic reptiles, crustaceans, aquatic insects	Stream and lagoon drawdown is now more limited or no longer occurs due to modified hydrology/aseasonal flows. Water management to reduce, reuse or divert aseasonal flows, or manipulate water levels.
Bare lagoon banks	Provides preferred predator safe roosting and resting areas for waterfowl.	Flock-forming waterfowl, like whistling ducks.	Could trial use of intense grazing, burning, or spraying to create.
Remnant vegetation corridors/landscape linkages	Provides opportunities for disturbance-sensitive wildlife to move between remnant habitat areas in developed landscapes to access food resources, find mates and distribute young to new areas.	Arboreal mammals (gliders, possums), macropods, dasyurids (quolls), reptiles.	The value of small vegetation remnants, even individual trees, can be important in providing this critical habitat and needs to be communicated to avoid incremental loss. Regional wildlife corridors transect most systems (see Appendix 1 values).
Exposed sand beds	Provide nesting sites for aquatic reptiles.	Turtles and freshwater crocodiles.	Now a limited resource due to lack of water level drawdown. Control of grass weeds could be used to create.
Closed 'rainforest'	Provides roosting sites protected from exposure to elements and predators and offers food resources for frugivorous (fruit-eating) fauna.	Owls, flying foxes, pigeons, frogs.	Fire sensitive. Existing closed forest reaches/sites warrant protection. Capacity to create with riparian revegetation should be supported at suited sites.
Low ground-covering bushes	Provides shelter from predators and refuge/resting areas for small mammals in open woodland habitats.	Small macropods, like spectacled hare wallabies, rufous bettongs, dasyurids (quolls), ground-nesting birds.	Impacted by pasture improvement, slashing, intensive grazing, and culture of 'parkland clearing', 'cleaning up scrub' as desired aesthetic. Fauna survey of sites retaining this critical habitat could demonstrate its value. Also, a useful revegetation target.
Logs/woody debris	In terrestrial habitat provides safe refuges for numerous species of small-to-medium-sized vertebrates. The aquatic habitat provides refuges and roosts for fish, birds, and reptiles.	Reptiles (snakes, lizards), dasyurids (quolls), and invertebrates.	Lost to frequent burning and 'cleaning up' of habitat remnants. Comparison fauna surveys of sites could demonstrate its value. Inclusion in rehabilitation objectives is valuable.
Rank grasses	Provides grass seed food sources for granivorous birds.	Finches, pigeons.	Critical habitat supported by grazing spelling/timing.

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Shed tree bark	Important refugial habitat for arboreal reptiles (like geckos) and numerous invertebrates, insects, spiders, etc.	Geckos, microbats, invertebrates.	Lost to frequent/hot burning. Target for fire regime management.
Flow-connected coastal drainage depressions	Provides a migratory pathway for diadromous fish to move between estuarine and freshwater habitats of the catchment.	Diadromous fish, like barramundi, mangrove jack, mullet, milkfish.	Impacted by aseasonal flows and cumbungi/anoxic reach establishment. Key system-scale rehabilitation target for most catchments.

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Climate stress

Types and impacts

The most recent and 6th Intergovernmental Panel on Climate Change report provides compelling evidence that the greater than 1°C global heating the planet has experienced since 1890 is unequivocally the result of human activity and is proceeding at a rate that is unprecedented over millennia (IPCC, 2022). In Australia, CSIRO modelling examined the future impact of global heating on regional climate patterns. These outputs can be interpreted at a local government boundary scale [Future Climate Dashboard | LongPaddock | Queensland Government]

Based on the globe's current greenhouse gas emissions trajectory, predicted impacts of most relevance to wetland system management include:

- Temperatures in Australia will increase by between 2.8 and 5.1°C by 2090 compared to 1986-2005; heatwaves will become more intense, more frequent and of longer duration; and the number of days of severe fire danger are likely to increase in southern and eastern Australia.
- Rainfall amounts are expected to decrease over southern Australia, accompanied by more frequent and more severe droughts. While rainfall trends for northern Australia are more uncertain, greater variability and more frequent, intense extreme rainfall events are projected.
- Fewer, but more severe, tropical cyclones are projected.
- Global sea levels are expected to increase by 45cm to 82cm by 2090, though these levels may be higher if a tipping point is reached which commits one or more land-based ice sheets to irreversible melting.
- Extreme high sea-level events will occur more frequently, increasing the risks of saltwater intrusion, flooding, and erosion in coastal areas.
- In line with global trends, sea waters around Australia are becoming more acidic (>30% since pre-industrial), as the oceans absorb much of the CO_2 released by human activities.

(NCCARF 2019) [Climate change and sea-level rise in the Australian region | CoastAdapt]

These projected changes – many of which have been increasingly realised over the past decade – have severe consequences for nature and human society, including agricultural production systems. For wetland system management, the following issues are nominated for consideration in the Lower Burdekin region:

Temperature and water quality

Risk – Higher water temperatures, increased rates instream bacterial decomposition of organic matter resulting in, lower dissolved oxygen (DO) levels; more widespread and frequent summer fish kills; and water quality fish passage barriers.

SMP focus – Greater extent riparian vegetation shading of waterway margins; reduced weed infestation/organic loads into waterway; and role for supplemented/pumped flows to increase DO during critical periods.

Catchment water quality

Risk – Higher intensity rainfall (coming off the back of extended/more extreme dry seasons); higher rates of runoff (potentially in drought stressed catchments); increased soil erosion and contaminant load carrying capacity; and loads exported more directly to receiving stream and wetland systems.

SMP focus – Improvement in contributing catchment condition, particularly vegetation condition; soil erosion pressure points; and increased focus of designed drainage modulus controls (litres/hectares/second) in constructed farm drainage networks, including re-establishing/improving runoff detention function (for example, constructed basins, vegetated drainage lines).

Flood resilience

Risk – Higher intensity rainfall; higher rates of runoff; greater flood peaks; greater frequency of channel break out flows (and associated erosion) across agricultural floodplains; and potential for erosion and undermining/undercutting of stream banks.

SMP focus – Improving condition (contiguousness and width) of riparian vegetation corridors to shade-out channel blocking weed growth; secure stream channel stability and baffle the velocity of channel break out flows; retain and re-establish floodplain overstorey vegetation to baffle overland flow velocities; manage floating aquatic weed and aquatic grass abundance to prevent channel blocking/infrastructure-destroying debris dams; retain natural wetland flow detention areas; and re-establish runoff flow detention within contributing catchment areas.

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Fire regime

Risk – Extended dry seasons; higher air temperatures; lower soil moisture conditions; reduced cool burn season; more extreme, hotter fire outcomes, with greater consequent death of mature trees and impacts to fire-sensitive vegetation; degradation of vegetation structure; and loss of habitat values.

SMP focus – Reducing fire fuel loads in understorey of valuable riparian and wetland/floodplain habitat remnants by promoting canopy closure and/or controlled grazing; promoting cultural change away from farm 'clean up' burning; promoting controlled, cool burning regimes for remnant habitat landholders; incorporating fire breaks in property/farm layouts; and engaging fire wardens in ecological fire management principles.

Fauna refugia

Risk – Drier climate; failed wet seasons; higher air temperatures; reduced soil moisture; poor plant fruiting/flowering, which places fauna species, like bats, birds and tree-dwelling mammals, under behavioural, physiological and/or nutritional stress, including lack of shelter, overheating, and lack of food.

SMP focus – Retention, protection (from fire, weeds, clearing, stock pressure) and rehabilitation of dense, structurally complex, floristically diverse, or highly productive habitat remnants. This includes riparian and floodplain forests adjoining streams, lagoons or wetland basins, and habitat nodes including fire refuges within variegated/developed landscapes.

Invasive species

Risk – Terrestrial ecosystems include native vegetation stressed in terms of growth vigour and/or attained structure by a climate trending towards a bioclimatic envelope outside its adaptive range, namely, too hot, dry, or wet. Other associated stressors, like larger cyclonic, flood, and extreme fire disturbance, present openings for opportunistic weeds or novel insect pests to gain a dominant niche. In aquatic ecosystems, the risk encompasses aquatic habitat quality being degraded outside of optimal conditions for native aquatic species. This includes the water being too hot, having low dissolved oxygen, and/or turbidity, which present advantageous conditions for opportunistic and generalist feral fish species, other novel aquatic pest species, or pathogens to gain a dominant niche. Higher temperatures, failed wets (no flushing flow), and elevated water nutrient status (no flushing dilution) support a longer and more vigorous growing season for aquatic weeds.

SMP focus – Management investment in the condition of terrestrial and aquatic ecosystems to increase system resilience by reducing pest and weed species abundance and maintaining active vigilance regarding identification and proactive control of 'sleeper', or new pest species, within the system.

Revegetation species providence

Risk – Seed or seedlings produced from local providence native plant stock may become stressed during their growth, in terms of their vigour, by climate trending toward a bioclimatic envelope outside its adaptive range, namely, too hot, dry, or wet. Stress can also be caused by disturbances like larger cyclonic, flood, drought, and extreme fire events occurring at a frequency, or for a duration, greater than the species has evolutionarily developed adaptive capacity.

SMP focus – Encourage vigilant observation by landholders and NRM practitioners working within the region of the vigour and potential die back of species comprising local vegetation communities across age classes. This includes areas that have undergone revegetation. Trial and compare the growth success of locally-occurring species from seed stock providences from outside (north, inland) the local latitudinal and longitudinal range.

Landward migration of coastal wetland mosaic

Risk – Sea level rise will increase the landward reach of tidal incursion within coastal wetlands. If protective barriers are created or increased to prevent this occurring, existing brackish environments below barriers will become marine, and important brackish habitats will be lost from the coastal wetland mosaic, potentially in conjunction with a reduction in fish passage connectivity. The ultimate transgression of such barriers could also create highly disturbed environments where freshwater vegetation dies in response to rapid salinity changes.

SMP focus – Identify opportunities, including incentives, to encourage the unimpeded incursion of tidal influence into the lower end of coastal wetland systems. This could include by supporting new bund development within upper reaches of coastal wetland basins in exchange for controlled breaching of existing lower reach bunds. This would allow for the staggered incursion of sea level rise into existing lower freshwater reaches of coastal wetlands, creating a brackish habitat, and facilitating an overall landward migration of the coastal wetland habitat mosaic.

Mitigation as well as adaptation

While the management issues identified above include various proposals to increase wetland system resilience to adapt to emerging climate stress, it is also important to consider the roles that wetland systems can play in mitigating climate change. Principal amongst these is carbon sequestration and storage. Woody wetland vegetation, including that associated with riparian zones and/or floodplains and organic material in wetland soils, represent stores of carbon. Adding to the biomass either through planting or regenerating woody vegetation, or the deposition and long-term burial of organic material in wetland soils, represents carbon

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sequestration. Conversely, wetland environments that promote organic decomposition and associated methane production contribute greenhouse gas (GHG) emissions to the atmosphere. Reducing GHG emissions, preserving existing stores of carbon, and sequestering additional carbon help to mitigate global warming. This knowledge needs to inform all natural resource management actions in a world facing a climate crisis.

System specifics

Considering the landscape, land use and condition context of the Collinson's Lagoon system, seven of the nine issues described above are relevant for system management planning that builds climate stress resilience. These issues include:

- temperature and water quality;
- catchment water quality;
- flood resilience;
- fire regime;
- fauna refugia;
- invasive species; and
- mitigation versus adaptation.

Summarising the identified SMP focal points discussed for these issues above, a Collinson's Lagoon system that is managed to have resilience in the face of climate stress would have the following features:

- Ability to withstand large, floodplain-inundating flows driven by channel breakouts of the Burdekin River, without significant damage to channel integrity or erosion of adjoining floodplain areas. Flow baffling and bands of mature riparian and floodplain vegetation along the Collinson's Lagoon system's bank margins and adjoining frontages would help to secure channel bank integrity against erosive forces. Further, open channel flow capacity would be maintained by the shaded exclusion of weed choke, and breakout flow velocities reduced. Pressure points for potential head-cutting erosion between the lagoon outlet at the highway and the downstream system would be rock armoured. Any available floodplain land, including road corridors within the BHWSS, would have revegetated floodplain vegetation established across overland flow paths to help baffle overland flow velocities.

- Lagoon margins and intervening creek channels shaded by developed riparian vegetation canopies. This shade would maintain cooler water temperatures, particularly during hot summer months, and exclude aquatic grasses from bank margins. Riparian vegetation canopies would help to reduce organic loading and water dissolved oxygen level degradation, and help to maintain flow capacity. This would include lower system drainage depression reaches within Lochinvar Station where dedicated revegetation around deeper wetland basins and channel reaches would provide fish refugia within an otherwise sunlit and shallow wetland system that is exposed to high water temperatures.

- A seasonal hydrological regime that allows for dry season lagoon water level drawdown, and intervening channel drying, that promotes an open channel and wetland basin condition prior to the annual wet season. During this time, water flows and fish passage are not impeded; dried organic material is exported to depositional environments; and water quality is not degraded by aquatic floating and grass weed chokes, including associated organic loading and biological oxygen demand (BOD).

- Specific design features within the BHWSS-constructed drainage network in its contributing catchment area to effectively cope with extreme rainfall events in a way that controls rates of runoff. This avoids erosion to channels and adjoining farmland and limits the transport of mobilised contaminant loads directly to receiving wetland systems. Such designs would incorporate bank stabilising and high flow-baffling riparian vegetation; in-channel vegetation; and constructed features, like bund walls and controlled flow outlets, that enable scheme sub-catchment areas to function as broad detention basins. These basins stage runoff to reduce high flood peaks at the bottom of the system, capture contaminant loads in first flush events, and lower the overall slope and discharge rate of the drainage network.

- Proactive controlled burning and fire regime management. Fire fuel loads in or adjoining areas of remnant vegetation, including BHWSS remnant vegetation areas, would be actively managed by slashing, grazing and/or controlled burning. Proactive management to reduce hot wildfire risks associated with extended dry seasons and elevated temperatures would include promoting riparian vegetation canopy cover and closure along the main lagoon and channel margins to reduce grass understorey. Also, implementing controlled grazing and/or cool burning of fire fuel loads in lagoon frontages, BHWSS remnant vegetation areas, riparian zones, and undeveloped land adjoining production areas that are dominated by an exotic pasture (guinea, para grass) understory; and maintaining functional fire breaks between extensive areas of unmanaged fire-prone remnant vegetation and vulnerable assets.

- Regional wildlife habitat corridors that link to adjoining remnant habitat areas and contain recognised wildlife refuge habitats. These have been consolidated through targeted regenerative activities, like revegetation, controlled grazing, weed, fire control, and are actively protected from threats. For example, riparian vegetation areas that incorporate denser refugial habitat nodes and better condition floodplain vegetation stands within the BHWSS that are poorly represented in the post development landscape, such as the structurally complex forested wetlands on gilgai soils.

- Controlled populations of weeds and feral invasive species through sustained management commitments. Also, vigilance to identify and eradicate infestation source areas, novel, or sleeper species, and to maintain the resilience of native terrestrial and aquatic ecosystems. For example, exotic pasture grasses managed to prevent hot wildfire risks, and aquatic floating and grass weeds kept below infestation levels.

A Collinson's Lagoon system managed to help mitigate global warming would encompass the following actions:

- Regenerate or revegetate all land not being used for pastoral or agricultural purposes. The aim is to support maximum standing woody biomass structure for the regional ecosystem type concerned, which could be a potentially greater biomass in the case of intentional agroforestry land use.

- Have a management regime for hydrological and associated vegetation, like aquatic weeds, that promotes long-term burial of organic material in depositional environments, for example, seasonal drying of bank and lagoon margins and generation of biochar by controlled burning. This regime also reduces the opportunities for creating methane emissions associated with decomposing organic material in depositional environments, such as weed chokes and mats in wet channels loading the water column with organic material.

Recommendations

1. Engage all management stakeholders in:
    a. understanding projected climate conditions over forthcoming decades and their likely expression on Lower Burdekin floodplain landscapes, including within wetland and production systems;
    b. identifying local site and individual, along with regional and collaborative, responses and management initiatives that can increase the resilience of natural resource assets of the floodplain to projected climate stress; and
    c. identifying local site and individual, along with regional and collaborative, responses and management initiatives that can increase the global warming mitigation role of floodplain natural resource management, particularly regarding carbon sequestration and minimising GHG emissions.

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> Innovative management

Why we need innovation

Environmental management is an imperfect science that is best progressed by an adaptive approach. Through this adjustive approach, different methods can be trialled and successes pursued, while mistakes are used as opportunities for learning and can be avoided in future efforts. There has been major improvement in the ecological condition of Lower Burdekin wetland systems due to management investments made over the past two decades. However, as identified through this plan, there are still outstanding environmental management issues confronting most wetland systems and some condition trends remain negative. To achieve further improvements in the environmental condition of wetland systems, there needs to be an ongoing commitment to improving management capacity and outcomes, while recognising the resource constraints for the tasks at hand. Crucially, to take the next step and deliver a new level of improved wetland system management outcomes requires things to be done differently. In some instances, this might involve doing existing approaches better. In other cases, it may call for investigating and applying innovative approaches – essentially drawing on new advanced and original methods.

Much of the environmental management gains achieved for Lower Burdekin wetlands over the past two decades can be attributed to innovation. The use of weed harvesters and excavators to remove neglected aquatic weed infestations; developing a cost-shared weed control program instituted through RMAs; and large reach-scale riparian revegetation outcomes, are all initiatives that Burdekin wetland management stakeholders should be proud of. At the time, these initiatives were truly innovative as it was the first time they had been applied in the seasonal dry tropics, or – in the case of RMAs – in Australia.

During the development of the initial SMP for Sheep Station Creek, 15 other innovative management methods, tools, and approaches were proposed. These are listed below, but are described in full in the Sheep Station Creek SMP (Econcern 2021). Another innovative management method (point 16) that was trialled and developed by NQ Dry Tropics Wetland Team Leader Scott Fry in recent years has also been added to the list. Seven additional innovative management approaches (point 17-23) were also proposed during the development of the Woodhouse Lagoon, Ironbark Creek – Healey's Lagoon and Horseshoe Lagoon SMPs (Econcern 2022a, 2022b, 2022c). The innovative management methods are:

1. Excavated channel weed control via riparian shade tree planting.
2. Alternate channel weed control methods utilising small in-channel machinery.
3. Pumped environmental 'freshening' flow during wet season critical water quality period.
4. Weed control via effective biomass removal and economically viable soil ameliorant product development.
5. Use of mobile herd to deliver controlled grazing outcomes throughout catchment.
6. Alternate distributary channel fish passage bypass route.
7. Establishing riparian forest and native water lily shading to reduce submerged plant growth.
8. Catchment line of control for floating aquatic weeds.
9. Establishing farm drainage line revegetation/detention function.
10. Use of monitoring drones.
11. Conducting cool burns in cane land habitat remnants.
12. Direct seeding vegetation regeneration methods for exotic grass-infested riparian zones.
13. Instream physical habitat interventions.
14. Fenceless grazing systems.
15. Alternatives to chemical weed control.
16. Use of drones for aquatic weed spraying.
17. Waiving overland flow/water course access/licensing fees for aseasonal flows originating from farm irrigation and/or BHWSS tailwater flows.
18. Intervention and re-use of farm/scheme area irrigation tailwater for off-stream pasture production.
19. Establishing a suitable water quality fish passage preferential flow path through an aquatic grass weed-dominated drainage depression via riparian shading.
20. Alienation of irrigation supply flows from naturally seasonal wetlands.
21. Forming dedicated catchment management groups to support enhanced aquatic weed and other environmental management of floodplain wetland systems.
22. Using water management and/or bypass infrastructure to reinstate a seasonal hydrological regime to the wetland system.
23. Using the state land tenure context of the landscape for developing a regionally-significant, protective management, biodiversity conservation planning outcome.

System specifics

Given the overlap in land and water use and condition context of the Collinson's Lagoon system with other wetland systems that have SMPs, many of the previously identified innovative management approaches are applicable. Eleven of the listed 23 points (1, 4, 8, 10, 13, 15, 16, 17, 18, 22 and 23) are incorporated in some form in management recommendations in this SMP and the complete set have some relevance.

Two management recommendations in this SMP are considered innovative proposals in their scope, but have been previously proposed in previous SMPs in concept. These are:

(1) Riparian zone regeneration/intensive revegetation efforts to create shaded, open, deeper water fish habitat refugia within a bunded coastal drainage depression wetland complex. This recommendation was made regarding the flow and aquatic weed-modified habitat of the lower system’s bunded drainage depressions, which have elevated water temperature and low dissolved oxygen status limitations to their fish habitat suitability. While the concept of riparian vegetation rehabilitation to improve fish habitat is not original, other than being one of the original motivations for doing such works, the concept of creating suitable habitat refuges within an otherwise degraded system is somewhat innovative for aquatic ecosystems, although commonly employed in terrestrial habitat conservation planning. Whether individual sites can maintain aquatic habitat suitability when surrounded by more extensive degraded areas that may ‘swamp’ the benefits of site improvements when inundated or connected by flow events would need to be ascertained. Good quality aquatic habitat nodes within a more degraded system improve overall system function. Another beneficial feature of this proposal is that it seeks to integrate habitat management outcomes within a broader production system that is desired by primary producers, yet has habitat quality limitations. The concept of dedicating just a small proportion of a property’s wetland resources away from production imperatives and toward biodiversity outcomes was proposed by Tait (2011) via dedicated grazing regimes to enhance wetland habitat condition outcomes. Such proposals are more likely to gain support from pastoral landholders rather than biodiversity-based management prescriptions that carry property-wide foregone production expectations.

(2) Trialling sequentially integrated habitat management prescriptions to deliver improved condition outcomes. Reference to the use of ‘integrated management’ techniques in natural resource management literature is commonplace. Often the term is used without any real definition of what it is that is being ‘integrated’. In essence, the term refers to the use of more than one management method concurrently or sequentially. During preparation of the Collinson’s Lagoon SMP, two management proposal areas were seen to have opportunities for improved outcomes via successful sequential integration of methods. These include the management of exotic aquatic pasture grass weeds on lagoon margins, and the recovery of cumbungi and exotic grass-dominated distributaries of the eastern catchment. Regarding the former, existing spraying and or controlled grazing efforts are not yet delivering a sustainable improved condition outcome. Recommendations to integrate seasonally-applied grazing pressure with spraying and burning (see *Aquatic weeds, Grazing regime* and *Fire regime* sections) could deliver a more effective condition outcome. The integration of grazing and burning by Tait (2011) (Photo 75, 76) delivered significantly improved habitat condition outcomes. Incorporating such efforts in the existing controlled grazing program on Collinson’s Lagoon could be equally as beneficial. Field investigations within the cumbungi and exotic grass-dominated distributaries of the eastern catchment, including assessment of recent and in situ management practices, suggest that physical excavation of cumbungi; along with grazing, burning and ‘fill in’ revegetation – potentially in that order (see *Lack of riparian vegetation* section) – provides a viable management pathway for reinstating the wetland habitat values and functions of these distributary systems. Committing to incorporate, rather than simply refer to, integrative methods would be innovative and worthy of management trials.

Recommendations

1. As per recommendations in the *Altered hydrology*, *Aquatic weeds, Lack of riparian vegetation, Fire regime* and *Grazing regime* sections, engage with landholders of Lochinvar Station about dedicated weed control and riparian zone regeneration/intensive revegetation efforts to create fish and other fauna habitat refugia at a small scale without decreasing production values. Aim to apply this approach in broader degraded areas of the Collinson’s Lagoon, or other SMP focal areas.
2. Incorporate integrated method trials into the existing controlled grazing and aquatic weed control programs on the main Collinson’s Lagoon system in relation to exotic aquatic grass margins, and apply integrated management to restore habitat condition within the degraded distributaries of the eastern catchment.

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> Appendix 1 – Reach values, management issues and nominated works descriptions

Reach values (V)
Short description – V1: Collinson's lagoon productive deep-water perennial deep-water habitat with native aquatic plants
V1 – Full description This large perennial lagoon occurs adjacent to the Bruce Highway and is surrounded by irrigated cane land development. Its main ecological values are associated with its aquatic habitat and wetland biota, which include populations of barramundi and other migratory and resident fish species, several species of turtles, two species of crocodile, and waterbirds. Riparian vegetation condition is poor due to historical clearing and more recent hot fire impacts, and this limits the complexity of instream habitat and the habitat value of the lagoon for woodland and forest birds. A peninsula of land projecting into the northern end of the lagoon retains the best remnant vegetation and this acts as a wildlife refugia including for agile wallaby populations. Some limited riparian revegetation along the margin of the main lagoon is also developing canopy shading (albeit small areas) along the lagoon's margins. Aquatic weed control management efforts over the past decade have recovered this lagoon from a very weed infested, degraded status. Its current open water condition has value, and is a testament to the benefits of management investment. Ongoing weed management of exotic aquatic grass margins and floating aquatic weeds have also seen the recovery of large floating beds of water lilies and other native macrophytes that now provide good instream habitat resources, in contrast to many regional lagoons that have lost these aquatic plant communities. Other relative values of this lagoon within the broader system are associated with being off the main conduit for aseasonal tailwater inflows and, consequently, retaining clearer water quality and some limited seasonality of water levels. State riverine wetland Aquatic Conservation Assessment gives the site a high value.
Short description – V2: High value remnant riparian and wetland habitat complex representative of Ayr land system
V2 – Full description The value of this complex of wetland and riparian habitats is underpinned by the diversity of juxtaposed habitat types, including seasonal and perennial freshwater wetlands; melaleuca forest; eucalypt woodland and rainforest elements; the diversity of plant species; the structural complexity of the habitat; and its representation of natural landscapes typical of the Ayr land system (Christian *et al* 1953) that have largely been developed to agriculture. The site's plant diversity and structural complexity provides associated feeding and nesting resources for nectivorous, insectivorous, and frugivorous birds and bats, arboreal mammals, and macropods. The site's core size, denser stands of vegetation and closed canopy cover also provide wildlife refugia and suit cover-dependent species, such as owls. Wetland habitats and productivity support wetland biota, including populations of barramundi and other migratory and resident fish species, frogs, several species of turtles, two species of crocodile and other reptiles, waterbirds, water rats, and raptors. The site is assessed to have state biodiversity significance as an ecologically significant wetland and very high ecosystem value. Matters of state environmental significance recognised for the site include regulated vegetation that is habitat for endangered or vulnerable wildlife species, or GBR riverine regrowth and defined watercourse vegetation. State riverine wetland Aquatic Conservation Assessment gives the site a high value and it forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).

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Short description – V3: Large regionally-connected good condition remnant floodplain vegetation
V3 – Full description This large area of remnant floodplain vegetation was set aside during the development of the BHWSS (previously the Burdekin River Irrigation Area, or BRIA) nominally for nature conservation purposes. It forms part of some 10,000ha of natural floodplain retained during the development of the then BRIA. State assessments recognise its regional biodiversity significance; its 'of concern' regional ecosystems; and the area having up to very high condition, context, and connection values; and high ecosystem value, ecosystem diversity, and wildlife refugia values. This study would nominate much higher than regional values to this and other retained floodplain habitats within the BHWSS. This would recognise the total cumulative size of retained areas; their connectivity via dedicated corridor retention, both laterally across the floodplain (from the Haughton to Burdekin Rivers) and longitudinally along drainage lines (from inland rangeland areas to the coast); observations of EVNT taxa not recognised by state assessments; and the uniqueness and natural heritage of this system of planned habitat retention within a government-developed irrigation area unparalleled anywhere else in Australia.
Short description – V4: Rare melaleuca swamp forest remnant on gilgai soils
V4 – Full description This site occurs within a corridor of remnant floodplain vegetation set aside during the development of the BHWSS (previously the Burdekin River Irrigation Area, or BRIA) nominally for nature conservation purposes. This specific site comprises paperbark (*Melaleuca dealbata*) swamp forest on a gilgai, or 'melon hole', soil landform that hosts numerous small wetland depressions following wet season rainfall or inundating flow events. This relatively small site is one of the last representative examples of a land-vegetation type that was historically much more extensive, extending from this site towards the coast and occurring in other broad drainage depressions of the Burdekin-Haughton floodplain. Besides its representativeness value, the small seasonal wetland habitats associated with it are reduced in abundance in the broader region and are important fish-free breeding habitat for frogs, and support wetland invertebrates, reptiles, and native aquatic plant communities. The density and structure of the woodland structure also provides good nesting and feeding habitat resources for nectivorous and insectivorous birds and bats, and refugial habitat for arboreal mammals, and macropods. Given the restricted size of the site, most of these values have not been recognised in coarse state-based assessments, although the site is recognised to have up to regional biodiversity significance, has at least one 'of concern' regional ecosystem, and a very high condition value and high ecosystem value.
Short description – V5: Regionally-significant wildlife habitat corridor
V5 – Full description This corridor of remnant floodplain vegetation was set aside during the development of the BHWSS (previously the Burdekin River Irrigation Area, or BRIA) nominally for nature conservation purposes. Its two main values are associated with the remnant floodplain vegetation it contains and the wildlife habitat connectivity it provides across the intensively developed floodplain. It forms part of some 10,000ha of natural floodplain habitat retained during the development of the then BRIA. This point of the corridor is near its terminus and forms a somewhat tenuous linkage with the remnant habitats associated with Mount Kelly, which links to the Burdekin River bioregional riparian corridor. Connectivity north and west from the indicated point runs through contiguous remnant floodplain

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habitat, all the way to the Haughton River bioregional riparian corridor. State assessments recognise it contains matters of state environmental significance, including ‘of concern’ regional ecosystems. It is also of regional biodiversity significance, having up to very high condition, context, and connection values; and high ecosystem value, ecosystem diversity, and wildlife refugia values; and medium value as habitat for endangered, vulnerable or near threatened (EVNT) wildlife species. This study would nominate state significant values to this and other retained floodplain habitats of the BHWSS. This would recognise their role as regional corridors, in this case, providing lateral connectivity across the floodplain (ultimately from the Haughton to Burdekin Rivers); observations of EVNT taxa not recognised by state assessments; and the uniqueness and natural heritage of this system of planned habitat retention within a government-developed irrigation area unparalleled anywhere else in Australia.

Short description – V6: ‘Green Swamp’ regionally-significant seasonal wetland type

V6 – Full description

This open, seasonal, wetland basin known locally as the ‘Green Swamp’ is a natural runoff detention area that fills during wet season rainfall or inundating flow events. Its hydrology has been impacted by constructed tailwater drains that now circumvent the drainage depressions that used to convey floodplain runoff into it. However, during large flow events, the site still fills with water. The native floodplain grasses that used to characterise it have now been displaced by invasive exotic aquatic pasture grasses. Historically, this seasonal wetland supported large populations of waterfowl and other wetland birds and biota. Despite its modified condition, the site still seasonally hosts a range of wetland birds and has functional values as a runoff detention area and nature conservation value as a representative example of a wetland type that used to characterise the Burdekin floodplain. The site is recognised as a matter of state environmental significance as an ecologically significant wetland, and for having regulated vegetation up to 100m from the defined wetland. It is also assessed to have regional biodiversity significance with high value as a wildlife refugia; and is assessed to have high conservation significance in state non-riverine wetland Aquatic Conservation Assessments.

Short description – V7: High value remnant vegetation representative of the Ayr land system

V7 – Full description

These three broad areas of better condition remnant vegetation occur within a matrix of degraded habitat impacted by woody weeds and clearing. Their value is associated with providing woodland habitat resources suited to a range of reptile, bird, mammal, and other wildlife; their juxtaposition with remnant wetland habitats; their collective role as a wildlife refugia and corridor; and their representation of natural landscapes typical of the Ayr land system (Christian *et al* 1953) that have largely been developed to agriculture. State assessments assess the collective area to have regional biodiversity significance, containing ‘of concern’ regional ecosystems; and having very high values for condition; high ecosystem value; and medium values as habitat for endangered, vulnerable or near threatened (EVNT) wildlife species.

Short description – V8: Perennial deep-water lagoon

V8 – Full description

This perennial deep-water lagoon is one of the smaller within the broader Collinson’s Lagoon system, but shares many values with larger examples and has some better condition factors. Its main ecological values are associated with its aquatic habitat and wetland biota, which include populations of barramundi, and other migratory and resident fish species; and several species of turtles,

freshwater crocodiles, and waterbirds. Riparian vegetation is discontinuous and condition is generally poor due to historical clearing, slashing-based bank maintenance and/or hot fire impacts; but does contribute to the complexity of instream habitat and the habitat value of the lagoon for woodland birds. Aquatic weed control management efforts over the past decade have recovered this lagoon from a very weed infested and degraded status. Its current open water condition has value as is a testament to the benefits of management investment. Matters of state environmental significance at the site include GBR riverine regrowth-regulated vegetation. The site is assessed to have high value in state riverine wetland Aquatic Conservation Assessments and forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V9: 'Lochinvar' state significant coastal wetland complex
V9 – Full description This large coastal wetland complex is located on the private pastoral property 'Lochinvar'. The site has been historically cleared and developed to improve pasture, but still retains very high habitat values for waterfowl and waterbirds. It also provides fishery nursery habitat, particularly for commercially and recreationally-important barramundi, and is known to host large individuals of saltwater crocodile. It is recognised to have matters of state environmental significance, including ecologically-significant wetlands; regulated vegetation, including GBR riverine regrowth; defined watercourses; mapped essential habitat, including up to 100m from mapped wetland boundaries; and for providing habitat for endangered, vulnerable or near threatened (EVNT) or least concern wildlife species. State biodiversity significance is associated with it being an ecologically-significant wetland; forming part of a bioregional riparian corridor associated with the lower Barratta Creek system; and having very high ecosystem value. State riverine wetland Aquatic Conservation Assessments define the area as being of high value, and non-riverine wetland Aquatic Conservation Assessments define the area as being of high conservation significance. This site also forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V10: Remnant habitat complex representative of the Ayr land system
V10 – Full description This site has been disturbed by past clearing and woody and grass weed invasion, but retains ecological and conservation values associated with the juxtaposition of woodland and wetland habitat types suited to a range of bird, reptile and mammal fauna; the structural complexity of provided habitat; its role as a wildlife refugia in an extensively developed landscape; and remnant vegetation, including large trees representative of the natural landscapes typical of the Ayr land system (Christian *et al* 1953) that have largely been developed to agriculture. Matters of state environmental significance recognised at the site include an ecologically-significant wetland, and regulated vegetation 100m from the defined wetland boundary. State biodiversity significance includes an ecologically-significant wetland; very high condition context, connection, and ecosystem value; and representation of 'of concern' regional ecosystems. Despite recognised condition impacts, the site is also assessed to be of high conservation significance by state non-riverine wetland Aquatic Conservation Assessments and forms part of the Burdekin – Townsville Coastal Wetland aggregation listed in the national Directory of Important Wetlands in Australia (DIWA).
Short description – V11: Remnant riparian and wetland habitat corridor

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V11 – Full description This relatively poor-condition riparian vegetation and wetland corridor has ecological and conservation value in representing the residual native biodiversity and wildlife refugia within an intensively developed landscape. One of the other main values associated with this habitat corridor lies in its potential for rehabilitation via management investment. Even in its current state, it retains stands of mature native riparian trees and palms; native emergent wetland plants; and aquatic habitats that support bird, reptile, and mammal fauna. Matters of state environmental significance within the site include GBR riverine regrowth regulated vegetation. Despite its apparent condition impacts, the site falls within an area assessed to have high value in state riverine wetland Aquatic Conservation Assessments.
Short description – V12: Revegetated riparian vegetation corridor
V12 – Full description The value of this site lies both in its habitat values and demonstration role. This successfully-revegetated stream reach has developed a diverse closed canopy structure, and now provides good habitat for a range of native fauna, including birds, reptiles, and mammals. It is also contributing to increased instream habitat complexity, like snags, and productivity, such as leaf litter fall. The benefits of establishing a riparian vegetation canopy are also being demonstrated at the site in terms of the exclusion of exotic understory grasses from both the bank levee (e.g., guinea grass) and stream margin (e.g., para grass and hymenachne). Also in terms of the associated reduction of fire fuel loads and associated wild/hot fire risks; rodent harbourage, and instream water quality impacts. Matters of state environmental significance at the site include regulated GBR riverine regrowth vegetation. The site falls within an area assessed to have high value in state riverine wetland Aquatic Conservation Assessments.
Short description – V13: Isolated floodplain wetlands with remnant riparian vegetation
V13 – Full description This aggregation of small perennial and seasonal wetlands occur within an area of disturbed remnant vegetation representative of the natural landscapes typical of the Ayr land system (Christian *et al* 1953) that have largely been developed to agriculture. Most have retained fringing riparian vegetation and some degree of isolation from hydrological and water quality impacts associated with aseasonal inflows of irrigation tailwater. Their ecological and conservation values are attributed to their representation of rarer habitat types; diverse and structurally-complex habitat resources; wildlife refugia; and for providing habitat opportunities for wetland biota, including aquatic plants adapted to seasonal hydrological conditions. Collective protective management of these wetlands and the broader matrix of remnant floodplain woodland surrounding them would represent a good nature conservation outcome.
Short description – V14: Coastal wildlife corridor
V14 (a to b) – Full description The relatively large complex of remnant and disturbed habitat occurring between Rose Road and the Bruce Highway represents an existing, although tenuous, wildlife habitat corridor for natural cover-dependent wildlife species distributing between the large areas of remnant floodplain habitat associated with reserved corridors in the BHWSS to the south; and the extensive coastal habitats associated with Lochinvar Station and Cape Bowling Green Bay National Park to the north. Recognition of this corridor connectivity

as an existing ecological value serves to guide any future land use intensification away from severing its connectivity and/or guide landscape rehabilitation activities toward consolidating it.

Short description – V15: Revegetated constructed wetland

V15 – Full description

This constructed wetland owes its origin to a soil borrow pit that has been inundated by a combination of wet season inflows and groundwater. The site has been the focus of a riparian and adjoining floodplain revegetation project, and much of this vegetation has now been established to a point of providing good quality habitat. The wetland basin experiences seasonal hydrological conditions, including drawdown of water levels, which has facilitated the establishment of a relatively diverse native aquatic plant community. The entire site now represents valuable habitat for waterfowl and waterbirds, and a range of other wetland biota including fish, frogs, and reptiles. The site is located within a large corridor of remnant floodplain vegetation retained within the BHWSS and adds to the overall diversity and ecological value of the retained habitat area. It also has value as a demonstration site, illustrating the biodiversity benefits of strategic revegetation targeting degraded or constructed wetland basins.

Management issues (M)

Short description – M1: Aseasonal inflows of irrigation tailwater and channel overflow from the BHWSS

M1 – Like all wetlands in the seasonal dry tropics, the natural hydrology and associated ecology of the Collinson’s Lagoon system was highly seasonal and related to the timing and magnitude of the annual wet season. In the contemporary modified system, the hydrology is dominated by inflows of irrigation tailwater and supply channel overflow from the BHWSS throughout its upper catchment. These aseasonal inflows contribute to near-perennial flows through the system downstream to receiving coastal areas, and a major reduction in dry season drawdown of water levels in lagoon and swamp waterbodies throughout the system. This altered hydrology has generated major changes in aquatic plants communities (increased aquatic weeds, decreased native communities), water quality (higher turbidity and nutrients), fish passage connectivity (barriers created by weed chokes) and associated habitat values for wetland fauna.

Short description – M2: Lack of active management – fire, weeds, grazing in high value habitat remnants retained for nature conservation

M2 – During the development of the BHWSS (formerly known as the BRIA), thousands of hectares of remnant floodplain habitat were set aside nominally for nature conservation purposes. A significant area of the Collinson’s Lagoon system catchment comprises this reserved area. Despite being ‘reserved’, this area has never been bought under any formal nature conservation tenure or management arrangements. Although having very high nature conservation values, the area’s condition is subject to longer term decline due to a lack of effective fire, woody weed, and grazing management. Wallaby populations within the reserved area and wildfire risks to adjoining cane farms also create management conflict with adjoining land users. In the absence of visible management, the area also suffers from inappropriate management practices such as waste dumping, vegetation clearing, and hot fire regime burns.

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Short description – M3: Ungrazed exotic grass understorey and resulting hot fires have degraded remnant riparian/floodplain vegetation

M3 – Historically, much of the floodplain drainage depression areas that constitute the upper catchment of the Collinson's Lagoon system hosted relatively open eucalypt and melaleuca woodland vegetation that was used for grazing purposes. With the development of the BHWSS to intensive irrigated agriculture, grazing was alienated from most retained remnant vegetation areas, though short term grazing leases have been reinstated at some larger sites. Ungrazed areas become prone to infestation by exotic pasture grasses, such as guinea and para grass, which create large fuel loads for dry season fires. When burning is conducted in the late dry season, when cane crops have been harvested and fire risks to crops are low, the resultant hot fires can severely impact vegetation. Hot fires can cause the death of mature trees and degrade the canopy extent and condition of riparian, as well as floodplain, vegetation communities, facilitating further dominance of invasive understorey grasses. As well as posing further hot fire risks to remnant vegetation, increasing pasture grass density also serves to suppress native seedling recruitment. Lacking active management, retained remnant habitat areas have also been used as common areas to borrow soil, place infrastructure, and conduct vegetation clearing and track making. These combined processes have diminished the condition and diversity of remnant floodplain vegetation in retained habitat areas throughout the BHWSS areas of its upper catchment.

Short description – M4: Loss of regionally-important wildlife corridor connectivity due to clearing and land use intensification

M4 – During the development of the BHWSS (formerly known as the BRIA), thousands of hectares of remnant floodplain habitat were set aside nominally for nature conservation purposes, including providing wildlife corridors across the developed landscape. 'Reserved' remnant vegetation in the Collinson's Lagoon catchment includes a designed corridor that runs east from the Barratta Creek system to the Collinson's Lagoon drainage line, and then north to south upstream towards Mount Kelly, following along the main drainage system feeding Collinson's Lagoon. At the terminus of this corridor near the Mt Kelly lowlands, the extent and condition of remnant vegetation is poor within the leasehold Sunwater land hosting the corridor, and adjoining freehold land that links to remnant habitat on Mount Kelly. The lack of native vegetation in this critical corridor linkage area undermines its functional viability for many species of disturbance-sensitive wildlife that could otherwise utilise it.

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Short description – M5: Runoff flow detention function of natural floodplain wetland basins circumvented by constructed drain network

M5 – Under pre-development conditions, the upper floodplain catchment of the Collinson's Lagoon area was defined by defuse drainage depressions that drained to natural basins and flow detention areas. These included the 'Green Swamp', an open grassy wetland between Butler and Hope roads; and a broad closed paperbark forest on gilgai/melonhole landforms near Sayers Road. With the development of the BHWSS, large constructed tailwater drains now drain irrigation tailwater, channel overflow, and catchment runoff through areas that previously only had a diffuse drainage system. Where these drains bypass the historical wetland detention areas, they are lower than the original wetland basins. This isolates the wetlands from inflows, except under large inundating flood conditions. When these wetlands get inundated by flood events, the adjoining drains also serve to drain them quicker than their historical hydrology allowed. The result of the interface between the historical floodplain and constructed drainage system is that catchment runoff rates are much greater, conveying higher flow velocities and flood peaks and associated elevated

sediment/nutrient loads to the lower catchment, while isolating the remnant wetland basins from providing flow detention and associated load processing functions.
Short description – M6: Potential connectivity of wildlife corridor to coast undermined by status and condition of remnant vegetation
M6 – Within the southern extent of the Collinson's Lagoon system's catchment, dedicated retention of floodplain habitat during the development of the BHWSS has created wildlife corridors that extend laterally west to east, and longitudinally north to south across the floodplain. These retained areas occur on state leasehold land. Remnant vegetation and undeveloped land associated with the Collinson's Lagoon system, extending north to the coastal Cape Bowling Green Bay National Park, occurs on freehold land. Collectively, these areas could provide south-north wildlife corridor connectivity between retained floodplain habitats and those of the coastal plain adjoining the national park. The viability of such a corridor would be vastly improved if landholders were supportive of retaining and regenerating native vegetation within a designated corridor area.
Short description – M7: Woody weed infestation (chinee apple) and clearing-based control methods present risks to remnant vegetation values
M7 – Remnant vegetation and undeveloped land associated with the Collinson's Lagoon system north of Sayers Road has high levels of woody weed infestation, primarily chinee apple, and other species such as parkinsonia. Cost effective methods used to control these weeds include clearing using heavy machinery. Remnant native vegetation distributed amongst woody weed stands is often inadvertently cleared during such control methods. Demarcation of higher value remnant vegetation as areas for more targeted control could support better nature conservation outcomes.
Short description – M8: Aquatic grasses and weeds in constructed drainage networks create debris dams in lower reaches during flood spates
M8 – Large constructed tailwater drains within the BHWSS convey water throughout most of the year and present conditions highly suited for the proliferation of aquatic weeds, including grasses, and submerged, emergent, and floating species. Although Sunwater manages weeds within these drainage systems, control interventions are not sufficient to remove all weed growth and large biomasses, including floating mats of aquatic weeds, establish within these drainage systems at times. When there are rainfall-driven high flow events, floating and grassy weed mats are transported downstream to receiving stream channels and/or lagoon basins, and can form channel-blocking dams where they accumulate on vegetation or bridge infrastructure. This poses both flooding risks to adjoining areas and impact risks to built infrastructure.
Short description – M9: Excavator access for channel clearing limits riparian revegetation, though strategic revegetation could reduce need
M9 – The flow capacity of the stream channel through this modified reach is periodically maintained by excavator clearing of aquatic weeds, both grasses and floating weed mats. To operate an excavator though this reach requires that the stream bank is clear of woody riparian vegetation. Ironically, the resulting open sunlit channel creates conditions highly suited to the reinfestation of the

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stream channel by aquatic grasses, while dense shade canopy-forming riparian vegetation provides a means of shading out and controlling fringing aquatic grasses along the stream channel. The integration of revegetation via dense shade-forming canopy species, such as Leichardt trees (e.g., on the western banks), with excavator access could support a less weedy channel condition that requires reduced excavator maintenance. This outcome has been achieved on other floodplain steams in the Lower Burdekin, for example, Sheep Station Creek.
Short description – M10: Riparian vegetation condition being impacted by woody weed and vine infestation
M10 – Within this drainage easement section of the system, the most significant remnant native vegetation providing wildlife habitat and corridor connectivity is remnant and regenerating riparian vegetation along the excavator-modified stream channel. This riparian corridor has low, but increasing, levels of woody weed (chinee apple, parkinsonia) and rubber vine infestations. In the longer term these weeds and/or methods used to control them could impact upon the riparian habitat values.
Short description – M11: Aquatic grass infestation and associated siltation reducing channel flow capacity
M11 – In this drainage easement section of the system, the channel broadens into a treeless drainage depression-shallow lagoon basin that is prone to aquatic grass (hymenachne, para) and floating aquatic weed infestation. The combined effect of the broader depositional zone channel and weed blockages is increased sediment deposition and shallowing within the reach. This decreases flow capacity, increases flooding risks, and further promotes aquatic weed infestation.
Short description – M12: Wallaby populations in remnant habitat area placing high pest pressure on adjoining cane lands
M12 – The retention and protection of remnant natural habitat can promote some wildlife species that act as pests to adjoining cane lands. These remnant paperbark forests and riparian woodlands support a large population of agile wallabies that have created ongoing pressure on adjoining cane lands, particularly via grazing pressure on young cane plants. The adjoining landholder has tried a range of control methods with limited success, and has retired one cane block adjoining the remnant habitat area that has become non-viable due to wallaby impact. The introduction of cattle grazing into the habitat remnant has provided some impact on wallaby numbers by reducing the availability of refuge areas. Ultimately, there is a case for supportive management arrangements, potentially including dedicated wallaby fencing, where the public benefit of protecting biodiversity is reciprocated by public investment in managing wildlife crop pests.
Short description – M13: Lack of high-water level refuge for grazing cattle limits seasonal duration grazing pressure in habitat remnant
M13 – Over the past decade, remnant riparian habitat within this section of the system has been subject to establishing controlled grazing via the support of public investment in fencing infrastructure. This has helped to manage fire fuel loads, and associated hot fire risks, created by pasture grass weeds and reduce the dominance of exotic aquatic grasses along lagoon margins. Currently the grazing regime applied to remnant habitat areas is seasonally constrained by cattle access to the wetland basins, with cattle not introduced to the site until wet season water levels have sufficiently receded. Cattle are removed from the site in advance of any inundating high flow event towards the end of the dry season. Stock access to a high-water refuge could increase the duration and weed-controlling effectiveness of grazing regimes applied within this habitat remnant.

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Short description – M14: Seasonal access limitation impacting effectiveness of woody weed (chinee apple) control in habitat remnant
M14 – Over the past decade, investment in woody weed control within this habitat remnant has reduced the abundance of woody weeds including chinee apple, leucaena and parkinsonia. Ongoing control effort is required to maintain condition gains. Residual areas not effectively targeted by control efforts hasten reinfestation. Wetted channels have restricted woody weed control access during recent management efforts. Seeking weed control access during dry season periods, or via the use of dedicated access-capable vehicles, would serve to improve woody weed control outcomes at this site.
Short description – M15: Reduced burning frequency leading to changes in vegetation community structure and composition
M15 – With the introduction of controlled grazing for fire fuel load reduction in this habitat remnant, the occurrence of hot fire has been avoided and the frequency of fires generally has also been reduced. One of the consequences of reduced burning is that the occurrence of generally fire-sensitive canopy species is increasing, and some of the habitat remnant is trending toward a more closed canopy structure. While there are weed management and habitat benefits associated with this, there is also merit in maintaining fire-mediated patches of habitat within the greater remnant habitat area in terms of promoting overall biodiversity. There would be nature conservation merit in examining options and suitable locations to reintroduce cool burns to appropriate sections of this habitat remnant.
Short description – M16: Limited dry seasonal drawdown of water levels prevents effective access of grazing pressure to aquatic grasses
M16 – Within the hydrologically-modified lagoon system, exotic aquatic grasses (hymenachne and para) have proliferated to dominate the water edge zone, extending both up bank and out onto the water's surface. Cattle grazing provides a non-chemical extensive control method for these grasses that, if successfully applied, can reduce their dominance, and help reinstate the native aquatic plant communities that previously occupied the shallow water to low bank zones. Where artificial inflows to Burdekin lagoon systems have reduced their seasonality, particularly the drawdown of water levels in the dry season, the effectiveness of grazing-based control of these aquatic grasses is significantly reduced. Any management approach capable of reducing aseasonal inflows to the lagoon system, and/or of instigating/accentuating the dry season lowering of lagoon water levels, would serve to vastly increase the effectiveness of grazing-based control of these grasses, and to decrease their dominance within the aquatic habitats of the system.
Short description – M17: Domination of wetland margins and shallow water zone by exotic grasses has resulted in loss of native aquatic plants
M17 – Within the hydrologically-modified lagoon system, exotic aquatic grasses (hymenachne and para) have proliferated to dominate the water edge zone extending both up bank and out onto the water's surface. Under seasonal hydrological conditions,

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including seasonally-variable water levels, the zone now occupied by these grasses hosted a diverse range of rooted floating (e.g., water lilies), submerged, and emergent native aquatic plants. These provided important habitat, feeding, and nesting resources for wetland fauna, including fish, amphibians, and birds. Within the main Collinson's Lagoon, which lies off the main aseasonal inflow conduit where water quality (turbidity) and hydrological impacts are not as pronounced, some of these aquatic plant communities, like water lilies, still persist.
Short description – M18: No riparian canopy shading leads to aquatic grass-dominated margins, higher water temps, and lower dissolved oxygen
M18 – Experience gained through site comparisons and revegetation of floodplain streams elsewhere in the Lower Burdekin floodplain, like Sheep Station Creek, indicates that dense riparian tree shading of the water's edge is an effective control for exotic aquatic grasses and serves to reduce their dominance and promote native species. Riparian shading is also demonstrated to reduce shallow margin water temperatures and increase its dissolved oxygen carrying capacity. Throughout the system, including along much of the main lagoon's margins, there are large opportunities to increase shading of the water's edge via riparian revegetation.
Short description – M19: Lagoon not directly on aseasonal drainage line has better water quality, hydrology, and native aquatic plant community
M19 – The main Collinson's Lagoon lies off the main channel conveying aseasonal flows from the BHWSS through the system and, therefore, has less pronounced water quality (turbidity, nutrients) and hydrological impacts, retaining some seasonal water level drawdown. This is reflected in retained native aquatic plant communities, including water lilies and several submerged species.
Short description – M20: Farm drainage running into seasonal wetlands alters hydrology, water quality, eutrophication, and weed status
M20 (a to e) – Like all wetlands in the seasonal dry tropics, the natural hydrology and associated ecology of the Collinson's Lagoon system was highly seasonal and related to the timing and magnitude of the annual wet season. In the contemporary modified system, the hydrology of most of the system is dominated by inflows of irrigation tailwater and supply channel overflow from the BHWSS. Even where seasonal wetlands lie off the main channel conveying aseasonal flows from the BHWSS, they still occur in low lying areas of the landscape, which are subject to irrigation tailwater inflows from surrounding farmland. As for the broader system, these aseasonal inflows contribute to reductions in dry season drawdown of water levels in receiving wetlands and generate changes in aquatic plants communities (increased aquatic weeds, decreased native communities), water quality (higher turbidity and nutrients), fish passage connectivity (barriers created by weed chokes or water quality) and associated habitat values for wetland fauna. Retaining seasonal wetlands that don't receive aseasonal inflows of irrigation tailwater is a worthy nature conservation objective for the region.
Short description – M21: Wildlife habitat and corridor value of remnants at risk woody weed infestation/control and land use intensification
M21 – Stands of remnant floodplain woodland and wetland riparian vegetation distributed across undeveloped freehold land associated with the Collinson's Lagoon system north of Sayers Road have high nature conservation values. They also have high

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levels of woody weed infestation, primarily chinee apple, and other species such as parkinsonia. Cost effective methods used to control these weeds include clearing using heavy machinery. Remnant native vegetation is often inadvertently cleared during such control methods. Demarcation of higher value remnant vegetation as areas for more targeted control could support better nature conservation outcomes.
Short description – M22: Head-cutting erosion upstream of old highway crossing threatens to lower lagoon system water levels
M22 – At the point where the old Bruce Highway crosses the Collinson's Lagoon system, the diffuse broad channel of the lagoon system narrows into a more incised channel that conveys water into the downstream Lochinvar Station wetland channels. During high flows, conveyed water has eroded the transition point between channel forms and has generated some head cutting that is progressing upstream toward the main lagoons. If this process was to continue, there is a possibility of lagoon water levels being lowered and reset to a lower level, which would reduce the aerial extent of the upstream wetland system.
Short description – M23: Sustained wetness of drainage depressions promotes dense hymenachne infestation inaccessible to effective grazing
M23 – The hydrological modification of the system associated with BHWSS inflows extends downstream of the Bruce Highway into receiving coastal drainage depression within Lochinvar Station. Here, as elsewhere in the upper system, exotic aquatic grasses (hymenachne and para) have proliferated to dominate the water edge zone, extending both up bank and out onto the water's surface. The dominance of these grasses has led to the demise of native aquatic plant communities that previously occupied the shallow water to low bank zones and provided important habitat, feeding, and nesting resources for wetland fauna, including fish, amphibians, and birds. While cattle grazing provides an extensive non-chemical control method for these grasses, the effectiveness of grazing-based control of these aquatic grasses is significantly reduced where the dry season drawdown of water levels has been reduced by aseasonal inflows and water depth and site wetness prevents cattle access for grazing. Any management approach capable of reducing aseasonal inflows to the system, and/or of instigating/accentuating the dry season lowering of water levels, would serve to vastly increase the effectiveness of grazing-based control and cattle utilisation of these grasses, and to decrease their dominance within the aquatic habitats of the lower system.
Short description – M24: Fish and bird habitat values of coastal wetlands reduced by loss of dry seasonality and exotic pasture dominance
M24 – Historically, wetlands of the lower system, including reaches within Lochinvar Station, were seasonal and included a diverse range of wetlands from perennial lagoons to shallow vegetation-dominated swamps. Native aquatic plant communities across these range of wetlands were also highly diverse and included a host of emergent sedge and spike rush communities; rooted floating beds of water lilies and pond lilies; and numerous submerged and emergent species found in the shallow and seasonally-drying margins. This range of native aquatic plants provided important habitat, feeding, and nesting resources for wetland fauna, including fish, amphibians, and birds. In the contemporary hydrologically-modified system, sustained aseasonal inflows of water prevent most wetlands from experiencing a drying cycle and the water's edge and bank zones are now dominated by exotic aquatic pasture

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grasses, including hymenachne and para grass, with resulting reduction in wetland habitat values. In some wetlands where higher salinity levels or retained seasonality still promotes native aquatic plants, greater habitat and faunal diversity is still observed
Short description – M25: Sustained inflows of farm tailwater have promoted cumbungi dominance of wetland basins and the loss of open water habitat
M25 – In these eastern tributaries of the system, irrigation tailwater inflows have generated sustained wetness within receiving drainage channels and promoted the dominance of cumbungi (bull rush) and para grass at the expense of the historically seasonal, open water, and native aquatic plant-dominated wetland communities.
Short description – M26: Hot fires in ungrazed para grass-dominated riparian zones is leading to condition decline and loss of remnant vegetation
M26 – With land use intensification, grazing uses of drainage lines and wetlands in this part of the system ceased, and riparian areas became dominated by ungrazed pasture grasses, including para grass in wet basins and guinea grass on elevated levees. Both these grasses produce large fire fuel loads, and it is common practice amongst landholders to ‘clean up the farm’ by burning these areas, usually in the late dry season after cane has been harvested and risks to standing crops can be avoided. The resulting hot fires often kill much of the overstorey vegetation, including mature trees, and leads to an opening of tree canopy cover and further invasion of the site by exotic grass species, including guinea grass, which is recognised to be pyrophytic (fire loving). Theis fuel load presents ongoing wildfire risks to adjoining farmland and acts as harbourage habitat for rodents. Means to reduce the dominance of the exotic grasses and the associated hot fire risk, like controlled grazing, would serve to promote the re-establishment and protection of shading riparian vegetation with both biodiversity and production benefits.
Short description – M27: Channel draining sub-catchment used for bagasse storage has poor water quality and major aquatic weed infestation
M27 – This tributary contains bagasse storage areas operated by the Pioneer Sugar Mill. Bagasse is known to be a high source of plant nutrients and to generate a high biological oxygen demand if introduced to aquatic environments. Observations of the water quality and weed status within this tributary drainage suggest that it has both high nutrient and low dissolved oxygen levels. Improved management arrangements for the storage of bagasse within the tributary, treatment of runoff, and addressing the weed status of the receiving environment could collectively deliver a range of ecological benefits to the system.
Short description – M28: Value of remnant habitat within sub-catchment impacted by ungrazed exotic grasses, hot fires, and woody weeds
M28 – Remnant vegetation adjoining bagasse storage areas within this tributary drainage are highly impacted by woody weeds, ungrazed exotic pasture infestation, and associated hot fires. Despite their poor condition, they still retain a range of nature conservation values, including mature trees, relatively high species diversity, and associated fauna habitat values. They also represent the only significant stands of native vegetation within this tributary stem and, as such, are locally important. Dedicated

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management of the woody weeds and hot fire risks associated with these areas would serve to improve their condition and biodiversity conservation value.
Short description – M29: Potential to reduce need for excavator maintenance of channel via establishing riparian vegetation shading
M29 – The flow capacity of this constructed channel network is periodically maintained by the excavator clearing of aquatic weeds, both grasses and floating weed mats. To operate an excavator though this reach requires that channel banks are clear of woody riparian vegetation. Ironically, the resulting open sunlit channel creates conditions highly suited to the reinfestation of the channel by aquatic grasses, while shade canopy-forming riparian vegetation could provide a means of shading out and controlling fringing aquatic grasses. Integrating revegetation via dense shade-forming canopy species, such as Leichardt trees (e.g., on western banks), with excavator access, could reduce the need for excavator maintenance of the channel, while providing habitat benefits. This outcome has been achieved on other floodplain steams in the Lower Burdekin, like Sheep Station Creek.
Short description – M30: Potential to improve functional design/capacity of water quality treatment wetland(s) receiving high BOD runoff.
M30 – This multi-celled wetland receives runoff with high biological oxygen demand (BOD) from the Pioneer Sugar Mill and bagasse storage areas in its contributing upper catchment. Apparent limitations in the configuration of the treatment wetland; including cell divisions that are inundated by high flow levels, and a bypass channel that circumvents a cumbungi bull rush tailwater polishing cell; suggest that there may be scope for improving the functional design and treatment capacity of the wetland. Water quality condition observed lower in the receiving system suggests that high organic nutrient loads get exported to the downstream system, which includes wetlands assessed to be matters of state environmental significance, and – further downstream – the internationally-significant Cape Bowling Green Bay Ramsar Wetland.
Nominated Works (W) The below section contains short descriptions only. For more information regarding these nominated works, refer to the mapping and recommendations throughout the SMP.
Short description – W1: Reduce in-flow volume and re-use BHWSS tailwater inflows
W1 – Full description
Short description – W2: Extend fenced controlled grazing area onto lagoon peninsula to reduce hot/wildfire risk and aquatic grass dominance of lagoon margins
W2 – Full description
Short description – W3: Expand riparian revegetation to entire lagoon margin (both banks) to generate canopy shading of exotic grasses, habitat, and reduced hot/wildfire risk and rodent harbourage
W3 (a & b) – Full description

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Short description – W4: Seek support of landholder to include high water level refuge for grazing stock in fenced controlled grazing area to enable extension of grazing season into and out of wet season
W4 – Full description
Short description – W5: Seek landholder support for including wetland basin in expanded controlled grazed area for habitat and production benefits, for instance, open water habitat, reduced hot/wildfire risk, and rodent harbourage
W5 – Full description
Short description – W6: Support community investment in wallaby-proof fencing in recognition of habitat protection public benefit and associated pest impact to cane production
W6 – Full description
Short description – W7: Seek stakeholder support and engagement to conduct cool burns (post-grazing or early season) within subsections of habitat complex to maintain fire-mediated mosaic and adapted species
W7 – Full description
Short description – W8: Schedule woody weed control contractors to access targeted control sites during dry season/low water levels to ensure comprehensive control
W8 – Full description
Short description – W9: Investigate head-cut erosion risks at lagoon outlet flow site and the opportunity/need for protective management works, potentially including a water level control structure capable of instating seasonal water level drawdown
W9 – Full description
Short description – W10: Implement integrated riparian rehabilitation program on stream reaches endorsed by landholder, including excavator reforming of shallow cumbungi edges, and establishing a shaded riparian canopy to create habitat and reduce exotic grasses, hot/wildfire risk, and rodent harbourage
W10 – Full description
Short description – W11: Seek landholder support for replicating riparian revegetation of western bank on eastern bank, and extending to upstream extent of reach
W11 – Full description

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Short description – W12: Excavate channel flow path and revegetate channel and lagoon margins with dense canopy-forming species, like Leichardt trees, to maintain open water flow conduits
W12 – Full description
Short description – W13 – W14 (a,b,c): Resource habitat sensitive (small machinery/personnel-based) woody weed and rubber vine control program to secure the high habitat values of remnant vegetation riparian corridor between Rose and Sayers roads
W13 and W14 – Full description
Short description – W15: Assess support of drainage easement stakeholders (landholder, Sunwater) for integrated management option for drainage channel that incorporates 'fill in' revegetation of canopy shade-forming riparian vegetation opposite excavator access banks to maintain open water channel
W15 – Full description
Short description – W16: Establish formal nature conservation management arrangements for BHWSS remnant habitat corridors and nodes
W16 – Full description
Short description – W17: Conduct management trials to change dominant vegetation of constructed tailwater drains away from exotic aquatic grass mats towards a mixed open water, native spike rush/bullrush community to reduce water quality impacts and export of flow-blocking mats downstream during flood spates
W17 – Full description
Short description – W18: Reinstate flow detention function and inundation of seasonal wetlands circumvented by constructed tailwater drains by removing excavated drain spoil levees limiting high flow inflows, and by leveeing off topographic lows conveying outflows
W18 – Full description
Short description – W19: Engage landholders in revegetation to re-establish regional wildlife corridor connectivity (Barratta floodplain – Kelly's Hill)
W19 – Full description

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Short description – W20: Seek landholder support to implement an integrated habitat regeneration program along the length of the riparian corridor, including fencing and controlled grazing; fire regime management; woody weed control; riparian revegetation; and excavator reinstatement of open water habitat in cumbungi-dominated reaches
W20 – Full description
Short description – W21: Engage constructed treatment wetland expertise to assess the performance of the existing wetland. Also, to scope configuration and design enhancements for a wetland treatment train facility that could provide the performance required to avoid the downstream export of contaminant loads and water quality impacts
W21 – Full description
Short description – W22: Develop site environmental management plan (EMP) with a focus on woody weed control, controlled grazing, and fire regime management to deliver improved habitat outcomes in both wetland and woodland
W22 – Full description
Short description – W23: Seek landholder support to trial the revegetation of one or two channel bank margins with dense canopy-forming tree species as a complimentary, or alternative, method to the excavator-based maintenance of a grass-free drainage channel
W23 – Full description
Short description – W24: Promote reduction and re-use of upper catchment irrigation tailwater flows emanating from the BHWSS to deliver seasonal water level drawdown/flow cessation in lower system to facilitate more effective grazing of exotic aquatic grass margins. This would promote open water habitat, improved water quality conditions, greater native aquatic plant diversity, and improved fish passage
W24 – Full description
Short description – W25: Negotiate with regulatory agency to seek water access licensing/cost concession incentives and assess landholder interest in off-stream water use proposals that could deliver flow cessation/drying events to main channel wetlands
W25 – Full description

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> Appendix 2 – Management plan map sheets separate attachments