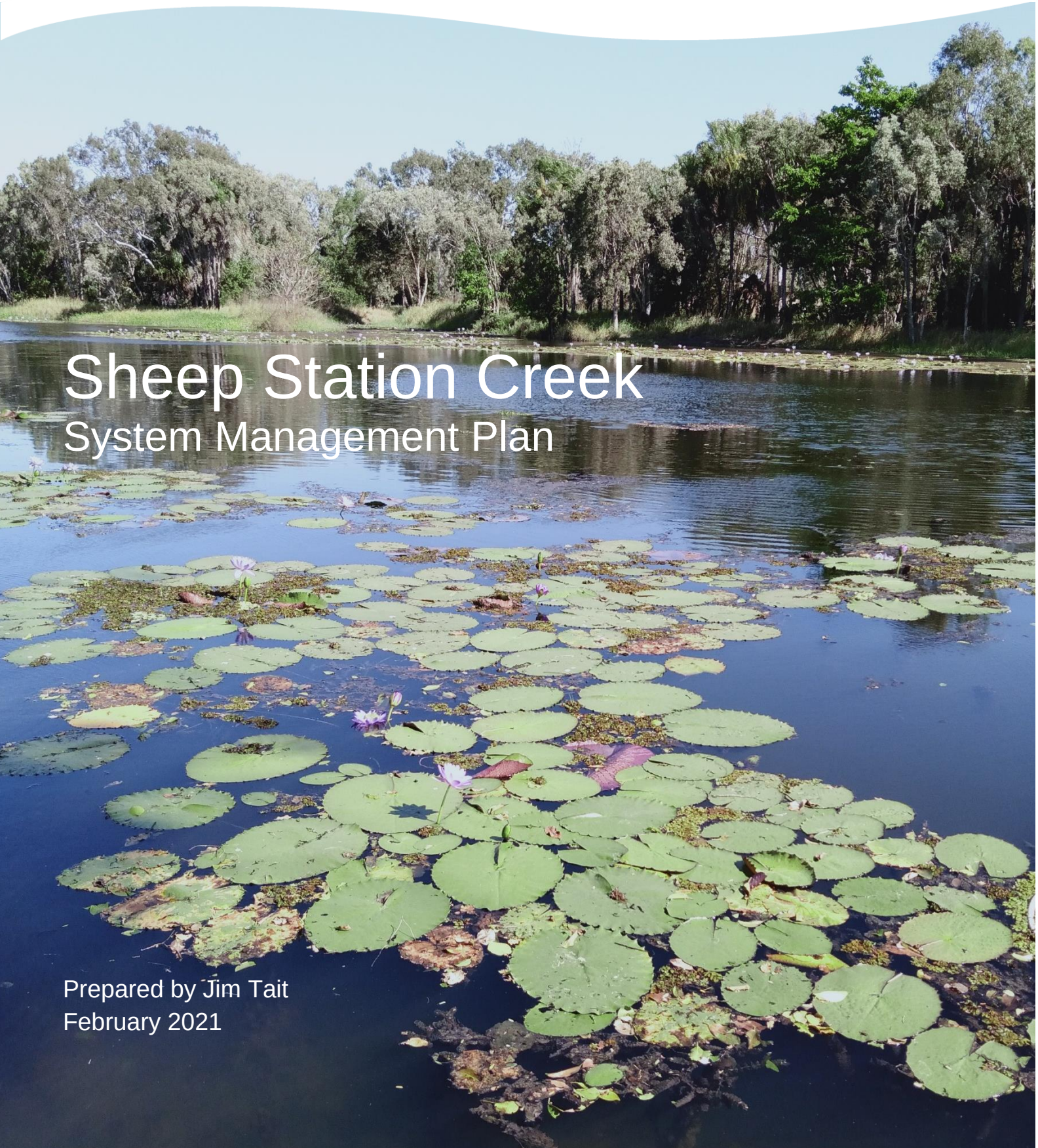
NQ DRY TROPICS

econcern

environmental consultancy
'local to global – catchment to coastal'



Sheep Station Creek
System Management Plan

Prepared by Jim Tait
February 2021

> Contents

> Executive summary

Econcern was contracted by NQ Dry Tropics to develop an environmental management plan for the Sheep Station Creek system in the lower Burdekin River floodplain located approximately 80km south of Townsville, North Queensland. The development of this plan forms part of the Restoring the Bowling Green Bay Ramsar Wetlands project, funded by the Australian Government's National Landcare Program. This plan aims to improve environmental management outcomes in Sheep Station Creek, and – with some site-specific adjustment – create a useful management template that may be applied to adjoining floodplain distributaries that comprise the Cape Bowling Green Bay Ramsar wetland catchment. Sheep Station Creek was chosen as the initial management planning focus because it has the longest history of environmental management investment of any lower Burdekin wetland system, which has provided much learning and delivered a range of innovative management outcomes. However, as detailed in this plan, there are a range of outstanding environmental management challenges, and – collectively – this experience provides a prudent basis for extending management planning to adjoining areas.

Sheep Station Creek is a floodplain distributary of the Burdekin River. It has a catchment area of approximately 20,500ha and a linear stream length of around 36km from distributary headwater to mouth. Land use in the upper and mid catchment is dominated by irrigated sugarcane agriculture while the lower catchment is utilised for cattle grazing and national park. The Mount Kelly sub catchment also includes rural residential, horticulture, and grazing. Historically, the creek system only flowed seasonally during the wet season and transitioned to a chain of isolated lagoons in the dry season. Wet season flows were generated by local catchment runoff and less frequently by Burdekin River breakout flood flows down the system. In the contemporary modified creek system, flows are near perennial on account of Lower Burdekin Water operational pumping of river water into the creek system to meet irrigator and aquifer recharge needs. Development of the water distribution system has seen an excavated channel network established through much of the non-lagoon reaches.

The main environmental management issues confronting the Sheep Station Creek system are associated with changed catchment hydrology, aquatic weed infestation, altered fire regimes, degradation of riparian zones, water quality impacts, and barriers to fish passage connectivity. These issues have arisen since European settlement with the intensive development of the catchment's land and water resources for irrigated agriculture and pastoral development. Hydrological change is arguably the primary driver of observed environmental impacts.

The intended 'clients' of this management plan are the range of management stakeholders associated with the Sheep Station Creek system. These include riparian landholders, most of which are cane farmers; Lower Burdekin Water, the local industry-funded water manager; local government (Burdekin Shire Council); catchment heavy industry (Wilmar); Traditional Owner groups (Gudjuda Reference Group); 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 innovative environmental management initiatives that have brought the creek system back from a point of near ecological collapse in the early 2000s to a relatively healthy, though modified, aquatic ecosystem today. Innovative management approaches implemented have included the use of weed harvesters and excavators to remove neglected aquatic weed infestations, the development of a coast-shared weed control program instituted through Riparian Management Agreements (RMAs), and a large reach-scale riparian revegetation program. At the time, these initiatives were truly innovative in that they had not been done before in the seasonal dry tropics, or in the case of RMAs, Australia.

This plan was prepared following site field work and landholder and other management stakeholder consultation undertaken in September 2020. A review of relevant literature was also conducted. Through the field work, literature review and stakeholder engagement, creek reach values, management issues and landholder nominated works were identified. The condition of riparian zone vegetation was also charted and a series of five management planning maps covering the catchment were prepared. This management plan examines the management needs of the creek system under 10 issue areas covering:

1. Aquatic weeds
2. Water quality
3. Fish passage connectivity
4. Riparian zone rehabilitation
5. Revegetation
6. Fire regime/controlled burning
7. Controlled grazing
8. Critical habitats
9. Instream physical habitat
10. Innovative management

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 their voluntary adoption by relevant management stakeholders and the availability of sufficient funding and material resources to facilitate them. NQ Dry Tropics will support the plan's implementation as funding becomes available by acting as a facilitator and coordinator of collective action by managing stakeholder groups and individuals, acting as an extension agency and broker for relevant information, and as a funder for specific activities and material resources that fall within the gamut of Government-funded programs, or draw the support of other NRM sponsors.

> Background

Internationally-significant Ramsar wetland

NQ Dry Tropics is funded by the Australian Government's National Landcare Program to restore wetlands in the catchment of the internationally-significant coastal Ramsar wetland Cape Bowling Green Bay. To approach this task strategically, it was necessary to first examine the management needs of an individual floodplain distributary stream that drains to the Ramsar site: Sheep Station Creek. Examining management arrangements for one entire creek system generates a useful template which can be applied, with some site-specific adjustment, to adjoining floodplain distributaries that comprise the Cape Bowling Green Bay Ramsar wetland catchment.

Sheep Station Creek

Sheep Station Creek was chosen as the initial management planning focus because it has the longest history of environmental management investment of any lower Burdekin wetland system (Waltham *et al* 2020). This investment has provided much learning and delivered a range of innovative management outcomes. However, as detailed in this plan, there are several outstanding environmental management challenges that still need to be addressed. Collectively, this experience provides a prudent basis for extending management planning to adjoining areas.

Figure 1. Sheep Station Creek Catchment (highlighted in white) relative to the Cape Bowling Green Bay Ramsar wetland site (green line).

Catchment description

Sheep Station Creek is a floodplain distributary of the Burdekin River. It has a catchment area of approximately 20,500ha and a linear stream length of around 36km from distributary headwater to mouth. Mount Kelly also forms part of the upper catchment area and is drained by low-order stream channels through granitic bedrock and sands. The remainder of the creek system drains through alluvial landforms that comprise the Burdekin River floodplain and delta. Historically, the creek system only flowed seasonally during the wet season and transitioned to a chain of isolated lagoons in the dry season. Wet season flows were generated by local catchment runoff and, less frequently, by Burdekin River breakout flood flows down the system. Few reaches within the original creek system had well-defined stream channels and connectivity between lagoons was generally via poorly-defined drainage depressions. Where the stream reaches the coastal plain, it bifurcates into an eastern and western branch and main channels are replaced with numerous branching shallow distributary depressions. These only reform into defined channels in tidally-influenced estuarine reaches that are mangrove-lined. The creek system has several mouths within the Cape Bowling Green Bay estuarine complex.

Some of the large freshwater lagoons within the system are understood to represent prior Burdekin River channel remnants. The entire system is underlain by shallow groundwater aquifers and most lagoons represent aquifer windows. In the contemporary modified creek system, flows are near perennial on account of Lower Burdekin Water operational pumping of river water into the creek system to meet irrigator and aquifer recharge needs. Development of the water distribution system has seen the establishment of an excavated channel network through much of the non-lagoon reaches.

Land use in the upper and mid catchment is dominated by irrigated sugarcane agriculture while the lower catchment is utilised for cattle grazing and National Park. The Mount Kelly sub catchment also includes rural residential, horticulture, and grazing.

Management issues

The main environmental management issues confronting the Sheep Station Creek system are associated with changed catchment hydrology, aquatic weed infestation, altered fire regimes, degradation of riparian zones, water quality impacts, and barriers to fish passage connectivity. These issues have arisen since European settlement with the intensive development of the catchment's land and water resources for irrigated agriculture and pastoral development. Hydrological change is arguably the primary driver of observed environmental impacts. Use of the creek system for conveying irrigation and aquifer recharge water supplied from a generally turbid Burdekin River has seen the creek system change from a seasonal clearwater system to a perennial, usually turbid system. The other major hydrological change is a reduced occurrence of Burdekin River flood outbreak flows down the creek system. The frequency of these events has been curtailed by a combination of constructed riverbank levees that have raised the height that flood breakouts can occur and by the Burdekin Falls Dam, which has reduced the frequency and height peak of floods in the lower catchment. These breakout flows historically generated important resetting of habitat and water quality conditions in the creek system and provided fish passage connectivity. Although not specifically addressed by this plan, the capacity for emerging impacts of climate change, including associated sea level rise, to exacerbate ecological management challenges within the creek system should also be recognised.

Management stakeholders and history

This management plan has been commissioned by NQ Dry Tropics and its intended 'clients' are the range of management stakeholders associated with the Sheep Station Creek system. These include riparian landholders, most of which are cane farmers; Lower Burdekin Water, the local industry-funded water manager; local government (Burdekin Shire Council); catchment heavy industry (Wilmar); Traditional Owner groups (Gudjuda Reference Group); 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 innovative environmental management initiatives that have brought the creek system back from a point of near ecological collapse in the early 2000s (Tait and Perna 2001), to a relatively healthy, though modified, aquatic ecosystem today. Innovative management approaches implemented have included the use of weed harvesters and excavators to remove neglected aquatic weed infestations, the development of a cost-shared weed control program instituted through riparian management agreements (RMAs), and a large reach-scale riparian revegetation program. At the time, these initiatives were truly innovative in that they had not been done before in the seasonal dry tropics, or in the case of RMAs, Australia.

This management plan seeks to document these management gains, the implementation issues surrounding them, and outstanding environmental management challenges facing the creek system. This is to further progress environmental condition outcomes for Sheep Station Creek and to apply relevant knowledge to adjoining floodplain distributary creek systems that form the catchment for the coastal Ramsar wetland Cape Bowling Green Bay.

Implementation

Implementation of this plan's recommendations depends entirely on their voluntary adoption by relevant management stakeholders and the availability of sufficient funding and material resources to facilitate them. In the absence of any formal 'catchment management group'; NQ Dry Tropics will support the plan's implementation by acting as a facilitator and coordinator of collective action by managing stakeholder groups and individuals, acting as an extension agency and broker for relevant information, and as a funder for specific activities and material resources that fall within the gamut of Government-funded programs, or draw the support of other NRM sponsors.

Plan preparation

This management plan has been prepared by Jim Tait senior environmental scientist of Econcern Environmental Consulting. Jim Tait is an aquatic ecologist with more than 35 years' experience of working in tropical and sub-tropical river systems in Asia, Papua New Guinea, tropical and sub-tropical Queensland and northern NSW, Australia. Jim's primary professional interests include freshwater fish, wetland and riparian ecosystems and catchment-based natural resource management. Jim has had a professional association with the lower Burdekin since he was involved in habitat corridor planning in the Burdekin River Irrigation Area in the late 1980s and was responsible for the formation of BBIFMAC in the late 1990s. His personal association with the Burdekin region including Sheep Station Creek is lifelong. Jim's family hails from within the catchment from Tait's Road, Maidavale, and his childhood included much time spent exploring and fishing the stream reaches and lagoons of Sheep Station Creek.

> Methods – assessment and reporting

Stakeholder consultation

Stakeholder consultation for the preparation of this management plan was undertaken during September 2020 and involved:

- on-site consultation with riparian landholders stratified through the upper, mid and lower catchment;
- meetings with representatives from community organisations involved in project work within the Sheep Station Creek catchment, including Lower Burdekin Landcare, BBIFMAC and NQ Dry Tropics;
- formal meeting with the Board and staff of Lower Burdekin Water and a catchment tour with a Lower Burdekin Water operational manager from the distal water delivery point upstream to the Rocks Pump Station;
- formal meeting with Burdekin Shire Council managers and operational staff involved in overseeing the aquatic weed control program service delivery;
- formal meeting with Wilmar environmental managers, and
- informal engagement with research officers from research and development (R&D) providers that have worked in the catchment, primarily at Tropwater JCU.

For each interviewed landholder, engagement involved a 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 'landholder nominated works' in Appendix 2 and presented on catchment management plan sheets (Appendix 3).

Formal minutes were recorded at both the Lower Burdekin Water and Burdekin Shire Council meetings.

Literature review

Literature reviewed for this 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 study area or adjoining drainage systems. 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 landholder visits and the tour with the Lower Burdekin Water operational manager. 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, an aerial drone was also used to gain high resolution aerial imagery of several creek reaches (see Photos 1, 2 and 39). This imagery was useful for examining riparian zone condition, including weed infestation status, and of sufficient resolution to define individual plant and weed species.

One lagoon was also surveyed by use of a boat provided by a landholder. One evening was devoted to spotlight surveying selected habitat remnants for arboreal wildlife.

Management planning mapping

To inform environmental management planning for the Sheep Station Creek system, maps of riparian vegetation condition were produced (Appendix 3). 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 (see below and Appendix 3):

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 creek reaches into these riparian condition classes provides a basis for:

- examining the overall and relative ecological condition of the creek system;
- identifying system-scale drivers of ecological degradation;
- developing generic management recommendations for reaches dominated by particular 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-referenced points collected in the field for reach values, management issues and landholder-nominated works are also displayed on the management plan maps (Appendix 3).

> Summary identified reach values, management issues and works

Reach values, management issues and landholder nominated works compiled during the development of this management plan are tabulated in Appendix 2 and presented on management planning maps (Appendix 4). They are described and summarised below.

Values

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

The range of reach values identified include:

- High value remnant riparian and wetland habitats. These included sites that:
    - Are identified as significant in Queensland Government regional and state Biodiversity Planning Assessments;
    - have large highly productive wetlands, especially lagoons with high fish and waterbird habitat values;
    - function as connected wildlife corridors or ‘nodes’ in a corridor network;
    - have rarer habitats representative of the catchment or creek’s predevelopment vegetation or hydrological condition;
    - function as refuges for certain groups of wildlife or at certain times, and
    - contain critical habitats required by specific wildlife types.
- Sites where ecological condition has been improved by landholder works. These included sites where:
    - landholders have implemented or managed riparian revegetation;
    - they have been protected from uncontrolled burning, and
    - controlled grazing or other forms of weed control have been used to improve the condition of remnant habitat.

Management issues

These include stream and riparian zone management issues that are characteristic of the reach or specific to it. They also include management issues that occur throughout the catchment that are well demonstrated by a particular reach example. Some identified reach management issues have impacts that affect the creek ecosystem at a catchment scale.

Identified reach management issues include:

- existing management arrangements not adequately addressing the targeted management issue;
- where opportunities for improved or alternative management approaches have been identified;
- having outstanding fish passage barrier structures or reach conditions;
- being in exceptionally poor condition and representing a priority for management investment;

- receiving or being a source of water quality issues associated with high organic loads, effluent or anoxic ‘blackwater’;
- losing specific habitat elements or values, or being under threat;
- aquatic or exotic pasture grass weeds generating remnant habitat impacts;
- impact by altered hydrological conditions;
- experiencing critical water quality events/fish kills, and
- requiring targeted monitoring to improve understanding regarding active degradation processes or impacts.

Works

This is a non-exhaustive list of potential stream and riparian zone works that were identified during consultation with riparian landholders over the course of project field work. They are proposals only and implementation would be subject to funding resourcing, appropriate agency approvals where required, and further landholder and management stakeholder engagement.

Landholder identified and nominated works included:

- stabilisation of sites with channel/bank erosion;
- woody weed control or other forms of management for areas of remnant vegetation;
- revegetation of suitable sites, including ‘fill in’ planting of previously revegetated sites and/or areas that have not previously been revegetated;
- improving fire management by creating fire breaks or other forms of fire management, including conducting ‘cool’ (controlled) burns;
- introducing or re-instating controlled grazing areas;
- sediment extraction or realignment of sections of stream channels;
- excavating lagoons filled with cumbungi or other neglected aquatic weed infestations;
- improving weed control at aquatic weed-impacted sites, and
- addressing duckweed growth impacts on pump intakes.

> Creek management needs, opportunities and recommendations

Creek 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 creek 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.

The following 10 management issues have been identified as important to the ecological health of the Sheep Station Creek system based on consultation with creek management stakeholders, literature review and field investigations. They include:

1. Aquatic weeds.
2. Water quality.
3. Fish passage connectivity.
4. Riparian zone rehabilitation.
5. Revegetation.
6. Fire regime/controlled burning.
7. Controlled grazing.
8. Critical habitats.
9. Instream physical habitat.
10. Innovative management.

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. Although not specifically addressed by this plan, the capacity for emerging impacts of climate change, including associated sea level rise, to exacerbate ecological management challenges within the creek system should also be recognised.

Photo 1. Imagery captured by aerial drone overlaid on background aerial photography.

Photo 2. Close-up drone imagery distinguishing individual aquatic weed species.

Photo 3. Aquatic weed harvester and excavator removing floating weed mats from Payard's Lagoon.

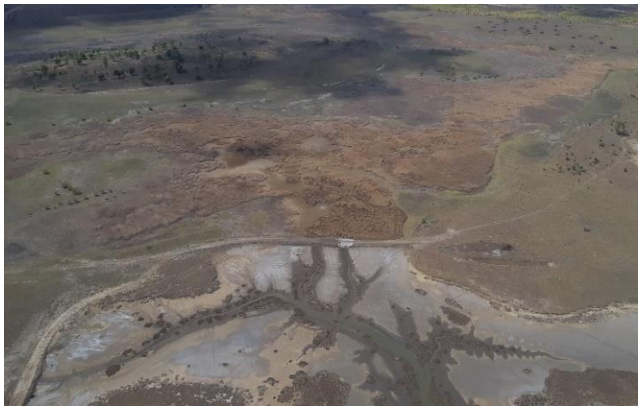


Photo 4. Large stand of cumbungi bull rush behind tidal bund wall killed by cessation of tailwater inflows /drying out

Photo 5. Three species of dead fish, including eels, from part of a wet season fish kill due to lack of oxygen.

Photo 6. Dick's Bank Lagoon. Water lilies shade the water column and reduce submerged duckweed growth. They need to be protected during aquatic weed control spraying.

Aquatic weeds

Types and impacts

Aquatic weeds are arguably the most significant cause of ecological impact within Sheep Station Creek and many other lower Burdekin floodplain creek 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, shade and outcompete native vegetation, generate high fire fuel loads within riparian vegetation, cause collapses in instream dissolved oxygen levels via organic loading, and cover open water surfaces, consequently impacting fish and fauna habitat availability and quality. While these impacts are attributed to weeds, it should be recognised that observed weed infestation levels are a symptom of other ecological impact drivers which promote weed proliferation. These include modification of stream flows from seasonal to near perennial, and increased availability of nutrients associated with catchment land use, which are pumped throughput of Burdekin River water. Given the ongoing use of Sheep Station Creek's land and water resources for irrigated agriculture, these drivers of weed proliferation will remain part of the modified creek ecosystem and effective weed management will need to be ongoing if management stakeholders want the creek's ecological values 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 provide for continuous improvement in management approaches.

A large range of aquatic weed species are recorded from Sheep Station Creek (see Table 1) including floating, submerged, and emergent growth forms. There are also a number of emerging aquatic weed risk species that have been identified in the *Burdekin Shire Biosecurity Plan* (BSC 2020) and that have been recorded in the shire or adjoining regions. While exotic species are more commonly recognised as 'weeds', a number of native aquatic plants (see Table 1) have also become weedy in nature under the modified ecosystem conditions of the managed creek system. Some native species (for example, cumbungi) 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 weed species are involved in impact-generating infestations (see Table 1).

Management history and approaches

Two decades ago, high levels of aquatic weed infestation led to the near collapse of Sheep Station Creek's aquatic ecosystem and an associated loss of biodiversity (Tait and Perna 2001). The main source of impacts were large floating weed mats comprised of water hyacinth and other floating species that were bound together by aquatic grasses. These covered significant portions of most lagoons and channel lengths within the creek system. The impact of these weed mats was to collapse instream dissolved oxygen levels, which impacted not only site fish populations and habitat values, but the whole creek system's fish community and populations by creating 'anoxic' (without oxygen) stream reaches that act as passage barriers to fish migration (Veitch *et al* 2007). Other impacts associated with these weed mats included reduced waterbird populations, blockages to flow and efficient water distribution, increased flood risk, and creation of mosquito habitat.

Since that time there has been great progress by management stakeholders in the development and implementation of aquatic weed management approaches that has restored the creek system to a level of ecological health not witnessed for a generation.

Key initiatives have included:

- Acquisition and operation of aquatic weed harvester – In 2001 the Burdekin Shire Council acquired an aquatic weed harvester. This machinery provided a capacity for tackling what were major 'neglect' weed mat infestations that had established in Sheep Station Creek and other lower Burdekin floodplain distributary systems in the absence of active weed control (see Photo 3). While the aquatic weed harvester proved only partially effective when operated individually, operational systems were developed in conjunction with Lower Burdekin Water Board excavators that enabled entire lagoons throughout Sheep Station Creek to be cleared of what had been persistent aquatic weed mats. Ecological monitoring following these operations demonstrated that both water quality and fish populations made a substantial recovery following weed mat removal (Perna and Burrows 2005, Perna *et al* 2012). More recently in 2020, the Lower Burdekin Water Board has trialled an aquatic excavator which has shown promise for addressing large weed mat infestations inaccessible and unassailable by existing weed harvester/excavator operations. Further evolution of weed management systems integrating use of machinery, including innovative trialling of new weed harvesting machinery, represents a potentially productive area for future weed management approaches (discussed below).
- Implementation of cost-sharing riparian management agreements (RMAs) – To prevent aquatic weed mats establishing further, and to maintain management gains achieved by weed harvester operations; it became apparent that an ongoing aquatic weed control program was required. In early 2004 a survey of Sheep Station Creek riparian landholders was conducted to assess their attitudes to the aquatic weed management problem and their preparedness to collectively participate in its management. Flowing on from this survey was a recommendation for a multi-stakeholder, cost-shared, aquatic weed spaying control program. In 2006 a two-year trial of a cost-shared aquatic weed control program involving four cost-sharing partners NQ Dry Tropics (then Burdekin Dry Tropics), Lower Burdekin Water (then North Burdekin Water Board), Burdekin Shire Council and riparian landholders was established. This involved the use of a weed spraying contractor with ongoing weed harvesting operations conducted by the Burdekin Shire Council and Water Board for reaches with residual weed infestations. The trial operated within budget and was considered successful in that:

- large lagoons were kept free of weed mat development;
- there were marked improvements in creek water quality and general ecological health;
- fish species were again recorded in lagoons where they had been absent;
- waterbird and waterfowl populations were observed to increase;
- general amenity of creek system lagoons was improved;
- stocked barramundi survived and grew to large sizes;
- reduced mosquito populations were experienced by local residents;
- there was improved functioning of the creek system as a distributary for regulated flows, and
- there were reduced flood impacts, including less damage to bridge infrastructure.

Following these early trials, the cost sharing/contribution arrangement with individual riparian landholders was formalised in the form of riparian management agreements (RMAs) with the Burdekin Shire Council (BSC). The BSC subsequently adopted the major service provider role with the establishment of a boat-equipped spray unit team that now delivers the RMA aquatic weed chemical spray control program. This program has continued with some minor variation to the present day. Weed control interventions are determined by the risk and decision matrixes presented in BSC's *Aquatic Weed Management Plan 2020-2025* (BSC 2020b).

Outstanding weed management issues and opportunities

While weed harvester and maintenance chemical spraying control programs have delivered a significant recovery of creek ecosystem health through much of the catchment over the last two decades, several persistent weed management challenges remain. Also, a number of control opportunities are yet to be fully explored. These are discussed below:

Cumbungi-infested drainage depressions in the lower catchment coastal plain – The lower catchment of the creek system is comprised of numerous bunded drainage depression distributaries that branch across the coastal plain to join the estuaries of Cape Bowling Green Bay. Although historically seasonal, branches of these distributaries that receive surplus water inflows from Lower Burdekin Water operations are now semi perennial to perennial. This change in hydrology has driven a proliferation of native emergent aquatic plants including sedges and bull rushes, particularly cumbungi (*Typha domingensis).* Cumbungi now forms impenetrable channel blocking stands of several hundred hectares. The extent of these infestations is mapped in Appendix 3 (Map sheets 4 and 5). These cumbungi-dominated reaches accumulate massive loads of organic material with a high biological oxygen demand (BOD) and have been implicated in creating anoxic 'blackwater' reaches and flows that function as fish passage barriers (Veitch *et al* 2007). While management trials involving chemical spraying and burning have proven ineffective, restoring seasonal hydrology and drying out cumbungi-dominated reaches has been shown to be a successful control method at lower Burdekin sites outside the Sheep Station Creek catchment (S. Fry Pers. Comms) and within distributary channel sites in the catchment where tailwater inflow volumes have been reduced (see Photo 4). For many of the cumbungi-infested reaches, seasonal drying out is not possible, or is at least problematic, because they are hydrologically-connected to Lower Burdekin Water supply channels or support ponded pasture production for coastal pastoralists.

Historical precedents suggest that coastal-ponded pasture production can be maintained under a seasonal hydrological regime, particularly if areas currently occupied by cumbungi are restored to pasture species. This premise is also supported by riparian condition mapping that shows coastal distributary systems that retain seasonal hydrology have the greatest areal extents and cover domination by exotic pastures (Appendix 3 – Map sheets 4 and 5). The potential to hydrologically isolate water supply channels from cumbungi infested drainage depressions also presents an opportunity for investigations seeking to restore hydrological seasonality to cumbungi-infested reaches.

Proliferation of duckweed in lower catchment lagoons – 'Duckweed' (*Ceratophyllum demersum)* is a native submerged aquatic plant that occurs throughout the Sheep Station Creek system, forming thick aquatic beds that provide productive habitats for instream invertebrates and fish and other predators that depend on them. Under natural conditions the abundance of duckweed was mediated by the dry season draw down of water levels that exposed plant beds to drying and via wet season flood flows that scoured out duckweed beds and reduced their re-establishment growth rate via higher water turbidity. Under the modified hydrological regime of the contemporary creek system, clear, open, perennial water conditions experienced in the mid and lower catchment following floating aquatic weed control has allowed duckweed to proliferate and form a large, submerged biomass. The increased abundance and density of duckweed beds has created problems for irrigators due to its ability to block pump inlets. Ecologically, the massive biomass of duckweed also creates water quality problems during its night time respiration when it causes instream dissolved oxygen levels to fall below levels required for maintenance of healthy aquatic ecosystems (Perna *et al* 2003). In summer when water quality stress is also generated by other factors (for example, high water temperatures, local catchment run-in, lack of flow, overcast days, inundation and decomposition of fringing vegetation), the cumulative impact – including respiring duckweed beds – can cause dissolved oxygen levels to drop below levels lethal to aquatic life and generate fish kills (Perna *et al* 2003).

Control of duckweed by physical (for instance, harvesting) or chemical methods is cost prohibitive and ecologically problematic. Pumped throughputs of turbid water have been previously considered as a means of reducing duckweed biomass but identified limitations include attenuation of turbidity through the creek system (water clears before reaching lower reaches), timing of water quality stress with non-pumping periods (wet season), and potential for initial water quality decline in response to turbid inflows due to respiration and decomposition of duckweed beds.

One of the most obvious controls of duckweed biomass is riparian vegetation shading. Pump intakes located beneath dense shade-casting bankside trees do not get blocked by duckweed and where dense riparian vegetation canopy shading covers channel and lagoon margins duckweed density is observed to be low to non-existent. Establishing riparian vegetation-shaded margins along lagoons and suitable channel reaches presents a viable opportunity for reducing duck weed biomass throughout the creek system and would also reduce water quality stress by reducing water temperature. In the shorter term, establishment of shade casting floating boom structures, floating wetlands (see: https://wetlandinfo.des.qld.gov.au/wetlands/management/treatment-systems/for-agriculture/treatment-sys-nav-page/floating-wetlands/) and/or promotion of shade casting native aquatic plant stands (for example, native water lilies) offer potential means of avoiding duckweed impacts on pump intake operation.

Biomass of fringing emergent aquatic grasses subject to wet season inundation – Water quality monitoring has found the wet season to be a period of water quality stress within the Sheep Station Creek system, particularly in relation to low dissolved oxygen levels (Veitch *et al* 2007). One contributory factor identified is the inundation and subsequent oxygen-consuming decomposition of the enormous biomass of aquatic grasses that occupy stream and lagoon margins. A significant reduction in the biomass of these grasses present in the riparian zone at the end of the dry season would reduce a key driver of wet season water quality stress. While no single method presents a silver bullet, pursuit of this aspirational goal via a range of contributory management actions – including establishment of riparian shading, controlled grazing and burning – could prove collectively effective.

Effectiveness of weed bio-control programs – Biological control agents are available for three of the key floating weed species impacting the Sheep Station Creek system: water hyacinth, water lettuce and salvinia. Constraints associated with climate, movement of weed mats, integration with spray control programs and availability of the biocontrol organisms have discounted their effective use for water hyacinth and water lettuce though populations remain in the system (BBIFMAC 1999). However, lower Burdekin NRM organisation BBIFMAC has maintained an active biocontrol program for floating water fern salvinia involving the breeding and distribution of the salvinia weevil (*Cyrtobagous salviniae)*, which has proven effective in controlling large open water body infestations of salvinia throughout the lower Burdekin. To-date this program has depended on volunteer labour and BBIFMAC receives no direct funding for weevil production. The program also suffers from a lack of coordination with other aquatic weed control programs in Sheep Station Creek and other lower Burdekin creek systems. In the past, to have enough weevils available ahead of the warmer salvinia proliferation months it has been necessary to warm their production tanks with heaters. Re-instatement of this practice is supported.

The salvinia weevil is more effective in closed (versus flowing) systems where floating plant mats are constrained in terms of dispersal movement. Use of a floating boom system to contain floating plant mats greatly assists the initial introduction, establishment and subsequent spread of weevils at sites. Removal of the bulk of salvinia infestations with physical or chemical control methods prior to weevil introduction also assists its control effectiveness, but edge spraying of salvinia when it is at low density impacts residual weevil populations and takes them out of the system, necessitating re-introduction. Once weevil predation has impacted the plant's buoyancy its gradual break up and sinking is assisted by wave and open water interactions. This occurs most readily at sites where edge riparian shading or wind-swept open water bodies retain open water areas.

Further investment in the salvinia weevil biocontrol program and greater distribution of it throughout the Sheep Station Creek catchment (and other systems) and collaborative integration with other weed management programs all offer scope toward greater biocontrol outcomes for salvinia and associated ecosystem health benefits.

Reinfestation potential of floating weed species and potential for catchment lines of control – Floating aquatic weeds are the major contributor to aquatic weed impacts in the creek system and present specific management challenges due to their mobility with wind and water flow. A lagoon system or stream reach cleared of floating weeds by control activities can be readily re-infested when colonising plants drift into the controlled area from refuge source areas upstream or outside of the controlled area. This re-infestation capacity of floating aquatic weeds necessitates ongoing monitoring vigilance and responsive control interventions to maintain management gains. Application of a catchment-based framework and the use of 'lines of control' to target weed refuges and reinfestation sources from the top of the catchment downstream could provide potential benefits in terms of reducing opportunities for reinfestation and the number of control interventions required to maintain good system condition. Strategically, the opportunity to implement such a management approach would be greatest following a major wet season flood flow which has flushed most floating aquatic weed plants from the system leaving a reduced weed refuge control target. To-date a lack of strategic impetus, along with site access and resource constraints, has not facilitated the use of a catchment line of control management approach for floating aquatic weeds in the creek system. A commitment to trial such an approach could potentially pay significant management dividends.

Dissolved oxygen impact of chemically-controlled weed mats – One of the consequences of dependence on chemical control for aquatic weed management is the depletion of instream dissolved oxygen levels with the sinking and decomposition of sprayed plants (Waltham & Fixier 2017). This impact of chemical aquatic weed control programs undermines one of the primary management intentions: to improve water quality and avoid critical low dissolved oxygen events. Regular control interventions provide one means of reducing this impact risk by limiting the biomass of weeds that establish between control events. Resources, seasonal access constraints and weed mat mobility all impact upon this ideal management regime. Alternatively, the development of cost-effective aquatic weed harvest/removal control methods would avoid the problem. Such an approach would also serve to remove the nutrients embedded in weeds and reduce the potential for eutrophication of water bodies. Existing weed harvester machinery is costly to operate and not highly efficient in terms of biomass removed per operational time and costs. If a financial return could be obtained from removed weed material (for example, by producing composted weed soil condition ameliorants or fertiliser) the cost viability of physical weed removal operations could be improved. More highly efficient weed harvesting machinery would also support such an outcome.

Alternatives to chemical-based control – Beyond concerns for dissolved oxygen depletion (above), the potential impact of herbicides on aquatic ecosystems is also a motivating reason for examining alternatives to chemical-based control. Existing control programs introduce thousands of kilos of herbicide into the aquatic ecosystem of Sheep Station Creek per annum. While products used are registered for such applications, community and outstanding scientific concerns (ANZECC 2000) provide a prudent case for continuing to identify options for reducing or replacing chemical-based control programs where possible. In addition to the range of options considered in preceding sections (for instance, water level manipulation, shading, controlled grazing and burning biocontrol and physical removal), other emerging nonchemical weed control options little trialled in aquatic ecosystems include use of steam weeding and flame throwers. While it is not suggested such tools would have broad application, they may address a particular seasonal or species niche in control targets (for example, fire-sensitive aquatic grasses). The key point is that creek system managers need to remain informed of emerging weed management tools and technology to serve continuous improvement in aquatic weed management outcomes as funding becomes available.

Recommendations

1. Pursue improvements to existing aquatic weed control programs.
    i. Seek full participation of riparian landholders in aquatic weed control programs. Facilitate a mailout to Sheep Station Creek riparian landholders not participating in current programs to inform them of the declared weed status of aquatic weeds within their reach of the system, the cost sharing merits of collaborative weed control and of the responsibility and intention of biosecurity officers to ensure legally-required control efforts are being expended by responsible landholders.
    ii. Establish a 'Sheep Station Creek Guardians' social media page, hotline or web portal for promoting improved communication about management of the system generally, but specifically for the purpose of establishing lines of communication between landholders and aquatic weed control service providers. This will help to maintain vigilance on the weed infestation status of creek reaches and the timing need for control interventions.
    iii. Identify opportunities to increase resources made available to aquatic weed control programs to enable a greater number of weed control interventions if required in response to more vigilant monitoring of weed infestation levels.
    iv. Identify opportunities to increase resources made available to aquatic weed control programs to invest in capital equipment to improve the capacity of spray equipment used by operators, specifically including a higher-pressure spray unit and a longer boom arms.
    v. Work with weed control service providers to draft a standard operating procedures (SOP) manual for adoption for aquatic weed control programs within lower Burdekin Creek systems, including guidelines for operations practices and acceptable outcomes (for instance, discrimination between native lilies water and weeds) and advertise and/or provide draft to riparian landholders for review prior to adoption.
2. Seek implementation of water distribution and efficiency management commitments that reduce or cease flows of water surplus to operational needs to the lower catchment coastal plain distributaries allowing for the reintroduction (and maintenance) of seasonal drying.
3. Investigate opportunities for hydrologically-isolating excavated channels adjoining cumbungi-infested drainage depressions for future prospects of introducing seasonal drying to cumbungi stands.
4. Promote and implement revegetation of lagoon and channel margins with dense shade casting canopy species to reduce the density and growth opportunities for duckweed (*Ceratophyllum demersum)* to serve improved summer water quality (dissolved oxygen) outcomes. With landholder support, also target sites adjacent to and shading over pump intakes to reduce problematic blockages. Where revegetation adjoining pumps is not possible, seek to establish trials of a floating shade or

native water lily growth protecting boom over pump intake areas as means of retaining landholder support for weed harvesting activities that have led to the proliferation of duckweed.

5. Support nursery-based mass production of potted native water lily (*Nymphaea gigantea)* to be used in boom protected plantings around pump intakes and duckweed exclusion plantings in shallow lagoon reaches.
6. Engage riparian landholders to work toward the aspirational goal of reducing standing biomass of aquatic grasses fringing stream channels and lagoon margins throughout creek system by the end of the dry season. This would be via implementation and support of controlled burning and grazing and establishing riparian vegetation canopy shading to reduce opportunities for oxygen depletion when grass margins are inundated in elevated wet season flows.
7. Provide funding commitments to support salvinia weevil biocontrol programs. Also, seek commitment from aquatic weed management providers to make their management itinerary of intended weed clearing/control operations to better integrate weevil population maintenance and biocontrol effectiveness outcomes with other aquatic weed management approaches.
8. Trial catchment-based line of control approach for floating aquatic weeds within the creek system. Initiate trial following a large flood flow and endeavour to eradicate weed refuges/reinfestation sources from the top of the catchment downstream, monitoring eradication effectiveness and ultimate reinfestation timing.
9. Engage aquatic weed management stakeholders and potential sponsors/investors in the pursuit of 'cost effective' aquatic weed harvesting/physical removal management approaches involving assessment and implementation of opportunities for:
    I. converting removed aquatic weed material into an economically valuable product, and/or
    II. developing or acquiring a highly-efficient aquatic weed harvester.
10. Maintain active dialogue with aquatic weed management stakeholders and facilitate trials where appropriate of alternative non-chemical aquatic weed control methods, technology and machinery. This potentially includes steam and flamethrower-based control methods and/or small in-channel machinery that can remove and emulsify grassy weeds, desilt sediment deposits and remove vegetation chokes.

Photo 7. A lagoon bank site nominated for revegetation by the landholder (Chris Pegoraro). Shade cast along this lagoon margin would serve to reduce submerged duckweed growth.

Photo 8. Treeless, shallow, lower reach lagoons are vulnerable to persistent aquatic weed infestation and associated poor water quality.

Photo 9. A weed-choked off channel lagoon nominated as a site for rehabilitation (weed excavation and revegetation) by the landholder.

Photo 10. Entrance to a cumbungi bull rush-choked reach which lacks dissolved oxygen and acts as a fish passage barrier.

Table 1. Aquatic weeds of the Sheep Station Creek system

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 infestation cover 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 (weev isolation methods 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 remo
Salvinia	*Salvinia molesta*	Floating species. Prefers still water. Covers and shades 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 effect is key to the management of this species.
Hymenachne	*Hymenachne amplexicaulis*	Emergent aquatic grass. Occurs on 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 t macrophytes and trees.
Aleman grass	*Echinochloa polystachya*	Emergent aquatic grass. Occurs on 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 t 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. T 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 weed mat. Good habitat.

*Cumbungi	*Typha domingensis*)	Emergent bull rush. Occurs in water edge zone in most of 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, harv of tailwater inflows/draining to create seasonal drying has been demonstrated to be ve
*Duckweed	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 protec
*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, creates foundation for accumulation of floating weed mats.		Not categorised		Registered chemicals, potentially water level manipulation and physical (harvesting, c
*Umbrella sedge	*Cyperus exaltatus*	Emergent sedge aggressive secondary coloniser on floating 'platforms' weeds. Occurs throughout creek system in 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, c
*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 we

Table 2. Emerging aquatic weed risk species of the Sheep Station Creek 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. *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 sealed plastic bag, leave in sunlight to decompose, then dispose of at council-approved landfill. Alternatively, leave material in 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 bank at 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. Has been subject to sale and distribution through Asian communities and gardeners.		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 body and pull plants out of surrounding banks, making sure to remove attached root system. Dispose of plant parts in an appropriate waste facility or rubbish bin. Water mimosa is a restricted invasive plant under the *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. 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 floodplain distributary streams such as Sheep Station Creek is naturally variable through the year. Under natural predevelopment conditions, water quality would have 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 draw down 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 River overbank flushes down the distributary system (Davis *et al* 2017).

In the contemporary, modified Sheep Station Creek system, water quality is largely driven by Lower Burdekin Water's pumping/regulated flow regime (including non-pumping periods); the condition of sourced Burdekin River water; the condition of creek reaches, particularly their weed infestation status, and by the quality and contaminant load of surface and groundwater inflows from the catchment.

Some of the processes and key drivers of water quality associated with predevelopment hydrological conditions no longer occur as frequently, or in the natural seasonal period or at all, for example, flow cessation, dry season water level drawdown, groundwater domination of inflows, Burdekin River overbank flood flow flushing and scouring. However, even under this modified regime, the creek system's water quality still experiences major seasonal differences with the summer wet season being identified as the period of greatest water quality stress (Veitch, *et al* 2007).

Until recently, Sheep Station Creek has not been a focus for regular water quality monitoring programs. Therefore, our state of knowledge is informed by studies examining water quality issues more generally across the lower Burdekin floodplain, but this does include some limited sampling within Sheep Station Creek and by specific fish habitat and weed management investigations (Davis *et al* 2013, 2014, 2017, Veitch *et al* 2007, 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

Water quality issues relevant to Sheep Station Creek and downstream receiving environments, such as the Cape Bowling Green Bay Ramsar wetland and the GBR World Heritage Area include these known or potential aquatic ecosystem impacts:

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

The drivers/likely causes, potential impacts, and data and management notes for most of these issues (except salinity) are summarised in Table 3. Relevant considerations to in this management plan are developed below.

Low dissolved oxygen (DO)

In terms of ecosystem health impact, low dissolved oxygen (DO) is arguably the most significant water quality issue affecting the Sheep Station Creek system. However, it needs to be recognised that the drivers of low DO are readily tied to other water quality issues and their symptoms, for example, nutrient loads – a large proportion of which are delivered by high turbidity in Burdekin River water pumped through the creek system (Perna 2003) – and resultant aquatic weed and submerged plant infestations that deplete instream oxygen levels (Veitch *et al* 2007, Table 3).

Low DO levels are responsible for impacts to a range of instream biota, most notably observed being fish (Photo 5), but also to invertebrate organisms, such as aquatic insects and crustaceans, which are important to the creek's ecological function and food chain linkages that lead to non-aquatic organisms such as birds.

Impacts from low DO can occur at the site where they are generated (for instance, fish kills in a weed-impacted reach), or can be extended beyond the site by flows of low DO water to downstream reaches or via the creation of anoxic (no oxygen) stream reaches that act as fish passage barriers and affect the makeup of the entire catchment's fish community (Perna 2003, Veitch *et al* 2007, Waltham *et al* 2020). This latter impact is highlighted in the failure of susceptible migratory fish (barramundi, mangrove jack, giant herring) to recruit from the estuary to the upper freshwater reaches of the creek system for over two decades (see section *Fish passage connectivity*).

Besides iconic fishery and migratory species, resident species are also impacted. During a period of chronic ecosystem collapse in the early 2000s, up to half of the species of fish historically recorded from the creek system disappeared from impacted lagoons and stream reaches (Tait and Perna 2001). Stream habitats impacted by low DO are also more suited to hosting exotic species (Perna 2003). One low DO susceptible resident species is the freshwater herring, otherwise known as bony bream (*Nematalosa erebi)*. This schooling fish is an

Table 3. Sheep Station Creek water quality issues

Issue	Drivers/likely causes	Potential impacts	Data and management notes

Low dissolved oxygen	• Aquatic weed infested stream reaches 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 water surface due to weed covering.
	• High BOD of organic loads in catchment run in during wet season, including from specific sub catchments, like Red Lily.
	• Deoxygenated groundwater inflows (especially during pumping shutdowns).
	• Cessation of pumped flows and lack of Burdekin River overbank flooding flushes in 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 macro invertebrates) and fishery resources.
		• Increased solubility and mobilisation of nutrients in sediments.
			Issue well documented by number of catchment studies (Perna 2003, 2004, 2005, 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.
			• Pumped environmental flows in summer.
			• Targeted monitoring to increase understanding of specific issues, including:
			  ○ sub catchment inflow contributions to main channel impacts;
			  ○ location and export of critical low DO conditions through lower fresh to estuarine reaches, and
			  ○ capacity of pumped environmental flows to improve DO conditions through creek system during summer wet season.

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 flood flows and has minimal colloidal settlement. • Regulated flows in Sheep Station Creek are pumped from Burdekin River flows supplied from persistently turbid Burdekin Falls Dam. • Distance down Sheep Station Creek determines amount of suspended material attenuated from through flows by bank-side vegetation, which reduces turbidity. • Catchment soil erosion and sediment loads carried in local catchment surface runoff influences turbidity levels during non-regulated flow period in wet season.	• 100s X natural run in loading of receiving water bodies with attached nutrients. • Impeded groundwater recharge/accession. • Reduced instream primary productivity. • Reduction 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. • Improved property management practices. Revegetation and runoff detention on farm drainages could reduce local catchment sources. • Manage symptoms of impacts, for example, weed infestations.

Issue	Drivers/likely causes	Potential impacts	Data and management notes
Nutrient loading	• Attached nutrient load in through volume of regulated flows pumped from turbid Burdekin River. • 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 tail water management, post-harvest runoff of high BOD sugar, and sugar mill effluent. • 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 nutrient loads. • Mobilisation of nutrient loads accumulated in bottom sediments.	• Eutrophication (nutrient pollution) of waterway. • 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 wetlands and GBR lagoon.	Issue documented regionally but limited monitoring data for the catchment. DES currently establishing real-time monitoring stations on creek system. Previous monitoring has recorded concentration exceedances above ecosystem health guidelines (Perna 2003, 2004, 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. • Removal and/or control of aquatic weed and submerged plant biomass. • Promotion of riparian and emergent aquatic plant stream margins with nitrate stripping/uptake functions. • Detention and interception of catchment and farm runoff by riparian vegetation and wetland/constructed basins.
Agri-chemical residues	• On-farm use and practices that lead to off-farm losses including inadequate chemical storage, application methods, timing (especially in relation to rain and irrigation events) and conditions, wash down, and irrigation practices. • Off-farm movement via irrigation tail water, 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 including growth rates, timing of metamorphosis, locomotor activity, antipredator behaviours, immune capacity, infections and gonadal condition. • Sublethal effects on endocrine systems of fish (for example, juvenile barramundi) and endocrine disruption in amphibians. • Export of pesticide residue loads to downstream receiving environments, for example, Ramsar wetlands and GBR lagoon presenting impact risks to mangroves, seagrass, algal endosymbionts in corals and benthic microalgae.	Issue documented regionally, including in adjoining drainages, groundwater and at farm drainage scale but limited monitoring data for the catchment. However, previous monitoring of creek system has recorded concentration exceedances above ecosystem health guidelines for both low and event flows. Research indicates mixed pesticide residues produce impacts effect 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 e.g., pesticide application rates and practices particularly timing in relation to rain and irrigation events, and 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.

important prey species and provides the foundation for populations of predatory species such as barramundi. It dies in exceptionally large numbers during low DO events affecting the creek's fisheries productivity. In addition to biological effects, low dissolved oxygen can also generate biochemical impacts. Low DO promotes increased solubility of bottom sediment bound nutrients. Once mobilised into the water column, these nutrients become available to algae and aquatic weeds, promote their growth, and contribute to an ongoing impact cycle.

The ability of management actions to address the range of primary and secondary drivers of low DO conditions in the creek system (Table 3) is variable. For example, there is limited opportunity to address some primary drivers, like the nutrient loading associated with throughput of Burdekin River water, which is critical to irrigated agriculture. Therefore, management needs to tackle the symptom of the driver, namely aquatic weed and submerged aquatic plant proliferation (see preceding section). An effective aquatic weed control program provides a key mitigative measure for reducing critical low DO events. As discussed in the weed management section, removal of surface aquatic weeds can facilitate massive growth of submerged duckweed itself another driver of critical low DO events. Currently shading by established riparian vegetation is the only identified option for reducing duckweed abundance. Promoting this management outcome would also address low DO risks by decreasing water temperature, which increases the water's DO-carrying capacity.

Other low DO drivers that are amenable to management actions include the organic, nutrient and sediment load in local catchment run-in during the wet season, and the lack of refreshing river outbreak flows down the creek system during the summer wet season.

The former requires an assessment of individual sub catchment conditions and contributions to main creek channel low DO outcomes and, where possible, mitigative management actions that reduce low DO generation at source. Another option is to provide an interception capacity for the exported contaminant loads contributing to low DO conditions in receiving reaches; for example, via riparian revegetation and/or detention of runoff in wetland/constructed basins. Para-grass dominated farm drains that convey irrigation tailwater and/or wet season runoff are a significant source or anoxic 'blackwater'. Revegetation of these with low, non-woody canopy species compatible with farm operations would remove this source of water quality stress.

The lack or reduced frequency of refreshing river outbreak flows down the creek system during the summer wet season can be attributed to Burdekin River levee construction that has increased the river flood height at which breakouts occur. Also, the construction of the Burdekin Falls Dam has reduced the frequency of higher flood peaks in the lower Burdekin River.

Historically, an important part of the water quality resetting process for the creek system, the chronic low DO conditions that now establish through the summer wet season non-pumping period can be partially attributed to the absence of refreshing river outbreak flows. The potential of a pumped environmental flow in the summer wet season mimicking a flood outbreak to maintain ecosystem health, and even potentially facilitate more effective fish passage, has long been identified (Veitch *et al* 2007). A monitored trial of such a process is highly recommended.

High turbidity/total suspended solids (TSS)

Under predevelopment conditions Sheep Station Creek would have only experienced high turbidity during the wet season following catchment run-in carrying eroded sediment, or during floodplain inundating Burdekin River flood flows down its distributary systems. Historically, clear water conditions were experiences in water bodies of the creek system outside of the wet season, although water quality could tend toward high organic loading and tannin staining in the late dry season. The sustained high turbidity water now experienced predominantly in the upper catchment for much of the year represents a substantial departure from these natural conditions. When an aquatic ecosystem undergoes change from a clearwater to turbid system there is range of impacts to its biota and ecological processes (Davis *et al* 2014, 2017, Table 3).

In the case of Sheep Station Creek, some beneficial impacts have also been attributed to high turbidity water. Given the high nutrient load status of the system, turbid water provides some inhibition to the occurrence of algal blooms and the proliferation of submerged plants that could generate impacts that typically occur in eutrophic (nutrient polluted) systems (Perna 2003). The use of pumped pulses of turbid water down the creek system has previously been considered as a control method for submerged duckweed that has proliferated where clear aquatic plant-filtered water conditions exist in lower catchment lagoons (Veitch *et al* 2007). This option has unresolved issues in still contributing to water quality stress (low DO) via respiring submerged plant biomass, plus the ability to be cost-effectively delivered in conjunction with water scheduling.

Ultimately the primary drivers of the most significant turbidity issues within the creek system lie outside of it, for instance, a turbid Burdekin Falls Dam, which is the origin of water pumped into the system. Given that the limnology of this dam and water demand by irrigators is unlikely to change, the associated turbidity experienced within the creek system is beyond the scope of this management plan.

A turbidity issue that is amenable to management is the local catchment run-in during the wet season. As identified in the dissolved oxygen section above, sediment along with nutrient and organic loads contributed to the creek system during the summer wet season adds to likelihood of critical water quality events. Initiatives to provide greater interception of these loads, for example, on-farm and/or sub catchment runoff detention basins /wetlands and riparian revegetation of drainage systems, would support the delivery of such ecosystems services.

Elevated nutrient levels

Concerns regarding the potential impact of nutrients (Table 3), including elevated loads exported from the GBR catchment area to the GBR lagoon, is one of the main motivations for water quality management programs on the tropical east coast of Queensland. Past monitoring of Sheep Station Creek has found dissolved inorganic nitrogen (DIN) levels that exceed the ANZECC 99% confidence guideline for ecosystem protection under both ambient and event flow conditions (Davis *et al* 2014). The primary source of these elevated loads is catchment land use, particularly irrigated agriculture and the associated use of inorganic fertilisers (Table 3).

The pursuit of Best Management Practice (BMP) on-farm regarding improved fertiliser, pesticide, irrigation and cultivation efficiencies provides the best opportunity for reducing off-farm exports of nutrients, pesticides and sediment to the creek system and downstream receiving environments. NQ Dry Tropics' Sustainable Agriculture Program (https://www.nqdrytropics.com.au/projects/sustainable-agriculture/) has several operating projects in the lower Burdekin Region, including sites within the Sheep Station Creek catchment. These projects include:

- Paddock to Reef;
- Reef Alliance Project (RAP) – Growing a Great Barrier Reef – RAP Burdekin Cane Project – Phase II, and
- Reef Trust Tender – Burdekin project.

Further engaging catchment sugar producers in these projects and/or promotion of their results and BMP generally by extension activities is recommended. Survey data collected on practice adoption within the catchment as part of the Paddock to Reef program could provide a useful means of targeting further extension investment. Establishing real time DIN monitoring at a sub catchment/individual farm drainage scale to provide correlation between practice adoption and off-farm exports of water quality contaminant loads has been implemented elsewhere in the lower Burdekin by the Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC). Resourcing an equivalent monitoring program within the Sheep Station Creek catchment could provide increased impetus for BMP adoption.

Other sources of nutrient loading to the creek system include phosphorus bound to colloids delivered with pumped inflows of turbid Burdekin River; dissolved organic nitrogen derived from inputs of organic material and the decomposition of aquatic plant biomass; nutrient mobilised from bottom sediments; and loads contributed by catchment runoff, which include inorganic and organic nitrogen and soil bound phosphorus. Only some of these drivers of nutrient loading are amenable to management initiatives within the context of a creek environmental management plan.

As noted for turbidity (in previous section), colloids and associated nutrient loads of Burdekin River water pumped into the system cannot be avoided due to industry's dependence on irrigation water. Management of the symptom – in this case, aquatic weed proliferation – provides the only management option. As discussed in the weed management section, removal of weed biomass instead of in situ control by spraying would provide a pathway for extracting nutrient loads from the creek system and is nominated as a key innovative management development need. In lieu of such capacity, management of aquatic weed proliferation by all available means (see *Aquatic weeds* section) still reduces the biomass of material available to contribute organic nutrient loading to the system during inundating flow events. It also reduces the opportunity for anoxic conditions developing, which promote secondary nutrient mobilisation from bottom sediments.

Interception of contaminant loads, including nutrients in local catchment wet season runoff, presents another opportunity for reducing nutrient pollution of the creek system. While such loads are likely to represent a small proportion of those delivered by other pathways (for example, regulated flows, irrigation tailwater and groundwater inflows, see Davis *et al* 2012), they are usually delivered during a hazardous water quality period. This can include high summer temperatures and lack of regulated flows; therefore their reduction could deliver ecosystem health benefits. As identified previously, catchment load interception capacity could be improved via riparian revegetation and/or detention of runoff in wetlands and/or constructed basins. Such features would also provide nutrient interception and/or processing of irrigation tailwater outside of the wet season period. Strategic revegetation priorities to address this capacity are identified in the *Riparian zone rehabilitation* section. Establishing a monitored drainage line riparian rehabilitation/flow detention site is recommended. This will help to gain an improved understanding of the potential nutrient/contaminant load interception capacity of such features in the lower Burdekin landscape.

Agri-chemical residues

Similarly to nutrients, concerns regarding the potential impact of agri-chemical residues (Table 3), including loads exported from the GBR catchment area to the GBR lagoon, is an important focus for water quality management programs on the tropical east coast of Queensland. The most commonly-detected pesticides associated with sugarcane in the GBR catchment are the Photosystem-II (PSII)-inhibiting herbicides atrazine, ametryn, hexazinone and diuron (Davis *et al* 2017). Past monitoring of Sheep Station Creek has recoded ANZECC guideline exceedances for both diuron and atrazine (Davis *et al* 2012).

As described for nutrients previously, management options for reducing agri-chemical residue loads to the creek system lie with improved adoption of BMP on-farm, real time monitoring, and improved catchment runoff interception capacity.

Salinity

In terms of the health of the creek ecosystem, salinity has not yet been identified as an issue. However, soil and groundwater salinisation associated with rising water tables is recognised for parts of the upper Sheep

Station Creek catchment and in the adjoining Burdekin Haughton Water Supply Scheme area (previously the BRIA), which is hydrologically connected.

Drivers of observed salinity issues potentially include irrigation accessions to groundwater, supply channel leakage, and clearing of vegetation from foot slopes of Mt Kelly. In the longer term, failure to manage these issues could result in elevated salinity in surface and groundwater discharges to the creek system with some potential for ecological impacts.

While management of these issues is beyond the scope of a creek environmental management plan, the issue needs to be recognised so catchment management stakeholders can keep watch and respond to proposed management options as they emerge, particularly if they impinge upon the Sheep Station Creek catchment.

Recommendations

1. Maintain an effective and innovative aquatic weed control program (see *Aquatic weeds* section) throughout the catchment to underpin water quality capable of supporting good ecosystem health by avoiding creating weed-choked anoxic reaches; preventing excessive aquatic weed biomass establishment and associated organic loading (including from sprayed weeds), and by trialling and developing weed biomass removal control methods.

2. Wherever compatible with farm and Lower Burdekin Water operations, pursue revegetation of lagoon and channel margins with shade-casting riparian forest communities to reduce submerged aquatic plant biomass and water temperature to deliver improved dissolved oxygen status.

3. Conduct a dissolved oxygen monitoring program stratified through the catchment during the wet season critical water quality period, including non-flow and flow events. This includes main sub catchments (for instance, Red Lily) and discharge points to estuarine reaches to further refine current status of DO through the system, sub catchment sources of blackwater/Biological Oxygen Demand (BOD), determine implications for ecosystem health and fish passage, and to provide baseline data for proposed pumped environmental flow trial.

4. Make use of Lower Burdekin Water operational pumping (flow) and non-operational (no flow) periods during the implementation of recommendation number 3 (above), plus also negotiate with Lower Burdekin Water and seek resources to trial a dedicated pumped environmental flow during a wet season rainfall-generated flow event to examine its impact on DO status and associated fish passage connectivity through the creek system.

5. Establish monitored riparian revegetation/flow detention rehabilitation demonstration sites on farm/sub catchment drainage systems, including revegetation of para grass-dominated farm drains with low, non-woody canopy species compatible with farm operations. Monitor it during ambient (irrigation tailwater) and catchment rainfall runoff events to establish the utility of the approach to intercept or mitigate nutrient and agri-chemical contaminant loads and 'anoxic' blackwater flows.

6. Foster further engagement of catchment primary producers in Sustainable Agriculture Program projects and promote findings and practice adoption by extension activities and demonstration sites/field days.

7. Conduct a survey/audit of levels of BMP adoption within the Sheep Station Creek catchment and use results to target further extension and Sustainable Agriculture Program engagement.

8. Establish real time monitoring of contaminant load exports at a farm/sub catchment scale to use to inform and further engage on BMP adoption.

9. Encourage catchment irrigators seek information and representation through Lower Burdekin Water on the status of salinity issues within the catchment and of any potential implications arising from Sunwater's management of the adjoining Burdekin Haughton Water Supply Scheme (formally BRIA) area.

Fish passage connectivity

Fish movement needs

Sheep Station Creek's native freshwater fish community (

Table 4) needs to undertake a range of movements to fulfill life history cycles and to distribute to suitable creek habitats (Veitch *et al* 2007, Carter and Tait 2010).

The main classes of life cycle movement include:

- 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 marine environment moves to freshwater to breed.
- Catadromous – breeds in marine/estuarine environments and recruits to freshwater.

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 movements within the creek 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 several life cycle types (discussed previously). 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.

Natural connectivity patterns

Historically, the Sheep Station Creek system flowed only 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 and/or Burdekin flood plain inundation generated flow events. These connective flows provided opportunities for resident species to recolonise seasonal habitats and – for 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 return movement of juveniles form coastal nursery swamps to upstream floodplain lagoons. The timing of fish movement activity is very much influenced by the seasonal conditions in which they evolved, although there is some component that is opportunistic.

Types of barriers

In the contemporary modified creek system, flows are near perennial on account of Lower Burdekin Water operational pumping of river water into the creek system to meet irrigator and aquifer recharge needs. While this results in the creek being hydrologically connected, numerous flow control structures and road crossing culverts now present a range of fish passage restrictions (namely high flow velocities, vertical water falls, darkened pipes) that limit free passage throughout the creek system.

Recognising the potential impact of these barriers on intra-catchment movement of fish, Lower Burdekin Water and NQ Dry Tropics have been collaborating in a barrier rectification program over the last two decades, spanning from the lower to the upper catchment. Works under this program have included installation of vertical slot fish ladders, retrofitting flow baffling structures to culvert walls, and construction of flow gradient reducing rock ramp fishways below culverts (see Photos 12 and 13). This program continues and several outstanding structural barriers to fish passage have been identified during assessments undertaken for this management plan (see Appendix 2, Table 1 M4, Table 2 M1, M9, Table 4 M2).

Non-physical barriers

Since the early 2000s to the present, subsequent fish surveys (Veitch *et al* 2007, Perna *et al* 2012(b), Waltham *et al* 2020) have failed to record naturally-recruited (not stocked) barramundi and other catadromous species previously recorded within the creek system up until at least the early 1990s (ACTFR 1994). Careful examination of the evidence suggests that it is barriers, rather than physical structures alone, that are responsible for this. Many of the identified, and subsequently rectified, structural barriers have been in place in some form for more than 50 years and barramundi and other catadromous species were still recruiting to the upper catchment up until 30 years ago (ACTFR 1994). Some catadromous species like tarpon (

Table 4) continue to recruit to upper catchment areas to the present day (Waltham *et al* 2020).

A reason that these species have been able to negotiate physical barriers is because much of their population movement is naturally timed to coincide with wet season high flow events that historically provided the main intra-catchment connectivity opportunities and still inundate physical barriers during larger events.

Table 4. Life cycle movement requirements of fish recorded from freshwater reaches of Sheep Station Creek (*exotic)

Name	Genus and species	Life cycle movement
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
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
'Boof headed' gudgeon	*Hypseleotris 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

Veitch *et al* (2007) identified the catadromous species that continue to successfully recruit from the estuary to the freshwater system are all low dissolved-oxygen (DO) tolerant. They also demonstrated that even during a hydrologically-connected elevated wet season flow event, cumbungi-infested reaches of the lower catchment remain anoxic (lack oxygen) and represent a chemical passage barrier to all but the most low-DO-tolerant species. As discussed in the *Aquatic weeds* section, these anoxic lower catchment reaches developed in conjunction with perennial aseasonal inflows to the bunded distributary channels of the lower coastal creek system. This followed the commissioning of the Burdekin Falls Dam in the late 1980s, which at the time, provided Lower Burdekin Water a previously-not-possible year-round operational pumping capacity. Until the

cumbungi-infested reaches and associated anoxic water conditions developed, wet season fish passage was still available during high flow events.

Successful management to remove cumbungi-infested reaches in the lower catchment (see the *Aquatic weeds* section) is the most outstanding need for reinstating effective fish passage within the catchment. Rectifying remaining physical barriers, including culverts and water control structures, is also still important; particularly for the upstream movement of juvenile catadromous fish whose movement timing often extends into the post-wet recessionary flow period when physical barriers are not inundated.

Importance of river outbreak flows

As discussed in the *Water quality* section, an important hydrological process that now occurs very infrequently is Burdekin River outbreak flows down the distributary creek system. The frequency of these events has been curtailed by a combination of constructed riverbank levees that have raised the height at which flood breakouts can occur, and by the Burdekin Falls Dam that has reduced the frequency and height peak of floods in the lower catchment. The diluting and refreshing impact of these river outbreak flows down the system on dissolved oxygen levels would have also helped effective fish passage between the estuary and upper catchment. Older landholders in the lower catchment anecdotally report that, preceding the 1990s, it was not until the initial catchment 'blackwater' runoff flow had passed and transitioned to a 'fresh flow' that barramundi could be netted migrating into the system (Veitch *et al* 2007). It is pertinent to note that the last demonstrated record of barramundi, and several other catadromous species, having recruited into the system (ACTFR 1994) was following Cyclone Joy when a breakout flow occurred.

As discussed in the *Water quality* section, a pumped environmental flow during the wet season could be trialled as a means of replicating a river breakout flow through the system and may potentially provide suitable water quality connectivity through to the estuary to reinstate effective fish passage. Such a trial is highly recommended. As part of any such trial it is also recommended that dissolved oxygen and fish passage hydrological connectivity be monitored and assessed through the system to the lowermost tidal bund-estuary interface (see Appendix 2 – Table 4, M6, Table 5, M6). The fishery implications of deoxygenated water being exported to upper estuarine reaches also remains an outstanding issue that has not yet been investigated in the field.

Alternate fish passage routes

While addressing the management of cumbungi-infested anoxic lower reaches presents an appropriate system scale rectification target, the capacity for delivering on this challenging task is yet to be proven. A prudent alternative option may be to use bunds and/or flow control structure to engage other lower distributary channel networks that have not received aseasonal inflows of scheme tailwater and remain relatively weed free, as alternative fish passage routes.

Lower Burdekin Water's excavated supply channels through cumbungi infested reaches of the lower eastern branch also provide a potential pathway for migrating fish. Water quality and fish surveys of these channels when operational have previously identified suitable habitat conditions for fish movement despite the anoxic conditions of the surrounding cumbungi infested reach (Veitch *et al* 2007). Several relatively weed free distributary channel systems that present potential alternative fish passage routes have been identified. In the lower eastern branch passage connectivity could possibly be provided in conjunction with excavated supply channels (see Appendix 2 – Table 4, M4, Table 5, M2, M4). Investigation of the wet season water quality status and existing fish usage of these distributary channels would provide an initial assessment of the viability of this proposal.

Recommendations

1. As the priority fish passage rectification action, engage with lower catchment distributary channel stakeholders to implement management measures to reduce or remove fish passage barriers created by bunded, cumbungi-infested, anoxic drainage depressions possibly including:
    - improved water supply distribution, efficiency, scheduling and other measures (for instance, bunding) that reinstate seasonality and drying out of coastal distributaries currently infested with cumbungi stands;
    - physical (including animal trampling), chemical or burning-based control/removal of cumbungi stands where deemed possible or useful; and
    - bund removal with or without allowing tidal ingress where landholder support is obtained.
2. As recommended in the *Water quality* section, seek resources to trial a dedicated pumped environmental flow during a wet season rainfall generated flow event to examine its impact on DO status and associated fish passage connectivity through the creek system.

3. Undertake wet season water quality and fish sampling and passage connectivity assessments at tidal bund-estuarine interfaces (see Appendix 2, Table 4 M6, Table 5 M6) under ambient wet season conditions, but ideally also during conducting of recommendation 2 (above) to identify dissolved oxygen status, hydrological connectivity, presence of fish recruits and blackwater/DO depression risks to upper estuary systems.
4. Continue to work with relevant stakeholders and landholders to identify and rectify fish passage at road crossing culverts and water control structures throughout the catchment with an aspirational goal to provide free-fish passage to the most upstream high value fish habitats/lagoons (see Appendix 2 – Table 1 M4, Table 2 M1, M9, Table 4 M2).
5. Conduct at least annual fish fauna surveys stratified throughout the catchment (upper, mid, lower) to provide ongoing assessment of the status of fish diversity and passage connectivity within the creek system.
6. In order to examine the viability of alternative options for fish passage: undertake wet season water quality sampling and fish usage/passage connectivity assessments of less weed-impacted distributary channel systems that – in conjunction with excavated supply channels (on lower eastern branch) – present potential alternative fish passage routes around cumbungi-infested lower reaches (see Appendix 2 – Table 4, M4, Table 5 M2, M4).
7. Promote the use of the most upstream lagoons in the catchment as sites for any future fish stocking to enable their passive downstream distribution past any remaining fish passage barriers in the system.

Photo 11. High flow velocities through road crossing culverts create fish passage barriers.

Photo 12. Rock ramp fish bypass established adjacent a Lower Burdekin Water control structure.

Photo 13. Rock ramp fishway installed below culvert on Five Ways Road reducing culvert flow velocity.

Photo 14. Large barramundi captured by a recreational fisher in a Sheep Station Creek lagoon.

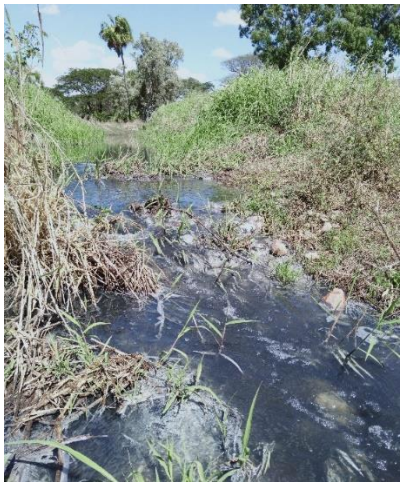


Photo 15. Anoxic sugar mill effluent with high biological oxygen demand (BOD) supporting sulphur-reducing bacterial growth.

Photo 16. Sugar mill effluent (left) flowing into the lower end of Church's Lagoon.

Photo 17. A 'gallery rainforest' reach that developed naturally in the upper catchment under fire exclusion.

Photo 18. Closed canopy community including naturally-germinated rainforest species created by revegetation and fire exclusion on Bruce Miller's farm.

Photo 19. Revegetated dense blue gum woodland with a shaded controlled grass fuel load just downstream of the Bruce Highway.

Photo 20. Revegetated dense closed canopy forest with no understorey fire fuel load at Dick's Bank Lagoon.

Riparian zone rehabilitation

What is it and why is it important?

The riparian zone is the interface between land and a river or stream. Riparian zone vegetation is an important component of the landscape because it supports a range of biophysical functions and values, including bank erosion protection; maintaining channel stability and form; nutrient uptake; interception of sediment loads; providing leaf litter food sources, and snag inputs to aquatic ecosystems; water shading; wildlife corridor and refuge habitat, and flood protection. 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, and the quality of instream aquatic habitats is often determined, to some degree, by the condition of the riparian zone (Figure 2). Due to these high ecological and catchment functional values, rehabilitation of the riparian zone is a priority focus for nature conservation and catchment management project investment.

Status of Sheep Station Creek riparian zone

In developed landscapes the condition of the riparian zone is often impacted by a range of land and water resource use pressures, some historical and some current. In the Sheep Station Creek catchment these include past and ongoing clearing of vegetation, altered stream flows and water levels, elevated nutrients, weed invasion, uncontrolled fire, grazing pressure, bank erosion, channelisation, land filling, and rubbish dumping.

Mapping of Sheep Station Creek riparian vegetation condition undertaken for this project (Appendix 3) shows it is highly variable throughout the creek system and includes intact remnant native vegetation, degraded remnant vegetation, revegetated areas, and extensive areas dominated by exotic grasses. The latter include guinea grass, para grass, and other aquatic grass species, for example, hymenachne and aleman grass. While these grasses can provide some functional benefits (like bank stability), they generally have low ecological value and generate management problems, including channel flow blockages and hot fire risks (see Figure 2).

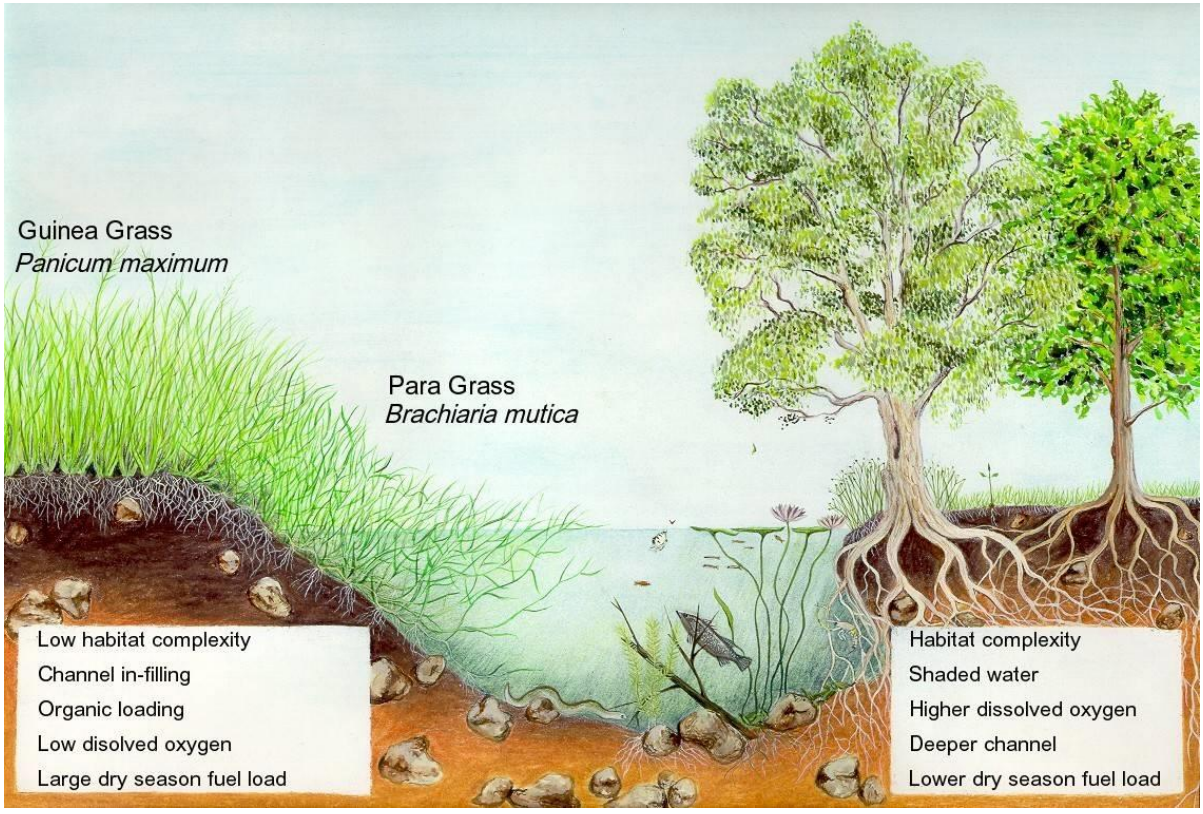


Figure 2. Contrasting ecosystem function and features of an exotic pasture dominated (left) versus native vegetation dominated (right) riparian zone (Illustration by Lois Genis). **NB: guinea grass is now *Megathyrsus maximus*.**

Learning from past rehabilitation efforts

In recent decades, a range of riparian zone rehabilitation approaches have been trialled or implemented within the Sheep Station Creek catchment, including intensive revegetation, controlled burning, and grazing trials (Tait 2005, 2011). Catchment aquatic weed management initiatives also represent riparian zone rehabilitation when they include bank margin areas, but this is covered under the *Aquatic weeds* section of this report. The most

substantial riparian zone rehabilitation effort has been invested in intensive revegetation courtesy of the state government-funded Burdekin Riparian Rehabilitation project that initiated large-scale revegetation projects in the catchment in the early 2000s. Beyond the controlled burning and grazing trials, extensive approaches to rehabilitation of riparian zone vegetation (protection and promotion of natural regeneration), have not been formally pursued and remain an area for further investigation.

Table 5. 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	Control/spay out with grass selective herbicides, monitor and protect natural regeneration, conduct 'in fill' planting revegetation (plus weed control and watering maintenance) if required for denuded sections, implement fire management suited to vegetation type. **Extensive 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	Control/spay out weeds, prepare site for revegetation (holes, mulch, irrigation/watering), plant and maintain (weed control, watering) and protect from fire at least until vegetation 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 site 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 with 'fill in' intensive revegetation.**	If 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 with 'fill in' intensive revegetation.**	Extended spelling that allows accumulation of a fire fuel load and conduction of a controlled burn suited to the vegetation type can promote recruitment of fire germinated species whose abundance has been reduced under a sustained grazing regime.

Experienced gained through past riparian revegetation projects and rehabilitation efforts provide a basis for progressing effective riparian rehabilitation approaches specifically suited to floodplain distributary streams of the lower Burdekin region. Some of the key learnings from past experience include:

- **Post planting maintenance** (watering and weed control) is key to successful vegetation establishment.

- **Dense canopy plantings,** including rainforest species not representative of the pre-development landscape, can be established under the near-perennial flows and associated soil moisture conditions of the modified creek system.
- Establishing a **closed-tree canopy on the water edge** provides an effective means of reducing aquatic grass (for instance, para grass) growth and anchor points.
- **Dense canopy** establishment on levee banks can effectively reduce understorey grass (for instance, guinea grass) growth and associated fire fuel loads, plus **reduce hot fire risks.**
- **Plantings** preceding and **too close to the annual wet season** risk being scoured out by high flows.
- **Revegetation established for more than a decade** can be lost to a **single uncontrolled burn** when surrounded by high-fire fuel loads associated with ungrazed exotic pastures.
- **Overuse of short-lived pioneer species** in planted communities leads to die-off canopy openings prone to reinfestation with grass weeds.
- **Planting survivorship** is **impacted by** soil class suitability and assessment of **broad soil type,** for example, loam, sand, and clay should be considered in assessing species site suitability.

Rehabilitation strategies, objectives and methods

Riparian zone rehabilitation techniques applicable in the Sheep Station Creek catchment include weed control, revegetation, fire regime management and controlled grazing. These are discussed in following sections. This section examines broader strategic considerations for implementing riparian zone rehabilitation programs.

Dependent upon the degradation pressures affecting a riparian zone and its current condition, different rehabilitation techniques will be appropriate.

Where a riparian zone has been highly modified from natural and little of the original vegetation remains, or natural ecosystem processes no longer operate (for example, areas affected by erosion or exotic grass infestation), more intensive rehabilitation methods (like bank forming) and revegetation may be required. Where the riparian zone retains more intact ecosystem components (reaches with degraded remnant native vegetation), rehabilitation outcomes may be achieved by less intensive interventions, for instance, weed or fire control that promotes natural regeneration processes of seedling/sapling establishment. Examples of contextual settings that may influence the choice of riparian zone rehabilitation approaches are presented in Table **5** above.

Approaching the rehabilitation of an entire creek system's riparian zone strategically requires a range of important considerations.

Goals and objectives

Riparian zone rehabilitation can address one or more objectives including:

- wildlife conservation;
- water quality;
- fish habitat;
- bank/soil erosion/channel stability;
- aesthetics and recreation, and
- providing ecosystem services.

Examples of how these objectives may be addressed by riparian rehabilitation/revegetation programs are presented in Table 6 below. Another important consideration are the goal(s) for investing in riparian zone rehabilitation. Such goals can be expressed as aspirational statements, or the vision that those engaging in riparian zone rehabilitation programs would like to see achieved. For Sheep Station Creek, such goals should ideally be set by the catchment community particularly riparian landholders and other management stakeholders such as the water board, shire council and general public. An example of an aspirational goal would be:

"Rehabilitate the Sheep Station Creek catchment's riparian zone to provide the highest levels of ecological value and function compatible with the productive use of catchment land and water resources".

More specific goal statements might include:

1. *Establish a contiguous wildlife corridor along the Sheep Station Creek system with linkages to adjoining habitat remnants.*

2. *Establish dense tree canopy bank margins to shade out aquatic grass weeds throughout as much of the creek system as possible.*
3. *Where possible, revegetate creek banks and levees to achieve sufficient canopy shading to reduce understorey grass density and associated hot fire risk.*
4. *Revegetate the banks of large water bodies with shade casting riparian forests that reduce submerged aquatic plant (duckweed) growth, decrease water temperature, and increase dissolved oxygen levels.*
5. *Manage bank margins on lagoons or natural channel sections to create grass-free exposed banks that provide high value waterfowl habitat.*
6. *Improve the riparian zone condition and associated water quality improvement function of farm and creek tributary drainage networks to provide sediment and nutrient load interception throughout the catchment.*
7. *Rehabilitate the riparian zone at suitable locations to create aesthetic sites suited to nature-based recreation.*

Table 6. Means to address different riparian zone rehabilitation/revegetation objectives

Objective	Means to address objective
Wildlife conservation	• Establish or consolidate wildlife corridor connectivity along the main riparian zone and to adjoining areas of remnant vegetation. • Provide or consolidate habitat for wildlife species affected by native vegetation loss. • Increase the occurrence of vegetation representative of regional ecosystems endangered within the catchment or region.
Water quality	• Revegetation that provides areas of filtration and/or flow detention for catchment runoff. • Rehabilitation of sites that intercept sediment and nutrient loads in catchment runoff or sub surface seepage. • Establish overstorey vegetation to shade stream edges to reduce water temperature and submerged plant growth and increase water dissolved oxygen carrying capacity. • Focal areas include tributary drainages (including constructed and on farm) conveying runoff and irrigation tailwater, degraded wetlands/depressions, and main creek riparian zone.

Fish habitat	• Riparian zone rehabilitation /revegetation that address water quality objectives (above) and/or results in:
	  ○ the shading of the water's edge;
	  ○ the exclusion of aquatic grass weed growth particularly that contributing to channel passage barriers;
	  ○ the maintenance of steep bank profiles, scour holes and undercut banks, and
	  ○ in the longer term, the contribution of snags to the water column.
	• Rehabilitation/revegetation that improves the water quality, habitat value and channel form variability of constructed channel reaches between lagoons.
	• Focal areas include unvegetated banks of lagoons and intervening constructed and natural channel networks, particularly aquatic grass weed-choked sections.

Bank/soil erosion /channel stability	• All riparian revegetation generally contributes to greater channel stability. • Lagoons subject to boat-based water sports, bank erosion, and undercutting are a specific focus for revegetation with binding root mat species. • Other focal areas include outside banks on erosional bends, existing areas of bank erosion and unvegetated tributary drainages. • Outside of the immediate creek system catchment sources of high sediment loads, for example, the slopes of Kelly Hill are also an appropriate focus for drainage line revegetation/rehabilitation activities that reduce soil erosion.
Aesthetics and recreation	• Riparian revegetation/rehabilitation generally contributes to greater aesthetic values and nature-based recreation opportunities. • Focal areas include high profile sites adjoining major roads though noting revegetation that blocks an attractive vista may undermine aesthetic values. • Revegetation serving other objectives that also create improved opportunities for picnicking, fishing, nature appreciation and other passive forms of recreation such as bushwalking, canoeing, and birdwatching. • Bank stabilising revegetation of lagoons used for boat-based water sports (see above).

Providing ecosystem services	All of the above rehabilitation objectives represent forms of ecosystem service delivery. Other ecosystem services provided by riparian zone rehabilitation/revegetation include: • carbon sequestration; • provision of crop pest predator habitat; • reduction in harbourage areas for crop pests, and • overbank flood scour protection.

Site and resource constraints

While an aspirational goal to rehabilitate the entire riparian zone of the Sheep Station Creek may be set, there are operating site and resource constraints that limit where rehabilitation activities can be conducted, or the nature of rehabilitation activities pursued at a particular site. Some of the most readily identified site constraints include:

- landholder support;
- proximity to farm operations;
- water board operational needs;
- site access, size, configuration, and
- soil conditions.

The implementation of large-scale revegetation projects in the early 2000s generated a range of concerns with Sheep Station Creek landholders. These included the high density of plantings that did not match the original riparian vegetation; the perceived potential for revegetation to create increased fire risks; the blocking of views and poor aesthetics attributed to dense plantings; perceived impact risk of re-established riparian forests on flood behaviour; conflicts between revegetated areas and farm operations, and concerns that species used for revegetation would provide cane beetle habitat.

Nearly 20 years later most of these concerns have not been borne out. During the field work and landholder engagement undertaken for this report, support amongst landholders for riparian zone rehabilitation and revegetation was overwhelming. Revegetation of riparian areas was one of the most commonly supported and nominated works amongst consulted landholders (see Appendix 2). Most residual concerns were directed at planting maintenance and program cost effectiveness. The need for maintaining a clear operational (suggested 12-15m) buffer zones between native vegetation areas and adjoining cane farms and/or program support for tree pruning maintenance was one issue nominated by several landholders.

Ultimately most sites available for riparian rehabilitation within the Sheep Station Creek catchment occur on private land and successful engagement of landholders, including addressing expressed concerns, is integral to the success of rehabilitation efforts.

Beyond site constraints, resource constraints will also affect the delivery of riparian rehabilitation projects. Three key resourcing issues are:

- availability of landholder time to support on farm activities;
- funds and personnel to support follow up weed and watering maintenance and infrastructure, and
- volume and timing of suitable species seedling production.

Ensuring that available resources match the scale of proposed rehabilitation projects is a key need in program implementation planning. Ideally, all proposals for riparian zone rehabilitation within the catchment should be subject to a formal assessment process that identifies and addresses all potential site and resourcing constraints.

Cost effectiveness

The scale of funding and other resources available for riparian zone rehabilitation works seldom matches the size of the task at hand. Cost effectiveness needs to be integral in the design and implementation of riparian rehabilitation programs. Activities such as revegetation are particularly resource intensive when considering the full gamut of associated works, spanning seedling production, site preparation, planting, watering and weed maintenance, through to plant establishment. Based on experience gained from past catchment revegetation initiatives and from riparian rehabilitation projects in other regions, the following are identified as opportunities to deliver cost-effective riparian zone rehabilitation:

- Plan rehabilitation activities within the context of an entire catchment system with identified priorities.
- Pre-assess site proposals in terms of constraints and suitability and develop operational and site plans for selected sites considering seasonal soil moisture, flood and fire risk.
- Give equal priority to the rehabilitation of existing areas of degraded remnant vegetation as to new ‘greenfield’ site development.

- Ensure areas of past investment in rehabilitation are secured ahead of establishing new sites.
- Develop and implement 'broad acre' or extensive riparian rehabilitation (for instance, promoted natural regeneration) in conjunction with more resource intensive forms of revegetation (such as tube stock planting).
- Prior to project implementation, secure resourcing (including personnel) to support post-planting watering and weeding maintenance through to plant establishment.
- Engage site landholders and provide resources to utilise and/or develop labour saving infrastructure and materials that support post revegetation watering and weed maintenance requirements (for example, header tanks and gravity fed irrigation lines, weed matting).

Table 7. Strategic riparian zone rehabilitation priorities across multiple objectives

Strategic rehabilitation priority	**Relevant objectives**	**Example reach values (V), management issues (M), landholder nominated works (W), see Appendix 2**
1. Consolidate the connectivity of the creek system's riparian vegetation corridor by revegetation of degraded weak links.	• Wildlife conservation • Water quality • Fish habitat • Providing ecosystem services	Table 1 – M5, W4, W6 Table 2 – M5, W4, W5
2. Maintain/secure sites of past revegetation/rehabilitation investment.	All	Table 1 – V4, W3, W9 Table 3 – V3, M1, W2
3. Secure and add value/improve condition of sites with existing high value remnant vegetation.	All	Table 1 – V1, V2, V3 (a & b), V6, W2 Table 2 – V2, V4, V5, M10, W1, W7 Table 3 – V2, V3, V5, W4 Table 4 – V1, V3, V4, V5, V6 Table 5 – V1, V2, V3
4. Restore riparian corridor habitat nodes and linkages to non-riparian habitat remnants to serve wildlife population movement and residency.	• Wildlife conservation • Providing ecosystem services	Table 1 – V1 (a), V3 (c), V6, V7, V9, W6 Table 3 – V4, V5, V6, M11, W5 Table 4 – V3, V4 Table 5 – V1
5. Revegetate tributary drainages and flow detention areas, including within constructed farm drains, to improve interception of sediment and nutrient loads.	• Water quality • Fish habitat • Providing ecosystem services	Table 1 – W5 Table 2 – M11 Table 3 – M3 Table 4 – V4
6. Revegetate the banks of lagoons with shade-casting riparian forests to reduce submerged aquatic plant growth and water temperature and to increase dissolved oxygen levels.	• Water quality • Fish habitat • Providing ecosystem services	Table 1 – W7 Table 2 – V1, V3, W2, Table 3 – V1, V7, V8, M4, W3 Table 4 – V2, W1
7. Establish dense water edge canopy cover to exclude aquatic grass anchor points at sites prone to aquatic grass infestation.	• Water quality • Fish habitat • Providing ecosystem services	Table 1 – V10, W10 Table 2 – V3, M2, W1, W2 Table 3 – V7, V8 Table 4 – V2, M1, M3, W1
8. Work within Lower Burdekin Water operational constraints to trial revegetation of constructed channels with shade casting overstorey to reduce in-channel grass weeds and excavator operational needs.	• Providing ecosystem services	Table 1 – M1 Table 2 – M3, M6, M8

Strategic rehabilitation priority	Relevant objectives	Example reach values (V), management issues (M), landholder nominated works (W), see Appendix 2
9. Utilise grazing or other grass control methods to create bare bank waterfowl habitat on lagoons with significant waterfowl populations.	• Wildlife conservation	Table 2 – V3, V6, M4, M7, W3, W6 Table 3 – V2
10. Stabilise and revegetate stream/channel banks subject to erosion and/or channel outbreak scouring.	• Water quality • Providing ecosystem services	Table 1 – W1 Table 3 – W1, W6

Priorities for investment

Priorities for investment in riparian zone rehabilitation will ultimately reflect a combination of strategic and opportunistic considerations. Strategic considerations are informed by different rehabilitation objectives (see above) and should ultimately be set by catchment management stakeholders. One of the main opportunistic considerations is landholder support. As previously noted, the majority of sites available to rehabilitation activities occur on private land and strategic priorities identified by technical assessment alone have little prospect of implementation without supportive landholders. Based on the mapping and assessment of riparian zone condition and associated values undertaken for this project (Appendix 2 and 3).

Table 7 (above) identifies strategic riparian zone rehabilitation priorities spanning several rehabilitation objectives and includes works nominated by landholders.

Operational planning

Successful riparian zone rehabilitation programs usually require a significant commitment of material and personnel resources and the coordination of work activities across sites and seasons. Effective operational planning is key to program success.

Specific planning needs will depend upon the type of rehabilitation works being implemented. Some of the main requirements for revegetation, fire regime management and controlled grazing are detailed in subsequent management plan sections. The generic issues that need to be considered as part of any operational plan are resourcing (both material and personnel) and activity timing.

The main phases common to most rehabilitation programs include:

- site selection and landholder negotiation;
- site preparation;
- site works (one off or staged/staggered), and
- follow up monitoring and maintenance until rehabilitation outcomes established/secured.

Within the Sheep Station Creek catchment the two most important timing considerations relate to weather (wet to dry season) and farm operations (crushing season and associated cane burning, harvesting, irrigation, and planting activities). Timing impacts rehabilitation activities via:

- site access;
- soil moisture;
- security established plantings (to flood, drought, fire);
- effectiveness of weed control;
- rates of plant establishment and growth;
- fire risks;
- farm traffic, and
- landholder availability.

The most important consideration for resourcing rehabilitation programs is matching program commitments with available resources. Commitments need to be defined across all identified phases of a rehabilitation program. It is more prudent to err on the side of successfully resourcing a smaller number or area or site works to completion, as opposed to not completing and risking losing investment associated with a more ambitious numbers or area of site works.

Ideally the aspirational goal of delivering riparian zone rehabilitation works across the Sheep Station Creek catchment should be served by a dedicated program team, operating under an operational plan developed for the entire catchment. This is a recommendation of this management plan.

Recommendations

1. Use shed meetings and/or public forums to engage riparian landholders in endorsing a catchment scale riparian zone rehabilitation strategy, including aspirational goals, strategic approaches, priorities and objectives identified by this management plan.
2. Establish a formal site assessment and operational planning process and proforma that examines and addresses site suitability and resourcing and other constraints associated with site proposals for riparian zone rehabilitation works and establishes an operational plan for their implementation.
3. When developing site proposals for riparian zone rehabilitation within the catchment, assess landscape context and existing riparian vegetation condition to consider an appropriate integrated mix of intensive (revegetation, weed control) and extensive (controlled burning, grazing) measures.

Photo 21. A remnant stand of fringing bluegum forest – an endangered regional ecosystem. Controlled grazing at this site has effectively removed hot fire risk.

Photo 22. A seasonal wetland managed with controlled grazing that has removed hot fire risks and pushed ground cover toward native species.

Photo 23. Pasture grass dominated riparian zone on Dick's Bank Lagoon a good site for further revegetation.

Photo 24. Control of grass weeds with herbicide leaves banks vulnerable to erosion. An established tree canopy would shade out grass weeds and provide bank and flood protection.

Photo 25. A grass-free understorey beneath the dense shaded canopy created by a stream bank Leichardt tree-

Photo 26. A grass free understorey beneath the dense shaded canopy created by lagoon bank Leichardt trees.

Revegetation

Definition and need

Revegetation is a form of riparian zone rehabilitation, which is defined as to: "*produce a new growth of vegetation on disturbed or barren ground*". Given the ecological and catchment function values of the riparian zone, its rehabilitation by revegetation is a high priority activity for catchment management programs. Broad strategic considerations for implementing riparian zone revegetation programs including objectives, goals and strategic priorities were covered in the preceding section. This section deals more specifically with revegetation approaches, planning and maintenance needs, and proposes the way forward to deliver strategic riparian zone rehabilitation across the Sheep Station Creek catchment.

The Sheep Station Creek catchment has had a long history of relatively intensive land and water resource development to support irrigated sugarcane agriculture. Prior to agriculture, the catchment also supported extensive pastoral land use. This land use history and other exploitative uses of native vegetation has resulted in the clearing and loss of the original native woodland and riparian forest along significant lengths of Sheep Station Creek. Besides direct clearing, the loss can also be attributed to other ecological pressures such as weed invasion (particularly pasture grasses) and uncontrolled burning. Some of the original riparian vegetation types occurring in the catchment were detailed in early land system assessments by the CSIRO (Christian *et al* 1953) and have more recently been described by State Government agencies as part of their 'pre-clear' regional ecosystem (RE) mapping (DES 2021).

The 'pre-clear' regional ecosystems of Sheep Station Creek's riparian zone recognised in state mapping coverages include fringing and floodplain woodlands and grasslands (

Table **8**). These regional ecosystems and information concerning their component species can provide useful rehabilitation targets. The limited extent of the catchment's riparian zone now mapped by state agencies as legally-defied remnant vegetation is indicative of its level of disturbance, but also reflects scale limitations of the mapping.

Table 8. Regional ecosystems (REs) mapped within the riparian zone of Sheep Station Creek

Broad type	RE number	Dominant species
Fringing (riparian) woodland	RE 11.3.25	Blue gum, paperbark, Leichardt, cabbage palm
Floodplain Woodlands	RE 11.3.7	Bloodwood, Morton Bay ash, ghost (Dallachy's) gum
	RE 11.3.9	Poplar gum, Morton Bay ash and bloodwood
	RE 11.3.4	Blue gum, Morton Bay ash, bloodwood, poplar gum
Freshwater wetlands	RE 11.3.27	Water lily, spike rush, reeds, plus submerged aquatic species
Grassland	RE 11.3.31	Cane, blue, couch, kangaroo, spear and blady grass

Finer scale riparian vegetation condition mapping undertaken by this project (Appendix 3) identifies remnant vegetation along greater lengths of the creek system than recognised by state mapping. However, the equal – if not greater – lengths of creek reach mapped as dominated by exotic pasture grasses and other non-remnant vegetation classes is perhaps the best depiction of both the level of degradation of the creek's riparian vegetation, and of opportunities for revegetation. Revegetation needs and opportunities and other management considerations associated with *Riparian vegetation condition classes* mapped for this management plan (Appendix 3) are presented in Table 9.

Revegetation approaches

There are essentially two types of revegetation approaches that may be used in the Sheep Station Creek Catchment, intensive and extensive (below).

Intensive revegetation – Most of the revegetation that has been conducted on Sheep Station Creek to-date is 'intensive'. Such approaches are described as intensive due to the human labour employed at a site level to plant trees (commonly germinated tube stock) by hand. Intensive revegetation is most appropriate for sites that are more degraded in terms of the loss of most, if not all, the original native vegetation. Intensive revegetation usually generates substantial maintenance requirements for at least for the first 12-24 months post-planting, though this can be reduced through careful site preparation, species selection, and planting timing.

Extensive revegetation – Extensive revegetation approaches use broad-acre tools such as weed control, and managed fire and/or grazing regimes to promote natural regeneration of native vegetation via sapling growth and seedling recruitment, which depends on soil or canopy stored seed or seed transported to the site by wind, water or animals. Direct seeding can also support extensive regeneration particularly where natural regeneration fails. Revegetation involving the use of promoted natural regeneration is only suited to areas which retain elements of the original native vegetation cover that can, if appropriately managed, provide a source of seed and/or recruiting saplings. Implementation of this approach involves identifying and removing the disturbance factors that are preventing natural recruitment and regeneration. With appropriate site

preparation, direct seeding approaches also offer opportunities for extensive revegetation at sites lacking remnant native vegetation. Extensive revegetation methods have not been widely used in the Sheep Station Creek catchment though at least one landholder has successfully applied it at a reach scale (Appendix 2 – Table 1 Value 5) and examples of where default management conditions (for example, light horse grazing) have led to extensive revegetation have also been identified (Appendix 2 – Table 3 Value 6).

Intensive or extensive revegetation approaches are generally suited to different riparian zone condition contexts, but are not exclusive. Both approaches can be integrated at a single site with extensive approaches used where remnant native vegetation occurs and intensive revegetation applied to more disturbed patches or where natural regeneration fails. Vegetation established by intensive approaches will ultimately depend upon cost-effective extensive management approaches to secure it in the longer term. The nominated appropriateness of intensive or extensive revegetation approaches for different riparian zone condition contexts is presented in Table 5 (preceding section).

Extensive revegetation has been little-trialled or intentionally practiced in the lower Burdekin relative to other regions such as south east Queensland (Chenoweth *et al* 2012). However, most landholders are familiar with observing periodic increases in the recruitment and regrowth of native tree saplings in different areas of local remnant vegetation. Understanding these natural regeneration processes, particularly to the degree that they can be 'turned on' to intentionally revegetate an area, holds the answer to cost-effective landscape scale revegetation in the lower Burdekin and elsewhere.

Operational and maintenance planning

Operational planning is critical to the success of revegetation efforts. Management efforts exerted in site preparation, plant establishment, maintenance, and protection of revegetated or regenerated vegetation stands ultimately decides the outcome of longer-term revegetation strategies. In some instances, management requirements can be minimal and even the doctrine of 'benign neglect' will work in some contexts. However, in the intensive agricultural landscape of the seasonally dry lower Burdekin region, there is usually some reoccurring management needs to be addressed in operational planning to achieve successful revegetation that does not conflict with neighbouring land uses. These management requirements apply equally to community organisations or landholders conducting revegetation at site to catchment scales and include issues associated:

- site selection (regarding Lower Burdekin Water and farming/harvesting operational needs);
- site preparation;
- planting;
- watering;
- weed management;
- fire management, and
- pest management.

Operational plans need to span at least a year to cover seasonal requirements, but also cover daily to monthly reoccurring management needs. To be pragmatic and adaptive, operational planning also needs to be reviewed regularly (at least at seasonal milestones) and modified where necessary to respond to changing conditions and circumstances. The distribution of revegetation operational management issues within a model annual planning cycle is presented in Table 10.

The scale of successful intensive revegetation efforts is largely determined by the resources available for site maintenance. In the Sheep Station Creek catchment, the primary maintenance needs are establishment watering, weed control, and fire management. If extensive maintenance approaches are being used (for instance, controlled grazing), there will be additional management needs associated with fencing infrastructure and grazing pressure. Based on experience gained from past revegetation programs, a set of management approaches and maintenance needs for intensive revegetation approaches have been identified (see Table 11).

Additionally, based on limited catchment examples, literature from other Queensland regions (Chenoweth *et al* 2012, Lovett & Price 2001, WetlandCare Australia 2008), and observations of natural regeneration in native vegetation remnants of the lower Burdekin; a set of extensive revegetation management approaches and maintenance needs have also been identified (see Table 11).

The recognition of distinct short term (establishment watering, weeding) and longer term (management fire risk) maintenance requirements is key to the success of revegetation efforts in the dry tropics.

Table 9. 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, hymenacne) onto water bodies blocks water flow and creates floating aquatic weed mats. This reduces water dissolved oxygen Biological Oxygen Demand (BOD) created when grass decomposes in water, particularly when inundated by elevated flows/water levels create 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. • Establishment of 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. • Condition can trend positively or negatively depending on operating pressures, including weed infestation, 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 promotion of natural regeneration is more appropriate where integrity of species composition 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. • Condition can trend positively or negatively depending on operating pressures including weed infestation, 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 should be used to target denuded areas and promotion of natural regeneration within remnant stands. • Integrated mix of intensive and extensive revegetation approaches is appropriate management focus and provides a catchment scale revegetation target.
Revegetated
• Observed ecological value is generally high, particularly where includes mature remnant stands or individual trees of the original vegetation community. • 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. • Good opportunity to Increase habitat values by dedicated understorey/ground cover planting and introduction of physical habitat feature, for example, logs, artificial nest hollows.
Exotic trees
• Ecological value is limited in monocultural plantings (orchards) but can be higher when mixed with remnant native species. Can provide some nesting and feeding habitat resources and range of useful functional values, for example, stabilising stream banks, shading out aquatic grass weeds, and duckweed 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 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 focus for intensive revegetation, particularly adjoining lagoons subject to aquatic grass weed infestation.

Table 10. Model annual revegetation planning and management cycle (Shading density indicative of activity level)

c	January	February	March	April	May	June	July	August	September	October	November	December
Site preparation	▪ Site preparation for wet and post-wet season planting.					▪ Site preparation for strategic pre-wet season planting in flood prone sites.					▪ End of crushing (less landholder time constraints) opportunity for site preparation for wet season planting.	
Planting	▪ Wet season planting in non-flood prone sites with limited establishment watering. ▪ Potentially suitable direct seeding period.		▪ Immediate post-wet season planting with lower establishment watering needs and greater (dry season) maintenance watering needs.		▪ Dry season planting only where establishment and maintenance watering commitments in place.			▪ Strategic pre-wet season planting in flood prone sites with commitments in place for higher establishment watering needs, recognising less (post-wet) maintenance watering needs.			▪ Pre-wet season planting in non-flood prone sites with short establishment watering period. ▪ Potentially suitable direct seeding period.	
Watering	▪ Infrequent establishment watering.		▪ Low frequency maintenance and establishment watering ~1 per 1.5 months.		▪ Higher frequency maintenance watering ~1 per month.				▪ Most frequent maintenance and establishment watering ~1 per fortnight.			
Weed control	▪ Wet season maintenance slashing and opportunistic (dry periods) herbicide maintenance or site preparation spraying.		▪ Growing season herbicide maintenance spraying and slashing, where appropriate.			▪ Less onerous weed management requirements, but potentially greater in more well-watered sites.				▪ Pre-wet season weed control herbicide spraying (not flood prone sites) and warmer growing period grass slashing.		
Fire management				▪ Seasonal opportunity for controlled cool burns. ▪ Targeted fuel load reduction (grazing and other methods). ▪ Establishment and maintenance of fire breaks for the dry season.					▪ Fires break establishment and maintenance.		▪ Opportunity for post cane harvest controlled burning in fuel reduced (grazed) sites.	
Grazing management	▪ Wet season spelling and maintenance of riparian fencing post-wet season flooding.			▪ Post-wet season 'crash' grazing (cattle) of guinea grass in habitat remnants.				▪ Extended dry season lower intensity grazing (including horses) including focussed pressure on wetland ponded pasture infestations. ▪ Removal of stock from riparian and wetland remnants for extended late dry and wet season spelling.			▪ Removal of stock from riparian and wetland remnants for wet season spelling.	
Operational and forward management planning review			**End of wet season** Key issues: ▪ Wet season planting. ▪ Growing season weed maintenance. ▪ Post-wet season planting. ▪ Riparian fencing maintenance. ▪ Implementation controlled grazing.				**End of Winter** Key issues: ▪ Pre-wet season planting and site preparation. ▪ Dry season fire risk protection. ▪ Dry season maintenance and establishment watering. ▪ Grazing spelling and stock movement.				**End of dry season** (and cane harvest) Key issues: ▪ Wet season planting. ▪ Growing (wet) season weed maintenance. ▪ Post-wet season planting site preparation.	

Table 11. Management and maintenance issues associated with intensive and extensive revegetation approaches

Issue	Intensive revegetation	Extensive revegetation
Pre-existing site condition	Primarily suited to degraded sites lacking remnant vegetation, but can be integrated as 'in fill' planting into barer areas within remnant vegetation stands or pursued anywhere a particular species suite is a desired outcome.	Primarily sites that retain elements of the original native vegetation, particularly desired canopy trees and potentially viable soil seed banks. Direct seeding can be applicable at any site.
Site preparation	Control of competing weed species by glyphosate 'spray out' and/or mulching (cane trash and harvested aquatic weed mats suitable). Chemically 'crashed' grass should be kept in place to retain some ground cover protection and provide a rudimentary mulch layer. For large-scale plantings, or sites where ground compaction may be an issue, use of a single tyne ripper can be appropriate. The use of special 'tree hole' (non-polishing) augers for tree hole digging is also appropriate for larger plantings. Crash grazing of exotic pasture grass weeds where possible can also assist in opening a site up for revegetation, but will usually require follow up spaying. Fire can also be a useful site preparation tool if conducted early enough prior to the wet season to avoid erosion risks and with due diligence to avoid impact to remnant native vegetation. Again, follow up herbicide spraying may be required to prevent rapid grass weed regrowth in specific planting sites. Complete removal of ground cover (by spraying/burning) and cultivation (rotary hoeing) represents an overly-intensive site preparation approach, which presents an erosion risk in the riparian zone; particularly on sloping areas if sites are prepared immediately prior to the wet season and is not recommended.	To initiate promoted regeneration in disturbed remnant vegetation, the initial step is to identify the existing constraints that may prevent or limit regeneration. Once identified, management prescriptions can be developed to create enhanced native vegetation growth and/or recruitment opportunities. Some or all the following may be appropriate: • excluding fire; • excluding or spelling grazing pressure; • reducing exotic grass cover and creating ground cover openings through methods such as 'knock down' herbicide spraying, controlled grazing or 'cool' burning (burn which occurs early dry season, or involves burning a reduced/grazed fuel load, or both), and • direct seeding with pioneer species (wattles), which may also require a complementary burn for successful germination post-seeding, or to create a germination bed pre-seeding. Prior to undertaking any of these management interventions, the layout of site remnant vegetation should be surveyed (below).
Planting density and layout	Determined by the desired revegetation outcome and proposed maintenance approach. High density (~1.5m separation) – Appropriate where the intention is to create a closed canopy or dense mixed stand of pioneers and secondary species, where weed maintenance will primarily be provided by a combination of chemical use and shading and where soil moisture conditions are not too limiting (for instance, loamy soils adjoining the water course). Low density (~3m separation) – Appropriate where the intention is to create an open woodland. Only secondary species are being planted and weed maintenance will primarily be provided by slashing, brush cutting or other 'intensive' mechanical means where access for machinery is required. Planting in lines allows relatively dense planting to be achieved in conjunction with mechanical maintenance. Patches of high density – This approach represents a mixture of both above strategies where denser or mixed (pioneer and secondary species) vegetation stands are the desired outcome, but slashing around the stand is intended to be a primary maintenance (grass weeds and fire risk) approach with complementary weed control by herbicide spraying within the stand.	For promoted natural regeneration, plant density and layout is determined at least initially by the location of remnant vegetation stands. These need to be surveyed and incorporated into a site plan that identifies areas: • where vegetation is intact and/or regeneration processes are still operating that require protection (fencing, fire breaks, slashed/sprayed buffers) rather than intervention; • where sapling recruitment exists but is subject to weed competition or other pressures (grazing, fire) that require specific interventions (see section above), and • areas that are denuded of remnant vegetation that may be suitable for more intensive site preparation and revegetation methods (slashing, spray out, tube stock planting). The flag taping of individual saplings, or barrier marking of sapling stands, will serve to protect them during subsequent management interventions.

Issue	Intensive revegetation	Extensive revegetation
Planting timing	When human resources, watering infrastructure and maintenance commitments are secured for a site, planting can occur at any time of the year, though using high soil moisture levels associated with the annual wet season presents the most strategic opportunity in terms of labour saving. Two approaches may be used: • pre wet season planting with maintenance watering required up to the wet season and potentially less requirement beyond it (dependent upon species, wet season duration and site location), and • during and post-wet season planting with limited establishment watering but a longer maintenance watering period required through the subsequent dry season(s). The former strategy has the least subsequent watering requirements, but where established seedlings are on the lower stream bank, they can be vulnerable to being scoured out in the event of wet season flood flows and an establishment lead time is required (2~3 months) prior to exposure to wet season flooding risks.	Generally, not applicable except where direct seeding is being used, then timing will be related to the natural seed fall period for the species concerned and soil moisture. May also be governed by timing of other management or seasonal interventions, such as burning to create ash seed bed, or high flow scouring to present exposed stream bed/bank. The most important timing considerations for extensive revegetation concerns other forms of management intervention, for instance, weed control, grazing, burning (Table 10).
Direct seeding/vegetation succession	Generally, not applicable, though direct seeding of preferred ground covers (native grasses or other herbaceous species) into mulched inter-planted areas has benefits (Hooker 2010). In the longer term, the maturation of plantings – particularly short-lived pioneer species like wattles – may initiate self-sowing based recruitment as well as seed brought to established revegetation sites via bird droppings. This natural recruitment is usually beneficial in terms of the ecological value and diversity of the revegetated site and needs to be recognised (and ideally tagged with flagging tape) when it occurs, and not be eradicated by the site weed management regime.	Direct seeding has been little-trialled on dry tropics floodplains so prescriptive management is lacking. It represents a great method development opportunity. The sowing of pioneer species (like wattles, cottonwoods) into grass-weed dominated creek reaches, possibly in conjunction with controlled burning or grazing, is one prospective method that has potential. Seeding of native grasses into sprayed-out sites to reduce erosion should also be trialled (Hooker 2010). Vegetation succession management in remnant habitat areas is associated with interventions that address weeds, fire and grazing regime and is discussed in relation to these issues below.
Watering	Critical activity for plant establishment in the dry tropics. Requirements can be minimised by strategic timing and location of planting (above). A minimum 12-month commitment to maintenance watering of new plantings is recommended with up to 24 months maintenance watering potentially required for some less hardy species or more water stressed sites (such as hard clays, free draining sands). Watering frequency required will vary in relation to site characteristics, establishment timing and season, but will range from fortnightly to bi-monthly in the first year. Revegetation at well-watered sites adjoining water courses or receiving irrigation tailwater will have less watering needs. Access to private, council or community organisation (Landcare)-owned mobile watering trailers is recommended for the maintenance of larger plantings.	Not applicable unless being used in conjunction with a direct seeding method, or where 'in fill' revegetation planting is integrated into extensive revegetation sites.

	Establishment of cheap irrigation infrastructure (fluming, poly pipelines with drippers, tanks, timers) is also appropriate for larger plantings at less publicly-accessible sites not exposed to vandalism.	

Issue	Intensive revegetation	Extensive revegetation
Weed management	Primary weeds of concern are grasses and vines. Intensive weed management involving up to four interventions (possibly greater number where mechanical control only used) in the first 12 months post-planting is a critical activity for survival of plantings. Greater levels of site preparation (like weed spray out and mulching) can reduce weed management needs. In the absence of dedicated fire regime management, control of grass weed generated fuel load is essential to the long-term survival of all native vegetation planted or remnant within the Sheep Station Creek catchment (see extensive approaches, right). Maintenance opportunities are largely governed by site access and planting density. Where machinery access is possible and more open planting densities, linear or patch layouts have been used, slashing is an appropriate weed management method. Where machinery access is not possible and/or denser planting densities have been used, biodegradable herbicide (glyphosate) is the most appropriate weed management method. Grazing also has some potential for maintenance of weeds (grasses) around protected plantings (below).	Given the dominance of pasture grass weeds in ungrazed habitat remnants, (most) grass weed control in conjunction with fire regime management are often the most important determinants for native vegetation regeneration in habitat remnants. This needs to be conducted with care to avoid remnant vegetation stands and tagged saplings. Grazing (discussed below) offers a broad acre tool for the management of grass and some vine weeds. Fire regime management (discussed below) is another broad acre tool for weed management in habitat remnants. Total fire exclusion at suitable sites, where feasible, will circumvent the need or priority for some grass weed control. Local observations indicate recruitment of native vegetation will proceed in guinea grass (but seldom para grass) in the absence of fire. Beyond landholder site maintenance, use of herbicide spraying of grass weeds as an approach for promoting natural regeneration has not been formally trialled at a reach scale and is recommended. The other significant weed issue impacting native vegetation regeneration in habitat remnants is woody weeds, including well-known declared pests such as chinee apple, parkinsonia, lantana, rubber vine and undeclared exotics, like tamarind trees. The control methods required for these species have been well-documented in Queensland Biosecurity literature.
Grazing management	Generally not applicable due to the potential for trampling of seedlings, though in the case of protected (fenced) patch or individual (tree-guarded) plantings, grazing can be used for the control of grass weeds and associated fire risk around intensive revegetation sites. Where plantings have been established for some time (~2+ years) light horse grazing (generally more selective than cattle) may provide broad acre grass weed maintenance around unprotected trees although some attrition will still occur. Field monitoring is a priority for this approach. In addition to the status of plantings, maintenance and management issues associated with the use of grazing include: • fencing infrastructure (key issue where sites adjoin cane farms and/or are situated in the riparian zone and subjected to wet season inundation; • pasture condition in relation to stock density, and	The use of grazing as a grass weed management tool in riparian and wetland areas of the lower Burdekin has been the subject of management trials and research (Tait 2011). Findings are discussed more fully in the controlled grazing section of the report. In summary: • Controlled grazing should ideally be applied via an adaptive management approach which responds to monitored vegetation condition indicators. • Crash grazing applications in late to post-growing season autumn-winter are effective for removing hot fire risks in degraded habitat remnants and create more open understorey that can promote sapling recruitment, but it is vulnerable to subsequent grazing events. • In better condition sites that can accommodate it, a long-term recovery regime using sustained low grazing pressure delivers reduced exotic pasture dominance and fire risk, plus increased vegetation regeneration. Not suited to heavily weeded sites. • Recovery transitional grazing regimes involve sequential range of grazing and spelling including both former grazing regimes. It seeks to move

	• movements of stock to facilitate spelling.	monitored habitat condition forward while minimising condition losses during grazed periods. Integrates cool burning, post burning grazing and timed grazing events in relation to wet season inundation (Tait 2011).

Issue	Intensive revegetation	Extensive revegetation
Fire regime	Management of grass weeds (by any of the approaches described above) is the primary requirement for reducing fire risks at intensive revegetation sites. Good site maintenance generally reduces risk of fire impacts, though combustible mulch may present an ongoing fire hazard. Establishment and maintenance of fire breaks between revegetation sites and any adjoining unmanaged land areas and/or cane farms prior to the cane burning season, and through the subsequent dry season, is a prudent fire risk management approach. As intensive revegetation sites mature ~2yrs+ there is a natural tendency to leave such sites to 'fend for themselves'. Catchment revegetation program experience has demonstrated that at sites where establishment of canopy closure is possible, the shading of the understorey can create a self-sustaining fire refuge. More commonly extensive pyrophytic (fire loving) exotic pasture grass (guinea grass) infestation means a single unmanaged hot fire can undo revegetation gains in a single event. As intensive revegetation sites mature, some will still require some extensive management approach (such as cool burning, grazing – see right) to be secured against fire risks into the future.	Management of fire is the single most important requirement for promoting native vegetation regeneration in most areas of the catchment retaining native vegetation remnants. Based on observed habitat responses addressing two fire regime issues – too frequent and/or too hot – will facilitate improved native vegetation recruitment (subject to management of other constraining factors). **Reducing fire frequency** Education – A large number of remnant habitat areas within the catchment are burnt almost annually either through neglect of cane fires or intentionally as part of a post-harvest farm 'clean up' with an ancillary goal being to reduce pest harbourage, fuel loads and farm fire risk in the following year. The impact of these practices on native vegetation and the negligible fuel load benefits gained through regular burning of pyrophytic (fire loving) guinea grass needs to be communicated to landholders. Annual burning is too frequent to enable successful native vegetation recruitment and greater inter-burn periods of 3~5 years (combined with fire intensity management – below) is recommended. Planned fire regimes – These need to be developed in conjunction with land managers for specific remnant habitat areas to prevent inadvertent burns (see Appendix 1). Fire breaks – These are a prudent and essential fire management requirement for extensive revegetation sites and provide the only chance of controlling fire frequency in a seasonally dry region with widespread burning practices. Fire exclusion – Appropriate where fire sensitive closed forest is the desired revegetation outcomes and the site readily lends itself to fire exclusion management in terms of natural breaks with adjoining areas. **Reducing fire intensity** The prevalence of ungrazed exotic pasture grasses provides high fuel loads and associated hot fire risks in most habitat remnants of the catchment. Fuel loads – Controlled grazing (discussed above) provides a broad acre means of reducing exotic pasture grass fuel loads in open woodland habitat remnants while slashings and herbicide spraying have application at small sites where such management investment can be made. Establishing a more closed forest canopy has also been demonstrated to control understorey fire fuel loads at several revegetation sites within the catchment (see Photos 19 and 20). 'Cool' burning – Controlled fires in the early dry season, during periods of greater moisture availability and during the evening all provide some opportunity for reducing the intensity of fires within areas of remnant habitat (see Appendix 1).

Species selection/targeted communities

One of the identified limitations of some past revegetation efforts within the catchment is the use of inappropriate species at some sites. While all species used have been native and suited to the catchment, some proved inappropriate in relation to specific site constraints of soil type, moisture availability and associated maintenance requirements. High stress and mortality observed for some plantings was attributed to species that prefer loamy soils being planted in hard clays, and closed canopy riparian species (gallery rainforest) with high water demands being planted in moisture-limited sites. Another concern that emerged was the predominance of short-lived pioneer species (such as wattles and cottonwoods) in some plantings.

With unlimited resources or maintenance commitments, most native species could be established at most sites, but this is an unrealistic proposition for catchment-scale revegetation. Even established plantings would be unlikely to be sustained in the longer term if unsuited to extreme dry seasons and/or fire risks. The ideal scenario is one where established plantings are suited to site soil and moisture conditions and become resilient in the longer term, requiring less resource-intensive maintenance approaches that primarily deal with grass fire fuel loads and fire regime management.

Table 12 presents a non-exhaustive list of native plant species recommended for revegetation within the Sheep Station Creek catchment. Each has been classified into seven non-exclusive categories that provides guidance as to their appropriate use. These categories include three broad soil types and four vegetation community/structural designations. The relevance of these classes in terms of species selection is described below:

Soil suitability

Loams – Being a delta distributary stream, loamy soils associated with active alluvial deposition are a common soil type of the levees, floodplain and some channel reaches of Sheep Station Creek. Loamy soils have some of the least constraints for plant growth in terms of texture, moisture retention, drainage, and nutritive status, and nearly all of the recommended species are suited to loam soils.

Sandy soils – Sandy soils are also common on the delta, particularly as elements of prior channels (in this case of the Burdekin River) and towards the coast as stranded old beach ridges. These soils often have some limitations in terms of moisture retention and nutritive status for plant growth and a smaller set of the recommended species are suited to them. However, many of the limitations of sandy soils can be overcome through extensive mulching and a commitment to higher levels of establishment watering.

Heavy clays – Heavy clays have perhaps the greatest level of constraint to plant growth, although they are a common soil type within the catchment and many native plants are well adapted to them. These soils occur in older alluvial sequences, back levee drainage depressions and swamps, and toward the coastal zone. Marine sediment-derived heavy clays on the coastal plain also often have high salinity associated with them and form relatively treeless grass plains.

Vegetation community/structural type

Primary riparian community

The species listed under this category include all those suited to stream-side planting and include a range of soil type preferences and vegetation community/structural types. Species indicated with a double cross in Table 12 are considered ‘signature’ riparian tree species for the catchment and occur in most riparian vegetation remnants. Propagation and establishment of these signature species is recommended as the primary focus of revegetation efforts to re-establish the basic ‘architecture’ of the creek’s riparian vegetation. Other listed species are also valuable revegetation candidates that offer a range of habitat or functional benefits.

Several species recommended for consideration have not been observed growing naturally on Sheep Station Creek despite being natives to more perennial streams of the lower Burdekin, including the Burdekin River, Haughton River and East Barratta Creek. These species are recommended in recognition of the modified (near perennial) flow conditions now associated with the creek system that now may make them more suitable for establishment than some of the original species adapted more to seasonal flow and water level conditions.

These species include:

Pendulous paperbark tree, weeping paperbark tree and weeping bottle brush – all provide good bank stability; a dense canopy that can exclude grass growth; cope well with sustained water levels, including inundation, and are reasonably fire resistant (common on Burdekin and Haughton Rivers).

Beach cottonwood – pioneer species; fast growing; produces dense (non-hardwood) overhanging canopy, which is good fish habitat and potentially capable of excluding guinea and para grass growth (common on west Barratta Creek). Recommended for weed control plantings on excavated waterboard channels.

Black ironbox – rarer eucalypt species, but relatively common on Burdekin and Haughton Rivers, and widely planted in past revegetation programs. Good bird habitat suited to well-watered loamy/levee soil conditions.

Pongamia tree – produces a closed overhanging canopy, which is good fish habitat and potentially capable of excluding guinea and para grass growth; grows on heavier soils, and is relatively fire resistant (common on West Barratta Creek).

Pioneer species

Although usually only short lived, pioneer species offer valuable contributions to revegetation efforts from several perspectives. They are fast growing and quickly develop a shading canopy for grass weeds and provide protective ‘living stakes’ for slower growing secondary species. They attract birds, which bring other colonising species in with their droppings, and some (like wattles) are nitrogen fixers, which can improve growing conditions at degraded/compacted sites. Most also provide a mid or understorey (below) which offers additional habitat and food resources for wildlife

species. Pioneer species also have potential use in direct seeding approaches (conducting wattle seed sowing) followed by controlled burning. This could offer the prospect of broad acre revegetation of degraded sites currently dominated by exotic pasture grass weeds. Pioneer species, as the name suggests, need to be succeeded by secondary species through intentional inter-planting or natural succession to develop mature 'climax' vegetation communities.

Understorey species

Much of the focus of revegetation efforts is on overstorey or canopy trees. However, most wildlife species depend equally on understorey species for habitat and food resources. Revegetation intended to provide improved wildlife habitat needs to give due consideration to the inclusion of understorey plantings.

Closed forest species

The biodiversity values of closed forest types are well recognised and several sensitive fauna species, including owls – which are predators of farm pests – require these habitat types. Historically, closed forest was not recorded within the Sheep Station Creek catchment due to highly seasonal rainfall, dry season fires, and a lack of natural fire refuges. However, many of the individual species that comprise closed forest elsewhere in the lower Burdekin (for instance, on Plantation Creek and Burdekin River gallery scrubs) are found in the catchment. On the modern creek system, stream flow is semi-perennial and land management also creates areas of fire refuge in some reaches. Some of these sites (see Photo 17) are observed to be or are succeeding toward closed canopy forest (see Appendix 3, Map sheet 1, Value 3 and 5*).* Prior revegetation efforts utilising closed forest pioneer species and dense plantings on some better-watered sites has also resulted in the development of closed forest vegetation communities (Photos 19 and 20).

Where sites have better quality soils (loams), are well watered (adjoin stream channel or receive irrigation tailwater), and present good prospects for fire exclusion (within steep banks, surrounded by roads, etc), closed forest establishment is a legitimate revegetation goal for suitable reaches of the creek system. Once established, closed forest communities that exclude understorey grass growth can be resilient to fire and serve to reduce fire risks to adjoining farms and remnant vegetation. Some closed forest species (like figs) have previously been identified as cane beetle habitat and this may deter some landholders from their use.

Trial and error (adaptive management)

When selecting and promoting suitable species for revegetation, preferences should be adaptive and based on the observed success of species within established revegetation. Monitoring and communicating the success of different species under variable site conditions is a role for community groups and landholders engaged in ongoing revegetation efforts.

Progressing a strategic catchment-scale riparian revegetation program

Information compiled by this management plan provides the basis for progressing a strategic, catchment-scale, riparian revegetation program for Sheep Station Creek. To have community ownership of such a program, it is important that landholders and other management stakeholders are engaged to endorse an overall aspirational goal for revegetation within the catchment and specific revegetation objectives that underpin it. Examples of these were presented in the preceding section.

Contributing elements to such a program that have been progressed by this management plan include:

- Recommended revegetation approaches for different riparian zone condition and land-use contexts (Table 5).
- Means by which different revegetation objectives can be addressed (Table 6).
- Strategic revegetation priorities across different objectives including related values, management issues and landholder nominated works, identified and mapped at a reach scale (Table 7 and Appendix 2 and 3).
- List of the catchment's pre-clear regional ecosystems, which provide useful rehabilitation targets (Table 8).
- Identified revegetation needs and opportunities associated with mapped riparian vegetation condition classes that define the works scope potential for a long-term revegetation program beyond currently nominated works sites (Table 9 and Appendix 3).
- A reference annual revegetation operational planning and maintenance management cycle (Table 10).
- Identified management and maintenance issues associated with both intensive and extensive (promoted natural regeneration) revegetation approaches (Table 11).
- Descriptions of revegetation community targets and suitable species (Table 12).
- Descriptions of revegetation promoting fire regimes (next section).
- Descriptions of revegetation promoting grazing regimes (next section).

To deliver an ambitious revegetation program that services multiple projects across the catchment will involve significant resources. Three key needs are:

1. Nursery produced seedlings.
2. Works sites and works endorsed by willing landholders.
3. Resourced work plan and personnel.

For nature conservation projects, the use of both local species and, ideally, local providence seedling stock, is best practice to avoid genetic integrity risks in future reproductive outcomes between remnant and revegetated vegetation. This requires locally-collected seed stock and nursery production and can represent a rate determinant step on the path

to conducting revegetation. Engagement of the Lower Burdekin Landcare nursery and/or other local providers in the production of selected species seedling stock is an immediate priority to progress a catchment revegetation program.

Revegetation works sites nominated and endorsed by riparian landholders during the consultation undertaken for this management plan (Appendix 2), particularly those that conform to identified strategic priorities (Table 7), provide an immediate focus for implementation of program works.

Implementing a catchment-scale revegetation program will require the full engagement and support of riparian landholders and Landcare volunteer resources. However, given seasonal constraints on the availability of both within the catchment, funding commitment should be sought for a dedicated professional work team to support works implementation – particularly site maintenance needs – across at least a 24-month program.

The success of past revegetation programs within the catchment particularly observed positive changes in creek ecosystem condition and landholder attitudes indicate such a program would represent a good investment.

Recommendations

1. Engage local Landcare nursery and/or other local providers in the mass propagation of seedlings of signature riparian species (Table 12) to support a catchment scale revegetation program.
2. Establish riparian zone rehabilitation demonstration sites that trial and monitor innovative promoted natural regeneration revegetation methods including:
    a. seedling/sapling recruitment opportunities created with glyphosate knock-down spraying of pasture grass weed groundcover beneath degraded remnant vegetation stands;
    b. response of sapling recruitment/survivorship to controlled grazing and cool burning regimes in degraded remnant vegetation, and
    c. direct seeding trials, including approaches integrated before or after controlled burns and into mulch beds created by:
        i. glyphosate (or preferentially grass selective herbicide) knock-down spraying of pasture grass weed, and
        ii. decomposed excavated/harvested aquatic weed mats.
3. Engage irrigation/water tank supply specialist to design a cost-effective small header tank irrigation system (with associated poly pipeline, drippers, timer) to provide to landholders engaging in intensive revegetation projects.
4. In planning and resourcing riparian revegetation projects: include clear operational (12-15m) buffer zones between native vegetation areas and adjoining cane farms and/or program support for tree pruning maintenance.
5. Seek resourcing for a dedicated program work team that operates under a multi-year operational plan and is focused on the aspirational goal of delivering riparian zone rehabilitation works across the entire Sheep Station Creek catchment.

Photo 27. A weed-choked-off channel lagoon nominated as a site for rehabilitation (weed excavation and revegetation) by the landholder.

Photo 28. Twenty-year-old revegetation (rear left) killed by an uncontrolled hot burn.

Table 12. Native plant species recommended for revegetation within the Sheep Station Creek catchment

Plant species	*Primary riparian community*	*Sandy soils*	*Loams*	*Heavy clays*	*Pioneer species*	*Understorey species*	*Closed forest species*
Acacia crassicarpa Beach wattle tree	X	X	X		X	X	
Acacia flavescens Wattle tree	X	X	X		X	X	
Acacia holosericea Silver leaf wattle shrub	X	X	X	X	X	X	
Acacia simsii Wattle shrub		X	X		X	X	
Albizia procera Forest siris tree	X		X		X		
Alphitonia excelsa Red ash tree	X	X	X			X	X
Callistemon viminalis Weeping bottlebrush shrub/tree	X*	X	X	X		X	X
Canarium australianum Mango bark tree	X	X	X				X
Casuarina cunninghamiana River she oak tree	X*	X	X				
Corymbia clarksoniana Bloodwood tree	XX		X				
Corymbia dallachiana Ghost gum tree				X			
Corymbia tessellaris Moreton Bay ash tree	XX	X	X				
Cupaniopsis anacardioides Tuckeroo tree	X	X	X			X	X
Erythrina vespertilio Bat wing coral tree	X		X				
Eucalyptus platyphylla Poplar gum tree	X		X	X			
Eucalyptus raveretiana Black ironbox tree	X*		X				X
Eucalyptus tereticornis Blue gum tree	XX		X				X
Ficus opposita Sandpaper fig shrub/tree	X	X	X		X	X	X
Ficus racemosa Cluster fig tree	X		X				X
Glochidion disparipes Cheese tree	X		X		X		X
Grevillea parallela Silver oak shrub/tree		X				X	
Grevillea striata Beefwood shrub/tree		X				X	
Hibiscus tiliaceus Beach cottonwood shrub/tree	X*	X	X		X	X	
Jagera pseudorhus Foam bark tree	X		X				X
Livistona decipiens Cabbage palm	XX	X	X	X			X
Lophostemon grandiflorus Swamp box tree	X		X	X			
Lysiphyllum hookerii Native bauhinia tree	X		X				
Macaranga involucrata Cottonwood shrub/tree			X		X	X	X
Macaranga tanarius Cottonwood shrub/tree			X		X	X	X
Mallotus philippensis Red kamala bush/tree	X		X			X	X
Melaleuca dealbata Silver leaf paperbark tree	XX		X	X			
Melaleuca fluviatilis Pendulous paperbark tree	X*	X	X				
Melaleuca leucadendra Weeping paperbark tree	X*	X	X				
Melaleuca nervosa Woodland paperbark tree		X		X		X	
Melaleuca viridiflora Broad leaf paperbark tree				X		X	
Melia azedarach White cedar tree	X		X		X	X	X
Nauclea orientalis Leichardt tree	XX	X	X	X			X
Pandanus whitei Pandanus tree	XX	X	X			X	
Planchonia careya Cocky apple shrub/tree	X		X	X	X	X	
Pleiogynium timorense Burdekin plum tree	X	X	X				X
Pongamia pinnata Pongamia tree	X*		X	X		X	X
Pouteria sericea Native plum tree	X		X				X
Sterculia quadrifida Peanut tree	X	X	X				X
Terminalia muelleri Damson tree	X		X				
Terminalia sericocarpa Damson plum tree	X		X				X

XX = 'Signature species' for Sheep Station Creek riparian zone

X = Native of lower Burdekin (not known from Sheep Station Creek), but highly suited to modified (semi-permanent flow) conditions.*

Fire regime/controlled burning

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 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 riparian vegetation condition in the Sheep Station Creek catchment (see Appendix 2 – Management issues and Photo 28). In recent years, uncontrolled burns have impacted not only high value remnant vegetation (for instance, within Castelanelli's sub catchment), but also mature stands of revegetation (such as downstream reach adjacent Bruce Highway, see Photo 29).

Most native vegetation within the catchment and 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 experienced fire regime 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 *Grevillia,* have seed 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 ground cover openings created by burning. A range of weed species, including rubber vine and para grass, are also 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 could be lost.

Causes/constraints

There are several factors contributing to the often-destructive fire regime experienced by riparian zones within the lower Burdekin floodplain, including Sheep Station Creek. These factors may also be considered constraints to implementing an appropriate fire regime. They include:

Large fuel loads – The fuel load available for burning in a vegetation remnant is determined by a range of factors including the interval period since the last fire, the length of the annual growing season, the amount of overstorey canopy cover, the resulting density and height of ground covering and mid-storey vegetation (grasses and shrubs), and the presence and/or impact of grazing on grass biomass. Along the Sheep Station Creek riparian zone, most habitat remnants are ungrazed. This – in conjunction with invasive pasture grasses (like guinea grass/green panic, para grass) and a long growing season due to seasonally extended soil moisture promoted by regulated stream flows and irrigation tailwater – commonly result in large annual fire fuel loads within most habitat remnants.

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. Other than the grazing land-dominated coastal plain, most remnant habitat areas in the Sheep Station Creek catchment occur near cane fields. Consequently, most habitat remnants 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 present in remnant habitat areas during or after cane field burning.

Risks to cane crops promote late dry burning – As cane crops mature, the amount of dry trash within the crop increases and they become more flammable. Premature burning of cane crops can result in significant economic loss. Consequently, most 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. 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'.

Landscape setting

Appropriate fire regime guidelines suited to the native vegetation types that occur in the Sheep Station Creek catchment have been defined by state government agencies (see Appendix 1). However, these guidelines assume that fire management is occurring in extensive natural landscapes. The lower Burdekin floodplain, including most of the Sheep Station Creek catchment, is dominated by irrigated agriculture. Remnant natural habitat occurs 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 vegetation remnants along Sheep Station Creek will vary with vegetation type and landscape setting (see Appendix 1). Importantly, it needs to be recognised that the most appropriate fire regime for many riparian habitat remnants is total fire exclusion. This applies particularly where the remnants include fire sensitive species, and/or are comprised of narrow riparian corridors with limited fuel loads, and/or separated sufficiently from adjoining cane farms to not be exposed to, or represent, an uncontrolled fire risk.

While the seasonally dry climate and seasonality of creek flows would have meant open woodland vegetation across the entire catchment was historically subject to periodic burning, the contemporary perennial creek system and the developed landscape now both serve to create fire refugia. Some areas are protected from fire on account of slashed headlands and other managed areas that isolate the habitat remnant from adjoining cane farms, which represent one of the main fire ignition sources. More commonly, fire refuges are developing where tree canopy cover gets sufficiently dense (to a 'closed forest' structure) which shades out grass understorey and associated fuel loads (see Photos 19 and 20). The development of denser-than-historical tree canopy cover along the creek system can be partially attributed to the modified, near-perennial steam flows and associated soil moisture conditions that allow denser vegetation communities to establish. However, these communities will generally only establish with the exclusion of fire. In this way, the exclusion of fire can ultimately establish a self-sustaining fire refuge once canopy cover becomes closed.

Examples of riparian vegetation now forming fire-excluding closed canopies can be found in reaches with remnant riparian vegetation that has developed naturally with fire exclusion toward a rainforest community (Appendix 3 – Map sheet 1, Value 3; see Photo 17); reaches where landholder revegetation, including fire exclusion, has created a closed canopy of native riparian species (Appendix 3 – Map sheet 1, Value 5; see Photo 18), and reaches where dense plantings during past intensive revegetation programs have created a dense canopy that excludes or significantly reduces the grass understorey (Appendix 3 – Map sheet 2, Value 6; Map sheet 3, Value 3; see Photos 19 and 20). Establishing dense canopy cover to create fire protected areas is recommended as a fire regime management approach for reaches of the creek system where soil types, moisture regimes and farming/Lower Burdekin Water operational needs will support it.

In more extensive open woodland vegetation remnants with a grass understorey – including sites that represent or are exposed to cane fire risk and stream reaches unsuited to the establishment of closed forest canopies – controlled burning using an appropriate fire regime will represent the best management practice. To deliver an appropriate fire regime, the previously identified landscape, land use, and riparian condition/fuel load constraints need to be addressed (see

Table **13** below).

Guidelines for the implementation of appropriate controlled burning/fire regimes for Sheep Station Creek's vegetation remnants within different landscape contexts have been developed as a separate appendix to this management plan (see Appendix 1).

Recommendations

1. Conduct a landholder and local fire warden extension program via shed meetings, other appropriate forums, field days and via published material. The intention is to understand motivations for existing cultural burning practices; communicate ecological literacy on the impact of uncontrolled 'hot' fires on the condition, values and function of lower Burdekin riparian zones, and describe appropriate fire regime practices and methods.
2. Produce controlled burning guidelines suited to the riparian zone and habitat remnants of lower Burdekin floodplain landscapes, including Sheep Station Creek, to support proposed extension program (above).
3. Prepare an inventory of riparian zone and associated habitat remnant sites where total fire exclusion is a desirable management outcome. Create this in conjunction with riparian landholders and circulate to local fire wardens.
4. Engage willing landholders (Appendix 3 – Map sheet 3, W1) who are prepared to conduct 'cool' burns ahead of cane harvesting and/or use methods to control fire intensity and impacts (such as pre-watering down, internal breaks, protected features) for controlled burns conducted after cane harvesting. Document and monitor outcomes and use as promoted demonstration sites.
5. Incorporate fire protection and/or controlled burn planning at riparian revegetation/rehabilitation sites.
6. Monitor controlled burning outcomes and use to promote riparian zone regeneration/rehabilitation.

7. Conduct series of spotlighting tours to improve ecological literacy/understanding of the habitat value of riparian vegetation with the aim of improving stewardship before the fire season.
8. Include fire fuel load-excluding tree canopy establishment and the planting of 'fire retardant' midstory species (like *Macaranga spp., Pipterus spp., Mallotus spp*.) as a specific objective in riparian zone revegetation works. Communicate and promote its benefits in terms of reducing uncontrolled fire risks to adjoining crop areas.

Table 13. Methods to address constraints on implementing appropriate fire regimes in vegetation remnants of Sheep Station Creek's agriculture dominated landscape

Constraint	Proposed methods to address constraint (one or more may be applied)
A. Annual exposure to surrounding cane fire	1. Communicate (via producer networks and shed meetings, etc) the ecological benefits of protecting habitat remnants from uncontrolled burns and the need to plan and manage cane fires to prevent them jumping to habitat remnants. 2. Establish fire protection buffer areas on the margin of habitat areas. These can include: a. slashed areas on margins of habitat remnants to broaden separation of cane field and habitat remnants; b. glyphosate-sprayed margins burnt early in late wet/early dry season, and c. maintained fire breaks (sprayed, slashed, earth tracks) within habitat remnants to limit extent of escaped cane fires. 3. Conduct intentional controlled burns of habitat remnants in late wet/early dry season ahead of cane harvest season.
B. Isolated remnants and narrow riparian corridors	1. Exclude fire from forested narrow riparian corridors and allow regeneration and/or conduct revegetation until canopy density is sufficient to shade out understorey grass fire fuel load development. 2. Establish water edge to levee bank fire breaks at intervals along forested narrow riparian corridors to enable burning of alternate sub sections in any one year, and longer-term fire intervals (3-5 years) for individual sections. 3. Establish water edge to levee bank fire breaks between forested sections of riparian corridors and grass infested/high fuel load sections of riparian corridors to enable fuel reduction burning of grass infested sections annually to protect forested sections. 4. Establish internal fire breaks (sprayed, slashed, earth tracks) within larger (non-riparian) remnants to enable burning of alternate sub sections in any one year, and longer-term fire intervals (2-7 years) for individual sections. 5. Where smaller habitat remnants occur in close proximity, plan inter-annually sequenced controlled burns across collective set of remnants (only subset burnt in any one year) to deliver targeted fire frequency/interval (2-7 years) for individual remnants.
C. Risks to cane crops promote late dry burning	1. Establish buffers on margins of habitat remnants (see A2 above) to enable late wet/early dry season-controlled burns to be conducted without risk to cane crops. 2. Pre-emptively assess status of crop cycle of cane fields adjoining habitat remnants to identify if/when young cane crop present opportunities to burn habitat remnants in late wet/early dry season without risk to adjoining cane fields. 3. Conduct controlled burns of habitat remnants post-harvest in late dry season but manage burn conditions, such as time of day, wind, soil moisture (e.g. post storm) and fuel load to deliver as cool as burn as possible. Where feasible, employ fire breaks (see B3, B4) to protect fire-sensitive assets, like riparian forests, fire-sensitive vine forest components, hollow trees. **NB: Any burning of creek channel areas in the late dry needs to consider the wet season high flow bank erosion risk.**
D. Large fuel loads	1. Promote regeneration/conduct revegetation of riparian forests to create dense canopy cover that excludes/reduces density of fire fuel load generating understorey grasses. 2. Where site is suitable, introduce seasonal crash grazing or sustained low grazing pressure to reduce fuel loads ahead of controlled burning. 3. Conduct limited extent late wet season/early dry season cool burns to reduce fuel load and create patchy burnt mosaic to reduce fuel loads ahead of late dry season 'hot' fire period. 4. Use established fire breaks (see B3) to enable burning of high fuel load sections of habitat remnants without impacting habitat areas vulnerable to hot fire impacts. 5. Where site conditions allow, conduct controlled burns away from hot fire sensitive habitat areas (such as riparian forests, hollow trees, vine forest), initiating fire near fire-sensitive elements on the edge of high fuel load areas and direct burn away from them.

Photo 29. Damaged and killed native vegetation following a 'hot' dense guinea grass fire in the upper catchment.

Photo 30. High value remnant habitat in the Castelanelli's Lagoon sub catchment is ungrazed and has very large fire fuel loads that expose it to hot fire risk.

Photo 31. Historical (~1970) image of a flock of plumed whistling ducks (rear bank right) on dry season-exposed lagoon bank Fiveways Road, Maidavale.

Photo 32. Contemporary photo of same site (Photo 31). Observed changes include dead waterlogged trees, aquatic grass (para) infestation and loss of water lilies.

Photo 33. Historical (~1970) photo of 'flock of plumed whistling ducks on dry season exposed lagoon bank near the Five Ways, Maidavale.

Photo 34. Historical (1960) photo of 'Waterloo' lagoon near the Five Ways, Maidavale. Note exposed banks due to dry season water level and abundant snag material.

Controlled grazing

Why is it a useful tool?

For most Australian landscapes, the conventional wisdom regarding nature conservation-based management is 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 disturbance is invasive exotic pasture species. These include a suite of aquatic grasses, such as para, aleman, hymenachne, 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 (see also Figure 2) of floodplain creek systems like Sheep Station Creek, including:

- out-competing and excluding 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 aquatic plants;
- reducing water quality by organic loading, reduced instream photosynthesis and by reducing water surface – air interactions;
- degrading fish and waterbird habitats (including loss of dry season-exposed banks used by waterfowl), and
- socio-economic impacts (including creating mosquito breeding habitat, crop weeds, water channel blockages).

Considering the disturbance caused by exotic pasture grasses, it is within this context that grazing and the lesser disturbance of grazing animals can be beneficial to the condition of riparian and wetland habitats. Ultimately, application of grazing as a habitat management tool requires an appreciation of its potential for impacts on native flora and fauna and bank compaction and soil erosion, and seeks to minimise these while maximising the benefits of reducing exotic pasture dominance.

Controlled grazing is not a suitable management approach for all sites and is not needed where other methods can be preferentially, or more effectively, be applied to control grass weeds. However, controlled grazing is a useful management tool because it can be applied at a landscape scale and fills an important role where other methods (such as chemical, and mechanical control, or tree canopy shading established by revegetation) may have limitations. 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 or ineffective fencing security.

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 a decade ago (Tait 2011). Findings from those guidelines are incorporated in this management plan's recommendations, but interested readers should refer to that document for a more comprehensive treatment of the issue.

Management roles and application

The primary objective of controlled grazing-based management of pasture grass weeds is not eradication, but sufficient control of grass weed dominance to: enable the reinstatement of beneficial ecosystem processes (native plant recruitment, water oxygenation, cool burns); improve native vegetation structure and diversity, and to reduce impact hazards (hot fires, water quality crashes) associated with extensive exotic pasture grass infestations. Trials have demonstrated that higher levels of control toward eradication are possible with longer term grazing regimes, integration with water level variations and fire, and effective use of (a lowered required volume) of chemical control on residual infestations (Tait 2011). The two principal applications of controlled grazing as a habitat management tool, which are not mutually exclusive, are the management of fire fuel loads generated by exotic pastures, and the rehabilitation of riparian habitats and native vegetation remnants.

Management fire fuel loads

Where grazing can be readily-established within a habitat remnant, its use for fire fuel load management can have advantages over other hot fire risk prevention methods (establishment and maintenance of fire breaks and/or conduction of controlled cool burns). It also facilitates the use of other methods by allowing the reintroduction of cool burns once fuel loads are reduced.

Table 14 presents several grazing strategies, each possessing range of advantages and disadvantages, that can be used for managing fire fuel loads generated by exotic pasture species.

Table 14. Grazing strategies for grass fuel load and fire management

Grazing strategy	Description	Advantages	Disadvantages
Sustained low intensity grazing	Maintaining continuous low intensity grazing pressure using a low stocking density. Most appropriate where the grazed area includes high (flood-proof) ground and a waterway acts as a stock retention boundary.	• Low level of management intervention. • Exotic pasture dominance and biomass reduced over time. • Exotic pasture fuel loads prevented from establishing.	• Native vegetation not spelled. • Wet season nesting waterbirds may be disturbed. • May promote non palatable weeds and trampling impacts. • Stock and fencing may be exposed to wet season flooding.
Single 'crash grazing' event during growing season	Application of medium to high grazing pressure for a short period (6-8 weeks) between summer (wet season) and autumn (early dry season).	• Limited period of grazing minimises habitat disturbance and management responsibility. • Grazing is timed to when pastures are most palatable and nutritious. • Higher soil moisture facilitates more rapid recovery of non-target browsed/trampled vegetation. • Exotic pasture dominance and biomass is minimised.	• Requires stock movement between sites. • Soil may be prone to compaction. • Stock and fencing may be exposed to wet season flooding. • Post wet season nesting birds and/or native vegetation recruitment may be disturbed. • Grass biomass may re-establish after grazing event.
Single 'crash grazing' post growing season	Introduction of high grazing pressure for a short period (6-8 weeks) during the dry season (winter-spring). Control provided by trampling as well as grazing of rank grass growth. May apply where riparian and wetland areas are used as a dry season fodder reserve, or when other site constraints limit options for grazing during the growing season.	• Avoids wet season risks to stock or fencing. • Soil less prone to compaction. • Native vegetation that has recruited during the wet season is not exposed to stock impacts until more advanced/established. • Grass fuel load unlikely to re-establish following grazing during dry season.	• Requires movement of stock between sites. • Exotic pasture dominance and biomass may still establish during pre-grazing growing season. • Fire risk may be present before grazing is conducted. • Rank pasture is not as palatable or nutritional to stock. • Stock may be exposed to fire risks.
Multiple grazing events in response to plant growth	Movement of stock into targeted areas based on the availability of pasture with the intent to prevent the development of exotic pasture dominance and fuel loads while minimising the impacts of overgrazing and trampling. Typically, two main grazing periods are conducted – post-wet/growing season and post-winter/dry season with paddocks spelled during wet season periods when flooding is a risk and during winter periods when grass growth is dormant.	• Prevents recovery of fire fuel load after single grazing event. • Limits opportunity for exotic pasture dominance or large fuel loads. • Provides spelled periods for native vegetation recovery. • Targets pasture when most nutritious and palatable for stock.	• Requires the most movement of stock between sites and requires access to adjoining or additional grazing land to allow the flexibility required. • Soils may be prone to compaction. • Stock and fencing may be exposed to wet season flooding. • Wet season nesting waterbirds or native vegetation recruitment may be disturbed.

Grazing-based rehabilitation of riparian habitats and native vegetation remnants

Rehabilitation of riparian habitats and vegetation remnants via the application of controlled grazing occurs where reduction of pasture cover dominance allows for the reinstatement of beneficial ecosystem processes, including native plant recruitment, water oxygenation, cool burns. It also reduces ecological impact hazards like hot fires and water quality crashes. Goals, management actions and considerations for the use of grazing to promote riparian habitat rehabilitation differ between wetland habitat types, including stream side 'riparian' wetlands and treeless open wetland basins (Table 15).

Table 15. Grazing to promote riparian habitat rehabilitation in different wetland types

Wetland type	Historical structure	Structure when invaded by exotic pasture	Management goal	Suggested management actions	Management consideration
Treeless wetland basins	Simple mono-storey structure of often diverse groundcovers including sedges, rushes and native grasses.	Dominated by monoculture of exotic pasture with no overstorey.	Remove biomass and dominance of exotic pastures, re-establish native ground cover and diversity.	• Short term or sustained use of high stocking density. • Or controlled hot burn of rank grass and accumulated thatch. • This is followed by applied light post-fire grazing pressure to exhaust plant reserves. • Keep exotic pastures cropped short until wetland inundated in wet season.	Native wildlife species, including turtles and echidnas, use exotic pasture grass-dominated wetlands as habitat and may be impacted by this 'bare earth' management approach. Grazing until arrival of wet season can create risks around stock removal if needed and site access affected.
Riparian woodlands	Complex structure including native overstorey trees, mid and understorey shrubs, saplings, native groundcovers, and wetland margin-emergent plants.	Over time invasive grass dominance and resultant hot fires prevent sapling recruitment and cause mature tree death and a simplified /degraded less diverse structure.	Reduce exotic pasture dominance and fire intensity, allow natural recruitment, maximise structural complexity and diversity.	• Low stocking density. • Exclusion or protection fencing around native tree and sapling stands. • Limited or seasonal grazing periods. • Extended spelling. • Reduced fuel loads prior to dry season to reduce hot fire risk/allow cool burns. • Use of internal firebreaks between higher fuel load areas and remnant vegetation.	Intense grazing and/or burning regimes potentially threaten existing native habitat values. More conservative grazing/burning applications are needed where habitat remnants retain good diversity and structure.

For riparian woodlands, gazing can assist rehabilitation by:

- reducing exotic pasture cover to 'open up' the understorey to create improved germination and seedling recruitment opportunities for native species;
- applying selective browsing/grazing pressure that reduces the dominance of more palatable exotic grass species in preference to less palatable native seedlings, ground covers and emergent edge species;
- controlling hot fire risk, and
- allowing reintroduction of cool burns and associated seed germination of fire dependent species.

For treeless wetland basins grazing can assist rehabilitation by:

- restoring native ground cover composition by favouring less palatable species including native wetland plants (sedges, rushes, forbs);
- creating open and/or bare ground for germination and recruitment sites;

- creating open bank margins (waterfowl habitat) and open water, and
- allowing reintroduction of cool burns.

Interactions between grazing, fire and hydrology

The effectiveness of controlled grazing for reducing exotic pasture dominance and promoting native habitat rehabilitation can be increased where there are opportunities to integrate its application with controlled burns and water level variations – natural or manipulated. Trials and monitoring conducted in the lower Burdekin (Tait 2011) including along Sheep Station Creek identified the following integrated management opportunities:

- **Hot burn kill-offs –** most aquatic grasses (like para and hymenachne) are fire sensitive. Where controlled 'hot' fires (large fuel load, late dry season) can be conducted at sites without risks to remnant overstorey vegetation, high levels of control (~80% plant mortality) of exotic 'ponded' pasture grasses can be achieved. Where cooler burns are more appropriate for a site, lower – but still effective – levels of control can be obtained.
- **Burning to the waterline –** Late dry season burning can also be used as a means of reducing living pasture plant extent back to the wetted margins of wetlands or stream banks. Follow up focussed grazing pressure on green pick regrowth produced by hot or waterline burns can further weaken plants. Targeted chemical control can also be usefully integrated at sites that have a higher level of management investment.
- **Water level recession and stock access –** Stock access to aquatic pastures is often limited by water depth. Improved opportunities for grazing-based control of exotic pasture dominance are provided by natural (dry season) or induced water level recession (pumping shut downs, bunded isolation from inflows, like Red Lilly Lagoon). At sites where seasonal recession of water levels does not occur, there can be a case for the integrated use of chemical control to reduce exotic pasture dominance of bank margin areas.
- **Inundation drowning of shortly cropped grass –** Rapid rises in water level and prolonged inundation can kill exotic pasture plants when inundated plants lack growing runners to the water's surface. This can occur where dry season water level draw down has enabled plants to be cropped short by late dry season grazing, and/or where controlled burns have been carried out to the 'waterline'. Such management approaches also reduce the biomass of exotic pasture that will decompose and deplete dissolved oxygen levels when inundated by wet season water level rises.
- **Un-anchoring weed mats –** Grazing (with or without integrated burning) provides a means of 'unanchoring' weed mats bound by ponded pastures in stream channels and floodplain lagoons. Site grazing trials have demonstrated the effective re-instatement of open water/channel conditions where late dry season grazing has created suitable conditions for the effective scouring of para grass stands by elevated flood flows (for example, at Church's Lagoon).

Integration with other revegetation methods

As discussed elsewhere in this plan, there are a range of management approaches that can be applied to the revegetation of Sheep Station Creek's riparian zone and effective outcomes are often achieved by integrated methods involving more than one approach. Opportunities for integrating controlled grazing as part of revegetation works include:

- controlling fire risk around 'intensively planted' (tube stock) seedlings or high value remnant stands;
- reducing grass biomass/cover (and required chemical volume) prior to use of chemical control;
- allowing re-introduction of non-damaging (cooler) burns to promote fire-germinated native plants as part of extensive revegetation strategies;
- creating open understorey seedling germination sites (bare ground, trampled grass leaf litter, ash bed following cool burn) for targeting by direct seeding methods, and
- using established cattle pads for access into woody weed infestations to facilitate control.

To spell or not to spell?

In a habitat management context, grazing spelling is primarily concerned with removing ecological pressures associated with grazing (vegetation browsing, trampling and ground compaction/erosion) to allow for the recovery and recruitment of native vegetation and to prevent land degradation processes (like soil erosion, compaction, scalding). The appropriateness of spelling is site sensitive and determined primarily by:

- site ecological condition starting point (are there values that can be impacted by overgrazing?);
- habitat management objectives (facilitation of cool burns/fire protection, promotion regeneration or exotic grass control);
- alternative paddock availability and fencing configuration (availability wet season refuges);
- site area and stock number, and
- ease of stock movement to alternate sites.

The habitat management merits of spelling riparian and wetland areas from grazing pressure need to be considered within the context of:

- the presence and reinvasion potential of exotic pasture weeds;
- the likely positive habitat responses of wetland plant communities present;
- seasonal presence of nesting or disturbance sensitive fauna (like nesting waterfowl), and
- interactions with other management inputs such as controlled burning.

Matching grazing pressure to available pasture avoids the need to spell pasture infestations targeted for control, though there can be merit in subsequent 'pulses' of intensive grazing pressure that weaken plant energy reserves with each subsequent regrowth event. The maintenance of heavy grazing pressure throughout the late dry season is counter to pastoral production guidelines once promoted for the sustainability of ponded pasture species because it contributes to their demise in the wetland vegetation community.

In the seasonally dry tropics, the wet season is often a default spelling period for wetland and riparian areas as flood risks and elevated water levels present conditions unfavourable for stock access. However, stock exclusion trials have indicated that continuous (albeit light) grazing pressure through the wet season can help maintain wetland vegetation condition by limiting the reinfestation potential posed by residual exotic pastures. For habitat management outcomes, balancing the recovery needs of the landscape and native vegetation against the reinfestation potential posed by residual or new exotic pasture stands is a key challenge.

Controlled grazing regime summary

Ultimately, the successful application of controlled grazing as a habitat management tool depends on an adaptive management approach where the condition of key indicators of habitat condition (below) are monitored over time and the grazing regime, including spelling, is altered in response to monitored condition. Useful indicators for monitoring include (noting some can require specialist support):

- percent bare ground;
- standing grass biomass;
- relative dominance ground cover species;
- tree recruitment density;
- soil compaction;
- pugging density;
- percent open water;
- native plant diversity, and
- waterbird diversity and populations.

The three main habitat management grazing regimes that were defined following trials at lower Burdekin sites (Tait 2011) include:

Crash grazing

- Involves a one or more short term (weeks to months) periods of applied high grazing pressure per annum, usually in the late to post growing season autumn-winter.
- Pasture biomass, cover and standing height is reduced by a combination of grazing and trampling.
- Primary application of crash grazing is removal of late dry season hot fire risk.
- Improved native vegetation recruitment can occur with the creation of more open understorey conditions, though this will be vulnerable to future crash grazing events.
- Most appropriate in disturbed riparian and wetland habitat remnants with an exotic pasture-dominated understorey or wetland basin.
- Suits sites where year-long grazing is neither feasible nor desired.

Long-term recovery grazing

- This regime usually involves sustained/long term application of light grazing pressure.
- Intention is to reduce exotic pasture cover dominance, or prevent its invasion by sustained selective grazing pressure.
- Will also usually reduce dry season hot fire risks and promote native vegetation recruitment.
- Most appropriate in better condition habitat remnants with a sub-dominant exotic pasture understorey or wetland margin.
- Suits sites where year-round grazing can be accommodated.

Recovery/transitional regimes

- Involve a sequential range of grazing and spelling regimes (including both of the above) integrated with other management inputs or events, such as controlled burns or wet season inundation.
- Aims to transition habitat condition to an improved status, with the practiced grazing regime responding to monitored habitat condition.
- Transitional regimes evolve across years as part of a 'transition' toward an improved habitat condition which, if achieved, may provide the opportunity for adopting a more consistent regime.
- Starting point is an exotic pasture dominated riparian zone or wetland basin.
- Long-term medium grazing pressure, or even sustained high (crash) grazing pressure, is applied initially to deliver major reduction in the dominance of the exotic pasture.
- Reduced standing grass biomass provides the opportunity where fire can be used for a non-damaging burn to further reduce fire-sensitive ponded pasture cover.
- In the case of ponded pasture-dominated treeless wetland basins with no remnant native vegetation, a hot burn can be pursued initially to kill off as much fire sensitive pasture as possible.
- Grazing pressure can be reintroduced on green picky post-burn to further exhaust plant energy reserves and maintain a short-cropped condition to expose plants to drowning with wet season inundation.
- Once an intense grazing/burning regime with or without wetland inundation has delivered a major reduction in exotic pasture dominance, a more conservative recovery/maintenance or short-term crash grazing regime (above) may be applied to maintain condition gains and deliver longer term recovery processes via selective grazing pressure and enhanced native vegetation recruitment.
- Spelling coinciding with native plant seeding or germination periods can be introduced to further enhance native vegetation recruitment or for other objectives associated with seasonal fauna use (nesting waterbirds) or land use constraints.
- Where spelling results in the recovery of exotic pasture cover, reintroduction of heavier grazing events can be used to prevent it regaining cover dominance.
- An alternative starting point for a transitional grazing regime may be a site that has been continuously grazed to the detriment of habitat values or native vegetation recruitment processes.
- In this instance, the initial step pursued can be an extended spelling period to provide for the development of habitat formed by rank native wetland vegetation or to accumulate sufficient fuel to support a controlled burn and/or enhanced recruitment opportunities for overstorey vegetation.
- A responsive 'transitional' grazing regime needs to be cognisant of maintaining habitat gains while preventing condition declines.

Stock management and the case for a mobile heard

Besides site suitability constraints, the greatest impediment to the adoption of controlled grazing as a habitat management tool within the Sheep Station Creek catchment is landholder willingness. Most riparian landholders are sugarcane farmers and grazing stock are notoriously incompatible with cane farming operations. Primary concerns lie with impact on farming operations, maintenance of fencing, meeting animal welfare needs and stock escapees. Unless farmers have a history of keeping grazing animals, most are unwilling to commit the time and other resources required for establishing grazing on farm habitat remnants. Fencing costs are another concern, particularly where long linear habitat remnants have a disproportionally high fencing cost relative to any potential economic returns.

An option pursued by some landholders who see merit in applying grazing to farm habitat remnants and riparian corridors is to enter agistment arrangements. Stock owners seeking access to on-farm pasture resources pay for grazing access and/or take responsibility for establishing fencing infrastructure and managing stock. Examples include horse owners and regional pony clubs and commercial pastoralists. Facilitating these types of arrangements for the benefit of managed habitat outcomes could represent a worthwhile investment for third party community NRM organisations such as NQ Dry Tropics. Contributing to habitat fencing costs presents one such opportunity.

During the landholder consultation undertaken for this management plan, several landholders indicated a willingness to allow stock owners grazing access to farm habitat remnants, subject to their trust in the individuals concerned and their commitment to stock and fencing responsibility. Several other landholders currently involved in grazing land use indicated their willingness to utilise pasture resources available on other properties where landholders were willing to enter such arrangements, and where sites are large enough to warrant moving stock onto them. Some existing grazing managers also expressed a willingness to extend their existing grazing operations onto adjoining riparian corridors where there were potential habitat management benefits (see Appendix 2).

Given the prevalence of pasture grass weeds and their contribution as a source of ecological impact affecting habitat values and ecosystem health throughout the Sheep Station Creek catchment, finding opportunities to support the use of grazing as a riparian landscape management tool is recommended. Considering many of the

grazing regimes identified to support improved habitat condition outcomes depend on only periodic grazing interspersed with spelling, flexible management arrangements that allow for movement of stock between sites would be most suitable. Establishing formal arrangements and incentives for the establishment of fencing infrastructure and mobile grazing pressure is recommended for the benefit of improved habitat condition outcomes along the Sheep Station Creek system.

Recommendations

1. Provide incentives (for example, fencing cost support) and facilitate arrangements to support the application of mobile grazing pressure as a habitat management tool within the Sheep Station Creek catchment.
2. Progress controlled grazing trials for suitable work sites identified by field work and landholder consultation undertaken for this management plan and between landholders who have expressed a willingness to manage or host mobile and/or controlled grazing-based management of remnant habitat areas (see Appendix 2 – Table 1, W2, W5, W10, Table 2, W3, W4, W6, W7, Table 3, W4, W5, W7, W8).
3. Provide project officer support to establish controlled and mobile grazing habitat management trials, and to provide expertise to monitor habitat condition indicators at nominated trail and demonstration sites.
4. Document results and, where successful, promote via publications and landholder forums.
5. If management programs prove successful, canvas willing landholders to extend program to additional stream reaches and/or remnant habitat sites.

Photo 35, Bank-side revegetation at Gorizia's Lagoon. Such revegetation needs to be very mature before it begins to contribute woody debris (snags) to the lagoon.

Photo 36. A 'fish hotel' being placed in the Merri River Victoria as part of instream physical habitat enhancement (source Ozfish.org.au).

Critical 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 or not 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'*.

Conserving and improving the wildlife biodiversity that occurs within the Sheep Station Creek catchment is an aspirational goal 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 local residents know koalas were once common in bluegum forests on the levees of the Burdekin River.

During the author's own lived experience in the Sheep Station Creek catchment from the 1960s to the present, there are several wildlife species that can be anecdotally reported to have become rare or even extinct from areas within the catchment. These include northern quolls, otherwise known as 'native cats' in the Mount Kelly area until at least the early 1970s; spectacled hare wallabies, or 'pademelons' once common throughout the catchment until the 1980s and now only recorded in rangeland areas on the margin of agricultural production areas; large, diverse (multi species) finch populations now reduced in species number and population size, and frill neck lizards once commonly-encountered in habitat remnants, 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 and can be operating even where areas of remnant habitat remain.

The intention of this chapter section is not to list all threatened wildlife species that potentially occur in the lower Burdekin and associated critical habitats, but to engender a greater appreciation of what sorts of features can constitute 'critical habitat' in riparian and other habitat remnants of the Sheep Station Creek catchment and how this knowledge can feed into landscape management decisions that support the conservation of wildlife. A non-exhaustive list of critical habitat features known to be significant within the catchment and their associated values and management implications are presented in Table 16.

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 come, not from required production activities, but from held cultural values including an attraction to parkland clearing, 'cleaning up the farm', removing problem trees, etc. 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 overstorey 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 the inclusion of a broader range of activities under habitat rehabilitation, including revegetation of components besides overstorey (for instance, mid storey and ground covers) 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 can inform better management by promoting recognition of the regional importance of site features; for instance, contributions of tree stands to functional wildlife corridors and/or regional uniqueness/importance of habitat features on a property.

Recommendations

1. Develop extension material around ecological literacy to engage stakeholders, including highlighting the benefits of healthy-functioning riparian areas (for example, trees reduce rat harbourages, attract owls, keep water cooler etc), and the issue of critical habitat relevant to lower Burdekin landscapes and use.
2. Assess critical habitat availability as part of riparian rehabilitation project planning and seek to include dedicated revegetation and/or physical habitat feature establishment as part of proposed works.
3. Identify opportunities to engage wildlife experts, and/or interest groups, and/or to support the formation of local wildlife conservation interest groups with local management stakeholders. This could be part of rehabilitation works implementation, monitoring or during demonstration site field days.

4. Seek project resourcing and/or engage student researchers to conduct some dedicated fauna survey work within the catchment to better define remnant vegetation fauna habitat values including those associated with critical habitat presence/absence.
5. Seek to engage industry stakeholders, or find other resourcing opportunities, to define wildlife corridor connectivity themes at scales relevant to local government planning schemes. This is through the agricultural areas of the lower Burdekin, including the Sheep Station Creek catchment.

Table 16. Examples of 'critical habitat' within Sheep Station Creek and implications for management

Critical habitat	Why important	Wildlife species/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 regime management required to avoid uncontrolled burning loss of old trees. Establishing artificial nest boxes can benefit dependent species.
Fringing 'riparian' communities	Has greater structural complexity, species 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.
Mid/understorey trees	Provides a broader range of food resources (wattle gum, broad lead 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.
Bare lagoon banks	Naturally occurring via dry season drawdown of lagoon water levels, provides roosting and resting areas for waterfowl free of predator risks associated with dense grass or vegetation.	Flock-forming waterfowl, like grass (or plumed) whistling ducks (see Photos 31-34).	Lagoon draw down no longer occurs due to modified creek hydrology. 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. These values need to be communicated to avoid incremental loss. Several regional wildlife corridor features transect the catchment (see Appendix 2 – Table 1, V1, V6, V7; Table 2, V2, V3, V4).
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 (Appendix 2 – Table 1, V1) could demonstrate its value. Also, useful revegetation target.
Logs/woody debris	Provides safe refuges for numerous species of small-to-medium-sized vertebrates.	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. Retention/inclusion in rehabilitation valuable.
Rank grasses	Provides grass seed food sources for granivorous birds.	Finches, pigeons.	Critical habitat supported by grazing spelling/timing.
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 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 catchment.

Instream physical habitat

Definition and management application

The term 'instream physical habitat' describes the physical features and characteristics that define the habitat available within an aquatic ecosystem. It includes both biotic features, such as aquatic plant beds and tree trunks, and abiotic features, such as water depth and flow velocities, bank form, and bed substrate types. In ecological assessments, physical habitat classification can be used to identify the suitability of an environment for different organisms based on their known habitat preferences. In modified aquatic ecosystems, assessed changes in physical habitat availability can be used to inform management actions intended to restore the suitability of the system for a healthy biological community.

Changes in sheep station creek instream physical habitat

As described throughout this document, Sheep Station Creek is a highly modified system. The primary driver of change has been the clearing and development of the catchment. This includes riparian vegetation for irrigated agriculture, and the use of the creek system as a conduit for regulated flows from the Burdekin River to serve aquifer recharge and irrigation supply. These actions have seen the creek transition from a seasonal to near-perennial flowing system, resulting in the loss of much of the original riparian vegetation and the excavation of connected channel networks where, historically, there were only seasonal drainage depressions. Many of the physical habitat changes that have occurred have resulted from the hydrological changes to the system. Perennial flows and a lack of dry season draw down have supported extensive floating aquatic weed, submerged aquatic plant, fringing aquatic grass and cumbungi growth, which seasonally – or permanently – reduces the amount of open water column, open water edges, open water bodies and open connected channels. Management actions intended to address these changes in physical habitat have been described through the plan sections addressing *Aquatic weeds*, *Riparian zone rehabilitation*, *Revegetation* and *fish passage connectivity.*

Outstanding physical habitat needs

Despite the level of modification that has occurred to the Sheep Station Creek system, a checklist inventory of instream physical habitat availability (Table 17) finds most physical habitats representative of the original creek system still available within it, albeit with some level of modification in character. Some that have been reduced or lost (described above) will be reinstated if management recommendations detailed throughout this plan are implemented. One outstanding instream physical habitat distinction is the lack of instream habitat complexity in lagoon reaches that have been cleared of their riparian vegetation, and channel reaches that have been created and/or maintained by excavation. Historical photos of natural lagoons and stream channel reaches within the catchment (see Photo 34) show the comparatively high abundance of snags and woody debris that occurred along marginal habitat with intact riparian forest communities.

Trialling snag placement/artificial structures

In the longer term, proposed riparian revegetation of denuded lagoon banks and constructed channels (where compatible with Lower Burdekin Water operations), will add instream habitat structural complexity to such reaches via root masses and stabilised undercuts at the water's edge, and via contribution of woody debris and snags to bank margins. A shorter term option could be to place physical structures such as actual snags (logs) or constructed structures (like 'fish hotels' – see Photo 36) along affected reaches. Such instream physical habitat enhancement activities have been successfully demonstrated in other GBR NRM regions – for instance, the Mackay Whitsunday Coast – and have shown to increase the recorded abundance of snag-dependent fish such as barramundi (Power 2017, Tonkin & Lyon 2016). Snags that extend from the water's surface not only serve structure associated fish, but also provide roosts for waterbirds and sunning sites for reptiles including turtles. Demonstrating that such structures can be adequately secured to remain in place during a high flood flow to avoid risks to downstream infrastructure, such as bridge crossings, would be important to gain support for such activities amongst management stakeholders. Choosing trial sites downstream of major infrastructure or within a sub catchment (such as Castelanelli's) not exposed to major flood flows could be prudent. Conducting pre and post-snag placement biological surveys to demonstrate fauna benefits in terms of increased abundance of and use by fish, reptiles and water birds would also serve to quantify the benefits of such investments.

Recommendations

1. Seek resources and landholder/management stakeholder support to trial increasing instream physical habitat along a denuded lagoon and/or channel reach via placement and fixture of snags. Conduct pre

and post-snag placement fauna surveys using methods that can quantify changes in fauna species records and abundance in association with physical habitat improvements.

Table 17. Checklist inventory of instream physical habitat availability and management response

Instream physical habitat	Availability in contemporary creek system	Management response *Not covered by other section management recommendations.
Open surface water bodies	Greater area due to perennial flows, sustained water levels. Some reaches are periodically or permanently impacted due to aquatic weeds.	Maintain aquatic weed control program.
Open stream margins	Reduced due to aquatic grass proliferation on water margin and lack water level drawdown.	Create via riparian revegetation/shading, controlled grazing and spaying program.
Open water column	Greater volume due to perennial flows, but impacted by submerged plant (duckweed) growth in response nutrients and sustained water levels.	Reduce submerged plant growth via riparian revegetation/shading.
Open connected distributary channels (wet season)	Reduced due to aseasonal inflows promoting cumbungi and other aquatic weed blockages of channels.	Reinstate seasonal drying to unblock weed infested distributary channels and/or use flow control structure to engage non infested channels in conveying wet season flows.
Deep pools	Greater maintenance of deep pools due to perennial flows. Some siltation reported for some weed-impacted channel reaches.	Maintain aquatic weed control program to enable pool maintaining wet season high flows pass effectively through system.
Runs and riffles	Greater availability due to perennial flows.	None required.
Scoured open channels	Less often created due to reduced occurrence of river breakout flushing flows.	Priority afforded to protection of property and production weighs against reinstatement.
Gravel beds	Greater availability due to perennial flows.	None required.
Sand substrates	Potentially less availability due to silt and organic load deposition.	None possible. Decadal occurrences of river break out flushing flows will reinstate.
Muddy/silt substrates	Potentially greater availability due to loads bought in with turbid flows.	None required.
Leaf litter/organic detritus	Potentially less availability of leaf litter due to reduced riparian vegetation cover, but greater volume organic detritus associated with aquatic weeds.	Increase riparian vegetation cover along stream reaches.
Aquatic plant beds	Greater extent due to perennial flows and elevated nutrients, but some forms reduced due to grass weeds (shallow margin communities or loss of seasonality, like seasonal wetland basin communities).	Protect and maintain some seasonal wetland basins within system. Graze aquatic grasses on stream margins.
Emergent plant beds	Some forms increased due to aseasonal flows (like cumbungi, umbrella sedge), while others reduced due to aquatic grass dominance creek margins.	Reinstate seasonal drying along distributary channels. Graze aquatic grasses on stream margins.
Undercut banks	Reduced due to reduction in riparian vegetation margins.	Increase riparian vegetation cover along stream reaches.
Bedrock outcrop	Naturally rare in system except for low order upper catchment drainage lines. Rock substrates increased with rock rip rap use adjacent infrastructure.	None required.
Large woody debris/snags	Reduced due to reduction in riparian vegetation margins and excavated clearing of channels.	Long term increase riparian vegetation cover along stream reaches. *Short term trial snag/log instream placement.

Innovative management

Why we need innovation

Environmental management is an imperfect science that is best progressed by an adaptive approach. This enables different methods to 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 Sheep Station Creek due to the management investments made over the past two decades. However, as identified through this plan, there are still some significant outstanding environmental management issues confronting this system. To achieve further improvements in the environmental condition of the creek system, there needs to be a commitment to ongoing management capacity and improved outcomes, while recognising the resource constraints for the tasks at hand. There is an adage that, 'to continue to do the same thing and expect a different result, is the definition of madness'. To take the next step and deliver a new level of improved management outcomes for the creek system 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 over the past two decades in Sheep Station Creek 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 Riparian Management Agreements (RMAs), and the large reach-scale riparian revegetation outcomes, are all initiatives that Sheep Station Creek management stakeholders should be proud of. At the time, these initiatives were truly innovative in the sense it was the first time they had been applied in the seasonal dry tropics, or in the case of RMAs, in Australia.

Through this management plan, there has been a range of other innovative management methods, tools, and approaches proposed. These are collectively presented below. Like all attempts at innovation, not all are likely to be successful, or adopted. However, given the catchment community's track record on being prepared to try something different, there are potential gains to be made by giving them a fair appraisal.

Excavated channel weed control via shade planting

Numerous reaches of the contemporary creek system are comprised of open excavated channels prone to invasion by exotic aquatic grasses (like para and aleman), requiring scheduled maintenance with a rake-mounted excavator to keep open. These channels are also relatively featureless in terms of the instream physical habitat. Experience gained from catchment revegetation outcomes shows that dense shade-producing tree canopies can effectively exclude understorey aquatic grasses, including from the bankside anchor points they use to colonise the stream channel. While large woody overstorey trees will generally be incompatible with Lower Burdekin Water channel maintenance operations, it is suggested that rapidly growing, non woody, shade-generating pioneer species (like Beach Cottonwood or Cottonwood see Table 12) planted on either one or both sides of an excavated channel would effectively shade out channel grass weeds, while stabilising channel banks, cooling water temperatures and providing some contribution to instream physical habitat features.

Recommendation: Negotiate with Lower Burdekin Water to establish a trial weed control shade planting on an excavated channel reach.

Alternate channel weed control methods utilising small in-channel machinery

As identified in the preceding point, retention of access for rake-mounted excavators to maintain the Lower Burdekin Water channel network within the Sheep Station Creek system imposes a constraint on riparian vegetation establishment. Examining the aquatic weed clearing/channel-maintaining machinery available internationally, searches show there are a range of semi-amphibious machines available that can conduct channel-maintaining operations from within the channel. Identifying and/or developing machinery capable of channel maintenance operations from within a riparian vegetated channel would enable the ecosystem services of a vegetated riparian zone (such as channel stabilisation, grass weed exclusion, cooler water temperatures, habitat provision, flood protection) to be provided, along with providing water supply conduits. Considering the demonstrated capacity of fully-vegetated channel reaches within the system to maintain a relatively weed free condition, such a management approach could potentially deliver an overall reduced maintenance need.

Recommendation: Lower Burdekin Water explore the opportunities to obtain and trial alternate channel weed control methods using small in-channel machinery that can remove and emulsify grassy weeds, desilt sediment deposits and remove vegetation chokes.

Pumped environmental 'freshening' flows in wet season

Historically, Burdekin River outbreak flows down floodplain distributary creeks, like Sheep Station, drove a range of important geomorphic and ecological processes. These include channel scouring, water quality refreshing and fish passage connectivity between the estuary and upper catchment. The frequency of these events has been curtailed by a combination of constructed riverbank levees, which have raised the height for flood breakouts, and by the Burdekin Falls Dam, which has reduced the frequency and height peak of floods in the lower basin. The opportunity to replicate some of these beneficial processes via a pumped environmental

flow during the critical water quality period the creek system experiences in the wet season has been described in the *Water quality* and *Fish passage connectivity* sections. A trial is highly recommended.

Recommendation: Negotiate with Lower Burdekin Water and seek resources to support a trial of a dedicated pumped environmental flow during a wet season rainfall-generated flow event to examine its impact on dissolved oxygen status and associated fish passage connectivity through the creek system.

Weed control via effective biomass removal and economically-viable product development

The implementation of the cost-shared aquatic weed control program within Sheep Station Creek has delivered major ecological benefits and served to reduce the standing biomass of aquatic weeds within the creek system. One downside of the program is its dependence of chemical control methods that result in dead weed biomass sinking into the creek system and generating biological oxygen demand. This decreases dissolved oxygen levels and recycles nutrients taken up by weed plants back into the ecosystem. Currently, aquatic weed harvesters that can remove weed biomass are expensive to operate and not particularly effective in the tonnages removed for time invested. The dual-pronged solution to solving this situation would be to develop an economically-viable soil ameliorant product with the removed weed biomass to subsidise, or cover, the cost of harvester operations, and to develop or acquire a much more effective weed harvester, emulsifying transport unit and composting facility than currently available. Achieving this solution would deliver ecological benefits in terms of the nutrient status and health of the creek ecosystem and economic benefits in terms of product sales and primary production returns.

Recommendation: Engage management stakeholders and potential sponsors/investors in the development of 'cost effective' aquatic weed harvesting/physical removal management approaches involving assessment and implementation of opportunities for (1) Converting removed aquatic weed biomass into an economically valuable product and/or (2) Developing or acquiring a highly efficient aquatic weed harvester, emulsifying transport unit and composting facility.

Use of mobile herd to deliver controlled grazing outcomes through catchment

Some of the most significant ecological weeds of Sheep Station Creek's riparian zone are exotic pasture grasses introduced to serve the pastoral industry, see *Aquatic weeds* section. The *Controlled grazing* section identifies how controlled grazing provides a useful tool to manage a range of impacts associated with pasture grass weeds and provides a means to promote broad acre regeneration of native riparian woodlands impacted by grass weeds. Impasses to the adoption of controlled grazing include the small non-economic size of most riparian habitat remnants, associated high fencing costs, and a reluctance/lack of experience of most cane farming landholders to maintain fencing infrastructure and the animal husbandry requirements of grazing stock. In contrast, experienced small-scale graziers see the cumulative pasture resource available through the catchment's riparian zone and remnant habitat network. Where these graziers are respected by other cane farming landholders and prepared to take responsibility for fencing infrastructure and stock management, there is an opportunity to develop a 'mobile herd' agistment arrangement that could be used to deliver beneficial ecological management outcomes.

Recommendation: Provide incentives (fencing cost support) and facilitate arrangements (willing landholder-grazier engagement) to support applying mobile grazing pressure as a habitat management tool within the Sheep Station Creek catchment.

Alternate distributary channel fish passage bypass route

Aseasonal flows to the lower catchment's main coastal distributary channel network have created cumbungi infestations and associated water quality impacts that act as system-scale fish passage barrier, preventing the natural recruitment of marine breeding species such as barramundi to the upper catchment (see *Aquatic weeds* and *Fish passage connectivity* sections). While addressing these cumbungi-blocked channels is nominated as the priority fish passage barrier rectification action for the catchment, a prudent secondary plan would be to examine opportunities for circumventing the existing blocked channels by facilitating connective flows through non-weed impacted distributary channels. Development of circumventing fish passage pathways could potentially have merit in many other similarly-impacted floodplain distributary creek systems.

Recommendation: Engage research partners to undertake wet season water quality sampling and fish usage/passage connectivity assessments of less weed-impacted distributary channel systems that – in conjunction with excavated supply channels (on lower eastern branch) – present potential alternative fish passage routes around cumbungi-infested lower reaches.

Establishing riparian forest and native water lily shading to reduce submerged plant growth

As discussed in the *Aquatic weeds* section, a consequence of removing floating aquatic weeds while the perennial flows and elevated nutrient levels that have promoted them remain, is the proliferation of submerged aquatic plants, or 'duckweed', to local landholders. The massive biomass of promoted submerged plant growth affects the daily cycle of dissolved oxygen levels and causes crashes below levels required to support fish life following night-time respiration periods. In the absence of plant biomass-removing management options, reducing the biomass of submerged plants that grow by shading the water column presents one of the few control options. Two options for achieving this are establishment of dense canopy shade-generating riparian forest along affected lagoon margins, and extensive promotion/translocation of native water lily stands within

shallow open channel areas. Neither of these approaches have been specifically trialled to reduce submerged plant biomass in order to achieve a water quality objective, but field observations and understanding of the biophysical constraints on submerged plant growth suggest it could work.

Recommendation: Resource a monitored reach-scale lagoon riparian rehabilitation project that pursues revegetation of lagoon margins with shade-casting riparian forest communities and establish native water lilies within shallow open channel sections. The monitored objective is to reduce submerged aquatic plant biomass and water temperature to deliver improved dissolved oxygen status. A suitable focus trial area could be on a known delivery choke where lineal plantings can be trialled; for instance, 5m wide along the length of the reach to guide delivery water (reduce submerged weed resistance). This will enable floating exotics to be treated on the sides and/or float past.

Catchment line of control for floating aquatic weeds

One of the challenges of controlling floating aquatic weeds is their mobility with wind and water currents. A controlled area can be readily re-infested from unmanaged upstream refuge areas. However, this feature also provides the opportunity to develop a management line of control, working from upstream to downstream areas, with the return on investment evident in areas with a controlled and cleared upper catchment being unsusceptible to reinfestation. This success assumes that sediment seed sources, in addition to mature floating plants, can be effectively exhausted/removed from above the line of control. This approach requires time resources, active vigilance, and ready access to identified refugial weed sources. It has not been trialled within the catchment. Natural high flow/flood spates that remove the bulk of refugial weed infestations provide an appropriate impetus to attempt to implement this management approach. Use of aerial drone monitoring (below) could deliver the virtual access needed to support vigilant control of remnant infestations. Strategic placement of floating booms could also form part of this control approach, with the booms placed at the downstream ends of major lagoons (within the connecting channels) to act as capture and contain areas to prevent downstream re-infestation.

Recommendation: Engage with aquatic weed control service providers and provide additional resources and technical skills, where required, to trial the implementation of a catchment 'line of control' weed control program for floating aquatic weeds (principally water hyacinth and water lettuce). Assess if such investment can deliver a longer term immunity to weed re-infestation.

Establishing farm drainage line revegetation/detention function

Given the highly seasonal and relatively low rainfall experienced in the lower Burdekin region, the management of rainfall runoff from farms has never received the level of management attention it does in high rainfall cane farming areas, like the Wet Tropics. The high permeability of delta soils and a historically low level of concern regarding off-farm losses of irrigation tailwater have also meant the need to intercept potential contaminant loads in off-farm surface water exports has received limited consideration. In recent years, real-time, farm-scale monitoring of contaminant loads and/or dissolved oxygen status in irrigation tailwater or wet season runoff has identified water quality risks (particularly deprivation of dissolved oxygen levels) to receiving creek ecosystems. It has also highlighted the potential merit of improving the riparian condition (from bare earth or para grass-dominated to revegetated) and detention function of farm drainage systems. Such works have been little trialled in the lower Burdekin and would represent an innovative approach to a component of the water quality management challenges faced in the region.

Recommendation: Identify potentially effective farm drain rehabilitation sites within the Sheep Station Creek catchment (Appendix 2 – Table 1, W5; Table 2, M11; Table 3, M3; Table 4, V4). Help resource a water quality-monitored farm drainage line riparian revegetation/detention function rehabilitation project to use (if successful) as a field day demonstration and extension material development site.

Use of monitoring drones

The use of aerial drones to conduct monitoring activities is increasingly common in NRM and for other commercial applications. There have been few trials for creek management applications in the dry tropics region to-date. While conducting field work for this management plan, a drone was used to gain current high resolution aerial imagery of several creek reaches (see Photos 1, 2 and 39). This imagery was useful for examining riparian zone condition, including weed infestation status and of sufficient resolution to define individual plant and weed species. Given the linear nature of creek systems, longitudinal runs along their channel line by aerial drones presents a fast and cost-effective means of collecting natural resource information. A range of applications for drone-based monitoring can be readily envisaged including pre and post-rehabilitation project monitoring, reconnaissance of aquatic weed infestation status to support targeted and timely control, and potentially fauna census, such as waterbirds.

Recommendation: Trial and develop drone-based monitoring approaches for a range of creek catchment management applications and establish baseline aerial drone captured high resolution imagery as a standard procedure preceding the implementation of riparian zone rehabilitation projects. Also examine other potential roles for drones, including targeted herbicide application.

Conduction cool burns in cane land habitat remnants

Uncontrolled burns, particularly during the late dry season, and in areas with large fire fuel loads, are one of the primary drivers of degradation of riparian vegetation condition within the Sheep Station Creek catchment and other lower Burdekin floodplain distributary creek systems (see *Fire regime/controlled burning* section). Culturally, the use of fire as a land management tool in remnant habitats within cane land areas preceding cane harvesting is seldom practiced due to the fire risks to unharvested crops. While this risk is real, lower Burdekin landholders are perhaps some of the most skilled in the careful use of controlled burns and would be more than capable of developing innovative methods to conduct controlled burns in habitat areas while minimising risks to adjoining crops.

Recommendation: Engage with local fire wardens and landholders to find some willing to trial conducting beneficial cool burns (late wet season/early dry season) in habitat remnants. Document techniques used to minimise risks to adjoining cane crops and use as material for developing extension and engagement with other landholders for conducting early season 'cool' controlled burns.

Direct seeding vegetation regeneration methods for exotic grass-infested riparian zones

One of the consequences of riparian zones being dominated by exotic pasture grasses for decadal periods is native vegetation is gradually excluded by competition at the ground layer and by hot fire impacts. This results in a loss of native vegetation soil seed stores. Revegetation of such areas cannot be left to natural regeneration and usually involves chemical control of the grass weeds, intensive revegetation approaches using planted tube stock, and an associated maintenance regime that can extend to a couple of years until plants are established. Developing alternative 'extensive' revegetation methods would potentially enable riparian zone revegetation outcomes to be achieved over greater areas and for less cost. Based on some field observations, a potentially viable approach could be to directly seed such areas with fast growing pioneer species, such as wattles, grevilleas, forest siris, cottonwoods, broad leaf tea tree (see Table 12), potentially preceding a controlled burn (for fire-germinated species), or following a controlled burn (for fire-sensitive seeds) to promote insitu seedling recruitment. While some follow-up herbicide spraying may be required to prevent exotic grass domination (for instance, use of haloxyfop herbicide post-fire in trials at Wongaloo has been demonstrated to promote enhanced native seedling recruitment) the main intention would be to investigate whether successful recruits within the grass layer grow (in the absence of hot fires) to create localised canopy shading. This shading could outcompete the exotic pasture grasses and create further opportunities for natural tree recruitment, for instance, via bird droppings and seed fall. Gaining an understanding of how to reinstate regenerative processes for native vegetation in guinea and para grass-dominated riparian zones would be a 'game changer' for revegetating floodplain distributary creeks in the seasonal dry tropics.

Recommendation: Engage with willing landholder(s) of exotic pasture-infested stream banks prepared to host a long-term trial of direct seeding based riparian regeneration methods and resource a monitored project trial in conjunction with local management stakeholders (Lower Burdekin Landcare, BBIFMAC) and/or research and development (R&D) providers.

Instream physical habitat interventions

Placing snags or establishing water lilies to change the availability of instream physical habitat features as described in the *Instream physical habitat* section is innovative in the sense it has not been trialled in the dry tropics region. The potential fish habitat and water quality benefits of these activities within degraded lagoon reaches of Sheep Station Creek's lower catchment warrant such trials if resources can be made available.

Recommendation: Seek resources and landholder/management stakeholder support to trials involving increasing instream physical habitat (snag placement) or manipulating instream physical habitat (water lily establishment) within a denuded lagoon reach (see *Instream physical habitat* section).

Fenceless grazing systems

One of the main cost and management impediments to the use of controlled grazing as an ecological management tool for exotic grass weeds in riparian areas is the establishment and maintenance of fencing infrastructure. Maintaining fencing is particularly problematic in riparian areas of the seasonal tropics due to the impacts on annual wet season flooding. A number of 'fenceless' grazing system technologies have been developed to retain grazing stock within defined areas, for example, Nofence, the 'world's first virtual fence for livestock' (https://www.nofence.no/en/). Whether such technology could be applied effectively to the narrow riparian corridors of Sheep Station Creek adjoining operational sugarcane farming areas is questionable. Certainly, the ecological benefits that could accrue if such technology was successful would be significant for not only the Sheep Station Creek system, but more broadly through coastal areas of the region and North Queensland generally.

Recommendation: Seek sponsorship or funding resources and a suitable site/willing landholder prepared to trial controlled grazing of habitat remnants utilising a fenceless grazing system technology.

Alternatives to chemical weed control

While the environmental management benefits of the aquatic weed control program in Sheep Station Creek have been substantial, one downside noted previously is the dependence on chemical control methods. Currently tonnes of glyphosate are being added to the creek system through this program annually. A proposed innovative alternative to this would be the development of an effective biomass removal method (described in

the section above). Other alternatives that would not avoid problems associated with dead sinking weed biomass, but could reduce chemical use, involve application of non-chemical control methods. Two methods gaining traction for some weed control applications involve the use of steam weeding or flame throwers. The utility of these methods for aquatic and fringing weeds has not been assessed. Certainly, many of the targeted fringing aquatic grass species are documented to be fire sensitive. At the minimum, local management stakeholder communication with proponents of these technologies and access to field demonstrations in local or equivalent operational settings could be informative regarding their utility.

Recommendation: Maintain active dialogue with aquatic weed management stakeholders and facilitate trials, where appropriate, of alternative non-chemical aquatic weed control methods and technology, potentially including steam and flamethrower-based control methods.

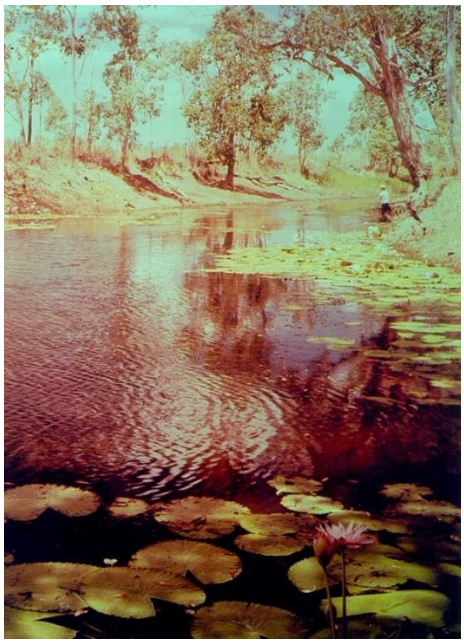


Photo 37. Historical (~1970) image of the report author fishing beneath a paperbark tree at the 'Round Waterhole'.

Photo 38. Current image of the same site (Photo 37). Paperbark tree is dead trunk, rear right. Observed changes include waterlogged trees, aquatic grass (aleman) infestation, loss of open water area and water lilies and stream bank revegetation.

Photo 39. Aerial drone used to capture high resolution imagery of the riparian zone. New technology presents a new range of potential monitoring and management tools.

Photo 40. Surveying a scenic (controlled grazed) reach of Sheep Station Creek with keen local recreational fisher Damien Gorizia and NQ Dry Tropics Project Officer Shakira Todd. The future of the creek system depends on its local custodians.

> Bibliography

ACTFR. 1994a. Burdekin River Irrigation Area Flora and Fauna Survey. Report No. 94/10 Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

ANZECC & ARMCANZ 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

BDTNRM (2005) Burdekin Dry Tropics Natural Resource Management Plan (2005-2010). Produced by the Burdekin Dry Tropics Board for the Burdekin Dry Tropics Community, Townsville.

Burdekin Dry Tropics Natural resource Management Plan 2016-2026 https://drive.google.com/file/d/0B2eYGb5_I-adVXJVOVN2bWcyOFE/view

BBIFMAC (1999) A Community based Natural Resource Management Strategy for the Burdekin – Bowen Floodplain Subregion of the Burdekin Dry Tropics prepared for the Burdekin – Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC).

BSC (2020). Burdekin Shire Council Biosecurity Plan 2020 – 2025. Produced by the Burdekin Shire Council, Ayr.

BSC (2020b). Burdekin Shire Council Aquatic Weed Control Plan 2020 – 2025. Produced by the Burdekin Shire Council, Ayr.

Brizga, S.O., Kapitzke, R., Butler, B., Cappo, M., Connolly, N., Lait, R, Pearson, R.J., Pusey, B., Smithers, S., & Werren, G.L. (2006). Burdekin Basin Draft WRP. Environmental Assessment Report. Phase 1 – Current Environmental Condition. Department of Natural Resources and Mines, Queensland.

Blackman J.G., (1978) The Swamps - A Habitat in Motion. In Exploration North - Australia's wildlife from desert to reef. H.J. Lavery (ed). Richmond Hill Press 1978.

Blackman J.G., Perry, T.W., Ford, G.I., Craven, S.A., Gardiner S.J. and De Lai R.J. (1999). Characteristics of Important Wetlands In Queensland. Environment Protection Agency, Queensland.

Burdekin Region Water Quality Improvement Plan 2016 https://drive.google.com/file/d/0B2eYGb5_I-adNGY0RERCWFB2aDQ/view

Carter, J., Tait, J.T.P., Kapitzke, R. and Corfield, J. (2007). Final Report Burdekin Dry Tropics NRM Region Fish Passage Study. 17 November 2007. Prepared by Alluvium Consulting for Burdekin Dry Tropics NRM.

Carter, J & Tait, J 2010, Freshwater Fishes of the Burdekin Dry Tropics, Townsville.

Christian, CS, Paterson, SJ, Perry, RA, Slayter, RO, Stewart, GA and Traves, DM 1953, 'Survey of the Townsville - Bowen Region, North Queensland, 1950', Land Research Series No. 2, CSIRO, Melbourne.

Connolly, N., Kahler, C, Mackay, S, Fry, S. and Cameron, R. 2012. Variations in wetland condition across Land Zones in the lower Burdekin. Aquatic weed distributions determined by underlying differences in water and salinity regimes. A report prepared for the NQ Dry Tropics NRM. Department of Environment and Heritage Protection, Queensland Government.

Coastal Ecosystem Management – Lower Burdekin Floodplain (GBRMPA 2013) http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/2901/2/Case_study_water_planning_Burdekin.pdf

Davis, A.M., et al., (2013) Environmental impacts of irrigated sugarcane production: Herbicide run-off dynamics from farms and associated drainage systems. Agric. Ecosyst. Environ. (2011), doi:10.1016/j.agee.2011.06.019

Davis A.M. et al. (2014) Water Resource Development and High Value Coastal Wetlands on the Lower Burdekin Floodplain, Australia. In: Wolanski E. (eds) Estuaries of Australia in 2050 and beyond. Estuaries of the World. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7019-5_13

Davis, Aaron M. , Pearson, Richard G. , Brodie, Jon E. , and Butler, Barry (2017) *Review and conceptual models of agricultural impacts and water quality in waterways of the Great Barrier Reef catchment area.* Marine and Freshwater Research, 68 (1). pp. 1-19.

DES (2021). Department Environment and Science, Queensland Government, Regional ecosystems descriptions, licensed under Creative Commons Attribution 4.0 sourced on 10 January 2021

DPI (1993). The Condition of River Catchments in Queensland. *A Broad Overview of Catchment Management Issues.* Queensland Department of Primary Industries Integrated Catchment Management 1993.

Draft Environmental Values and Water Quality Objectives for the Estuarine and Coastal areas of the Lower Burdekin region (Burdekin Dry Tropics NRM)

Freshwater wetlands of the Barratta Creek catchment management investment strategy. Report prepared by Econcern and Tropwater for the Burdekin Dry Tropics NRM (Tait, J. and Veitch, V. 2007)

https://researchonline.jcu.edu.au/cgi/users/login?target=https%3A%2F%2Fresearchonline.jcu.edu.au%2F29261%2F1%2F29261_Tait_2007.pdf

Hooker, N 2010, Native Grasses for Revegetation in the Townsville Region, Coastal Dry Tropics Landcare Inc., Townsville.

Hunter HM, Eyles AG and Rayment GE (1996) Downstream Effects of Land Use. Queensland Department of Natural Resources.

Hunter, H.M., Hargraves, P.M. and Rayment, G.E. (1998) 'Pesticide Residues in Surface Waters of the Burdekin River Irrigation Area' Draft Report Department of Natural Resources, Resources Sciences Centre.

Hunter, H.M. (2012). Nutrients and herbicides in groundwater flows to the Great Barrier Reef lagoon: processes, fluxes and links to on-farm management. ISBN: 978-1-7423-0969.September, 2012

Keating, B.A., Bauld, J., Hiller, J., Ellis, R., Weier, K.L., Sunners, F. and Connell, D. (1995) 'Leaching of Nutrients and Pesticides in Queensland Ground Waters,' in Hunter, H.M., Eyles, A.G. and Rayment, G.E. (eds) *Downstream Effects of Land Use*, Department of Natural Resources, Brisbane.

Perna, C. 2003. Fish Habitat Assessment and Rehabilitation in the Burdekin Delta Distributary Streams. Report No. 03/22 Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Perna, C., 2004. Impacts of Agriculture and Restoration of the Habitat Values, Water Quality and Fish Assemblages of a Tropical Floodplain. Masters of Science Thesis, James Cook University, Townsville, Australia, 144pp.

Perna, C. and Burrows, D. 2005. Improved dissolved oxygen status following removal of exotic weed mats in important fish habitat lagoons of the tropical Burdekin River floodplain, Australia. Marine Pollution Bulletin 51: 138-148.

Perna, C. O'Connor, R. and Cook, B, 2012(a), *Hydroecology of the lower Burdekin River alluvial aquifer and associated groundwater dependent ecosystems*, Department of Environment and Resource Management, Queensland Government.

Perna, C.N., Cappo, M., Pusey, B.J., Burrows, D.W., Pearson, R.G., 2012(b). Removal of aquatic weeds greatly enhances fish community richness and diversity: an example from the Burdekin River floodplain, tropical Australia. River Res. Appl. 28, 1093–1104. https://doi.org/10.1002/rra.1505

Power, T., (2017) Gooseponds Fish Hotels – Increasing habitat complexity. Summary report for Mackay Regional Council. Catchment Solutions, Mackay

Smith, B., Burrows, D., Veitch, V., Tait, J. and Hudson, D. (2007). Great Barrier Reef Coastal Wetland Protection Program Pilot Program 2005-2007– *Final Report June 2007.* Prepared for the Commonwealth Department of Environment and Water Resources by a consortium including Conservation Volunteers Australia, Wetlandcare Australia, Econcern and the Australian Centre for Tropical Freshwater Research, James Cook University.

Tait, J.T.P (1999) A Community based Natural Resource Management Strategy for the Burdekin – Bowen Floodplain Subregion of the Burdekin Dry Tropics prepared for the Burdekin – Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC).

Tait, J and Perna, C. (2001) Fish Habitat management challenges on an intensively developed tropical floodplain – Burdekin River North Queensland. RIPRAP Edition 19 LWRRDC's Riparian Lands Management Journal

Tait, J.T.P (2004) Burdekin Dry Tropics Natural resource Management Plan: Regional Overview. Report for the Burdekin Dry Tropics Board. Econcern.

Tait, J.T.P (2005a) Sheep Station Creek Draft Catchment Management Plan – *Key Management Issues – Chapter 5 - Riparian and Remnant Vegetation. Draft report prepared for the Lower Burdekin Landcare Association.*

Tait, J.T.P (2005b) Sheep Station Creek Draft Catchment Management Plan – *Appendix 7 – habitat Complexes Draft report prepared for the Lower Burdekin Landcare Association.*

Tait, J.T.P (2005c) Sheep Station Creek Draft Catchment Management Plan – Appendix 9:

Sheep Station Creek Revegetation Master Plan – A Proposal –Draft report prepared for the Lower Burdekin Landcare Association.

Tait, J.T.P (2009) Sheep Station Creek Draft Catchment Management Plan – Key Management Issues – Water Quality DRAFT February 2009

Tait, J.T.P. & Veitch, V. (2007). Freshwater Wetlands of the Barratta Creek Catchment – Management Investment Strategy. Report prepared for the Burdekin Dry Tropics Board by Econcern and Australian Centre for Tropical Freshwater Research (ACTFR) October 2007.

Tait, J., 2011, Guidelines for the Use of Grazing in the Management of Exotic Pasture Weeds in Wetland and Riparian Habitats. Developed for the Coastal Floodplains of the NQ Dry Tropics NRM Region. WetlandCare Australia, Ballina, NSW.

Tait, J.T.P. (2013) Coastal Ecosystem Management: Lower Burdekin Case Study. An examination of management arrangements for coastal ecosystems and processes linked to the ecological health of the Great Barrier Reef World Heritage Area on a floodplain dominated by irrigated agriculture. Report prepared for the Great Barrier Reef Marine Park Authority by Econcern July 2013.

Wetlands in the Great Barrier Reef Catchments Management Strategy https://wetlandinfo.ehp.qld.gov.au/resources/static/pdf/management/policy/wetlands-gbr-strategy2016-21v13.pdf

Tonkin, Z. and Lyon, J. (2016). 'Is Wood Good for Fish'. In *RipRap* Edition 39. Published by the Australian River Restoration Centre, Canberra.

Veitch, V., Tait, J., Burrows, D.W., 2008. Fish Passage Connectivity Issues Lower Sheep Station Creek: Dry and Wet Season Investigations of Water Quality and Fish Assemblages. Australian Centre for Tropical Freshwater Research (08/02), James Cook University, Townsville.

Waltham, N.J., Fixler, S., 2017. Aerial herbicide spray to control invasive water hyacinth (Eichhornia crassipes): water quality concerns fronting fish occupying a tropical floodplain wetland. Tropical Conservation Science 10. https://doi.org/10.1177/ 1940082917741592

Waltham, N.J, Coleman, L.,1 , Buelow C., Fry S. & Burrows, D., (2020) Restoring fish habitat values on a tropical agricultural floodplain: Learning from two decades of aquatic invasive plant maintenance efforts. Ocean & Coastal Management Volume 198, 1 December 2020, 105355

> Appendix 1 – Fire regime management guidelines

Fire regime/controlled burning management planning for riparian and remnant vegetation

Fire has a major influence on the condition of remnant vegetation within the Sheep Station Creek catchment. Better management of fire could deliver substantial improvement in the condition and ecological value of the creek's natural habitat. This section of the management plan examines the fire management issues and needs for specific riparian and remnant habitat settings and develops fire management guidelines suitable for use by local fire wardens

Background

Within the NQ Dry Tropics region, fire is an important driver of ecosystem character and condition. Traditional land managers have utilised burning as a landscape management tool for millennia and most terrestrial ecosystems and component species show some adaptation to fire and benefit from its controlled use.

Fire regime

The pattern of burning experienced by a site is described as its 'fire regime' 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).

Nature conservation-based fire regime management recommendations have been developed by Queensland government agencies for the range of regional ecosystems that occur as remnant vegetation within the Sheep Station Creek catchment. These include wetlands, creek fringing riparian woodlands, floodplain woodlands, grasslands and vine forests (Table 1).

Although these recommendations have broad applicability, they have been primarily developed for use in extensive natural landscapes, such as reserves and pastoral areas. In the context of the intensive agricultural landscape of the lower Burdekin region and Sheep Station Creek catchment specifically, other considerations and constraints apply when determining an appropriate or possible controlled burning regime (below).

Controlled burning considerations and constraints lower Burdekin

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. Other than the grazing land use dominated coastal plain, most remnant habitat areas in the Sheep Station Creek catchment occur near cane fields. Consequently, most habitat remnants 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 present in remnant habitat areas during or subsequent to cane field burning.

Small isolated remnants and narrow riparian corridors

The lower Burdekin floodplain, including most of the Sheep Station Creek catchment, is dominated by irrigated agriculture. Remnant natural habitat occurs 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 habitat 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.

Risks to cane crops promote late dry burning

As cane crops mature the amount of dry trash within the crop increases and they become more flammable. Premature burning of cane crops can result in significant economic loss. Consequently, most farmers are loathe to consider utilising fire as part of surrounding landscape management until cane crops have been harvested, to avoid the risk of uncontrolled fire. 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 the opportunity to conduct beneficial cool or less intense 'controlled burns' is less.

Large fuel loads

The fuel load available for burning in a habitat remnant is determined by a range of factors including the interval period since the last fire, the duration of the annual growing season, the amount of overstorey canopy cover, the resulting density and height of ground covering and mid-storey vegetation (grasses and shrubs) and the presence and/or impact of grazing on grass biomass. Throughout Sheep Station Creek catchment, the majority of habitat remnants are ungrazed. This, in conjunction with invasive pasture grasses (guinea grass/green panic, para grass), and a long growing season due to seasonally extended soil moisture promoted by regulated stream flows and irrigation tailwater, commonly result in large fire fuel loads being generated annually within most habitat remnants.

Fire regime/controlled burn management guidelines for remnant habitat benefits

To develop useful guidelines for fire management of remnant habitat areas within the Sheep Station Creek catchment, the following approach has been adopted:

Examine relevant regional ecosystem fire management recommendations (Table 1) in state government (https://apps.des.qld.gov.au/regional-ecosystems/) and other natural resource management publications, for example, Reef Catchments (2012).

Consider the specific constraints on controlled burning practices operating in the lower Burdekin landscape (discussed above) for different remnant habitat landscape settings and identify means by which they can be addressed.

Seek review and input from local fire wardens from within the catchment to develop practical and implementable guideline outcomes.

Table 1. Published fire management recommendations for regional ecosystems within the Sheep Station Creek catchment

Regional ecosystem (RE) type	Season	Interval	Intensity	Extent	Notes
Freshwater wetlands RE 11.3.27	Not defined	Not defined	Not defined	Not defined	Protection relies on management surrounding country with numerous small fires through year to limit extent of wildfires. Intense and extensive fires degrade vegetation structure. Critical habitat and best not to burn in some situations. Hollow trees are critical habitat. If guinea grass is an issue, an intensive grazing regime for short periods may be necessary to limit potential of wildfire. Implement burning when water level is deep enough to protect the bases of aquatic plants. Where needs to be burnt to reduce fuel loads should occur when there is good soil moisture and active growth. Care should be taken where a dry peat or accumulated thatch layer has developed (particularly in degraded situations).
Fringing (riparian) woodland RE 11.3.25 Blue gum	Early dry	3-5 yrs	Low	Restrict	
Floodplain woodlands RE 11.3.7 Bloodwood RE 11.3.9 Poplar gum, Morton Bay ash and bloodwood RE 11.3.4 Blue gum	Predominantly early dry, some later, i.e. early storm season and/or after spring rain RE 11.3.4 Late wet – early dry	2-7 yrs (some longer)	Predominantly low – moderate Occasionally high (small areas)	25% of the grassy woodlands within a landscape in most years RE 11.3.4 less than 30%/yr	Burning should begin very soon after the wet season, to secure boundaries and adjacent fire-sensitive vegetation. Subsequent repeat ignitions can be used weeks or months after boundaries secured by early burning, to produce a mix of burnt areas with multiple ignition dates. Use topographical features to ignite areas as soon as they dry out. Burn away from riparian communities. Burning that starts immediately after the wet season, with follow up small fires ignited progressively over multiple dates increases availability of grass and herb seed a critical food source for birds and small mammals. Fire mosaic protects habitat and reduces wildfires. Low to moderate intensity burns with good soil moisture minimise the risk of losing hollow trees. Occasional late season burn promote grasses and legumes. Ensure a diverse grass layer, maintenance of hollow-bearing trees, and vegetation structure.
Grassland RE 11.3.31	Late wet – early dry Implement storm burning when there is sufficient fuel	2-5 yrs	Not defined	Less than 30%/yr	Begin burning soon after the wet season so that fires will carry only a small distance. Patchy burns are preferred. Burn under conditions of good soil moisture when plants are actively growing.

Regional ecosystem (RE) type	Season	Interval	Intensity	Extent	Notes
					Where woody thickening is an issue, implement burns soon after high rainfall events, before woody seedlings become established. Patchy burning provides mix of fresh and older tussocks and regenerates associated herbs. Fire can be used to control weed invasions, although there are also risks of promoting weeds. Encroachment of woody-stemmed plants (acacia/atalaya) through over-grazing and lack of burning may be a problem. Ensure open grassland plains are maintained. Create a patchily burnt landscape.
Gallery vine forest RE 11.3.40	Requires protection from wildfire				Protection relies on numerous small fires through year in surrounding country to limit potential wildfire extent. Maintenance of fire breaks may be appropriate on flat country. Fuel reduction burning in surrounding vegetation under low fire danger conditions and/or revegetation of cleared areas reduce the risk of damaging wildfires. Exotic grasses, such as guinea grass, can fuel fires that carry into and damage vine thickets. Maintain or re-establish native vegetation communities adjacent to this ecosystem. Herbicide control of exotic grasses, or short-term grazing, on edge of vine thickets will reduce risk of wildfires damage.

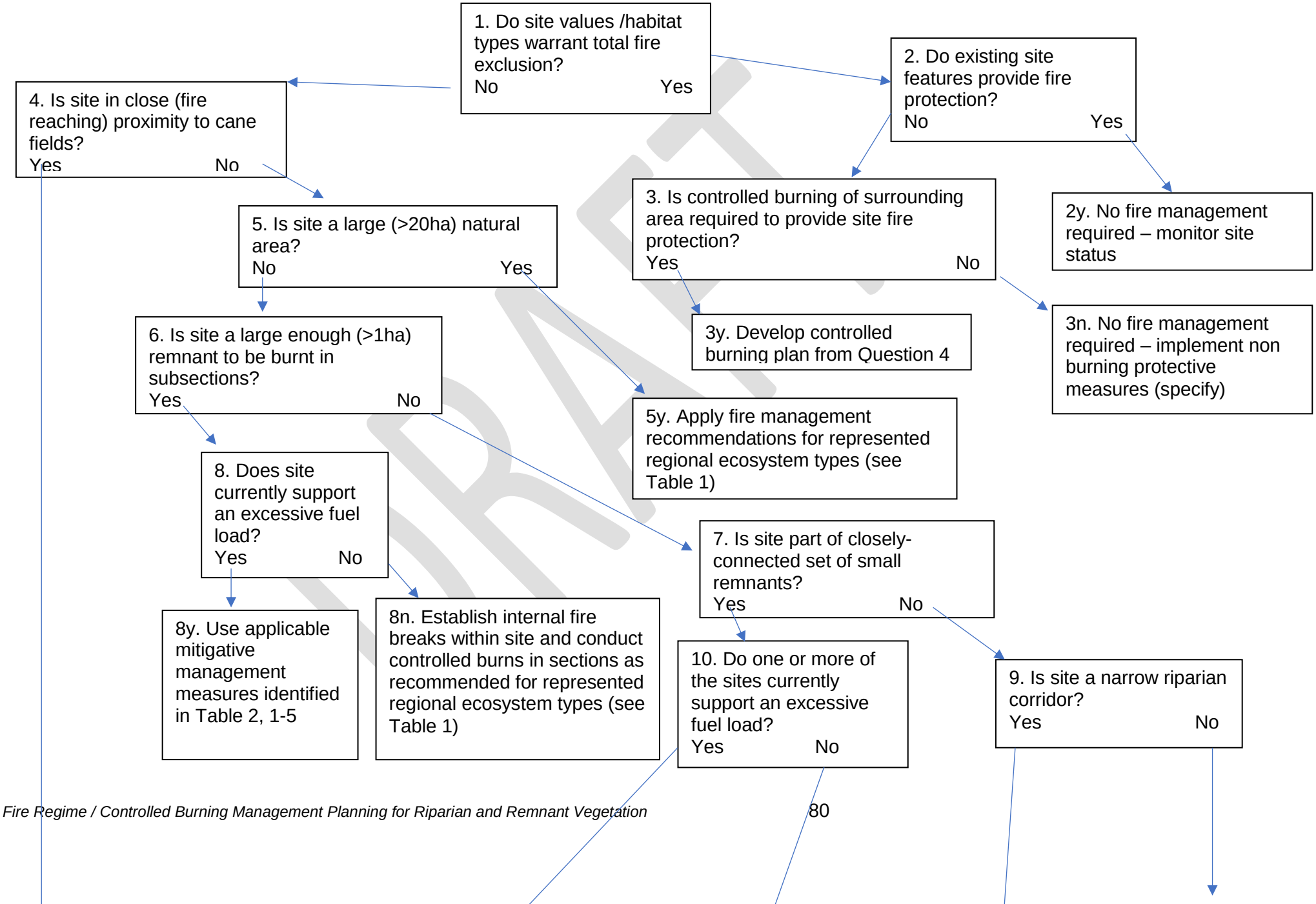
Table 2. Proposed controlled burning guidelines/methods for habitat remnants in agriculture-dominated landscapes of Sheep Station Creek catchment

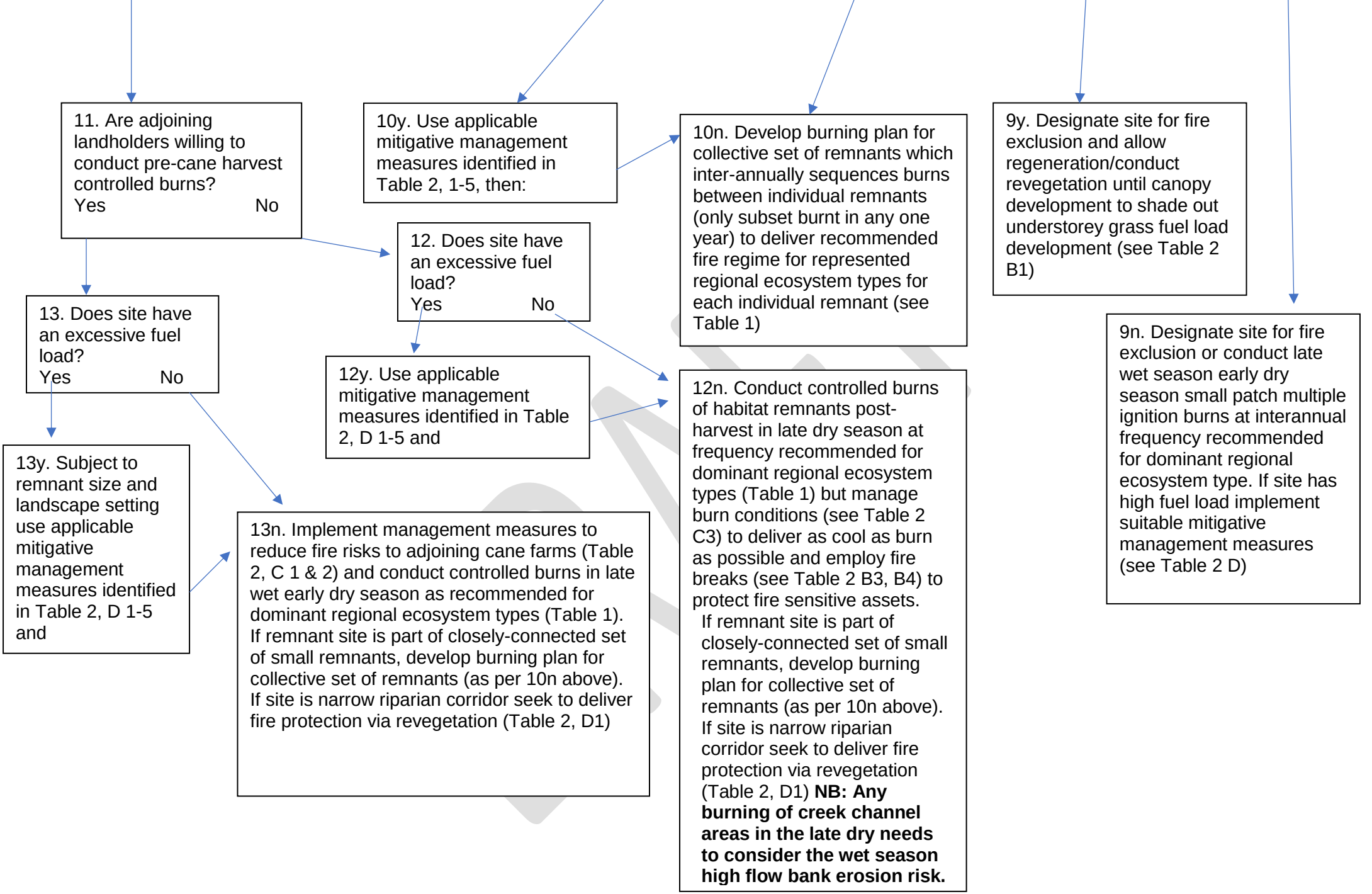
Constraint	Proposed methods to address constraint (one or more may be applied)
A. Annual exposure to surrounding cane fire	1. Communicate via producer networks and shed meetings, etc, about the ecological benefits of protecting habitat remnants from uncontrolled burns and the need to plan and manage cane fires to prevent cane fires jumping to habitat remnants. 2. Establish fire protection buffer areas on margin of habitat areas. These can include: a. slashed areas on margins of habitat remnants to broaden separation of cane field and habitat remnants; b. glyphosate-sprayed margins burnt early in late wet/early dry season; c. Maintained fire breaks (sprayed, slashed, earth tracks) within habitat remnants to limit extent of escaped cane fires. 3. Conduct intentional controlled burns of habitat remnants in late wet/early dry season ahead of cane harvest season.

Constraint	Proposed methods to address constraint (one or more may be applied)
B. Isolated remnants and narrow riparian corridors	1. Exclude fire from forested narrow riparian corridors and allow regeneration and/or conduct revegetation until canopy density sufficient to shade out understorey grass fuel load development. 2. Establish water edge-to-levee bank fire breaks at intervals along forested narrow riparian corridors to enable burning of alternate sub sections in any one year and longer-term fire intervals (3-5 years) for individual sections. 3. Use mechanical or chemical means to establish water edge to levee bank fire breaks between forested sections of riparian corridors and grass infested/high fuel load sections of riparian corridors to enable fuel reduction burning of grass infested sections annually to protect forested sections. 4. Establish internal fire breaks (sprayed, slashed, earth tracks) within larger (non-riparian) remnants to enable burning of alternate sub sections in any one year and longer-term fire intervals (2-7 years) for individual sections. 5. Where smaller habitat remnants occur in close proximity, plan inter-annually sequenced controlled burns across collective set of remnants (only subset burnt in any one year) to deliver targeted fire frequency/interval (2-7 years) for individual remnants.
C. Risks to cane crops promote late dry burning	1. Establish buffers on margins of habitat remnants (see A2 above) to enable late wet/early dry season-controlled burns to be conducted with a very low risk to cane crops. 2. Pre-emptively assess status of crop cycle of cane fields adjoining habitat remnants to identify if/when young cane crop present opportunities to burn habitat remnants in late wet/early dry season without risk to adjoining cane fields. 3. Conduct controlled burns of habitat remnants post-harvest in late dry season but manage burn conditions, including time of day, wind, soil moisture (post storm) and fuel load to deliver as cool as burn as possible and where possible employ fire breaks (see B3, B4) to protect fire sensitive assets, such as riparian forests, fires sensitive vine forest components, hollow trees. **NB: Any burning of creek channel areas in the late dry needs to consider the wet season high flow bank erosion risk.**
D. Large fuel loads	1. Promote regeneration/conduct revegetation of riparian forests to create dense canopy cover that excludes/reduces density of fire fuel load generating understorey grasses. 2. Where site is suitable, introduce seasonal crash grazing or sustained low grazing pressure to reduce fuel loads ahead of controlled burning. 3. Conduct limited extent late wet season/early dry season cool burns to reduce fuel load and create patchy burnt mosaic to reduce fuel loads ahead of late dry season 'hot' fire period. 4. Use established fire breaks (see B3) to enable burning of high fuel load sections of habitat remnants without impacting habitat areas vulnerable to hot fire impacts. 5. Where site conditions allow, conduct controlled burns away from hot fire sensitive habitat areas (riparian forests, hollow trees, vine forest) initiating fire near fire sensitive elements on edge of high fuel load areas and direct burn away from them.

Proposed use of guidelines

To apply the fire regime/controlled burn guidelines presented above, a decision tree method (see below) can be applied to the specific conditions presented by the site being considered. Ideally, for the benefit of nature conservation within the Sheep Station Creek catchment, all areas of natural habitat should be subject to fire regime management, recognising that in some instances the most appropriate burning regime may be fire exclusion.


1. Do site values /habitat types warrant total fire exclusion?
No Yes
2. Do existing site features provide fire protection?
No Yes
4. Is site in close (fire reaching) proximity to cane fields?
Yes No
3. Is controlled burning of surrounding area required to provide site fire protection?
Yes No
2y. No fire management required – monitor site status
5. Is site a large (>20ha) natural area?
No Yes
3y. Develop controlled burning plan from Question 4
3n. No fire management required – implement non burning protective measures (specify)
6. Is site a large enough (>1ha) remnant to be burnt in subsections?
Yes No
5y. Apply fire management recommendations for represented regional ecosystem types (see Table 1)
8. Does site currently support an excessive fuel load?
Yes No
7. Is site part of closely-connected set of small remnants?
Yes No
8y. Use applicable mitigative management measures identified in Table 2, 1-5
8n. Establish internal fire breaks within site and conduct controlled burns in sections as recommended for represented regional ecosystem types (see Table 1)
10. Do one or more of the sites currently support an excessive fuel load?
Yes No
9. Is site a narrow riparian corridor?
Yes No


11. Are adjoining landholders willing to conduct pre-cane harvest controlled burns?
Yes No
10y. Use applicable mitigative management measures identified in Table 2, 1-5, then:
10n. Develop burning plan for collective set of remnants which inter-annually sequences burns between individual remnants (only subset burnt in any one year) to deliver recommended fire regime for represented regional ecosystem types for each individual remnant (see Table 1)
9y. Designate site for fire exclusion and allow regeneration/conduct revegetation until canopy development to shade out understorey grass fuel load development (see Table 2 B1)
9n. Designate site for fire exclusion or conduct late wet season early dry season small patch multiple ignition burns at interannual frequency recommended for dominant regional ecosystem type. If site has high fuel load implement suitable mitigative management measures (see Table 2 D)
12. Does site have an excessive fuel load?
Yes No
12y. Use applicable mitigative management measures identified in Table 2, D 1-5 and
12n. Conduct controlled burns of habitat remnants post-harvest in late dry season at frequency recommended for dominant regional ecosystem types (Table 1) but manage burn conditions (see Table 2 C3) to deliver as cool as burn as possible and employ fire breaks (see Table 2 B3, B4) to protect fire sensitive assets.
If remnant site is part of closely-connected set of small remnants, develop burning plan for collective set of remnants (as per 10n above).
If site is narrow riparian corridor seek to deliver fire protection via revegetation (Table 2, D1) NB: Any burning of creek channel areas in the late dry needs to consider the wet season high flow bank erosion risk.
13. Does site have an excessive fuel load?
Yes No
13y. Subject to remnant size and landscape setting use applicable mitigative management measures identified in Table 2, D 1-5 and
13n. Implement management measures to reduce fire risks to adjoining cane farms (Table 2, C 1 & 2) and conduct controlled burns in late wet early dry season as recommended for dominant regional ecosystem types (Table 1).
If remnant site is part of closely-connected set of small remnants, develop burning plan for collective set of remnants (as per 10n above).
If site is narrow riparian corridor seek to deliver fire protection via revegetation (Table 2, D1)

> Appendix 2 – Reach values, management issues and landholder-identified works descriptions

Table 1. 'Rocks to Waterview Road reach'

Sheep Station Creek Management Plan: Map sheet 1 (of 5) 'Rocks to Waterview Road reach'
Reach values (V)
Short description – V1 (a, b, c & d): High nature conservation value remnant floodplain vegetation with regional wildlife corridor function.
V1 – Full description (a) The most proximal linkage point between remnant habitat of the Mount Kelly complex (and beyond to the Barratta Creek floodplain) and the Burdekin River main channel riparian corridor (b, c, d). Remnant vegetation with: 1) High representativeness value (represents type extensively developed on alluvial plains). 2) Fauna refuge habitat value including for species now rare in the developed landscape. 3) Connectivity value providing corridor linkages between hills and across the extent of the Mount Kelly habitat complex and to the Burdekin River riparian corridor.
Short description – V2: High nature conservation value remnant floodplain vegetation representative of creek's predevelopment condition.
V2 – Full description Remnant vegetation with: 1) High representativeness value (represents seasonal distributary channel typical of creek system's historical hydrology and woodland typical of alluvial landforms that have been extensively developed). 2) Fauna refuge habitat value including for species now rare in the developed landscape. NB: V2 & V3 collectively form a high value remnant habitat complex.
Short description – V3: High nature conservation value remnant riparian vegetation with rainforest and ecotonal (edge) communities.
V3 – Full description (a & b) Closed canopy riparian forest that has formed under the exclusion of fire over decades. Includes many rainforest species and provides habitat for dense cover dependent species such as owls. Provides evidence of the rainforest associated vegetation that can be established on the creek system under modified near perennial flow conditions. Also demonstrates the beneficial role of canopy shading for excluding weedy grass growth in the understorey and for limiting the growth opportunities for aquatic weeds within the stream channel. (c) Open woodland and seasonal drainage channel that presents an 'ecotone' (ecological boundary) to the main channel riparian forest and a broader habitat node with additional habitat resources for dependent fauna.
Short description – V4: Revegetated distributary channel lagoon that retains more natural seasonal hydrology and water quality.
V4 – Full description This distributary channel lagoon occurs off the main channel and acts as a groundwater window. Consequently, the lagoon has hydrological features more like a historically natural condition lagoon, i.e. it has clear tannin-stained water (lacking fine colloids associated with river water) and experiences seasonal drawn down.

Short description – V5: Regenerated and revegetated riparian vegetation with high nature conservation values including rainforest species.
V5 – Full description A structurally-complex and floristically rich riparian forest corridor established by landholder revegetation and regeneration efforts including the use of controlled grazing, exclusion of fire, tree planting and weed control. Has developed a dense canopy which excludes fire promoting understorey grasses and shades weeds within the stream channel. Includes rainforest species some of which have self-recruited. Sugar gliders have been recorded at the site.
Short description – V6: High nature conservation value remnant vegetation representative of back swamps with wildlife corridor function.
V6 – Full description (a, b & c) Riparian forest remnant typical of off main channel back swamps. Includes species such as broad leaf tea tree not common on the active stream channel. Also provides habitat corridor connectivity between the Mount Kelly habitat complex and the Sheep Station Creek riparian corridor. (b) Riparian forest remnant typical of off main channel back swamps. Includes species such as broad leaf tea tree not common on the active stream channel. (c) Riparian forest remnant typical of off main channel back swamps. Includes species such as broad leaf tea tree not common on the active stream channel.
Short description – V7: Degraded woodland remnant that has nature conservation value associated with regional wildlife corridor function.
V7 – Full description (a & b) Degraded open woodland remnant that has connectivity value provided by habitat corridor linkages through the Mount Kelly habitat complex to the Rocks and the Burdekin River and westwards to habitat corridors retained through the Burdekin Haughton Water Supply Scheme Area.
Short description – V8: Island created by sand deposition that provides turtle and crocodile nesting site.
V8 – Full description Quartzose sand island formed by wash out deposits from the Red Lilly Lagoon catchment that provides nesting substrates for freshwater turtles and crocodiles.
Short description – V9: High nature conservation value riparian corridor habitat node that includes ecotonal (edge) communities.
V9 – Full description Open woodland that presents an 'ecotone' (ecological boundary) to the main channel riparian forest and a broader habitat node within the riparian corridor.
Short description – V10 Productive deepwater lagoon with high fish habitat value including snags and fringing riparian vegetation.
V10 – Full description Productive deepwater lagoon fish habitat. Historically this lagoon held populations of large barramundi. The high fish habitat values of this lagoon are associated with lagoon size and depth, habitat complexity (including snags) and productivity including dense freshwater herring populations.
Management issues (M)
Short description – M1: Propose trialling establishing riparian vegetation shading to reduce need for excavator clearing of channel grass weeds.

M1 – Full description The upper catchment drainage system is comprised of long extents of narrow sunlit excavated channel that are prone to aquatic grass infestations that require regular clearing by excavator. These excavated channel reaches present site opportunities to trial and compare alternative management approaches including the establishment of shade canopy generating riparian overstorey (on one or both sides of the channel) or the use of controlled grazing access (present on some reaches of the upper catchment).
Short description – M2: Inaccessible weed infestation within broader (sunlit) forested channel section.
M2 – Full description Broader channel reaches of the upper catchment with dense riparian vegetation limiting excavator access are prone to in channel aquatic grass weed infestation. Dedicated methods and/or machinery need to be trialled to be able to control such infestations.
Short description – M3: Most upstream lagoon in creek system provides aquatic weed refuge and good site for fish stocking.
M3 – Full description This most upstream lagoon in the creek system provides a refuge for floating aquatic weeds particularly water hyacinth. Catchment-based lines of control that sought to eradicate aquatic weeds from this site and all upper reaches of the creek system would serve to reduce the weed reinfestation potential faced by lower reaches and if trialled could provide an impetus for extending such lines of control downstream. Given the fish passage barriers limiting upstream movement of migratory barramundi, this site presents a suitable stocking site that would allow for downstream distribution of established fingerlings.
Short description – M4: Stream road crossing culvert/control structure that acts as fish passage barrier under some flow conditions.
M4 – Full description (a-f) Throughout this mapped reach, there are several stream road crossing culverts with or without water control structures that under some flow conditions act as fish passage barriers downstream of high value fish habitat. To achieve the aspirational goal of providing migratory fish access to the most upstream high value habitats, these culverts should be subject to assessment and prioritised rectification works possibly including retrofitting flow velocity reducing structures within culverts and the placement of flow gradient reducing rock ramp structures below them.
Short description – M5: Most degraded riparian vegetation condition stream reach in upper catchment priority for revegetation.
M5 – Full description The stream reach between Airville and Barrett Roads has the poorest riparian condition for a natural creek channel within the upper catchment, and is a priority for riparian vegetation restoration.
Short description – M6: Red Lilly Lagoon sub catchment source of low oxygen ‘blackwater’ flows that impact lower reaches in wet season.
M6 – Full description Wet season water quality monitoring has identified that flows into Sheep Station Creek from the Red Lilly Lagoon sub catchment can include 'blackwater’ pulses very low in dissolved oxygen that can result in fish kills in downstream receiving reaches including Payard's Lagoon. Investigation and management of these anoxic inflows in a priority for the ecosystem health of the upper catchment.
Short description – M7: Ineffective management of aquatic weeds in Red Lilly Lagoon back swamp.
M7 – Full description

Aquatic weed management effectiveness within this back reach of the Red Lilly Lagoon system has proved problematic. Given the water quality impact of this sub catchment on the main creek system, delivery of more effective weed control in the sub catchment is a priority.
Short description – M8: Need to investigate source of de-oxygenated ‘blackwater’ inflows and potential role of levee to divert.
M8 – Full description A constructed levee wall creates an artificial catchment divide between the lower Red Lilly Lagoon system and the south western catchments of Mount Kelly and directs flows from these catchments into the Collinson's Lagoon system to the west. The catchments of south-west of Mount Kelly have been extensively cleared and developed including to intensive land uses such as irrigated ponded-pasture and feed lots. Catchment development is believed to have created greater rates of rainfall runoff. During wet season, high rainfall events the constructed levee divide is breached, and flows discharge via the confluence to Sheep Station Creek. Monitoring of water quality and flows during these events is required to identify management options for the water quality impacts of this sub catchment on the lower creek system.
Landholder identified works (W)
Short description – W1: Stabilisation of erosion on channel banks.
W1 – Full description Erosional washouts along excavated channel banks have been identified as needing stabilisation.
Short description – W2: Woody weed control and vegetation regrowth thinning to improve ground cover
W2 – Full description Woody weeds need to be controlled in remnant habitat. Also proposes thinning of mid-storey vegetation to increase pasture yields. Also prepared to mobilise his cattle to other sites/properties to provide controlled grazing program support.
Short description – W3: Establishment of fire breaks to support controlled burns and ‘in fill’ revegetation to create grass weed shading canopy.
W3 – Full description (a, b & c) This reach has previously (~2002) been subject to revegetation activities. Further 'fill in' tree planting and revegetation of creek banks outside of areas used for excavator channel clearing operations is supported. The creation of dense canopy shading that reduces the growth of fire risk generating and/or channel blocking grasses is particularly supported. Also proposed that establishment and maintenance of fire breaks within grassy levee banks would provide greater opportunities for controlled burns.
Short description – W4: Riparian revegetation and regeneration to support grass weed exclusion along degraded reach
W4 – Full description This reach is one of the most degraded in terms of riparian vegetation condition in the upper catchment of the creek system. The landholder is supportive of tree planting that emulates the habitat conditions created by revegetation in the reach downstream of this site.
Short description – W5: Use of mobile cattle herd to provide controlled grazing of grass weeds on rehabilitated seasonal lagoon
W5 – Full description This back-channel lagoon has previously been cleared of weed infestations (cumbungi), revegetated and subject to episodic horse grazing. Fencing infrastructure is still in place and the landholder is supportive of more sustained grazing pressure (possibly by

mobile cattle herd managed by others) being maintained on the site to remove the grass biomass which presents hot fire risks to the revegetation and adjoining farm and provides rat harbourage.
Short description – W6: Revegetation of degraded reach to provide wildlife corridor to Red Lilly Lagoon sub catchment.
W6 – Full description Landholder supports revegetation of riparian corridor linking Sheep Station Creek to Red Lilly Lagoon.
Short description – W7: Revegetation to create riparian vegetation shaded margin along Red Lilly Lagoon.
W7 – Full description Landholder wants increased shade creating riparian vegetation planted along margins of Red Lilly Lagoon
Short description – W8: Excavation of sand island to reduce erosion pressure on eastern bank and backwater debris accumulation at pump site.
W8 – Full description Excavation of some of sand slug island that is pushing current onto the eastern bank and creating a backwater that deposits pump blocking debris at pump intake.
Short description – W9: ‘In fill’ revegetation to shade understorey grass weeds and further stabilise creek bank.
W9 – Full description Landholder supports 'in fill’ planting to increase canopy closure and shading of understorey grasses and increase bank stability along reach downstream to Waterview Road.
Short description – W10: Reintroduction of controlled cattle and ‘in fill’ revegetation to create waterline grass weed-shading tree canopy.
W10 – Full description Landholder intends to cattle graze reach from Red Lilly Lagoon channel confluence to Waterview Road. Landholder supports 'in fill’ planting of dense shade-producing species capable of excluding aquatic grass anchor points along creek frontage of this reach.

Table 2. 'Waterview Road to Bruce Highway reach'

Sheep Station Creek Management Plan: Map sheet 2 (of 5) 'Waterview Road to Bruce Highway reach'
Reach values (V)
Short description – V1: One of largest lagoons in creek system with high value fringing waterfowl and deepwater fish habitat.
V1 – Full description Payard's Lagoon. One of the five longest lagoons in the creek system. Productive deepwater fish habitat. Historically this lagoon held large populations of barramundi. The high fish habitat values of this lagoon are associated with lagoon size and depth, habitat complexity (including snags) and productivity including dense freshwater herring populations. Shallow margins adjoining the upstream end of the lagoon have historically supported large seasonal populations of waterfowl.
Short description – V2: Rare, large, seasonal wetland and woodland habitat complex with high conservation values for wetland fauna and flora.
V2 – Full description Kelly's Swamp. Large seasonal wetland formed on a flood distributary of the creek system. This wetland is part of a larger remnant habitat complex which includes several other seasonal wetland basins and regrowth woodland. It remains largely alienated from irrigation tailwater inflows and retains a natural wet dry cycle. This and sustained grazing pressure have limited the infestation of the site by exotic pasture species. As a consequence, the site retains a high diversity of native wetland flora and provides high value habitat for waterbirds, waterfowl, frogs and other wetland fauna.
Short description – V3: Off channel back lagoon with diverse native aquatic plant community and high fish and waterfowl habitat values.
V3 – Full description Kelly's Lagoon. Off channel back lagoon. Historically this site was a declared fauna sanctuary which as a consequence of its shallow sloping and seasonally-exposed banks supported large populations of waterfowl. It also supported good fish populations including large barramundi. This lagoon remains partially isolated from the channel conveying pumped flows and therefore experiences distinct water quality (clearer) than lagoons on the active channel system. While seepage and groundwater connectivity to the main channel system have impacted seasonal drawdown, it retains high wetland habitat values including a diverse suite of native aquatic plants.
Short description – V4: Seasonal wetland basin with high value remnant vegetation and waterbird habitat values.
V4 – Full description This shallow wetland basin has remnant vegetation representative of seasonal wetlands largely loss to agricultural development and remains partially isolated from the pumped flows of the main creek channel and therefore retains a seasonal wet-dry hydrological cycle. In combination with a sustained grazing regime this supports native aquatic plants and associated waterbird habitat values lost to modified hydrology and invasive aquatic grasses elsewhere within the catchment.
Short description – V5: Sub catchment habitat complex with very high value remnant vegetation, clear water quality and fauna refuge function.
V5 – Full description Castelanelli's Lagoon sub catchment has very high ecological values associated with being off the main channel and partially isolated from pumped flows of the regulated creek system. It includes three main lagoon basins that retain naturally clear water

quality supporting dependent fish and plant species and has acted as a refugia for a number of species during times of severe weed infestation and water quality stress within the broader catchment. The three lagoon basins and associated channel system also retain one of the best examples of remnant riparian vegetation within the upper Sheep Station Creek catchment. A number of sites on the upstream lagoon systems have also been successfully revegetated. In conjunction with the remnant vegetation communities and lagoons the overall sub catchment forms a high value habitat complex.
Short description – V6: Largest lagoon in Sheep Station Creek system with high value fish and waterfowl habitat and diverse riparian vegetation.
V6 – Full description 'Dick's Bank' is the largest lagoon within the Sheep Station Creek system. It has high ecological values associated with highly productive shallow and deepwater fish habitats, marginal waterbird habitats and remnant riparian vegetation. It has also been the site of successful riparian revegetation which has added significantly to the availability and complexity/diversity of riparian forest assemblages at the site. Historically, the site was renowned for hosting large barramundi including individuals to in excess of 100lbs (>45kg). The current condition of the lagoon is a testament to management efforts implemented over the last 20 years, which has seen it recover from a state of severe aquatic weed infestation and associated water quality stress to its current relatively healthy ecosystem status.
Management issues (M)
Short description – M1: Stream road crossing culvert that acts as fish passage barrier under some flow conditions.
M1 – Full description (a, b & c) Throughout this mapped reach there are several stream road crossing culverts with or without water control structures that under some flow conditions act as fish passage barriers downstream of high value fish habitat. To achieve the aspirational goal of providing migratory fish access to the most upstream high value habitats, these culverts should be subject to assessment and prioritised rectification works possibly including retrofitting flow velocity reducing structures within culverts and the placement of flow gradient reducing rock ramp structures below them.
Short description – M2: Shallow mud flats and islands in stream channel provide anchor points for aquatic grass weed infestation.
M2 – Full description (a & b) Shallow mud flats and islands within the stream channel provide anchor points for the formation of extensive aquatic grass weed mats that are not effectively controlled by the narrow intervention (1.5m) zones employed by the aquatic weed control service providers. Use of an amphibious excavator and/or employment of greater intervention reach by aquatic weed controllers is required to provide longer term management of these weed reinfestation sites. Where more well formed in-channel islands occur, revegetation with dense canopy-forming species could provide another option for preventing aquatic grass weed proliferation from channel island sites.
Short description – M3: Propose trialling establishing riparian vegetation shading to reduce need for excavator clearing of channel grass weeds.
M3 – Full description This is one of several examples of a 'double bank excavator access reach' within the creek system. The requirement for excavator access to both sides of the channel to remove weed mat blockages and maintain flow capacity negates the opportunity for establishing channel bank riparian vegetation with concomitant impacts to habitat values, stream processes and wildlife corridor

connectivity. Developing and trialling riparian revegetation strategies for these reaches, including single or alternate bank revegetation options, and using established overstorey shading to reduce aquatic weed growth, thereby reducing excavator maintenance needs, are proposed management investigations.
Short description – M4: Loss of dry season exposed bank margin waterbird habitats due to sustained water levels and grass weed infestation.
M4 – Full description Seasonally-exposed banks and mud flats on the margin of lagoons (including this specific site) were historically-important waterbird habitat that supported large populations in the late dry season. The near-perennial flowing status of the modern creek system limits the occurrence of water level draw down in the dry season. These conditions also support the extensive growth of semi aquatic grasses, such as para, on lagoon margins, which does not provide the bare bank habitat favoured by waterfowl. Options to create bare exposed banks to provide suitable waterfowl habitat potentially include: seasonal grazing, weed control, burning and water level manipulation. These warrant management investigation.
Short description – M5: Very poor riparian vegetation condition requiring revegetation/regeneration integrated with controlled grazing.
M5 – Full description This lagoonal reach below Payard's Lagoon has little riparian vegetation due to a combination of historical clearing, water logging associated with modified flows and hot fire regimes. A lack of riparian vegetation impacts habitat values, wildlife corridor connectivity and stream processes associated with overstorey shading. Revegetation strategies potentially integrated with the aspirations of the landholder to reinstitute controlled grazing are a management focus for this reach.
Short description – M6: Channels with low habitat value suitable site for trialling riparian revegetation to reduce need for excavator operations.
M6 – Full description This reach has been channelised for groundwater recharging purposes. Most represents a 'double bank excavator access reach'. A lack of riparian vegetation within this channelised section limits habitat values and wildlife corridor connectivity and impacts stream processes. Developing and trialling riparian revegetation strategies for these reaches, including single or alternate bank revegetation options, is proposed for management investigation.
Short description – M7: Off-channel lagoon's loss of seasonality due to regulated flows impacting site condition and waterbird habitat values.
M7 – full Description This historically-isolated billabong off the main channel now remains permanently full due to hydrological connectivity with perennial main channel flows. This prevents the development of dry seasonally exposed banks and mud flats on the margin of the lagoon (this specific site), which was an important waterbird habitat historically that supported large populations in the late dry season. Permanent inundation also supports the extensive growth of semi aquatic grasses, such as para, on lagoon margins, which does not provide the bare bank habitat favoured by waterfowl. Options to create bare exposed banks to provide suitable waterfowl habitat potentially include: seasonal grazing, weed control, burning and water level manipulation. These warrant management investigation. Management interventions that provide seasonal draw down of the lagoon's water levels would also serve a range of other condition and ecological process needs of this high value site.

Short description – M8: Propose trialling establishing riparian vegetation shading to reduce need for excavator clearing of channel grass weeds.
M8 – Full description This is another 'double bank excavator access reach'. A lack of riparian vegetation impacts habitat values, stream processes and wildlife corridor connectivity. Developing and trialling riparian revegetation strategies for these reaches, including single or alternate bank revegetation options and using overstorey shading to reduce aquatic weed growth, thereby reducing excavator maintenance, needs are proposed management investigations.
Short description – M9: Fish passage barrier created by water control structure (proposed site for fishway)
M9 – Full description This water board culvert control structure has been identified to be a fish passage barrier and is nominated by landholders as a cause of reduced fish migration to upper catchment reaches. A rock ramp fishway has been proposed for this site and is due for construction in 2021.
Short description – M10: Controlled grazing and ‘cool’ controlled burns required to protect high value remnant vegetation from ‘hot’ fires,
M10 – Full description This sub catchment channel and lagoon system retains high habitat value remnant vegetation. The proliferation of ungrazed pasture grasses in the understorey annually develops into a large fuel load. In years that fire does occur at the site, it most commonly occurs in the post-sugarcane harvest dry season as a 'hot' burn that does some permanent damage to the remnant vegetation. Management methods that could reduce the impact of a hot fire regime at this site including controlled grazing and controlled cool burns are nominated for management investigation.
Short description – M11: Revegetation of drainage channel to provide wildlife corridor and weed management and water quality benefits.
M11 – Full description Within intensively-developed landscapes, constructed drainage networks present one of the few opportunities for re-establishing native vegetation into the farming landscape. While such revegetation needs to remain aware of potential impacts to farming operations – particularly machinery access and fire risks to adjoining farms – strategically-located revegetation, such as this gap between a natural drainage line and a revegetated corridor, provides a number of ecological benefits including wildlife corridors, weed shading and nutrient uptake.
Short description – M12: Sustained water levels and shallows created by sediment deposition creating cumbungi infestation sites.
M12 – full Description (a & b) Where sediment has deposited within lower velocity reaches of the stream channel or in backwater sections of the main lagoon, the native reed cumbungi has established dense stands. Under natural seasonally variable water levels, such stands would not persist through the exposure of the dry season. Under perennial flow conditions they form persistent stands which have limited habitat value and serve to promote further sedimentation and weed harbourage. Use of an aquatic excavator to deepen such areas and/or targeted spray control programs could restore the habitat value of these sites by reinstating open water habitats.
Short description – M13: Aquatic weed control program promotes duckweed and impacts beneficial water lilies that shade pump intakes.

M13 – Full description Aquatic weed control programs that reduce the density of surface-floating aquatic weeds, such as water hyacinth, can lead to a proliferation of submerged aquatic plants such as duckweed (*Ceratophyllum demersum*). Indiscriminate weed spraying programs can also impact native water lilies (*Nymphaea gigantea*), which provide a native plant surface covering. An end result reported by landholders throughout the creek system can be blockages of pump intakes by duckweed. Greater targeting during the implementation of aquatic weed control programs and the establishment/protection/maintenance of water lily stands over pump intakes, possibly involving the use of constructed floating booms, are suggested as two potential management options.
Landholder identified works (W)
Short description – W1: 'In fill' and water edge revegetation to reduce fire fuel load and shade anchor points for aquatic grass growth.
W1 – Full description (a & b) Greg Miller: Supports 'in fill' and water edge planting within remnant vegetation stand impacted by uncontrolled fire to create dense canopy cover to reduce understorey grass fire fuel load and stream edge anchor points for aquatic grass growth.
Short description – W2: 'In fill' and water edge revegetation to shade out aquatic grass growth, stabilise bank and increase amenity.
W2 – Full description Landholder supports 'in fill' planting of stream channel margin to create overstorey shade to exclude aquatic grass growth and to increase bank stability and amenity of reach used for eco-tourism.
Short description – W3: Reinstatement of controlled grazing to reduce hot fire risks and improve habitat values.
W3 – Full description (a & b) Landholder (a) supports reinstatement of grazing. Previously grazed, this area of remnant paperbark forest and low-lying bank margins at the top of Payard's Lagoon has now been overgrown by para grass presenting a hot fire risk to the remnant vegetation and reducing its waterfowl habitat value. Fencing infrastructure remains in place, but has been impacted by high wet season flows and requires maintenance/refurbishment. (b) Supports reinstatement of grazing. Previously grazed this riparian area at the top of Payard's Lagoon now has an ungrazed guinea grass understorey presenting a hot fire risk to the remnant vegetation. Fencing infrastructure remains in place, but requires maintenance/refurbishment.
Short description – W4: Revegetation of banks with water edge-shading vegetation integrated with controlled grazing of fire fuel load.
W4 – Full description Landholder is supportive of introducing grazing to this lagoon bank. Has existing grazing on downstream reaches and extension upstream to this area would involve establishment of appropriate fencing. Is also supportive of revegetation of lagoon bank with shade generating overstorey and was interested to considered methods that could be integrated with grazing stock.
Short description – W5: 'In fill' revegetation of lagoon bank to shade out understorey grasses and associated weed and fire risks.
W5 – Full description Landholder is supportive of 'in fill' riparian planting to generate canopy shade to exclude exotic grass understorey and associated weed and fire risks. Suggests maintenance is key to seedling establishment, particularly watering in early establishment stages, and proposed that use of poly tank and pipe trickle system be considered as part of any funded revegetation efforts.

Short description – W6: Reinstatement of controlled grazing of lagoon banks to reduce exotic grass dominance and increase habitat value.
W6 – Full description Landholder is supportive of reinstating grazing on banks of lagoon to control dominance and associated fire fuel load of exotic pasture grasses.
Short description – W7: ‘In fill’ revegetation and reinstatement and extension of controlled grazing across remnant habitat to prevent hot fires.
W7 – Full description Landholder has previously grazed the upper reaches of the Castelanelli Lagoon habitat complex. Fencing infrastructure remains in place and he is keen to reinstate controlled grazing in the upper riparian system. Subject to fencing infrastructure being established and broader landholder support being gained, is also willing to be involved in extending controlled grazing throughout the downstream reaches of the habitat complex to control the growth of pasture grass weeds and to remove the hot fire risk from the remnant vegetation. Is also supportive of ‘in fill’ planting to increase riparian zone shading of the grass understorey within the upper reaches of the lagoon system.
Short description – W8: Regeneration of lagoon by excavation and control of weed infestations and revegetation of shaded riparian zone.
W8 – Full description Landholder is supportive of this degraded lagoon basin being regenerated via excavation and control of weed mats within the lagoon and planting of shade forming riparian vegetation on its margins.
Short description – W9: Trialling of methods to promote and protect water lily growth over pump intakes to shade out submerged duckweed.
W9 – Full description Landholder is keen to investigate means of establishing stands of native water lily above pump intakes to prevent growth of duckweed and associated intake blockages. Would like to trial transplant methods and possible use of floating booms to protect stands from drifting water hyacinth mats.

Table 3. 'Bruce Highway to Toll Road reach'

Sheep Station Creek Management Plan: Map sheet 3 (of 5) 'Bruce Highway to Toll Road reach'
Reach values (V)
Short description – V1: Large lagoon with productive and high value fish and waterfowl habitat and revegetated riparian zone.
V1 – Full description Church's Lagoon is a large water body that has high ecological values associated with highly productive shallow margins and deepwater fish habitats, marginal waterbird habitats and remnant riparian vegetation. It has also been the site of successful riparian revegetation, which has added significantly to the area and complexity/diversity of riparian forest at the site. In recent years the site has been recognised to host large (>1m) barramundi and to support an associated recreational fishery.
Short description – V2: High profile, but degraded, rare seasonal wetland with high value remnant vegetation and waterbird habitat potential.
V2 – Full description This site, referred to as the 'highway wetland', bridges the catchment divide between the Sheep Station Creek catchment to the east and the Barratta Creek catchment to the west. It retains a small, yet high integrity example, of a paperbark swamp forest type extensively cleared for agriculture throughout the region. The site is dominated by a shallow seasonal wetland basin that historically supported large and diverse populations of waterfowl and waterbirds. This shallow basin is now filled with dense cumbungi bullrush stands, which have established under a modified near-perennial hydrological regime caused by irrigation tailwater inflows to the site. The high-profile nature of the site adjoining the highway and its capacity to provide an ambassadorial role for lower Burdekin wetlands add to its value.
Short description – V3: State and regionally-significant woodland/wetland habitat remnant representative of the pre-development landscape.
V3 – Full description Church's Lagoon habitat remnant. This remnant habitat complex has very high value because it is representative of the Ayr/delta land system and at least three associated regional ecosystem types that have been largely developed to agriculture. It includes blue gum open forest on alluvial soils, fringing riparian, and freshwater wetland communities. The condition of the site has been improved in the past decade by the removal of woody weed infestations and the implementation of controlled grazing that has reduced the fire fuel load and the dominance of exotic pasture grasses in the wetland aquatic plant community. Surveys of the site have found a range of vertebrate fauna present, including arboreal mammals (brushtail possums), nesting raptors (wedge-tail and sea eagles) and reptiles (turtles and goannas).
Short description – V4: Remnant habitat node connected to riparian corridor that provides wildlife refuge and part of state-significant wetland.
V4 – Full description Railway habitat node. This site has value as a node of habitat within a remnant habitat network mainly comprised of a narrow riparian corridor. Such nodes are important refuges for vertebrate fauna including birds, mammals and reptiles, and this site includes a mix of canopy and mid-storey species, and associated feeding and nesting resources.
Short description – V5: Diverse and high value remnant vegetation of state significance that provide good fauna habitat.
V5 – Full description

This habitat remnant is a dense structural example of blue gum and paperbark fringing woodland on alluvial soils with a diverse mix of broad leaf canopy species including Leichhardt (*Nauclea orientalis*) trees and cabbage (*Livistona*) palms. In the absence of regular burning, it has developed a dense, complex structure that would provide habitat for cover-dependent species such as owls and a host of reptiles and amphibians, particularly tree frogs. It has been alienated from grazed adjoining area due to excavation of channel, which has created a high fuel load and associated hot fire risk.
Short description – V6: State and regionally significant woodland/wetland habitat remnant with grazing maintained aquatic plant community.
V6 – Full description Landholder's horse paddock. This habitat remnant is another good representative example of the largely developed Ayr/delta land system and includes both fringing eucalypt and melaleuca woodland on alluvial soils and wetland basin communities. Its value is underpinned by its size, habitat diversity and floristic integrity. The latter is related to its long history of use as a horse grazing paddock. Sustained low grazing pressure has limited the dominance of the site by exotic pasture grasses and maintained a diverse suite of native ground covers including native sedges, nardoo and other aquatic plants. The site seasonally supports good diverse populations of waterbirds.
Short description – V7: Large lagoon with productive and high value fish and waterfowl habitat that forms part of state-significant wetland.
V7 – Full description Lando's Lagoon is a large water body that has high ecological values associated with highly productive shallow margins, deepwater fish habitats and marginal waterbird habitats that extend to the adjoining wetland habitat complex referred to as Scott Burke's horse paddock (V6). In recent years the site has been recognised to host large (>1m) barramundi and to support an associated recreational fishery.
Short description – V8: One of largest lagoons in creek system with high value fish and waterfowl habitat and regenerating riparian vegetation.
V8 – Full description Gorizia's Lagoon is one of the largest (longest) lagoons within the Sheep Station Creek system. It has high ecological values associated with highly productive fish habitat, marginal waterbird habitats and remnant riparian vegetation. It has also been the site of successful riparian revegetation, which has added significantly to the riparian forest assemblages at the site. The current condition of the lagoon is a testament to management efforts implemented over the last 20 years which has seen it recover from a state of severe aquatic weed infestation and associated water quality stress to its current relatively healthy ecosystem status.
Management issues (M)
Short description – M1: High grass fuel load and uncontrolled 'hot' fire impacts to revegetated riparian zone.
M1 – Full description Hot fire damage to riparian revegetation. This reach was the site of extensive revegetation conducted almost two decades ago (~2002). In recent years uncontrolled burning of large exotic pasture (guinea grass) fuel loads has resulted in significant damage to the established vegetation, including the death of some trees and major reduction in canopy health of others. While demonstrated in outcomes on this reach, this management issue is ubiquitous throughout the catchment. Subject to reach conditions, appropriate management interventions to address it include: extension to landholders regarding hot fire impacts to riparian vegetation, dense

riparian planting and regeneration interplanting to shade understory grasses, use of controlled grazing to reduce fire fuel loads, and implementation of controlled 'cool' burning regimes.
Short description – M2: Irrigation tailwater inflow to seasonal wetland resulting in loss of drying cycle, weed invasion and loss of habitat values.
M2 – Full description Irrigation tailwater inflow to seasonal wetland. This high value seasonal wetland basin acts as a receiving sump for irrigation tailwater running off cane land in its catchment. The near perennial inflow of water to the site and the subsequent loss of its historically-seasonal hydrology has resulted in the dominance of the site by cumbungi bull rush and the loss of native aquatic plants that historically provided high value waterbird feeding and nesting resources. Appropriate management interventions to address this issue could include increased irrigation water use efficiency on adjoining farms, the construction of tailwater recycling pits to intercept inflows, and/or construction of a controlled outlet level drain from the site.
Short description – M3: Mill effluent with high biological oxygen demand (BOD) inflow to creek system.
M3 – Full description Mill effluent inflow. This site receives sugar mill cooling water effluent with a high biological oxygen demand (BOD) that creates mats of sulphitic bacteria indicative of anoxic (without oxygen) environments at the discharge point. Although observed volumes are small relative to the receiving water body, inflows would add additional water quality stress to the creek system, particularly when already under pressure due to aquatic weed infestations. While there is approximately 600m of receiving creek/lagoon reach upstream of the discharge point, the poor condition of the reach including dense weed infestations create an anoxic environment that result in the quality of the effluent being unimproved prior to its discharge to the creek system. Appropriate management interventions to address this issue could include diversion of flows to dedicated retention/treatment areas or improvement of receiving reach conditions, for example, weed removal to promote oxygenation and biological treatment of the effluent prior to reaching the creek discharge point.
Short description – M4: Summer wet season fish kills due to low oxygen levels generated by decomposing vegetation and lack of flushing flows.
M4 – Full description Wet season fish kills. This lagoon and other upstream and downstream of it regularly experience wet season/summer fish kills. These kills are associated with low dissolved oxygen levels exacerbated by aquatic weed covering of surface water, inundation and decomposition of grassy margins and instream aquatic plants during wet season high flows and by sediment/nutrient loads carried in wet season rainfall runoff from the catchment. Appropriate management interventions to address this issue could include effective aquatic weed control prior to the wet season, reductions in grassy margin biomass by grazing, riparian shading, and/or controlled burning prior to the wet season, reduction in instream aquatic plant density by riparian shading or pulses of turbid water prior to the wet season, lowering water temperature and increasing its oxygen carrying capacity via more extensive riparian vegetation shading, and implementation of refreshing pumped environmental flows of Burdekin river water to the creek system during the wet season period.
Landholder identified works (W)
Short description – W1: 'In fill' revegetation to reduce understorey grass fuel load and trial 'cool' winter burns.
W1 – Full description

‘In fill’ planting of site damaged by hot fire. This reach was revegetated almost two decades ago and, where a closed canopy condition has been achieved, the risk of hot fire has been substantially reduced by the reduction of grass biomass in the understorey. At this site (and adjoining sites) a hot dry season fire has damaged the canopy cover resulting in increased grass density and associated fire risk. Targeted ‘in fill’ planting of canopy producing species is proposed to reduce future fire risks to the vegetation and adjoining farm areas. The landholder has also expressed a willingness to trial ‘cool’ winter-controlled burns.
Short description – W2: Proposed straightening of creek channel and riparian revegetation to stabilise outside bank erosion vulnerability.
W2 – Full description Straightening of erosional bend in creek channel via excavation of straight channel cut and associated riparian revegetation of bank batter and levee. The bend in this reach of the creek channel is presenting a bank erosion concern to the landholder over possible ultimate loss of farmland due to erosion. His proposed works solution is to excavate a straight channel cut across the inside bend and to stabilise the outer bank with revegetation of the bank batter and levee. Such works would be subject to departmental approval to work within a water course and should also entail a geomorphic assessment of whether bank erosion risks would be transferred further down the system by proposed channel straightening.
Short description – W3: Excavate cumbungi and re-establish open water habitat and fill in planting of riparian vegetation.
Full description – W3 Excavate cumbungi and re-establish open water habitat and fill in planting of riparian vegetation. This shallow back water of Church's Lagoon has become dominated by cumbungi due to the loss of seasonality associated with the use of the creek system for conveying regulated flows for irrigation and groundwater recharge. This cumbungi-dominated area has low wetland habitat values and provides breeding areas for mosquitoes. Proposed works would entail excavating the cumbungi to create a deeper open water habitat and using the spoil to create a levee for extra riparian vegetation establishment.
Short description – W4: Excavation of shallow lagoon margins to form bank edge for revegetation with shade generating riparian forest.
W4 – Full description Excavate shallow lagoon margins and revegetation eastern bank of Church's Lagoon including borrow pit on northern end. Proposed works are to replicate the revegetation achieved on the western bank of the lagoon on the eastern bank. As opposed to the steep western bank the eastern bank is shallow and poorly defined and it is proposed that excavation be conducted initially to deepen the eastern margin of the lagoon to reduce weed infestation potential and to create a more defined bank for revegetation. The landholder has also proposed that, rather than revegetating in one continuous linear corridor, the revegetation be progressed as nodes that could be more easily managed for weeds and associated fire risks.
Short description – W5: ‘In fill’ revegetation of stream bank, woody weed control follow up and extension of controlled grazing to other sites.
W5 – Full description ‘In fill’ planting of riparian forest margins, support with woody weed control and expansion of grazed area. The improved condition of this high value habitat remnant can largely be attributed to the efforts of the current grazing lessee who has invested in woody weed control and maintained managed grazing pressure on the site. Given the habitat and associated community benefits of improved condition of the site, the landholder would welcome support with ongoing woody weed control targeting the seven-year

seed germination cycle of chinee apple. He has fenced off the immediate riparian frontage and would welcome 'in fill' planting to increase bank shading and stabilisation. With Lower Burdekin Water support, he would also like to extend his grazing area to include the peninsula projecting into the northern end of Church's Lagoon. The landholder is also willing to be engaged in grazing agistment arrangements to provide controlled grazing or riparian areas elsewhere within the creek system.
Short description – W6: Establish fencing to support controlled agistment grazing to reduce fuel load and hot fire risk.
W6 – Full description Fence and control graze habitat remnant to reduce hot/uncontrolled fire risk. This habitat remnant has been the site of uncontrolled hot fires in the past. Not only have these fires degraded the condition of the habitat remnant, but they have also resulted in damage to adjoining Queensland Rail bridge infrastructure. If funding support can be obtained to establish fencing, the landholder has indicated they would welcome an agistment arrangement to provide grazing-based control of the site's pasture grass understorey and associated fire fuel loads.
Short description – W7: Revegetate riparian zone to shade out grass weeds, stabilise bank and protect adjoining farms from flood breakouts.
W7 – Full description Revegetate bank with dense canopy-forming riparian species to shade our para grass, stabilise bank erosion and slow flood breakout flows. Remnant riparian vegetation along the half kilometre reach downstream of the Queensland Rail bridge is degraded and reduced to single widely spaced trees, which allow dense para grass stands to develop creatin weed risks to the waterway and adjoining cane paddocks. Spray based control of this grass creates bank erosion risks. Dense canopy planting along this reach using species such as Leichardt and paperbark trees would effectively shade out para grass and stabilise the bank and provide some protection to adjoining paddocks during high flow events. Excavator access for channel weed control is provided on the opposite bank along this reach.
Short description – W8: Construct crossing on stream channel and establish fencing to support controlled grazing of remnant vegetation.
W8 – Full description Provide stock access to swamp forest remnant and establish required fencing to allow grazing-based control of grass understorey fire fuel load. This high value remnant occurs on the landholder's land, but has been alienated from grazing conducted on his adjoining land holdings by a channel excavated to improve flow through the reach. The ungrazed pasture grasses at this site now generate a large fire fuel load and has resulted in uncontrolled hot fires over the last decade impacting the condition of the remnant vegetation and presenting risks to adjoining farm areas. Construction of a culvert causeway, or equivalent, across the channel, or alternatively, delivery of stock to the remnant vegetation via the eastern side of the system would facilitate grazing-based control of the site's pasture grass understorey and associated fire fuel loads. Landholders on both sides of the remnant vegetation stand have indicated support for introducing grazing to the site.
Short description – W9: Establish fencing to support controlled agistment grazing to reduce para grass dominance of lagoon margins.
W9 – Full description Fence and control graze para grass-dominated lower banks and silt spits within lagoon to reduce anchorage points for lagoon infestation, dry season hot/uncontrolled fire risk and pest harbourage. While the landholder has no direct interest in managing

grazing stock, if funding support can be obtained to establish fencing, the landholder has indicated he would welcome an agistment arrangement to provide grazing-based control of the lagoon's para grass infestations.

Table 4. 'Western branch – Toll Road to tidal reach'

Sheep Station Creek Management Plan: Map sheet 4 (of 5) 'Western branch – Toll Road to tidal reach'
Reach values (V)
Short description – V1 Floodplain swamp forest remnant assessed of state and regional biodiversity significance that contains 'of concern' regional ecosystems.
V1 – Full description This area of remnant vegetation is representative of regional ecosystems that were once widespread across well-watered alluvial landforms of Burdekin floodplain prior to development. Consequently, it could be expected to provide habitat and support fauna populations that are under ecological pressure in the broader regional landscape. These habitat types are not well represented in the adjoining National Park. Appropriate management investments at this site could include fauna survey, weed management and dedicated burning and grazing regimes and enhancement of site conservation values via revegetation of adjoining areas.
Short description – V2: One of longest lagoons in system with high fish and waterbird habitat values and clear water quality.
V2 – Full description Jack's Lagoon is one of the longer lagoons within the Sheep Station Creek system. It has ecological values associated with highly productive fish habitat, marginal waterbird habitats, instream aquatic plant communities, and clear water quality. Identified as significant wetlands within area of state significance (DES Biodiversity Planning Assessment), which includes 'of concern' regional ecosystems that have a very high ecosystem value to bioregion. Being in the downstream reaches of the creek system, it experiences greater water clarity than upstream systems which are closer to the source of often turbid Burdekin River water pumped into the uppermost reach of the creek system. This water undergoes filtration via attenuation of fine colloids to instream plant communities as it moves downstream. Most of the lagoon is also subject to riparian grazing by cattle, which serves to limit the invasion of aquatic pasture grasses onto the water surface supporting the sustained persistence of native water lilies and submerged aquatic plant. Appropriate management considerations for this lagoon include control of aquatic weeds, revegetation of fringing riparian communities and improvements of fish passage/connectivity to lower estuarine reaches.
Short description – V3: State and regionally significant, good condition and diverse coastal plain woodland and wetland habitat complex
V3 – Full description High value, good condition coastal plain woodland and wetland habitat complex assessed to be of state and regional significance (DES Biodiversity Planning Assessment). Contains a high diversity of regional ecosystems, including those listed 'of concern' and having very high value as a wildlife refugia. This remnant habitat complex sits on a bifurcation of the Sheep Station Creek main channel and is representative of regional ecosystems that were once widespread across well-watered alluvial landforms of the coastal plain prior to clearing for pastoral development. Consequently, it could be expected to provide habitat and support (EVNT) fauna populations that are under ecological pressure in the broader regional landscape. These habitat types are not well represented in the adjoining national park.

Appropriate management investments at this site could include fauna survey, weed and feral animal management and dedicated burning and grazing regimes.
Short description – V4: Key woodland and forest remnants of coastal distributary drainage network in area of state biodiversity significance.
V4 – Full description (a, b, c, d & e) – Coastal plain woodland and forest vegetation remnants within distributary drainage network of lower creek system. Identified as key remnants within area of state significance (DES Biodiversity Planning Assessment), these wooded habitat remnants are representative of regional ecosystems that were once widespread across well-watered alluvial landforms of the coastal plain prior to clearing for pastoral development. They contribute to the high ecosystem diversity of the landscape, have very high wildlife refugia values, include 'of concern regional ecosystem' and provide habitat for endangered, vulnerable and near threatened fauna (EVNT). These habitat types are not well represented in the adjoining national park. Appropriate management investments at this site could include fauna survey, weed and feral animal management and dedicated burning and grazing regimes.
Short description – V5: State significant wetlands distal from irrigation tailwater inflows that retain seasonality and native plant dominance.
V5 – Full description (a, b, c & d) – Seasonal wetlands isolated and/or distal from irrigation system tailwater inflows retaining dominance of native aquatic plant communities and high wetland habitat values, including for waterbirds. Identified as significant wetlands within area of state significance (DES Biodiversity Planning Assessment). Within the coastal plain, many freshwater wetland systems of the lower creek catchment have been hydrologically modified by bunding and artificial aseasonal inflows of water from the irrigation supply system. Where wetlands remain more isolated from artificial inflows, they retain grater seasonality representative of their predevelopment condition. This results in less invasion by exotic pastures and weedy native species and they maintain a seasonal, though productive, aquatic plant community and water quality conditions suited to supporting dependent biota, including birds and fish. Appropriate management considerations for such sites include retention of existing hydrological isolation and potentially dedicated grazing regime in conjunction with its use by dependent fauna. Such sites also have value as a historical baseline equivalent for guiding management efforts that could seek to replicate the condition outcome on other sites and systems.
Short description – V6: State significant brackish swamps with 'bulkuru' sedge communities with high waterbird and fish nursery habitat values.
V6 – Full description (a, b, c, d & e) – Terminal brackish swamps supporting *Eleocharis* 'bulkuru' sedge communities with high waterbird habitat values and potential fish nursery habitat values. Identified as significant wetlands within area of state significance (DES Biodiversity Planning Assessment). The most downstream freshwater wetlands within the bunded coastal drainage depressions of the lower catchment occur on marine clays with a high salt content. Some are also subject to limited tidal inflows. Consequently, most have brackish water conditions for extended periods of the year and support bulkuru sedge communities adapted to seasonally brackish water regimes. These sedge communities are limited in extent in the post-settlement landscape and are known to be important

feeding and breeding habitats for waterbirds and – where connected to estuarine reaches with suitable water quality – high value fish nursery habitat including for barramundi. Appropriate management efforts for these sites include surveys to ascertain their existing hydrological and water quality conditions, including connectivity to the estuary, and fish and fauna surveys to document existing habitat values. Such surveys could inform further management initiatives including works to manipulate site hydrology and estuarine connectivity.
Management issues (M)
Short description – M1: Summer fish kills due to low oxygen levels linked to respiring duckweed, high water temps and lack of freshening flows.
M1 – Full description High water clarity and lack of fringing riparian vegetation shade leading to extensive submerged aquatic plant (duckweed – *Ceratophyllum*) growth, low dissolved oxygen levels and associated fish kills in summer. Lagoon basins of the lower creek system experience much greater water clarity than upper catchment sites. This, along with a lack of riparian vegetation shading, promotes extensive submerged aquatic plant growth. In warmer summer conditions when dissolved oxygen (DO) carrying capacity of water is lower, the additional oxygen demand caused by respiring submerged vegetation results in DO sags below levels required to maintain fish populations, leading to fish kills. Management options that could be examined in relation to this issue include the role of riparian zone revegetation in lowering water temperatures and decreasing aquatic plant biomass within the lagoon, and possibly the use of pumped environmental flows of turbid Burdekin River flood water for reducing submerged plant biomass and increasing lagoon dissolved oxygen levels.
Short description – M2: Stream road crossing culvert that acts as fish passage barrier under some flow conditions.
M2 – Full description (a-c) Throughout this mapped reach there are several stream road crossing culverts with or without water control structures that, under some flow conditions, act as fish passage barriers downstream of high value fish habitat. To achieve the aspirational goal of providing migratory fish access to the most upstream high value habitats, these culverts should be subject to assessment and prioritised rectification works. This possibly includes retrofitting flow velocity reducing structures within culverts and the placement of flow gradient reducing rock ramp structures below them.
Short description – M3: Shallow lagoon reach prone to permanent aquatic weed infestation and creation of water quality fish passage barrier.
M3 – Full description (a & b) – Shallow lagoon basins in lowermost creek reaches, unsuited to weed harvester operations and prone to perennial aquatic weed infestations and associated poor water quality. This lower reach of the creek system has presented an insurmountable weed management challenge, although it has been cleared of aquatic weeds in some years. Weed mats that establish and accumulate in this reach, assisted by rooted aquatic grasses and sedges, persist even through medium wet season flows present a water quality barrier for migratory fish and result in low wetland habitat values. Management considerations for this issue could include a more concerted weed control effort involving specialised machinery (amphibious excavator) and integrated spraying operations, extensive bankside revegetation to shade out aquatic grass anchor points, and possibly the mitigation of poor water quality via dedicated environmental flows.

Short description – M4: Weed-free distributary channels potential alternate fish passage route around cumbungi-infested main channel.
M4 – Full description (a & b) – Potential alternate wet season fish passage/migration pathways via seasonal weed free distributary channels as an alternative to the cumbungi-infested main creek distributary channels. Effective fish passage from the estuarine reaches of the creek system to productive freshwater fish habitats in the upper catchment is essential for a large number (>10) of catadromous (estuarine breeding) fish species (including barramundi) to be able to naturally recruit and persist in the creek system. While the weed infestation and water quality issues of the main creek channel remain insurmountable, the possibility exists to provide a circumventing alternate fish passage corridor via better condition distributary channels that could be connected by wet season flow events with or without complementary management measures (i.e. dedicated flows, flow diversion structures). At least two potential alternate fish passage corridors via distributary channels have been identified in the western branch (options a & b). These channel systems are highly seasonal and weed-free and would potentially have better wet season water quality. To explore this management option further, initial investigations should be directed at the existing water quality status within these channel systems, particularly during the wet season. The fish community that occurs within them during the wet season could also be sampled to ascertain if there is any evidence of catadromous species recruiting into their lower reaches.
Short description – M5: Cumbungi infestation, water quality and fish passage impacts due to aseasonal inflows to bunded coastal wetlands.
M5 – Full description (a, b, c, d & e) – Water board scheme tailwater flows to coastal swamp/bunded drainage depression channel network resulting in reduced seasonality of wetlands, cumbungi and other aquatic weed infestation, low habitat values, poor water quality and fish passage barriers. Operational inefficiencies in the water distribution network result in significant tailwater volumes surplus to irrigation needs being discharged to wetlands on the coastal plain downstream of agricultural areas. Historically, these once seasonal wetlands were bunded by constructed earthen walls to increase their water holding capacity to provide a source of water and ponded pasture forage for cattle grazing operations. Under seasonal hydrological conditions, cattle grazing provided an effective means of reducing the standing biomass of pasture and created a relatively clean open channel with limited organic biomass with facilitated effective fish passage through the channel network when inundated by wet season high flow events. Sustained grazing pressure also ensured that exotic pastures did not obtain dominance over the native seasonal aquatic plant community. With the advent of sustained inflows of tailwater, deeper areas of the drainage depressions have become infested with perennial stands of cumbungi bullrush and sedges. In shallower wetland basins exotic pasture dominance has also increased to the benefit of grazing operations, yet to the detriment of wetland habitat values, water quality and fish passage. Management options that could restore ecological values and functions to this coastal wetland system could include greater water efficiencies in irrigation supply operations resulting in reduced tailwater inflows; enhanced wetland seasonality, including a greater drying period potentially via alternating flow diversion between channel networks or constructing an upstream bund control structure; and dedicated weed control, possibly including spraying, targeted excavation and controlled reinstatement of tidal inflows in lower reaches.
Short description – M6: Status of wet season connectivity, water quality and fish community at estuarine interface with lowermost bund walls.

M6 – Full description (a, b, c, d, e, f, g, h & i) – Status of wet season hydrological connectivity and water quality at interface between tidal estuarine reaches and lowermost bund walls on coastal plain wetland systems. Natural movement and recruitment of estuarine breeding freshwater fish from tidal reaches to upper Sheep Station Creek has not been demonstrated since the early 1990s. While fish passage barriers created by weed infestation and associated poor water quality are recognised to be the most likely cause, the wet season connectivity and water quality cues present at the interface between tidal estuarine reaches and lowermost bund walls on coastal plain wetland systems could also be an operating issue. Management investigations involving wet season sampling of the water quality conditions and fish community present at the outflows of the lowermost bund walls and the grade, flow velocities, depth and other hydrological conditions of the connective flows between the bunded systems and lower tidal reach would inform whether fish passage issues occur these sites and – if so – help identify potential rectification options. Sampling of water quality condition conditions at these sites will also help identify the viability of alternative fish migration pathways and contrast water quality at outlets downstream of cumbungi-infested reaches (M6, g & f), versus downstream of relatively open creek channel (M6, h & i), and versus downstream of seasonal coastal drainage depressions (M6, a, b, c, d & e).
Landholder identified works (W)
Short description – W1: Revegetation of lagoon bank with shade generating riparian forest.
W1 – Full description Landholder is supportive of riparian frontage revegetation along ~250m lagoon frontage of farm block on low alluvial terrace adjoining lagoon. Seeks dense planting to shade out weedy grasses and to cast shade over edge of water body.

Table 5. 'Eastern branch – Jack Road to tidal reach'

Sheep Station Creek Management Plan: Map sheet 5 (of 5) 'Eastern branch – Jack Road to tidal reach'
Reach values (V)
Short description – V1: State and regionally significant coastal woodland/wetland habitat complex with 'of concern' regional ecosystems.
V1 – Full description High value coastal plain woodland and wetland habitat remnant assessed to be of state and regional significance (DES Biodiversity Planning Assessment) and to contain regional ecosystems 'of concern'. This remnant habitat complex is representative of regional ecosystems that were once widespread across well-watered alluvial landforms of the coastal plain prior to clearing for pastoral development. Consequently, it could be expected to provide habitat and support fauna populations that are under ecological pressure in the broader regional landscape. These habitat types are not well represented in the adjoining national park. Appropriate management investments at this site could include fauna survey, weed and feral animal management and dedicated burning and grazing regimes.
Short description – V2: Coastal wetlands isolated from tailwater retaining seasonality, native plant dominance and waterbird habitat values.
V2 – Full description (a & b) – Seasonal wetland more isolated from irrigation system tailwater inflows retaining dominance of native aquatic plant communities and high wetland habitat values, including for waterbirds. Within the coastal plain freshwater wetland systems of the lower creek catchment, most have been hydrologically modified by bunding and artificial aseasonal inflows of water from the irrigation supply system. Where wetlands remain more isolated from artificial inflows they retain grater seasonality representative of their predevelopment condition. This results in less invasion by exotic pastures and weedy native species and they maintain a seasonal though productive aquatic plant community and water quality conditions suited to supporting dependent biota, including birds and fish. Appropriate management considerations for such sites include retention of existing hydrological isolation and potentially dedicated grazing regime in conjunction with its use by dependent fauna. Such sites also have value as a historical baseline equivalent for guiding management efforts that could seek to replicate the condition outcome on other sites and systems.
Short description – V3: State significant brackish swamps with bulkuru sedge communities with high waterbird and fish nursery habitat values.
V3 – Full description (a, b & c) – Terminal brackish swamps supporting *Eleocharis* bulkuru sedge communities with high waterbird habitat values and potential fish nursery habitat values. The most downstream freshwater wetlands within the bunded coastal drainage depressions of the lower catchment occur on marine clays with a high salt content. Some are also subject to limited tidal inflows. Consequently, most have brackish water conditions for extended periods of the year and support bulkuru sedge communities adapted to seasonally brackish water regimes. These sedge communities are limited in extent in the post-settlement landscape and are known to be important feeding and breeding habitats for waterbirds, plus have a high value fish nursery habitat (including for barramundi) where connected to estuarine reaches with suitable water quality.

Appropriate management efforts for these sites include surveys to ascertain their existing hydrological and water quality conditions, including connectivity to the estuary, and fish and fauna surveys to document existing habitat values. Such surveys could inform further management initiatives, including works to manipulate site hydrology and estuarine connectivity.
Management issues (M)
Short description – M1: Perennially-inundated drainage depressions creating cumbungi-infestation, water quality and fish passage impacts.
M1 – Full description Cumbungi and aquatic weed infestation associated with perennial wetness of drainage depressions resulting in poor water quality, low habitat values and chemical and physical fish passage barriers. Throughout this branch of Sheep Station Creek the natural drainage network is comprised of shallow drainage depressions. Under the modified hydrological conditions created by their use for water distribution, they are perennially inundated. This is in contrast to the seasonal drying they experienced historically under natural conditions. As a consequence, they have become infested with thick stands of cumbungi bull rush along with other weedy native aquatic plants (e.g. sedges and rice grass), floating aquatic weeds (e.g. water hyacinth, water lettuce and salvinia) and exotic pasture grasses (e.g. para, hymenachne and aleman). The resulting weed infestation has very low habitat value and has created a thick mat of semi-buoyant organic material that blocks flows; has a high 'biological oxygen demand' (BOD) that creates insitu deoxygenated water, which forms a chemical and physical fish passage barrier; and is exported to downstream receiving environments during high flow events. While the system status quo is functionally meeting the needs for water distribution, there are issues with its efficiency and with its poor ecological function and values. Potential management options that could address these issues including excavation/clean out of drainage depressions, channel isolation and seasonal drying warrant dedicated investigation.
Short description – M2: Potential provision of effective fish passage through lower creek system via the excavated channel network.
M2 – Full description Potential of management measures to facilitate effective fish passage through the lower creek system, including to estuarine reaches via the excavated channel network. A network of excavated channels has been constructed and maintained to provide a conduit for irrigation water throughout the lower eastern branch of Sheep Station Creek. During operational flows, these channels provide the only effective connectivity for fish movement through this branch of the creek system, though flow gates still present some barriers. In the absence of operational flows (i.e. in the wet season) when irrigation water is not required, water quality within the channels is overwhelmed by the poor water quality of the adjoining hydrologically-connected weed-infested drainage depressions. During channel-inundating wet season high flow events, water quality through the reach is similarly impacted by the high biological oxygen demand of its extensive weed infestations. There is some historical evidence that major flood events involving Burdekin River breakouts across the floodplain may dilute the poor water quality sufficiently to facilitate fish passage. The ability of dedicated management measures (e.g. environmental flows, channel isolation, physical barrier removal, connection to weed free lower distributary networks) to improve fish connectivity through this channel network, including during the critical wet

season fish migration period, warrants further investigation. Potentially this could provide a fish passage pathway pass the weed-infested reaches of the lower creek system.
Short description – M3: Cumbungi infestation, water quality and fish passage impacts due to seasonal inflows to bunded coastal wetlands.
M3 – Full description Water board scheme tailwater flows to coastal swamp/bunded drainage depression network resulting in reduced seasonality of wetlands, aquatic weed infestation, lower habitat values, poorer water quality and reduced fish passage. Operational inefficiencies in the water distribution network result in significant tailwater volumes, surplus to irrigation needs, being discharged to wetlands on the coastal plain downstream of agricultural areas. Historically, these once-seasonal wetlands were bunded by constructed earthen walls to increase their water-holding capacity to provide a source of water and ponded pasture forage for cattle grazing operations. Under seasonal hydrological conditions, cattle grazing provided an effective means of reducing the standing biomass of pasture and created a relatively clean open channel with limited organic biomass with facilitated effective fish passage through the channel network when inundated by wet season high flow events. Sustained grazing pressure also ensured that exotic pastures did not obtain dominance over the native seasonal aquatic plant community. With the advent of sustained inflows of tailwater, exotic pasture dominance has increased to the benefit of grazing operation but to the detriment of wetland habitat values, water quality and fish passage. Management options that could restore ecological values and functions to this coastal wetland system could include greater water efficiencies in irrigation supply operations, resulting in reduced tailwater inflows; enhanced wetland seasonality, including a greater drying period, potentially via alternating flow diversion between channel networks or bund control structure; and dedicated weed control, including possibly by reinstatement of tidal inflows in lower reaches.
Short description – M4: Weed-free distributary channels potential alternate fish passage route around cumbungi-infested main channel.
M4 – Full Description (a, b & c) – Potential to use more seasonal, less weed-infested, distributary channels as an alternative to the main creek channel as a conduit for wet season fish passage. Effective fish passage from the estuarine reaches of the creek system to productive freshwater fish habitats in the upper catchment is essential for a large number (>10) of catadromous (estuarine breeding) fish species, including barramundi, to be able to naturally recruit and persist in the creek system. While the weed infestation and water quality issues of the main creek channel remain insurmountable, the possibility exists to provide a circumventing alternate fish passage corridor via better condition distributary channels that could be connected by wet season flow events with or without complementary management measures (i.e. dedicated flows, flow diversion structures). At least three potential alternate fish passage corridors via distributary channels have been identified in the eastern branch (options a, b & c). These channel systems currently retain a less weedy and potentially better water quality status on account of receiving less irrigation tailwater inflows and retaining greater seasonality. To explore this management option further, initial investigations should be directed at the existing water quality status within these channel systems, particularly during the wet season. The fish community that occurs within them could also be sampled to ascertain if there is any evidence of catadromous species recruiting into their lower reaches.

Short description – M5: Status of wet season connectivity, water quality and fish community at estuarine interface with lowermost bund walls.
M5 – Full description (a, b, c, d, e, f, & g) – Status of wet season hydrological connectivity and water quality at interface between tidal estuarine reaches and lowermost bund walls on coastal plain wetland systems. Natural movement and recruitment of estuarine breeding freshwater fish from tidal reaches to upper Sheep Station Creek has not been demonstrated since the early 1990s. While fish passage barriers created by weed infestation and associated poor water quality are recognised to be the most likely cause, the wet season connectivity and water quality cues present at the interface between tidal estuarine reaches and lowermost bund walls on coastal plain wetland systems could also be an operating issue. Management investigations involving wet season sampling of the water quality conditions and fish community present at the outflows of the lowermost bund walls; and the grade, flow velocities, depth and other hydrological conditions of the connective flows between the bunded systems and lower tidal reach; would inform whether fish passage issues occur at the seven such sites (4a through to 4g) on the eastern branch. And, if so, help identify potential rectification options.

> Appendix 3 – Management plan map sheets (5) separate attachments

Map sheet 1 (of 5) ‘Rocks to Waterview Road reach’

Map sheet 2 (of 5) ‘Waterview Road to Bruce Highway reach’

Map sheet 3 (of 5) ‘Bruce Highway to Toll Road reach’

Map sheet 4 (of 5) ‘Western branch – Toll Road to tidal reach’

Map sheet 5 (of 5) ‘Eastern branch – Jack Road to tidal reach’