Water resource assessment for the Southern Gulf catchments

A report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid

Editors: Ian Watson, Caroline Bruce, Seonaid Philip, Cuan Petheram and Chris Chilcott

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CSIRO Southern Gulf Water Resource Assessment acknowledgements

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The Assessment was guided by two committees:

i. The Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland Department of Regional Development, Manufacturing and Water

ii. The Southern Gulf catchments Steering Committee: Amateur Fishermen's Association of the NT; Austral Fisheries; Burketown Shire; Carpentaria Land Council Aboriginal Corporation; Health and Wellbeing Queensland; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Prawn Fisheries; Queensland Department of Agriculture and Fisheries; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Regional Development, Manufacturing and Water; Southern Gulf NRM

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to their release.

This report was reviewed by Mr Mike Grundy (Independent consultant). Individual chapters were reviewed by Dr Peter Wilson, CSIRO (Chapter 2); Dr Andrew Hoskins, CSIRO (Chapter 3); Dr Brendan Malone, CSIRO (Chapter 4); Dr James Bennett, CSIRO (Chapter 5); Dr Nikki Dumbrell, CSIRO (Chapter 6); Mr Darran King, CSIRO (Chapter 7). The material in this report draws largely from the companion technical reports, which were themselves internally and externally reviewed.

For further acknowledgements, see page xxviii.

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo

Saltwater Arm, a tributary of the Albert River. This view typifies the tidal rivers and estuaries along the southern coast of the Gulf of Carpentaria. Source: Shutterstock

7 Ecological, biosecurity, off-site and irrigation-induced salinity risks

Rob Kenyon, Rocio Ponce Reyes, Danial Stratford, Linda Merrin, Lynn Seo, Matt Gibbs, Simon Linke, Justin Hughes, Heather McGuinness, Ian Watson, Cuan Petheram, Peter Zund, John Virtue, Katie Motson

Chapter 7 discusses a range of potential risks to be considered before establishing a greenfield agriculture or aquaculture development. These include ecological implications of altered flow regimes, biosecurity considerations, irrigation drainage and aquaculture discharge water, and irrigation-induced salinity.

The key components and concepts of Chapter 7 are shown in Figure 7-1.

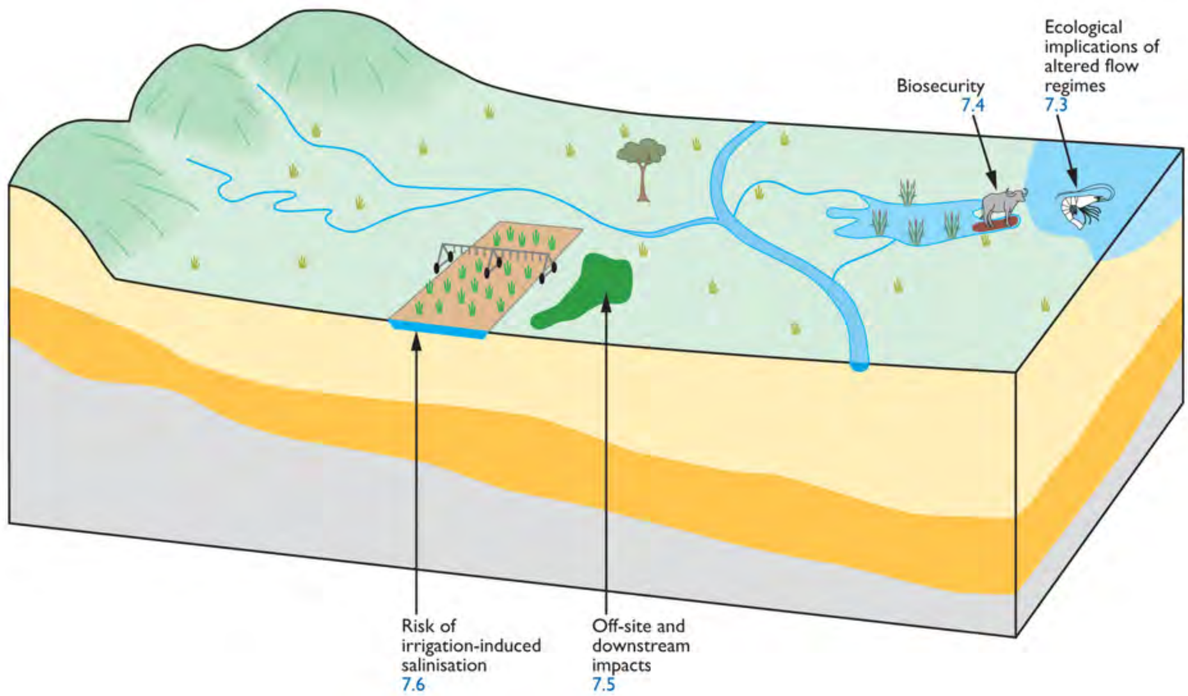

Figure 7-1 Schematic diagram of the components where key risks can manifest when considering the establishment of a greenfield irrigation or aquaculture development

Numbers in blue refer to sections in this report.

7.1 Summary

This chapter provides information on the ecological, biosecurity, off-site and downstream impacts and irrigation-induced salinity risks to the catchments of the Southern Gulf rivers – that is, Settlement Creek, Gregory–Nicholson River and Leichhardt River, the Morning Inlet catchments and the Wellesley island groups[1] – from greenfield agriculture or aquaculture development. It is principally concerned with the risks from these developments to the broader environment but also considers biosecurity risks to the enterprises themselves.

The ecological impacts of vegetation clearing associated with irrigated agriculture are not explicitly examined in the Assessment as it is considered of secondary concern to potential impacts on water dependent ecological assets. This is because irrigated agriculture occupies a very small proportion of the landscape (typically less than 0.5%) but can result in a disproportionately high degree of regulation of river flow. Consequently, the Assessment placed greatest effort in understanding the potential ecological impacts of changes in streamflow on aquatic dependent ecosystems.

7.1.1 Key findings

Ecological implications of altered flow regimes

The freshwater, terrestrial and near-shore marine zones of the Southern Gulf catchments contain important and diverse species, habitats, industries and ecosystem functions supported by the patterns, volumes and quality of river flows. Although irrigated agriculture only occupies a small percentage of the landscape, changes in the flow regime can have profound effects on flow-dependent flora and fauna, their habitats and ecosystem service provision. These effects may extend considerable distances onto the floodplain and downstream, including into the marine environment.

Hypothetical future scenarios for water harvesting, instream dams and groundwater development produced a range of water volumes and patterns of flow with a variety of impacts on ecology. The findings are summarised below:

- The level of impact resulting from water resource development was highly dependent on the type of development, the extraction volume and the mitigation measures implemented. For most assets, water extraction had negligible to minor impacts on key aspects of river flows.
- Large instream dams had a greater mean impact on surface-flow-dependent ecology averaged across the Southern Gulf catchments than did water harvesting. Large instream dams resulted in significantly larger local impacts on flow ecology in reaches below the dam wall than did water harvesting. A dam on the perennial Gregory River had major impacts on downstream flows that were important to several species or groups, while a dam on Gunpowder Creek, a major tributary of the Leichhardt River, had negligible to minor impacts on important flows for most assets.

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[1] Only those islands greater than 1000 ha are mapped

- Mitigation measures can reduce the negative impacts of flow modification on catchment ecology and key biota by maintaining aspects of flow that have been identified as critical to ecosystem service provision. Mitigation strategies, such as transparent flows (environmental flows that pass the dam wall) from dams that mimic historical flow patterns, guaranteed annual end-of-system flow volume prior to water extraction, and river flow pump-initiation thresholds below which water extraction cannot occur have been identified as effective in reducing risks.

Water harvesting outcomes were sensitive to the volume of extraction. Mitigation measures also changed ecology outcomes across the Southern Gulf catchments, with mitigation reducing the effect on flows from moderate to minor, or minor to negligible. Harvesting 50 to 300 GL of water resulted in negligible to minor changes to most asset means across the catchments with impacts often accumulating downstream past multiple extraction points. Threadfin, prawn species, mud crabs and mullet were among the ecological assets most affected by flow change for water harvesting (moderate change). For low water harvest extraction volumes, suitable levels of end-of-system flow requirements, commence-to-pump thresholds and pump rates improved mean outcomes across ecological assets and negligible change at catchment scales. Mitigation strategies demonstrate the importance of protecting minimum flows and annual 'first flows' for many of the ecological assets and that deployment of mitigation has considerable potential to reduce impacts on water-dependent ecosystems.

For instream dams, the location of the dam in the catchment matters as there is potential for extreme risks of local impacts. Improved outcomes were associated with maintaining attributes of the natural flow regime via the provision of transparent flows. A single dam on either Gunpowder Creek or the Gregory River resulted in negligible to minor (respectively) mean change to assets flows at the catchment scale, but local impacts were often with considerably higher and reached extreme levels. Mangroves, mullet, cryptic wader birds, prawns and mud crabs were among the ecological assets most affected by instream dams. Providing transparent flows (environmental low-flows) improved flow regimes for ecological service provision at both local and catchment scales: mean outcomes for mangroves could be improved from major to moderate mean change, and outcomes for catfish, cryptic wader birds and inchannel waterhole assets from moderate to minor mean change across the catchment.

Beyond flow, other impacts and considerations are also important. At catchment scales, the direct impacts of irrigation on the terrestrial environment are typically small. However, indirect impacts, such as weeds, pests and landscape fragmentation, particularly to riparian zones, and changes in fire regimes may be considerable. Changes in water quality may also affect ecology but are not considered in the quantitative analysis. The combined changes of a potentially drier future climate and hypothetical water resource development produced greater impacts than did each factor on its own.

Biosecurity considerations

Biosecurity is the prevention and management of pests, weeds and diseases, both terrestrial and aquatic, to limit their economic, environmental, social and cultural impacts. Economic impacts include reduced crop yield and product quality, interference with farming operations, loss of market access and costs of implementing control measures. Environmental impacts include loss of biodiversity and changes to ecosystem processes such as fire regimes. Social and cultural impacts of pests, weeds and diseases include diminished value of areas for recreational or traditional uses.

Despite its relative isolation, there are many human-mediated and natural pathways by which pests, weeds and diseases can spread to and within the Southern Gulf catchments. New pests, weeds and diseases may spread from adjacent regions, other parts of Australia or even neighbouring countries. Biosecurity is a shared responsibility that requires governments, industries and the community to each take steps to limit the introduction and spread, detect and respond to incursions, and manage the impacts of key biological threats. A further complication for the cross-border catchment is being aware of biosecurity requirements for both the NT and Queensland, including the latter's general biosecurity obligation.

A range of current and potential pests, weeds and diseases could affect irrigated cropping in the Southern Gulf catchment. These include fall armyworm (*Spodoptera frugiperda*), which consumes C4 grass crops; cucumber green mottle mosaic virus, which infects a wide range of cucurbit crops; incursion risks from overseas such as citrus canker (*Xanthomonas citri* subsp. *citri*) and exotic fruit flies; and parthenium weed (*Parthenium hysterophorus*), which is a crop competitor, seed contaminant and allergen. Farm biosecurity planning to identify, prevent, detect and manage key pest, weed and disease threats is fundamental to a successful enterprise. Such planning includes following government and industry best practice regarding movement of plants, plant products and machinery, control of declared species, pesticide use, farm stewardship and market access requirements.

Preventive biosecurity practices are crucial in aquaculture facilities as diseases can be difficult to eliminate. There are many diseases of production concern, whether overseas, having entered Australia (e.g. white spot syndrome virus of crustaceans) or naturally occurring in Australian ecosystems. Aquaculture biosecurity planning needs to consider hygiene actions needed for key pathways of disease entry, early detection and diagnosis, quarantining and treatment.

Invasive species, whether pest, weed or disease, are commonly characterised as occurring across multiple land uses in a landscape. Their impacts will vary between land uses, but their coordinated control requires action across all tenures. Various high-impact weeds listed as declared (NT) or restricted (Queensland) are present in, or threaten to invade, the Southern Gulf catchments, including aquatic plants, grasses, shrubs and trees. There are also pest vertebrates (e.g. large feral herbivores, exotic fish), pest invertebrates (e.g. exotic ants) and plant pathogens (e.g. *Phytophthora*) that can cause disease. NT and Queensland government legal requirements to prevent or control invasive pests, weeds and diseases need to be followed. Regional and local irrigation and industry infrastructure development, including road networks, should include prevention and management of invasive species in their environmental planning processes. Choice of crops and aquaculture species should also consider the invasive risk and any management required to prevent their spread into the environment.

Off-site and downstream impacts

Agriculture can affect the water quality of downstream freshwater, estuarine and marine ecosystems. The principal pollutants from agriculture are nitrogen, phosphorus, total suspended solids, herbicides and pesticides. Most of the science in northern Australia concerned with the downstream impacts of agricultural development has been undertaken in the eastern-flowing rivers that flow into the Great Barrier Reef lagoon. Comparatively little research on the topic has been done in the rest of northern Australia.

Degraded water quality can cause a loss of aquatic habitat, biodiversity and ecosystem services. Increased nitrogen and phosphorus can cause plankton blooms and weed infestation, increase hypoxia (low oxygen levels) and result in fish deaths. Pesticides, used to increase agricultural productivity, can harm downstream aquatic ecosystems, flora and fauna. Fertiliser nutrients and pesticides can enter surface water bodies and groundwater via infiltration, leaching, and runoff from rainfall events and irrigation.

Losses via runoff or deep drainage are the main pathways by which agricultural pollutants enter water bodies. Management of irrigation or agricultural drainage waters is a key consideration when evaluating and developing new irrigation systems, and it should be given careful consideration during the planning and design process. Seasonal hydrology, particularly 'first-flush' events following irrigation or significant rainfall, plays a critical role in determining water quality. Studies have shown that pesticide concentrations in runoff are highest following initial irrigation events but decrease in subsequent events. Similarly, nitrogen concentrations in runoff are often higher following early-season rainfall, when crops have not yet fully absorbed available nitrogen, leading to increased transport in runoff. Minimising drainage water by using best-practice irrigation design and management should be a priority in any new irrigation development in northern Australia.

While elevated contaminants and water quality parameters can harm the environment and human health, there are several processes by which aquatic ecosystems can partially process contaminants and regulate water quality. Denitrification is a natural process that can remove and reduce nitrogen concentrations within a water body. Phosphorus, however, does not have a microbial reduction process equivalent to denitrification. Instead, if it is not temporarily taken up by plants, phosphorus can be adsorbed onto the surface of inorganic and organic particles and stored in the soil, or deposited in the sediments of water bodies, such as wetlands.

Aquaculture can be affected by poor water quality and can also contribute to poor water quality unless aquaculture operations are well managed. Aquaculture species are particularly vulnerable to some of the insecticides and other chemicals used in agricultural, horticultural and mining sectors, and in industrial and domestic settings. Aquaculture management is designed to discharge water that contains low amounts of nutrients and other contaminants. The aim is for discharge waters to have similar physiochemical parameters to the source water. Because aquaculture management in northern Australia has largely been developed to ensure that the waters of the Great Barrier Reef lagoon do not receive excessive contaminants, there is considerable experience in operating aquaculture enterprises in northern Australia under world's best practice.

Irrigation-induced salinity

Naturally occurring areas of salinity, or 'primary salinity', occur in the landscape, and their ecosystems are adapted to the saline conditions. Any change to landscape hydrology, including clearing and irrigation, can mobilise salts, resulting in environmental degradation in the form of 'secondary salinity'. This occurs where rising groundwater mobilises salts in the soil and substrate materials, moving the salts into the plant root zone and/or discharging salts on lower slopes, in drainage depressions or in nearby streams. Soil knowledge and best-practice management of irrigation timing and application rates can reduce the risk of irrigation-induced salinity.

Note that the material in this chapter provides general information regarding soils suitable for irrigation development. The risk of secondary salinisation at a specific location in the Southern Gulf catchments can only be properly assessed by undertaking detailed field investigations at a local scale.

Existing salinity is not prominent in the Assessment area apart from the salt plains along the coast, which are not considered for irrigation development. However, the cracking clay soils on the Armraynald Plain, particularly the black soils along the Gregory River backplain, have subsoils that are high in salt and susceptible to irrigation-induced secondary salinity. These cracking clay soils can be successfully irrigated if they can be managed to prevent waterlogging and the mobilisation of salts in the profile. The clay soils (soil generic group (SGG) 9, see Section 2.3) on the Barkly Tableland have low subsoil salt levels. Where they are underlain by porous limestone and dolomite, a build-up of salts due to irrigation is not expected.

The sandy, loamy and sand or loam over friable brown, yellow and grey clay soils on the Doomadgee Plain also have negligible salts within the soil profile. However, due to other risk factors, care would need to be exercised when clearing the silver box, bloodwood and broad-leaf paperbark savanna landscapes for rainfed or irrigated cropping. Groundwater aquifers contained by underlying ferricrete, the likelihood of soils having variable depths, and the very gently undulating plain make it difficult to manage irrigation water discharge on lower slopes and in drainage depressions, causing salts to accumulate in these areas in the long term. In places where these soils are shallow, it would be necessary to monitor the depth of watertables and manage irrigation rates accordingly. In addition, over-irrigation is likely to have off-site impacts in the long term, as the lateral flow of water can 'wick' from the lower slopes in these landscapes to form scalds. From these scalds, salts can potentially be mobilised towards nearby streams.

7.2 Introduction

Water and irrigation development can result in complex and, in some cases, unpredictable changes to the surrounding environment and communities. For instance, before the construction of the Burdekin Falls Dam, the Burdekin Project Committee (1977) and Burdekin Project Ecological Study (Fleming et al., 1981) concluded that the dam would improve water quality and clarity in the lower river and that para grass (*Brachiaria mutica*), an invasive weed from Africa that was then present at relatively low levels, could become a useful ecological element as a result of increased water delivery to the floodplain. However, the Burdekin Falls Dam has remained persistently turbid since construction in 1987, greatly altering the water quality and ecological processes of the river below the dam and the many streams and wetlands into which that water is pumped on the floodplain (Burrows and Butler, 2007). Para grass and, more recently, hymenachne (*Hymenachne amplexicaulis*), an ecologically similar plant from South America, have become serious weeds of the floodplain wetlands, rendering innumerable wetlands unviable as habitat for most aquatic biota that formerly occurred there (Tait and Perna, 2001; Perna, 2003, 2004).

Thus, there are limitations to the advice that can be provided in the absence of specific development proposals, so this section provides general advice on the considerations or externalities most strongly affected by water resource and irrigation developments. It is not possible to discuss every potential change that could occur. In particular the ecological impacts of vegetation clearing associated with irrigated agriculture are not explicitly examined as it is considered of secondary concern to potential impacts on water dependent ecological assets. This is because irrigated agriculture occupies a very small proportion of the landscape (typically less than 0.5%) but can result in a disproportionately high degree of regulation of river flow. Consequently, the Assessment placed greatest effort in understanding the potential ecological impacts of changes in streamflow on aquatic dependent ecosystems. It is noted, however, that areas of high agricultural potential may also be highly valued with respect to biodiversity conservation (Kutt et al., 2009). For these and other reasons the northern jurisdictions have formal processes in place for the approval (or not) of clearing native vegetation. Clearing approvals are only provided by the jurisdictions where they consider the ecological impact to be minimal given the extent and protection of vegetation type in the region (e.g. Queensland Government, 2023a).

The remainder of the chapter is structured as follows:

- Section 7.3 Ecological implications of altered flow regimes examines how river regulation affects inland and freshwater assets in the Southern Gulf catchments and marine assets in the near-shore marine environment. It also examines how the impacts can be mitigated.
- Section 7.4 Biosecurity considerations discusses the risks presented to an irrigation development by disease, pests and weeds, and the risks that new agriculture or aquaculture enterprise in the Southern Gulf catchments may present to the wider industry and broader catchment.
- Section 7.5 Off-site and downstream impacts considers how agriculture can affect the water quality of downstream freshwater, estuarine and marine ecosystems.
- Section 7.6 Irrigation-induced salinity briefly discusses the risk of irrigation-induced salinity to irrigation development and to the downstream environment in the Southern Gulf catchments.

Other externalities associated with water resource and irrigation development discussed elsewhere in this report include the direct impacts of the development of a large dam and reservoir on:

- Indigenous cultural heritage (Section 3.4)
- water quality (Section 7.5)
- the movement of aquatic species (Section 5.4)
- terrestrial ecosystems within the reservoir inundation area (Section 5.4).

These externalities are rarely factored into the true costs of water resource or irrigation development. Even in parts of southern Australia where data are more abundant, it is very difficult to express these costs in monetary terms, as perceived changes are strongly driven by values, which can vary considerably within and between communities and fluctuate over time. Therefore, the material in this chapter is presented as a stand-alone analysis to help inform conversations and decisions between communities and government.

Note that this chapter primarily focuses on key risks resulting from irrigated agriculture and aquaculture, although the section on biosecurity considers both risks to the enterprise and risks emanating from the enterprise into the broader environment. Other risks to irrigated agriculture and aquaculture are discussed elsewhere in this report, including risks associated with:

- flooding (Section 2.5)
- sediment infill of large dams (Section 5.4)

- reliability of water supply (sections 5.4 and 6.3)
- timing of runs of failed years on the profitability of an enterprise (Section 6.3).

Material within this chapter is largely based on the companion technical reports on ecology (Merrin et al., 2024; Ponce Reyes et al., 2024) but also draws upon findings presented in the Northern Australia Water Resource Assessment technical reports on agricultural viability (Ash et al., 2018) and aquaculture viability (Irvin et al., 2018). Further information can be found in those reports.

7.3 Ecological implications of altered flow regimes

7.3.1 Water resource development and flow ecology

The ecology of a river is intricately linked to its flow regime, and its species are broadly adapted to the prevailing conditions under which they occur. Changes in freshwater flows can affect the persistence or ephemerality of rivers, the volumes of river flows, and patterns of floodplain inundation and discharges. These changes directly affect species, habitats and ecosystem functions. Freshwater-flow-dependent flora, fauna and habitats are defined here as those sensitive to changes in flow and sustained by either surface water or groundwater flows or a combination of both. In rivers and floodplains, activities like water capture, storage, release, conveyance and extraction can significantly alter the environmental ecohydrology on which rivers function. Water regulation is frequently considered one of the biggest threats to aquatic ecosystems worldwide (Bunn and Arthington, 2002; Poff et al., 2007). Water resource development can cause changes in flow during both wet and dry periods, including the magnitude, timing, duration and frequency of flows (Jardine et al., 2015; McMahon and Finlayson, 2003). These changes can affect flora, fauna and habitats, and effects often extend far downstream, reaching near-shore coastal and marine areas as well as floodplains (Burford et al., 2011; Nielsen et al., 2020; Plagányi et al., 2024; Pollino et al., 2018). Water resource development can also result in changes to water quality, which is discussed in Section 7.5.

The environmental risks associated with water resource development are particularly complex in northern Australia. This is in part because of the diversity of species and habitats distributed across and within the catchments and near-shore zones. In addition, wet-season precipitation is critical to sustain the ecology of Southern Gulf landscapes throughout the approximately 8-month annual dry season (Section 2.4). From the ecosystem scale, such as the coastal mangrove/estuary/salt flat complex, to the microhabitat scale, such as riverine pond refugia, communities and species depend on wet-season rainfall and runoff to invigorate the catchment-to-coast ecosystem following 9 months of negligible rainfall, high evaporation and no freshwater runoff or inflows (Duke et al., 2019; McJannet et al., 2014). Across northern Australia, monsoon rains relieve the extended period of dry conditions in the landscape (Petheram et al., 2008; Petheram et al., 2012). As a result, water resource development can divert water critical for ecosystem services, leading to a wide range of direct and indirect environmental impacts.

Impacts on flow-dependent species and habitats can include flow regime change, loss of habitat, loss of function (such as connectivity), changes to water quality and the establishment of pest species. Instream dams create large bodies of standing water that inundate terrestrial habitat and result in the loss of the original stream and riverine conditions (Nilsson and Berggren, 2000; Schmutz and Sendzimir, 2018). Dams can capture flood pulses and reduce the volume and extent of water that transports important nutrients into estuaries and coastal waters via flood plumes (Burford et al., 2016; Burford and Faggotter, 2021; Tockner et al., 2010). Even minor instream barriers, such as road causeways, can disrupt migration and movement pathways, causing fragmentation of populations and loss of essential habitat for species that need passage along the river (Crook et al., 2015; Pelicice et al., 2015). Increased human activity associated with water resource development, such as irrigation, can introduce additional pressures, including biosecurity risks from invasive species that may spread into new or modified habitats or may be at increased risk of establishment (Pyšek et al., 2020).

This section provides an analysis of the risks associated with flow regime change in the Southern Gulf catchments to freshwater, estuarine and near-shore marine ecology and terrestrial systems dependent upon river flows. The impacts of habitat loss within hypothetical dam impoundments and of loss of connectivity due to the development of new instream barriers and impact associated with land use change due to the creation of an impoundment are discussed in the companion technical report (Yang et al., 2024). Existing and other potentially threatening processes for ecological assets, including their possible synergistic impacts, are discussed qualitatively in the companion ecological descriptions report (Merrin et al., 2024). For more details of the ecological asset analysis and details of analysis for all assets, see Ponce Reyes et al. (2024).

7.3.2 Ecology of the Southern Gulf catchments

The Southern Gulf catchments span 108,200 km² across the NT and Queensland, encompassing several significant protected areas (Merrin et al., 2024). These areas feature national parks like Boodjamulla and Finucane Island national parks, and 13 wetlands listed in the Directory of Important Wetlands in Australia. Among these wetlands is the Southern Gulf Aggregation (the largest continuous estuarine wetland in Australia), where the Gregory River crosses the Nicholson River Basin and Leichhardt River Basin (the largest perennial river in semi-arid and arid Queensland), and the Wentworth Aggregation (Department of Agriculture, Water and the Environment, 2021).

The ecology of the Southern Gulf catchments is shaped by its wet-dry tropical climate, characterised by an extended dry season and a wet season during which the most rainfall occurs. In the dry season, river flows decrease and many of the catchment's streams recede into isolated waterholes. However, in parts of the catchment, water persists during the dry season, supported by groundwater-fed perennial rivers like the Gregory and O'Shannassy rivers and Lawn Hill Creek, along with other water sources such as creeks, permanent lakes and inchannel waterholes. These water sources provide essential refuge habitats for a diverse array of aquatic species, particularly in this semi-arid environment (McJannet et al., 2023; Waltham et al., 2013).

A significant landscape within the Southern Gulf catchments is the low-gradient, tidally influenced coastline characterised by some of the most extensive supratidal salt flats and chenier plain formations of the Australian coastline (Short, 2020). The salt flats are fronted by a beach-barrier shoreline (west of Mornington Island, 87% of the coastline is sand beach) and mangrove-fringed mudflats (east of Mornington Island, 13.5% of the coastline is sand beach). The salt flat complex is most extensive east of Mornington Island and can extend 30 to 50 km inland. It is dissected by several major rivers and multiple mangrove-lined creeks, creating a distinctive supra-littoral and littoral estuarine and marine environment that provides critical habitat to many species. The coastal ecosystem is characterised by an extremely low gradient, both in terrestrial habitats landward of the salt flat complex and in intertidal and subtidal habitats to seaward, contributing to the southern gulf of Carpentaria coastline being the most low-energy region of the open Australian coastline (Short, 2020).

Within the multiple estuaries, mangrove forests, intertidal and supratidal sea-flats of the coastal zone of the Southern Gulf catchments, primary production from microalgae within the estuarine water column and subtidal, intertidal and supratidal sediments rivals productivity from other sources, such as the macrophytes (Burford et al., 2016; Burford et al., 2012). Annual flood flows deposit thousands of tonnes of nitrogen and phosphorus within flood plumes into the Gulf of Carpentaria, particularly in years of high floods (Burford et al., 2012; Burford and Faggotter, 2021). In addition, annual wetting of the salt flats due to rainfall and overbank flows invigorate extensive senescent algal crusts that cover the hundreds of square kilometres of salt flats, contributing an additional 13% to the primary productivity of estuarine/salt flat complex of the southern Gulf of Carpentaria (Burford et al., 2016). Primary productivity contributes to populations of mollusc, crustacean and annelid meiofauna and macrobenthos within estuarine and coastal sediments of the Southern Gulf (Lowe et al., 2022; Venarsky et al., 2022), forming the basis of the coastal food web. The volume and persistence of wet- and dry-season river flows have strong influences on the abundance and species diversity of infauna within estuarine and shallow coastal sandflats (Duggan et al., 2014; Lowe et al., 2022).

This coastal matrix ecosystem is critical habitat for many bird, reptile, fish and crustacean species. Wader birds that migrate between the northern and southern hemispheres use the littoral habitats of Southern Gulf catchments as a crucial stopover on their biannual flyway (Garnett, 1987; Tait, 2005). Many of the bird species are threatened, endangered or critically endangered. Key fish species such as barramundi, threadfin, barred-grunter, sawfish, mullet and catfish, as well as crustaceans such as cherubin (in the brackish ecotone), mud crabs and multiple species of penaeid prawns, are abundant within estuarine and coastal habitats (Leahy and Robins, 2021; Robins et al., 2020; Staples and Vance, 1986). Freshwater and saltwater crocodiles are common within the catchments (Read et al., 2004).

During the wet season, significant flooding occurs in the Southern Gulf catchments, inundating floodplains and connecting wetlands to the river channels, which enhances primary and secondary productivity. This process is particularly notable in the lower parts of the catchment, including the floodplain wetlands and the extensive intertidal salt flats along the mainland coastline, particularly south of Bentinck and Sweers islands. These nutrient-laden flood discharges into the marine waters of the south-western Gulf of Carpentaria support high levels of marine productivity, which in turn sustains important fisheries and ecological processes.

The Southern Gulf catchments have high biodiversity. They support at least 170 species of fish, 150 species of waterbirds, 30 species of aquatic and semi-aquatic reptiles, 60 species of amphibians and 100 macroinvertebrate families (van Dam et al., 2008b). Notable species include the freshwater or largetooth sawfish (*Pristis pristis*; listed as Vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)) and the Gulf snapping turtle (*Elseya lavarackorum*; Endangered). The catchments also serve as crucial stopover habitats for migratory shorebird species listed under the EPBC Act, including the eastern curlew (*Numenius madagascariensis*; Critically Endangered) and the Australian painted snipe (*Rostratula australis*; Endangered).

The ecology of the Southern Gulf catchments is further detailed in the companion report on ecological assets (Merrin et al., 2024).

7.3.3 Scenarios of hypothetical water resource development and future climate

The ecology analysis used modelled hydrology from a river model for the Gregory– Nicholson and Leichhardt catchments (see companion technical reports on river model calibration and simulation (Gibbs et al., 2024a,b)) to explore the possible impacts of water resource development in the Southern Gulf catchments using a range of hypothetical scenarios. The scenarios were configured to explore how different types and scales of water resource development, such as instream infrastructure (i.e. large dams) and water harvesting (i.e. pumping river water into offstream farm-scale storages) affect water-dependent ecosystems. The impact of a hypothetical development on water-dependent ecological assets is inferred and reported here in terms of a catchment-weighted, percentage change in key 'flow dependencies' (at key stages of the life cycle) relative to a baseline, averaged over the Assessment time period (i.e. 1 September 1890 to 31 August 2022). The catchment-weighted value is calculated by spatially weighting percentage change in key flow dependency calculations using the modelled likely habitat of each asset across the study area. This is referred to as the spatially weighted mean impact on key flow dependencies. The ecological analysis used Scenario AE as a reference (Section 1.4.3), recognising that current conditions likely reflect a stabilised state following past development in the catchments (Gibbs et al., 2024b). Changes in flow dependencies do not necessarily correlate with changes in asset condition, as this depends on the relative importance of river flow compared to other factors such as rainfall, soil water, groundwater and local runoff.

Section 1.2.2 discusses the plausibility of development pathways and should be consulted when evaluating the likelihood of a hypothetical development scenario occurring. Broad scenario definitions used in the Assessment are described in Section 1.4.3 and summarised in Table 7-1. The scenarios were chosen to cover a range of potential ecological outcomes for the selected assets. The location of the river modelling nodes referred to in this section are shown in Figure 7-2. Further details of the river system model simulations are provided in the companion technical report on river model simulation (Gibbs et al., 2024b).

Key terms used in Section 7.3

Water harvesting – an operation where water is pumped or diverted from a river into an offstream storage.

Offstream storages – usually fully enclosed, circular or rectangular earthfill embankment structures situated close to major watercourses or rivers to minimise the cost of pumping.

Large engineered instream dams – usually constructed from earth, rock or concrete materials as a barrier across a river to store water in the reservoir created and intercept a drainage line (Yang et al., 2024).

Annual diversion commencement flow requirement (DCFR) – the cumulative volume passing the most downstream node in catchments with water harvest (on the Leichhardt River node 9130071, Albert River node 9129040 and Nicholson River node 9121090) from the start of the water year that is required before water harvest pumping can commence.

Pump-start threshold – a daily flow threshold above which pumping or diversion of water can commence. This is usually implemented as a strategy to minimise the ecological impact of water harvesting.

Pump capacity – the capacity of the pumps expressed as the number of days it would take to pump the entire node irrigation target.

Reach irrigation volumetric target – the maximum volume of water extracted in a river reach over a water year. Note that the end use need not be irrigation; users could also be involved in aquaculture, mining, urban or industrial activities.

System irrigation volumetric target – the maximum volume of water extracted across the entire study area over a water year. Note that the end use need not be irrigation; users could also be involved in aquaculture, mining, urban or industrial activities.

Transparent flow – a strategy to mitigate the ecological impacts of large instream dams by allowing all reservoir inflows below a flow threshold to pass 'through' the dam.

Note that each potential water resource development pathway results in different changes to flow regimes. This is due to differences in rainfall and upstream catchment sizes, inflows, the attenuation of flow through the river system (including accumulating inflows with river confluences), and also the many ways each water resource development could unfold and be implemented and managed. These scenarios were not analysed because they were considered likely or recommended by CSIRO; rather, they were selected to explore some of the interactions between location and the types and scale of development, to provide insights into how different types and scales of water resource development and mitigation measures may influence ecology outcomes across the catchment.

Some of the hypothetical scenarios listed in Table 7-1 provide the minimum level of dedicated environmental provisions and have been optimised for water yield reliability, without considering policy settings or additional restrictions that may help mitigate the impacts on water-dependent ecosystems. These scenarios are useful for considering impacts across various development strategies in the absence of mitigation strategies or policy settings (or could be representative of regulatory non-compliance). Furthermore, management and regulatory requirements in a real-world setting would likely provide a range of safeguards for environmental outcomes, possibly establishing a combination of transparent flows (river flows that are managed to pass a regulating structure to support ecology), end-of-system requirements, extraction limits and/or minimum flow thresholds. Each of these safeguards, if implemented, would likely improve the environmental outcomes. Furthermore, many of the scenarios explored, while technically feasible, exceed the level of development that would reasonably occur (see Section 1.2.2). These scenarios were included as a stress test of the system and can be useful for benchmarking or contrasting various levels of change.

The development scenarios are hypothetical and are for the purpose of exploring a range of options and issues in the Southern Gulf catchments. In the event of any future development occurring, further work would need to be undertaken to assess environmental impacts associated with the specific development across a broad range of environmental considerations.

Figure 7-2 Locations of the river system modelling nodes at which flow–ecology dependencies were assessed (numbered) and the locations of hypothetical water resource developments in the Southern Gulf catchments

The flow ecology of the environmental assets was assessed in subcatchments downstream of the river system nodes. The locations of assets across the catchment are documented in Merrin et al. (2024). Marine assets used a combined end-of-system node (9100000), which combined flows from the Nicholson (9121090 and 9129040) and Leichhardt (9130071) rivers.

Table 7-1 Water resource development and climate scenarios explored in this ecology analysis

Gibbs et al. (2024a) and Gibbs et al. (2024b) describe the river system modelling and additional scenario details.

SCENARIO	DESCRIPTION	ASSUMES FULL USE OF EXISTING LICENCES	TRANSPARENT FLOW THRESHOLD (% OF MEAN INFLOW)	TARGET EXTRACTION VOLUME (GL)	ANNUAL DIVERSION COMMENCEMENT FLOW REQUIREMENT (GL)	PUMP-START THRESHOLD (ML/d)	PUMP CAPACITY (d)
Scenario A	**Historical climate and no hypothetical development**						
AN	No development – natural conditions	No (no use)	na	0	na	na	na
AE	Current (2023) levels of development	No (current) (29.9 GL)	No	0	0	variable	variable
A	Full use of existing entitlements	Yes (113.5 GL)	No	0	0	variable	variable
Scenario B	**Historical climate and hypothetical future development**						
B-D$_{GPC}$ **B-D$_{GR}$**	Single hypothetical dams‡	Yes (113.5 GL)	No	na‡	na	na	na
B-D$_{2}$	Two hypothetical dams together (B-D$_{GPC}$ and B-D$_{GR}$)	Yes (113.5 GL)	No	na‡	na	na	na
B-D$_{GPCT}$ **B-D$_{GRT}$**	Single hypothetical dams with transparent flows	Yes (113.5 GL)	Q = 20	na‡	na	na	na
B-D$_{2T}$	Two hypothetical dams together with transparent flows (B-D$_{GPCT}$ and B-D$_{GRT}$)	Yes (113.5 GL)	Q = 20	na‡	na	na	na
B-W$_{T150P600R30E0}$	Water harvesting varying target extraction volume (T), annual diversion commencement flow requirement (E), pump-start threshold (P), and/or pump capacities (R)	Yes (113.5 GL)	na	T = 50, 150, 300	E = 0, 150…	P = 200, 600…	R = 10, 20…
Scenario C	**Future climate and current level of development**						
CE$_{dry}$	Dry GCM†† projection (see Section 2.4.5)	No (current) (29.9 GL)	No	0	0	variable	variable
Scenario D	**Future climate and hypothetical future development**						
D-D$_{GPC}$	Single hypothetical dams‡ with Scenario Cdry	Yes (113.5 GL)	No	na‡	na	na	na

SCENARIO	DESCRIPTION	ASSUMES FULL USE OF EXISTING LICENCES	TRANSPARENT FLOW THRESHOLD (% OF MEAN INFLOW)	TARGET EXTRACTION VOLUME (GL)	ANNUAL DIVERSION COMMENCEMENT FLOW REQUIREMENT (GL)	PUMP-START THRESHOLD (ML/d)	PUMP CAPACITY (d)
D-D_2	Two hypothetical dams (same as B-D_2) with Scenario Cdry	Yes (113.5 GL)	No	na‡	na	na	na
D-D_{2T}	Two hypothetical dams (same as B-D_2) with Scenario Cdry with transparent flows	Yes (113.5 GL)	Q = 20	na‡	na	na	na
D-$W_{T150P600R30E0}$	Water harvesting with Scenario Cdry	Yes (113.5 GL)	na	T = 50, 150, 300	E = 0, 150, 250…	P = 200, 600…	R = 30…

‡No target volume for hypothetical dam scenarios; instead a target extraction volume that could be met with 85% reliability was identified.
††GCM = general circulation model.
na = not applicable.

7.3.4 Ecology outcomes and implications

The ecology activity used an asset-based approach to analysis, building on the work of Pollino et al. (2018) and Stratford et al. (2024). For the Southern Gulf catchments, 21 ecological assets (Table 7-2) were selected for analysis across 79 nodes, including the end-of-system node for near-shore marine assets (Figure 7-2). Both the ecology asset descriptions technical report (Merrin et al., 2024) and the ecology asset analysis technical report (Ponce Reyes et al., 2024) should be consulted in conjunction with the material provided here.

The selected ecological assets encompass freshwater, marine and terrestrial habitats that depend on river flows to varying extents, and they were modelled with regards to changes to surface water. Assets were included if they were distinctive, representative, describable and significant within the catchment. The assets' flow ecologies and locations were described in Merrin et al. (2024), which also provides species and habitat distribution maps, including species distribution models developed for many of the species. Each asset had different needs and linkages to the flow regime, and these assets occurred across different parts of the catchment or the near-shore marine zone. Understanding the flow ecology of assets and their locations across the catchment was important for identifying the potential risks of changes in catchment hydrology, as not all types of changes will affect assets equally.

Table 7-2 Ecological assets used in the Southern Gulf catchments Water Resource Assessment and the different ecology groups used in this analysis

Twenty-one assets are modelled in the ecology analysis; assets may be assigned to more than one group. Description of the ecological assets and their distribution is provided in Merrin et al. (2024). Assets marked with an asterisk are presented in this report. Analysis and interpretation for all assets is provided in Ponce Reyes et al. (2024).

ASSET GROUP	ASSET	SYSTEMS
Fish, sharks and rays	Barramundi (*Lates calcarifer*)	Freshwater and marine
	Bullshark	Freshwater and marine
	Catfish (order Siluriformes)	Freshwater
	Grunters (family Terapontidae)	Freshwater
	Mullet (family Mugilidae)	Freshwater and marine
	Sawfishes (*Pristis* and *Anoxypristis* spp.)*	Freshwater and marine
	Threadfin (*Polydactylus macrochir*)	Marine
Waterbirds	Colonial and semi-colonial nesting wading waterbirds	Freshwater
	Cryptic wading waterbirds	Freshwater
	Shorebirds	Freshwater and marine
	Swimming, grazing and diving waterbirds*	Freshwater
Prawns, turtles and other species	Banana prawns (*Penaeus merguiensis*)	Marine
	Endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*)	Marine
	Tiger prawns (*Penaeus semisulcatus* and *P. esculentus)*	
	Freshwater turtles (family Chelidae)	Freshwater
	Mud crabs (*Scylla serrata*)	Marine
Flow-dependent habitats	Floodplain wetlands*	Freshwater
	Inchannel waterholes	Freshwater
	Mangroves	Marine
	Saltpans and salt flats	Marine
	Seagrass	Marine
	Surface-water-dependent vegetation	Freshwater and terrestrial

The flow dependencies (hydrometrics) modelling calculated for each asset an index of flow regime change resulting from the different scenarios using asset-specific hydrometrics using metrics based upon Kennard et al. (2010). Hydrometrics are statistical measures of the long-term flow regime and can include aspects of flow magnitude, duration, timing, frequency and rate of change (Kennard et al., 2010). Merrin et al. (2024) details each asset's ecology and relationship to flow, including:

- habitat dependencies (e.g. floodplain inundation, refuge, recharging of groundwater)
- life cycle processes (e.g. flow to trigger spawning)
- migration and movement pathways (e.g. high flows to enable migration into floodplain wetlands and along the river)
- flow to support productivity and food resources (e.g. nutrient plumes into coastal areas).

Hydrometrics were calculated for each scenario and used to quantify relative change in important parts of the flow regime as percentile change relative to the distribution of annual values of Scenario AE, calculated over the Assessment period (i.e. 1 September 1890 to 31 August 2022). The index of change is calculated as:

$$\text{Percentile change} = \frac{\text{x} - \text{scenario median}}{\text{scenario median}} \times 100 \qquad (1)$$

Where *x* is the median of metric *i*, for the hypothetical scenario, and all values are for individual nodes.

The assets' important metrics are combined by averaging, with each metric being weighted, considering the knowledge base to support it and its significance to the asset's ecology. The percentile change is weighted downstream of nodes by the habitat value of each reach in which the asset occurs based upon results of species distribution models, and the change in flow dependency is calculated for each node. The species distribution models were developed using a combination of Random Forests, Generalised Linear Models (GLMs), and Maxent algorithms (see Stratford et al., 2024a). These models were applied to a 2.5 km buffer surrounding the rivers within the Southern Gulf catchments to quantify habitat suitability. The change in the flow dependencies was weighted by habitat suitability for each asset between the river system model nodes of each river reach. As such, river reaches with important asset habitat quality or values are weighted higher than marginal habitat. Aggregation of these weighted flow dependency values is undertaken to calculate the catchment means of asset–flow dependencies from the individual node values (see Ponce Reyes et al., 2024 for more details).

Hydrometrics have been broadly used in ecohydrology assessments in national and international contexts for a range of purposes, including water allocation planning, and in ecohydrology research and literature (Leigh and Sheldon, 2008; Marsh et al., 2012; Olden and Poff, 2003). For this analysis, the flow dependencies modelling considered reach and catchment-wide changes in each asset's important flow dependencies across the subcatchments in which the assets occur, including the near-shore marine zone. The impact of a hypothetical development on water-dependent ecological assets is inferred and reported here in terms of a habitat-weighted percentile change in asset-specific important flow dependencies.

For interpretation of results, larger values represent greater change in the parts of the flow regime that are important for the asset, and qualitative descriptors are provided in Table 7-3. As the values are percentile change from the distribution in Scenario AE, the asset's flow dependency values can be referenced against the historical variability. For example, a value of 25 for a metric represents a change from the median (50th percentile of the historical distribution) to the 25th percentile. Using mean annual flow as an example metric, the value of 25 would represent the scenario median now being similar to the driest 25% of years for this metric.

Table 7-3 Reporting qualitative values for the flow dependencies modelling as rank percentile change of the hydrometrics

Values consider the change in mean hydrometric value against the natural distribution observed in the modelled baseline series of 132 years. For more information including metric and habitat weighting see Ponce Reyes et al. (2024). For more information see Ponce Reyes et al. (2024).

PERCENTILE VALUE	RATING	IMPLICATION
>0-2	Negligible	The mean for the asset's metrics under the scenario has negligible change as considered against the modelled historical conditions and lies well within the normal conditions experienced at the model node. The asset's hydrometrics are within two percentile of the historical Scenario AE mean
2-5	Minor	The change is minor with the mean for the asset's metrics for the scenario between two and five percentile of Scenario AE and the historical distribution of the hydrometrics
5-15	Moderate	The change is moderate with the mean for the asset's metrics under the scenario between five and 15 percentile of Scenario AE and the historical distribution of the hydrometrics
15-30	Major	The change is major with the mean for the asset's metrics for the scenario between 15 and 30 percentile of Scenario AE and the historical distribution of the hydrometrics
>30	Extreme	The change is extreme with the mean for the asset's metrics under the scenario being very different from the modelled historical conditions, with and metrics occurring well outside typical conditions at the modelled node. The scenario mean is more than 30 percentile from the historical Scenario AE mean

In addition to comparing against the historical variability of Scenario AE, benchmarking the level of change in asset flow dependencies is achieved by comparing to asset results modelled at the end-of-system of the Ord River, taking into account the modelled changes in flow associated with the development of the Ord River Irrigation Scheme (with and without Top Dam) near the end-of-system. In addition, three natural periods of low-flow conditions are assessed and plotted alongside the hypothetical development and projected climate scenario values. For the Southern Gulf catchments, these were the periods with the lowest 30-year flow, lowest 50-year flow and lowest 70-year flow across the historical climate (Scenario AE). Additional context is provided by calculating the change in asset flow dependency that has been modelled to occur in the Gregory and Leichhardt catchments since European settlement (i.e. by comparing key flow dependency metrics under Scenario AN and Scenario AE). These are benchmarks, so flow conditions and outcomes of change would not necessarily be equivalent to these if development were to occur, but they provide a useful comparison of the potential level of change under the scenarios.

Note that this ecology analysis is broad in scale, and the results include significant uncertainty. This uncertainty is due to a range of factors, including, but not limited to, incomplete knowledge, variability within and between catchments, and limitations associated with modelling processes and data. Furthermore, thresholds, temporal processes, interactions, synergistic effects and feedback responses in the ecology of the system may not be adequately captured in the modelling process. There is also uncertainty associated with the projected future climates, such as rainfall patterns and any additional synergistic and cumulative threatening processes that may emerge and interact across scales of space and time, including producing potentially novel outcomes. The region that the Southern Gulf catchments occur within is vast and diverse, and the knowledge base of species occurrences is limited. More broadly, the understanding of freshwater ecology in northern Australia is still developing.

Provided below is a sample of outcomes for three representative assets for the Southern Gulf catchments: sawfishes; swimming, diving and grazing waterbirds; and floodplain wetlands. For more details and for results on other assets see Ponce Reyes et al. (2024).

Sawfishes

Four species of sawfish inhabit the Gulf of Carpentaria, primarily in inshore marine habitats and estuaries. Tropical Australian waters are one of the last strongholds for sawfishes (Phillips et al., 2011). The two largest species, largetooth or freshwater sawfish (*Pristis pristis*) and green sawfish (*P*. *zijsron*) are listed as Critically Endangered on the IUCN Red List of Threatened Species and Vulnerable under the Commonwealth EPBC Act. The dwarf sawfish (*P. clavata*) is listed as Critically Endangered (IUCN) and Vulnerable (EPBC Act), while the narrow sawfish (*Anoxypristis cuspidata*) is listed as Critically Endangered (IUCN) and not listed under the EPBC Act.

Freshwater sawfish juveniles inhabit riverine reaches before moving to coastal and marine environments as adults. Juvenile dwarf sawfish have been recorded in upper estuaries and lower rivers, while adults are found offshore. Green sawfish are common in estuaries and occasionally in riverine habitats. In the Southern Gulf catchments, sawfishes occupy estuarine, freshwater and offshore habitats. Estuarine and riverine connectivity is critical for the survival of freshwater sawfish, which pup in estuarine and inshore waters (Dulvy et al., 2016; Morgan et al., 2017). Sawfishes are vulnerable to human activities and also used as a food source (Naughton et al., 1986). In Australia, only Indigenous Australians are allowed to capture sawfishes.

Freshwater sawfish, in particular, are affected by variability in the flow regime despite sustained riverine and estuarine connectivity during the wet season. Strong upstream recruitment of juveniles to riverine habitats only occurs during the highest flood flows (Lear et al., 2019). The higher the volume of flood flows, the greater the sustained body condition of sawfish during the subsequent dry season (Lear et al., 2021).

The key threats to sawfishes are associated with the loss of high-level flood flows to support upstream recruitment and with any reduction in low-level dry-season flows that would reduce instream connectivity or create barriers among deep-water pools and reduce their persistence or water quality during the dry season. The analysis considers change in flow regime and related habitat changes but does not consider the loss of potential habitat associated with the creation of a dam impoundment or instream structures (see also Yang et al. (2024) for dam impoundments).

Flow dependencies analysis

Sawfishes were assessed across a total of 3948 km of river reaches in the Southern Gulf catchments and the marine region, with flows from 63 model nodes (Ponce Reyes et al., 2024). The locations for modelling sawfishes were selected based on the species distribution models of freshwater or largetooth sawfish (*Pristis pristis*) (see Merrin et al. (2024)).

Hypothetical water resource development in the Southern Gulf catchments led to varying changes in key flow metrics important for sawfish (see details and results for all the scenarios in Ponce Reyes et al. (2024)). Hypothetical dam scenarios showed a range of change in key flow metrics from negligible (0.6 under Scenario B-D_{GPCT}) to moderate (5.2; Scenario B-D_2). Change in key flow metrics under water harvesting scenarios was negligible, with values ranging from 0.5 (Scenario B-$W_{T50P600R30E250}$) to 1.4 (Scenario B-$W_{T150P200R30E0}$). Under Scenario Cdry, there was a moderate change (6.5) in flow metrics. The variation in flow regime changes across dam, water harvesting, and climate scenarios is due to differences in spatial patterns of flow and the distribution of important habitat for sawfish (Figure 7-4).

Water harvesting and changes in important flows for sawfish

The change in important flows for sawfish under water harvesting varied depending on extraction targets, pump-start thresholds, pump rates and annual diversion commencement flow requirements (Ponce Reyes et al., 2024). Under a low extraction target of 50 GL (Scenario B-$W_{T50P600R30E0}$), the change in flow was negligible (0.5), and it increased to 0.9 with an extraction target of 300 GL (Scenario B-$W_{T300P600R30E0}$) (Figure 7-5). Raising the pump-start threshold from 200 ML/day (Scenario B-$W_{T150P200R30E0}$) to 600 ML/day (Scenario B-$W_{T150P600R30E0}$) reduced asset dependent flow changes, with values ranging from 1.4 to 0.7. Protecting key parts of the flow regime, such as maintaining low flows and limiting extraction volumes, is crucial for sawfish ecology. Flow modifications, particularly reduced high flows and shorter peak durations, can disrupt species reliant on floodplain inundation and wetland connectivity. Additionally, water impoundment or upstream extraction may reduce the depth and persistence of critical riverine pools during the dry season.

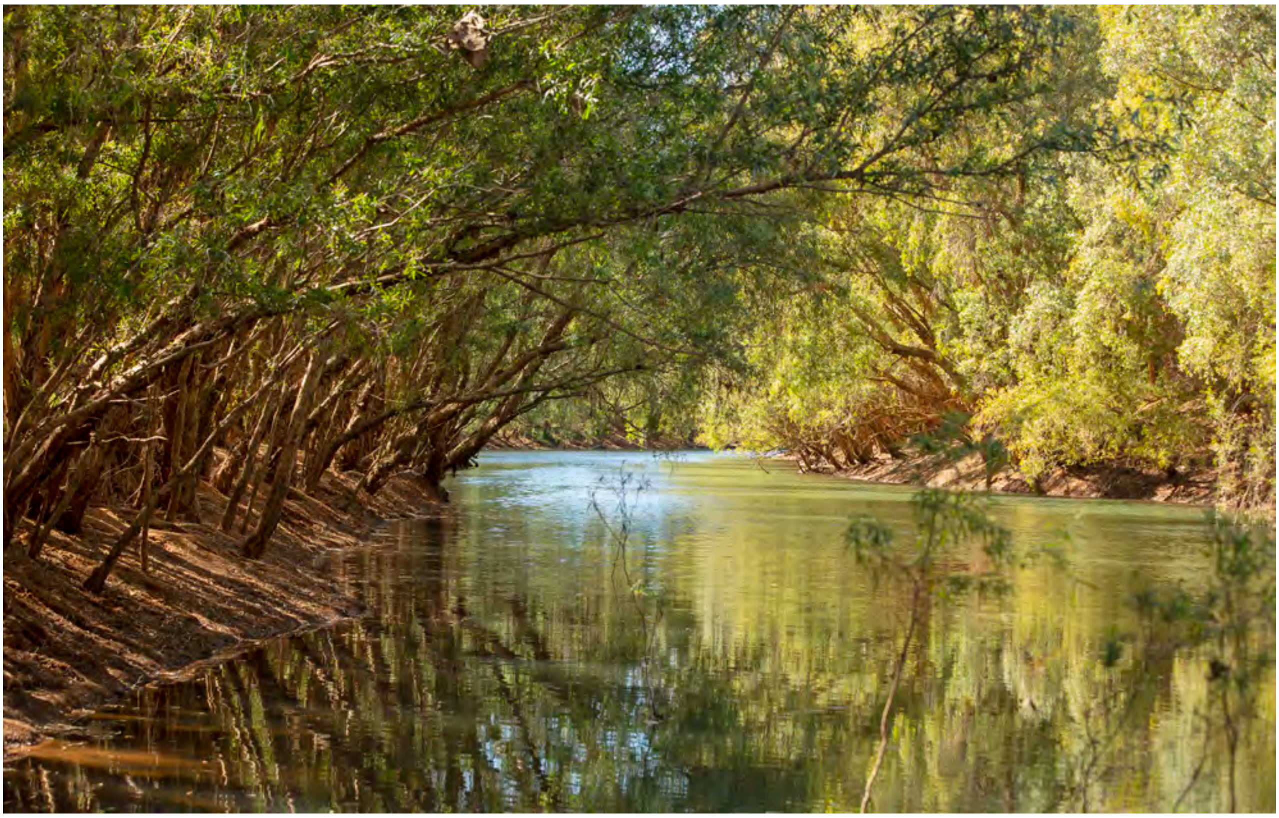

Figure 7-3 Riparian vegetation along the Leichhardt River – riparian zones are often more fertile and productive than surrounding terrestrial vegetation

Photo: CSIRO – Nathan Dyer

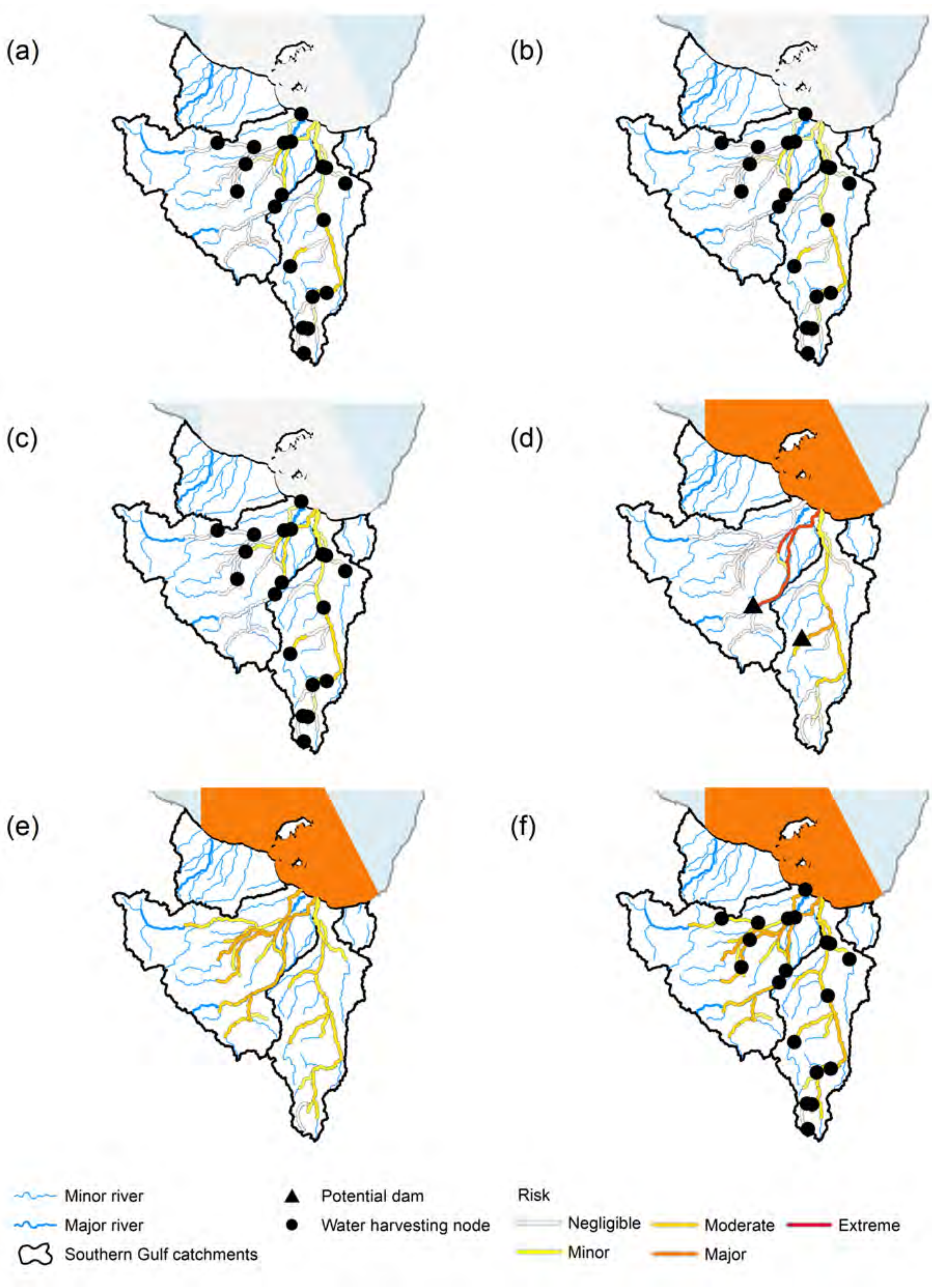

Figure 7-4 Spatial heatmap of habitat-weighted changes in flow for sawfish, considering the assets important locations across the catchment

Scenarios are: (a) B-$W_{T150P600R30E0}$, (b) B-$W_{T150P600R30E150}$, (c) B-$W_{T300P600R30E0}$, (d) B-D_2, (e) CE_{dry} and (f) D-$W_{T150P600R30E0}$. River shading indicates the level of flow change of sawfish important metrics weighted by the habitat value of each reach.

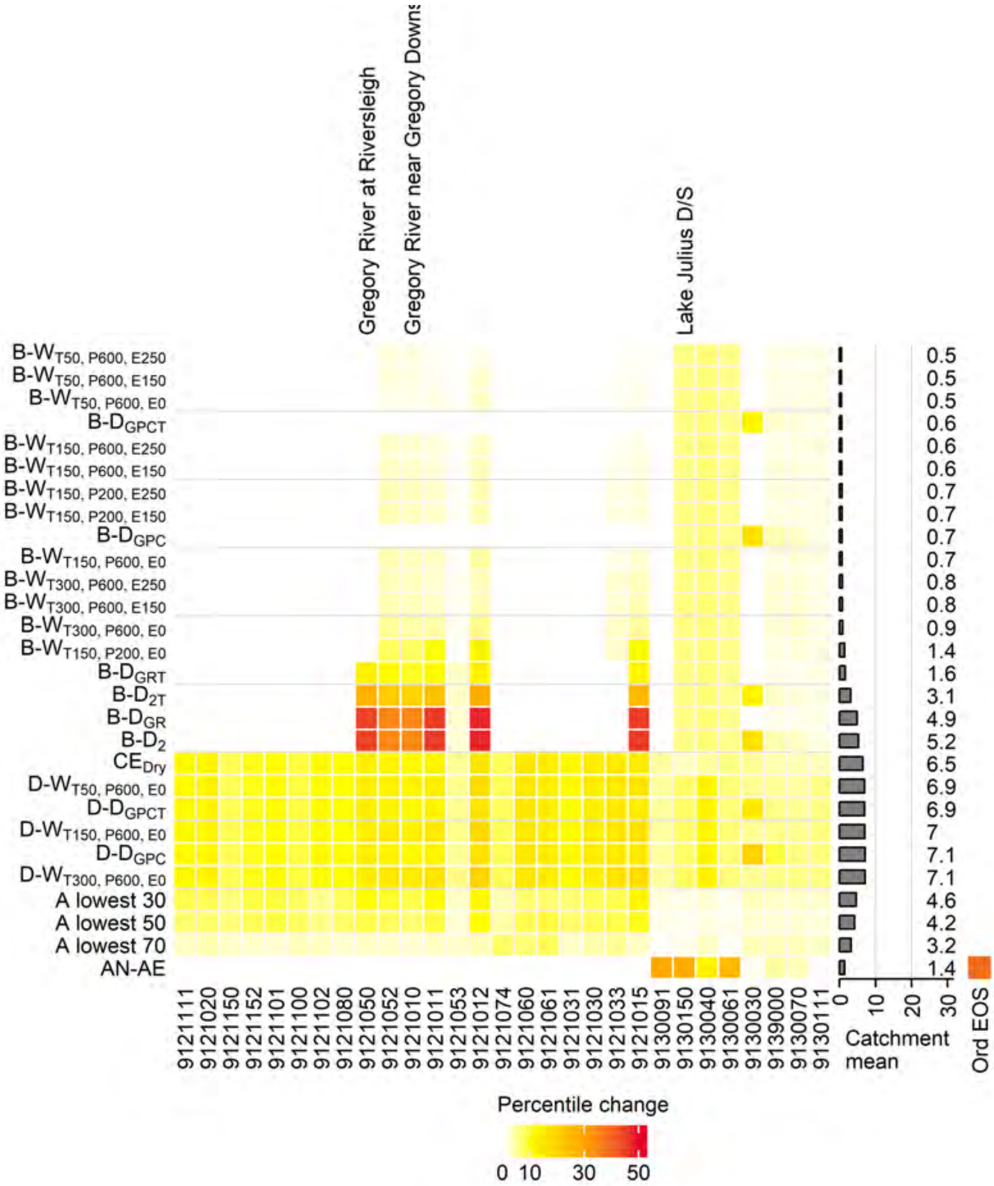

Figure 7-5 Habitat-weighted change in sawfish flow dependencies by scenario across model nodes

Colour intensity represents the level of change occurring in important flow metrics as percentile change from the historical conditions weighted by the importance of each reach for sawfishes. Equivalent colour intensity (i.e. corresponding to the asset flow dependency change value) for the Ord River below Lake Kununurra shown bottom right. Scenarios are ordered on the left axis by the magnitude of change with the mean across nodes shown on the right axis. Horizontal grey bars and number correspond to the mean change across all model node locations. Only the 30 highest impact nodes are shown (*x*-axis). Results under Scenario A corresponding to changes in asset flow dependency for the lowest 30-year (A lowest 30), 50-year (A lowest 50) and 70-year (A lowest 70) time periods provide a reference for the modelled changes under different hypothetical development and projected future climate scenarios. AN-AE corresponds to the change in asset flow dependency in the Nicholson and Leichhardt catchments that has already occurred since European settlement.

Dams and changes in important flows for sawfish

Under the hypothetical dam scenarios, Scenario B-D_{GPC} (without transparent flows) resulted in a negligible change in important flow metrics (0.7) when averaged across the 63 sawfish assessment nodes. Implementing transparent flows (Scenario B-D_{GPCT}) reduced this to 0.6. Scenario B-D_{GR} resulted in a minor flow change (4.9), which was reduced to negligible (1.6) with transparent flows (Scenario B-D_{GRT}). Scenario B-D_2, involving two dams, showed a moderate change (5.2), which was reduced to 3.1 with transparent flows (Scenario B-D_{2T}). As expected, Scenario B-D_2 resulted in a larger mean change in flow dependency than either of the individual dam scenarios due to the combined effects of two dams and the larger portion of the catchment affected. Transparent flows consistently mitigated impacts, improving environmental outcomes for sawfish.

The greatest habitat-weighted changes occurred at node 9121012, with an extreme change (48.2). Nodes directly downstream of the dams saw major (16.3) and extreme (45.4) changes, which were reduced to moderate levels (11.7 and 12.9) with transparent flows. Dams placed higher in the catchment reduced potential impacts, but sawfish remain vulnerable to a combination of factors, including changes in flow and connectivity loss (see Ponce Reyes et al. (2024)).

Climate change and water resource development for important flows for sawfish

Scenario Cdry resulted in a moderate change (6.5) in important flow metrics for sawfish across the 63 sawfish assessment nodes, which is higher than the changes seen in scenarios B-D_{GPC} and B- $W_{T150P600R30E0}$ (both negligible; 0.7). However, note that local changes in flows under some water resource development scenarios can be considerably higher than the catchment means. Combined impacts of climate change and water resource development resulted in moderate changes of 7.1 (Scenario D-D_{GPC}) and 7 (Scenario D-$W_{T150P600R30E0}$), indicating a significant impact on sawfish flow dependencies via flow reduction. These changes, especially reductions in wet-season flood flows and late-dry-season low flows, could reduce neonate recruitment upstream and disrupt connectivity to wetlands. Dams further impede access to juvenile habitats (see Yang et al. (2024)), while large flood flows are critical for the recruitment, growth and survival of largetooth sawfish within riverine freshwater habitats (Lear et al., 2019; Lear et al., 2021). Flow modifications, particularly reductions in high flows and shortened peak water levels, can negatively affect species relying on floodplain inundation and wetland connectivity (Close et al., 2014; Hunt et al., 2012; Jellyman et al., 2016; Morgan et al., 2016; Novak et al., 2017). Among Australian tropical rivers at similar latitudes, water resource development and a drying climate have been modelled to have significant negative impacts on sawfish populations (Plagányi et al., 2024). Measures to protect important parts of the flow regime can support ecology; for example, reducing the extraction target puts limits on the volume of water extracted in any water year, and increasing the pump-start threshold protects the low flows that are important for sawfish ecology. Flow modifications, particularly the reduction of high flows and shortened duration of the peak water levels (upper 25% of flows), can affect species such as the sawfish that rely on floodplain inundation and wetland connectivity. Furthermore, the maintenance of depth and persistence of important riverine pools during the dry season may be reduced by water impoundment or upstream extraction.

Swimming, diving and grazing waterbirds

The swimming, diving and grazing waterbirds group comprises species with a relatively high level of dependence on semi-open, open and deeper water environments, who commonly swim when foraging (including diving, filtering, dabbling, grazing) or when taking refuge. In northern Australia, this group comprises 49 species from 11 families, including ducks, geese, swans, grebes, pelicans, darters, cormorants, shags, swamphens, gulls, terns, noddies and jacanas (see species list in Merrin et al. (2024)). Reduced extent, depth and duration of inundation of waterhole and other deep-water environments are likely to reduce habitat availability and food availability for swimming, diving and grazing waterbirds. Reduced high-level flows increases competition, and predation also increases the risk of disease and parasite spread. Conversely, species in this group that nest at water level or just above, such as magpie geese (*Anseranas semipalmata*), are particularly at risk of nests drowning when water depths increase unexpectedly. The analysis focuses on flow regime changes and excludes habitat changes associated with a dam creation (see also Yang et al. (2024)).

Flow dependencies analysis

Swimming, diving and grazing waterbirds were assessed across a total of 3948 km of river reaches in the Southern Gulf catchments using flows from 62 model nodes The locations for modelling these birds were selected based on species distribution models of the magpie goose (*Anseranas semipalmata*) (see Merrin et al. (2024)).

Hypothetical water resource development in the Southern Gulf catchments led to varying levels of change in key flow metrics important for these waterbirds. Across all 62 analysis nodes, dam scenarios showed changes ranging from negligible (0.5; Scenario B-D_{GPCT}) to minor (3.5; Scenario B-D_2). In contrast, water harvesting scenarios resulted in negligible changes 0.4 to 1.1 for scenarios B-$W_{T50P600R30E150}$ and B-$W_{T150P200R30E0}$, respectively. Scenario Cdry resulted in a moderate change (5.1) in important flow metrics. The impact associated with these scenarios varied due to spatial differences in flow regime changes and the distribution of important habitat for swimming, diving and grazing waterbirds (Figure 7-6).

Water harvesting and changes in important flows for swimming, diving and grazing waterbirds

The hypothetical water harvesting scenarios for swimming, diving and grazing waterbirds resulted in a negligible mean change ranging from 0.4 to 1.1 for scenarios B-$W_{T50P600R30E150}$ and B-$W_{T150P200R30E0}$, respectively. Changes in important flows under water harvesting scenarios varied depending on extraction targets, pump-start thresholds, pump rates and annual diversion commencement flow requirements (Figure 7-6). With a low extraction target of 50 GL (Scenario B-$W_{T50P600R30E0}$), the mean weighted change in flows remained negligible at 0.4. This increased slightly to 0.7 with a higher extraction target of 300 GL (Scenario B-$W_{T300P600R30E0}$). The pump-start threshold is important for protecting low flows by preventing pumping when the river is below this threshold. With a 150 GL extraction target, increasing the pump-start threshold from 200 ML/day (Scenario B-$W_{T150P200R30E0}$) to 600 ML/day (Scenario B-$W_{T150P600R30E0}$) reduced the mean change from 1.1 to 0.6 (negligible) (Figure 7-6). Measures such as limiting extraction targets and increasing the pump-start threshold can help protect the low flows that are important for swimming, diving and grazing waterbirds ecology.

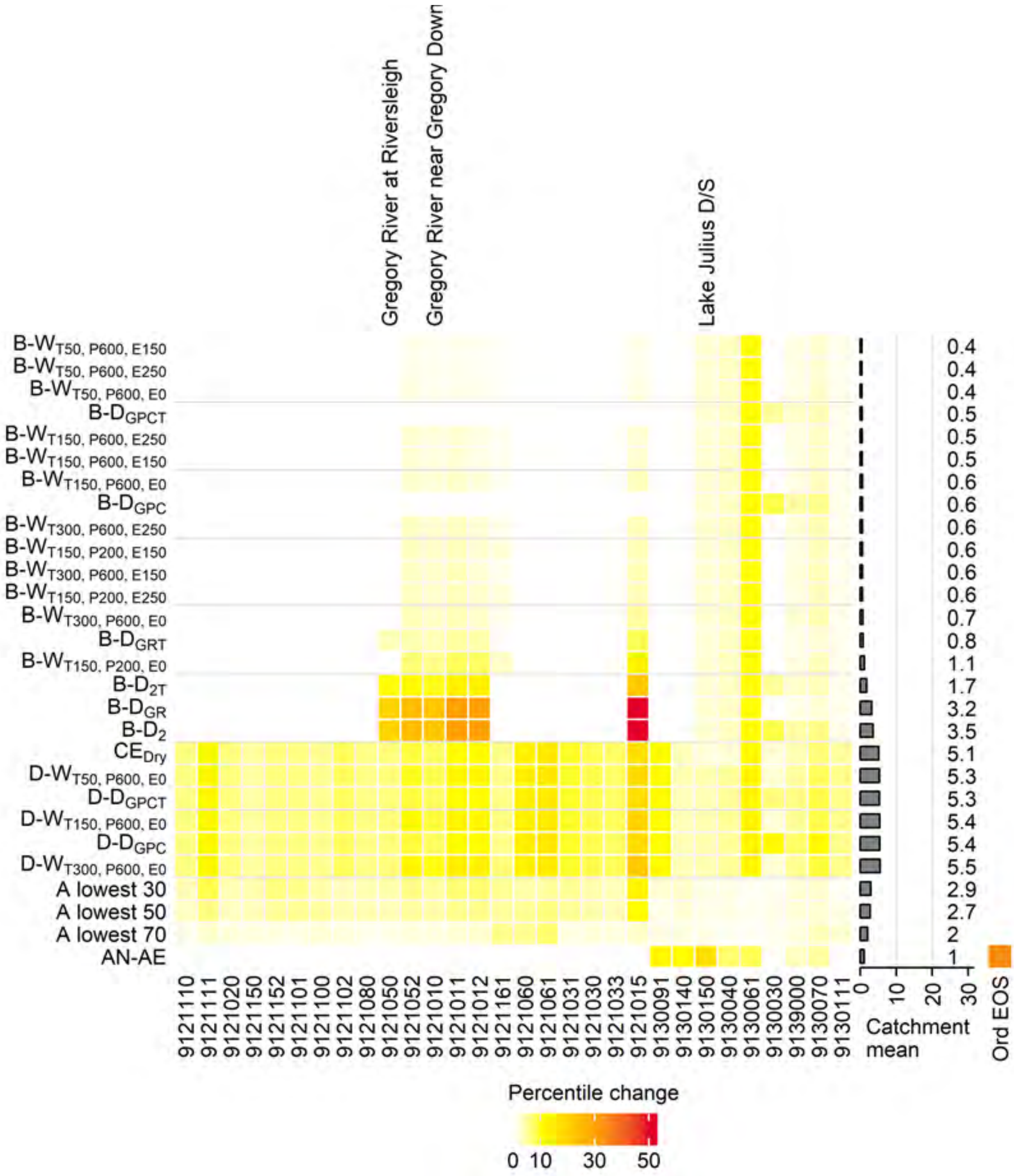

Figure 7-6 Habitat-weighted change in swimming, diving and grazing waterbirds flow dependencies by scenario across model nodes

Colour intensity represents the level of change occurring in important flow metrics as percentile change from the historical conditions weighted by the importance of each reach for swimming, diving and grazing waterbirds. Equivalent colour intensity (i.e. corresponding to the asset flow dependency change value) for the Ord River below Lake Kununurra shown bottom right. Scenarios are ordered on the left axis by the magnitude of change with the mean across nodes shown on the right axis. Horizontal grey bars and number correspond to the mean change across all model node locations. Only the 30 highest impact nodes are shown (*x*-axis). Results under Scenario A corresponding to changes in asset flow dependency for the lowest 30-year (A lowest 30), 50-year (A lowest 50) and 70-year (A lowest 70) time periods provide a reference for the modelled changes under different hypothetical development and projected future climate scenarios. AN-AE corresponds to the change in asset flow dependency in the Nicholson and Leichhardt catchments that has already occurred since European settlement.

Dams and changes in important flows for swimming, diving and grazing waterbirds

Under the dam scenarios, Scenario B-D_{GPC} resulted in a negligible change (0.6) in important flow metrics when averaged across the 62 swimming, diving and grazing waterbirds assessment nodes. With the implementation of transparent flows in Scenario B-D_{GPCT}, the change was further reduced to 0.5 (negligible). Scenario B-D_{GR}, in contrast, resulted in a minor change (3.2), which was reduced to negligible (0.8) with the transparent flows under Scenario B-D_{GRT}. Scenario B-D_2, which includes both the B-D_{GPC} and B-D_{GR} dams, resulted in a larger mean flow change across the catchment compared to either single dam scenario. The mean change across the catchment without transparent flows was minor (3.5) and this was reduced to negligible (1.7; Scenario B-D_{2T}) with transparent flows. The greater change under Scenario B-D_2 compared to the single dam scenarios is due to the combined effects of the two dams and their larger impact on the catchment. Scenario B-D_{2T} (with transparent flow) resulted in a smaller change than scenarios without transparent flows, demonstrating the importance of providing flows to support environmental outcomes for swimming, diving and grazing waterbirds (Figure 7-6).

Under dam scenarios, node 9121015 showed the greatest habitat-weighted changes in important flows for swimming, diving and grazing waterbirds (Figure 7-6) with the change recorded as extreme (51.5). Nodes directly downstream of the dams under scenarios B-D_{GPC} and B-D_{GR} resulted in moderate (8.7) and major (19.5) changes in important flows, respectively. These changes were reduced to moderate (5.1) and minor (3.7), respectively, when modelled with transparent flows. This pattern reflects the combined effect of flow changes directly downstream of the dams and the benefits of providing flows to support environmental outcomes.

Climate change and water resource development for important flows for swimming, diving and grazing waterbirds

Scenario Cdry resulted in a moderate change (5.1) in important flow metrics based on the mean across the 62 swimming, diving and grazing waterbirds assessment nodes (Figure 7-6). This indicates that the dry climate scenario led to a larger mean change than did Scenario B-D_{GPC} and B-$W_{T150P600R30E0}$, both of which showed negligible changes (0.6). However, note that local changes in flows can be considerably higher than the catchment means under some water resource development scenarios. When considering the impacts of climate change combined with water resource development, scenarios D-D_{GPC} and D-$W_{T150P600R30E0}$ both resulted in moderate changes (5.4), which is higher than the impacts of Scenario Cdry or either of scenarios B-D_2 and B-$W_{T160P200R30}$ alone.

Species in the swimming, grazing and diving waterbirds group are sensitive to changes in the depth, extent and duration of perennial semi-open and open deeper water environments such as wetlands and waterholes (Marchant and Higgins, 1990; McGinness, 2016). They can also be sensitive to changes in the type, density or extent of the fringing aquatic or semi-aquatic vegetation in and around these habitats. These changes can occur when water is extracted directly from these habitats or when the time between connecting flows or rainfall events that fill these habitats is extended (Kingsford and Norman, 2002). Climate change as explored through the Scenario Cdry and extremes are likely to interact with changes induced by water resource development, including inundation of freshwater habitats by seawater, and inundation of nests by extreme flood events or seawater intrusion (Nye et al., 2007; Poiani, 2006; Traill et al., 2009a; Traill et al., 2009b). The reduced extent, depth and duration of inundation of waterholes and other deep-water environments is likely to reduce their habitat and food availability, increasing competition and predation and also increasing risk of disease and parasite spread. Conversely, species in this group that nest at water level or just above, such as magpie geese, are particularly at risk of nests drowning when water depths increase unexpectedly (Douglas et al., 2005; Poiani, 2006; Traill et al., 2010; Traill et al., 2009a; Traill et al., 2009b).

Floodplain wetlands

For this analysis, floodplain wetlands are defined as freshwater lakes, ponds, swamps and floodplains with water that can be permanent, seasonal or intermittent, and can be natural or artificial. The Southern Gulf catchments contain 13 nationally significant wetlands listed in the Directory of Important Wetlands in Australia, although none are listed under the Ramsar Convention (see Merrin et al. (2024)). Wetlands provide permanent, temporary or refugia habitat for a range of species, are important for driving both primary and secondary productivity, and provide a range of additional ecosystem services (Junk et al., 1989; Mitsch et al., 2015; Nielsen et al., 2015; van Dam et al., 2008a; Ward and Stanford, 1995).

Floodplain wetlands are influenced by the timing, duration, extent and magnitude of floodplain inundation, which significantly affect their ecological values, including species diversity, productivity and habitat structure (Close et al., 2015; Tockner et al., 2010). In the southern Gulf of Carpentaria, during high-level flood flows, floodplain wetlands connect with coastal salt flats as a 'shallow lake' continuum. Freshwater fauna move downstream and brackish-water-tolerant estuarine species move from the river channels onto the inundated, productive salt flats to forage and reproduce, taking advantage of the food web that depends on the floodwater-stimulated algal crusts that invigorate from their dry-season senescence (Burford et al., 2016; Burford et al., 2010).

The key threats to floodplain wetlands are changes in flood regimes, specifically the timing, duration, extent and magnitude of floodplain inundation and the ensuing effect on the habitat structure, size and permanence of the wetlands and thus on species diversity and community productivity.

Flow dependencies analysis

Floodplain wetlands were assessed across a total of 2027 km of river reaches in the Southern Gulf catchments with contributing flows from 34 model nodes (see Ponce Reyes et al. (2024)). Key river reaches for floodplain wetlands in the Assessment catchments were modelled downstream of nodes 9139000, 9130140 and 9130050, which were selected based upon wetland and floodplain mapping (see Merrin et al. (2024)).

Hypothetical water resource development in the Southern Gulf catchments resulted in varying changes to key flow metrics affecting floodplain wetlands. The mean weighted change in flow of the hypothetical dam scenarios across all 34 floodplain wetlands analysis nodes ranged from negligible (0.3; Scenario B-D_{GPCT}) to minor (3.6; Scenario B-D_{2T}). In contrast, water harvesting scenarios ranged from negligible (0.6; Scenario B-$W_{T50P600R30E0}$) to minor (2.3; Scenario B-$W_{T300P600R30E0}$). Scenario Cdry resulted in a moderate change in important flow metrics (12.9) for floodplain wetlands. The level of flow regime change associated with dam construction, water harvesting and climate scenarios varied due to the differing spatial patterns of flow regime change and the distribution of important habitat for floodplain wetlands (Figure 7-7).

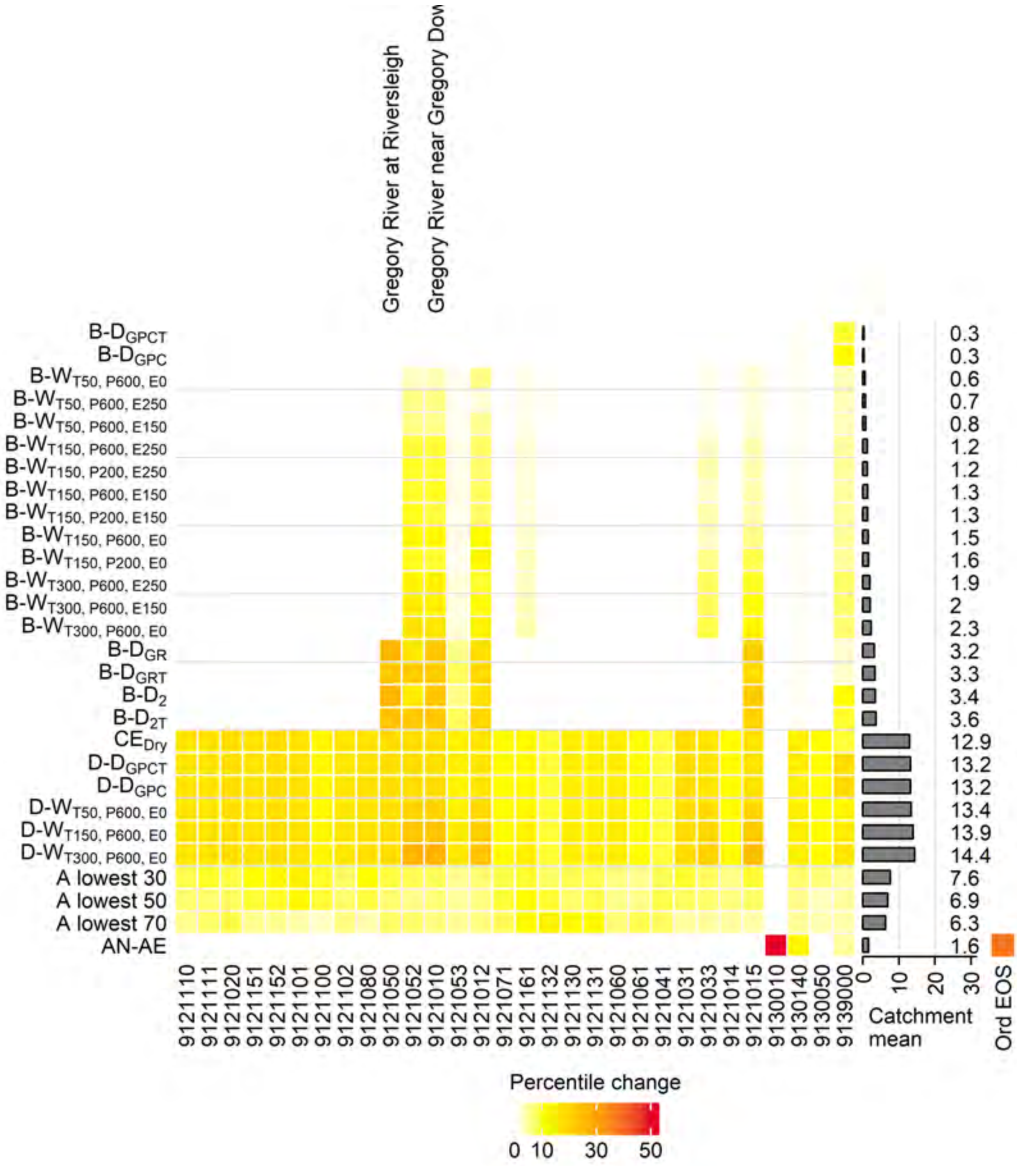

Figure 7-7 Habitat-weighted change in floodplain wetlands flow dependencies by scenario across model nodes
Colour intensity represents the level of change occurring in important flow metrics as percentile change from the historical conditions weighted by the importance of each reach for floodplain wetlands. Equivalent colour intensity (i.e. corresponding to the asset flow dependency change value) for the Ord River below Lake Kununurra shown bottom right. Scenarios are ordered on the left axis by the magnitude of change with the mean across nodes shown on the right axis. Horizontal grey bars and number correspond to the mean change across all model node locations. Only the 30 highest impact nodes are shown (*x*-axis). Results under Scenario A corresponding to changes in asset flow dependency for the lowest 30-year, 50-year and 70-year time periods provide a reference for the modelled changes under different hypothetical development and projected future climate scenarios. AN-AE corresponds to the change in asset flow dependency in the Nicholson and Leichhardt catchments that has already occurred since European settlement.

Water harvesting and changes in important flows for floodplain wetlands

The hypothetical water harvesting scenarios resulted in a mean change across floodplain wetland assessment nodes from negligible (0.6; Scenario B-$W_{T50P600R30E0}$) to minor (2.3; Scenario B-$W_{T300P600R30E0}$). The changes varied depending on extraction targets, pump-start thresholds, pump rates, and annual diversion commencement flow requirements (Figure 7-7). For a low extraction target of 50 GL (Scenario B-$W_{T50P600R30E0}$), the flow change was negligible (0.6), and this increased to minor (2.3) with a higher extraction target of 300 GL (Scenario B-$W_{T300P600R30E0}$). The pump-start threshold is important for protecting low flows by preventing pumping when the river is below this threshold. With a 150 GL extraction target, raising the pump-start threshold from 200 ML/day (Scenario B-$W_{T150P200R30E0}$) to 600 ML/day for (Scenario B-$W_{T150P600R30E0}$) slightly reduced the flow change from 1.6 to 1.5 (Figure 7-7). Measures to protect important parts of the flow regime can support ecology; for example, reducing the extraction target puts limits on the volume of water extracted in any water year, and increasing the pump-start threshold protects the low flows.

Dams and changes in important flows for floodplain wetlands

Under the dam scenarios, when averaged across the 34 floodplain wetlands assessment nodes, Scenario B-D_{GPC} (without transparent flows) resulted in a negligible change (0.3) in flow metrics for floodplain wetlands. This change remained the same with transparent flows (Scenario B-D_{GPCT}). Scenario B-D_{GR} resulted in a minor change (3.2), which slightly increased to 3.3 with transparent flows under Scenario B-D_{GRT}. In Scenario B-D_2, which includes both dams, a minor (3.4) mean change occurred, and this increased to 3.6 with transparent flows. Scenario B-D_2 resulted in a larger mean flow change across the catchment than either of the single dam scenarios. This increase was due to the combined effects on flows downstream and the larger portion of the catchment affected.

Habitat-weighted flow changes were most significant at node 9121050 and directly downstream (Figure 7-7), with a major change (26.5; Scenario B-D_{GR}). This was reduced to 22.5 (major) with transparent flows (Scenario B-D_{GRT}). This pattern reflects the combined effect of flow changes directly downstream of the dams and the benefits of providing flows to support environmental outcomes. Dams can have a significant impact on floodplain wetlands, as they capture runoff from rainfall events that would otherwise spill onto floodplains during larger events and facilitate the connection of the wetlands to the main river channel. The reduction in flood magnitude due to dams can change the connectivity between the river channel and the floodplain wetlands, significantly affecting the size of the inundated area. A loss of connectivity between the river channel and the floodplain wetland may also occur. This disconnection can alter the frequency and duration of wetland inundation, potentially leading to changes in the structure, function and biodiversity of these wetland habitats (Poff and Zimmerman, 2010; Richter et al., 1996).

Climate change and water resource development for important flows for floodplain wetlands

Scenario Cdry resulted in a moderate change (12.9) in important flow metrics for floodplain wetlands based on the mean across the 34 floodplain wetland assessment nodes (Figure 7-7). This indicates that the dry climate scenario led to a larger mean change across all catchment nodes than scenarios B-D_{GPC} (negligible; 0.3) and B-$W_{T150P600R30E0}$ (negligible; 1.5). However, it is important to note that local changes in flows under some water resource development scenarios can be considerably higher than the catchment means. Considering the combined impacts on flow associated with climate change and water resource development, scenarios D-D_{GPC} and

D-$W_{T150P600R30E0}$ resulted in moderate (13.2 and 13.9, respectively) changes when weighted across all floodplain wetland assessment nodes. This shows that the changes of scenarios D-D_{GPC} or Ddry$W_{T150P600R30E0}$ were higher than those of Scenario Cdry or either of scenarios B-D_2 and B-$W_{T160P200R30}$ alone.

7.3.5 Management of impacts on ecology

The magnitude and spatial extent of ecological impacts arising from water resource development are highly dependent on the type and location of development, the extraction volume and how the type of changes in the flow regime affect different aspects of flow ecology. Mitigation measures seek to protect key parts of the flow regime and can be important for sustaining ecology under water resource development. This section explores the effectiveness of different mitigation measures, including providing transparent flows for dams, different rules for water harvesting and different overall targets for water extraction.

Instream dam development

Two potential locations for instream dams (Gregory River and Gunpowder Creek) were selected for modelling and analysis (Yang et al., 2024) and simulated following the hydrology modelling approach outlined in Gibbs et al. (2024b). Their locations are shown in Figure 7-2. The objective of this analysis is to test the effect of different dam locations and configurations on changes to streamflow to understand the effect on downstream ecology. Dams are modelled individually (i.e. scenarios B-D_{GR} and B-D_{GPC}), as well as both together (Scenario B-D_2) to better understand cumulative impacts and to have variants with and without the mitigation measure of providing transparent flows (see Ponce Reyes et al. (2024) for definitions). Instream dams create a range of impacts on streamflow associated with the capture and extraction of water, affecting the timing and magnitude of downstream flows. The change of downstream flow associated with instream dams is explored here across broad asset groups, and results are shown as the mean of asset values. Impacts associated with loss of connectivity due to the dam wall and loss of habitat associated with the dam inundation extent are discussed in Yang et al. (2024). The dam scenarios and the resulting ecology flow dependencies are discussed in more detail for each asset in Ponce Reyes et al. (2024).

Assessment of the individual dams found varying levels of effect on ecology flow dependencies (Table 7-4). Scenario B-D_{GPC} resulted in no asset group having changes in important flow dependencies greater than negligible averaged across their assessment nodes, although local impacts on flows were often higher. However, Scenario B-D_{GR} resulted in major change for the ‘other species’ group including the turtles and prawn species. The dams vary in size, inflows and capture volumes, and the location of the dam in the catchment also influences outcomes, particularly in the freshwater reaches. Impacts on flow directly downstream of modelled dams can often be high and may cause extreme changes in ecological flow dependencies. Areas further downstream have contributions from unimpacted tributaries, and for the marine region, from flows from other catchments that help support ecological outcomes of flow regimes. Dams further up the catchment may, however, affect a larger proportion of streams and river reaches in terms of flow regime change but may have lower impacts in terms of connectivity. The Southern Gulf catchments, in particular, are complex and braided, and they have many tributaries that may be unimpacted within the freshwater sections of the catchment. Effects on important flows are not equivalent across assets, and large local impacts may lead to changes in ecology across other parts of the catchment due to the connected nature of ecological systems.

The cumulative change in flow dependencies associated with two dams (Scenario B-D_2) are greater than those of individual dams (Table 7-4). However, the largest contribution of change to Scenario B-D_2 originates from B-D_{GR}. Cumulative change in flows on ecology may be associated with a combination of a larger portion of the catchments being affected by changes in flows and residual flows being lower due to the overall greater level of water use and losses from dams (Table 7-4).

Table 7-4 Scenarios of different hypothetical instream dam locations showing mean changes of ecology flows for groups of assets across each asset's respective catchment assessment nodes

Higher values represent greater change in flows important to the assets of each group. Values are asset means across their respective catchment assessment nodes (see Appendix A in Ponce Reyes et al. (2024)). Some assets are considered in multiple groups, where the mean across the nodes is used. Asset means include values from all nodes that the asset is assessed in, including in reaches that may not be affected by flow regime change.

SCENARIO	DESCRIPTION	ALL ASSET MEAN	FISH	WATER BIRDS	OTHER SPECIES	HABITATS	FRESHWATER ASSETS	MARINE ASSETS
B-D_{GPC}	Gunpowder Creek dam	0.8	0.4	0.8	0.1	0.5	0.8	0.2
B-D_{GPCT}	Gunpowder Creek dam with transparent flows	0.7	0.3	0.7	0.1	0.5	0.7	0.2
B-D_{GR}	Gregory River dam	4.1	8.9	4.0	18.2	6.4	4.4	12.7
B-D_{GRT}	Gregory River dam with transparent flows	1.5	1.8	1.7	3.8	2.8	1.7	3
B-D_2	Both B-D_{GPC} and B-D_{GR}	4.5	9.1	4.4	18.3	6.7	4.7	12.8
B-D_{2T}	Both B-D_{GPC} and B-D_{GR} with transparent flows	2.7	5.5	2.7	12.7	4.1	2.9	8.4

Measures to mitigate the flow-related impacts of large instream dams, such as transparent flows (inflows let to pass the dam wall for environmental purposes), resulted in lower change to ecological flow dependencies broadly across all assets compared to instream dams without these measures (Table 7-4). Particularly strong benefits are shown in the reduced change to important flow dependencies resulting from transparent flows for members of the fish and waterbird groups (see Ponce Reyes et al. (2024) for groupings and more detail). Instream dams capture inflows and change downstream flow regimes. Transparent flows are a type of environmental flow provided as releases from dams that mimic or maintain some aspects of natural flows. Staged offtakes to maintain natural water temperatures are required. However, providing transparent flows from a dam it lowers the volume of water in storage and thereby increases the capture of early flood events in the following year. This might also result in the lowering of flood peaks, resulting in smaller inundation events during periods of floods affecting assets such as surface-water-dependent vegetation (see Ponce Reyes et al. (2024)). Modelling transparent flows uses inflow thresholds on dams and was designed primarily to preserve lower flows during periods of natural inflow. Inflow thresholds used in the transparent flows analysis were similar to the commence-to-pump thresholds used in water harvest scenarios, facilitating comparison. Transparent flow scenarios are provided across both individual dams and under Scenario B-D_2 (Gibbs et al., 2024b).

Water harvesting

For water harvesting scenarios, several measures can mitigate the impacts of flow-related changes from extraction. These include limiting system targets to reduce extraction across the catchment, implementing a pump-start threshold to restrict pumping during low river flows, setting an annual diversion commencement flow requirement to allow a volume of water to pass through the system before pumping, and limiting the pump rate for extraction (see Ponce Reyes et al. (2024) and Gibbs et al. (2024b) for more details). These measures improve environmental outcomes compared to scenarios without them.

Reducing system targets decreases the changes in flows across asset groups, while larger extraction volumes lead to moderate increases in flow dependencies across the catchment's ecological assets. Groups like turtles, prawns and other species and the marine assets (Table 7-2), experience greater changes at higher system targets of 400 to 500 GL/year (Figure 7-9) (see Ponce Reyes et al. (2024) for details on individual assets). Providing minimum flow thresholds or annual diversion commencement requirements can help mitigate these changes. An annual diversion commencement flow requirement of 250 GL improves ecological flows across asset groups with smaller requirements proportionally reducing flow changes (see Ponce Reyes et al. (2024)). The largest benefits for smaller irrigation targets are often seen with an initial 100 GL requirement, as this delays the start of pumping, retaining early wet-season flows and shortening the water harvest period (Gibbs et al., 2024b).

Increasing the pump-start threshold to 1000 ML/day significantly reduces changes in flow dependencies across several asset groups, particularly for fish, sharks, rays and freshwater-dependent habitats (Table 7-2) (see Ponce Reyes et al. (2024) for details on individual assets). Compared to lower thresholds of 200 or 400 ML/day, the improvements are particularly notable beyond 600 ML/day, where the impacts on freshwater-dependent habitats and marine environments are reduced (Figure 7-9) (see Ponce Reyes et al. (2024) for more details). Higher pump-start thresholds appear most effective when system targets are limited to about 200 GL/year and when annual diversion commencement requirements are low or absent, as substantial flows may have already passed through the system before the pump threshold is activated (see Ponce Reyes et al. (2024) for more details). This indicates that optimising the pump-start threshold is crucial for reducing the strain on ecosystems, particularly during periods of low flow.

Varying levels of end-of-system (EOS) flow requirements also affect different ecological assets in relation to system targets. For fish, sharks and rays, increasing the EOS requirement from zero to 250 GL/day results in minimal changes in flow dependencies, particularly at lower system targets (~100 GL/year). However, other groups, such as turtles, prawns and other species, experience significant impacts at lower EOS requirements (below 50 GL/day). As the EOS requirement increases, these impacts are mitigated, especially at higher system targets. Flow-dependent habitats and marine environments are also sensitive to lower EOS requirements, with notable reductions in ecological change when the EOS requirement reaches 150 to 250 GL/day. Overall, impacts are more evenly distributed across EOS requirements with the least change occurring when EOS requirements are higher and system targets are kept below 200 GL/year. This suggests that increasing EOS flow requirements provides substantial ecological benefits, particularly for groups sensitive to flow changes, such as turtles, prawns and flow-dependent habitats (see Ponce Reyes et al. (2024) for more details).

Finally, limiting pump capacity helps reduce changes in flow dependencies during water harvesting. Slower pump rates and minimum thresholds restrict water extraction during the wet season. Additionally, limiting pump capacity at higher extraction volumes further reduces the total volume extracted and lessens ecological impacts (Gibbs et al., 2024b).

Figure 7-8 Lake Moondarra near Mount Isa is used for urban water supply and is a popular water and recreational reserve

Photo: CSIRO – Nathan Dyer

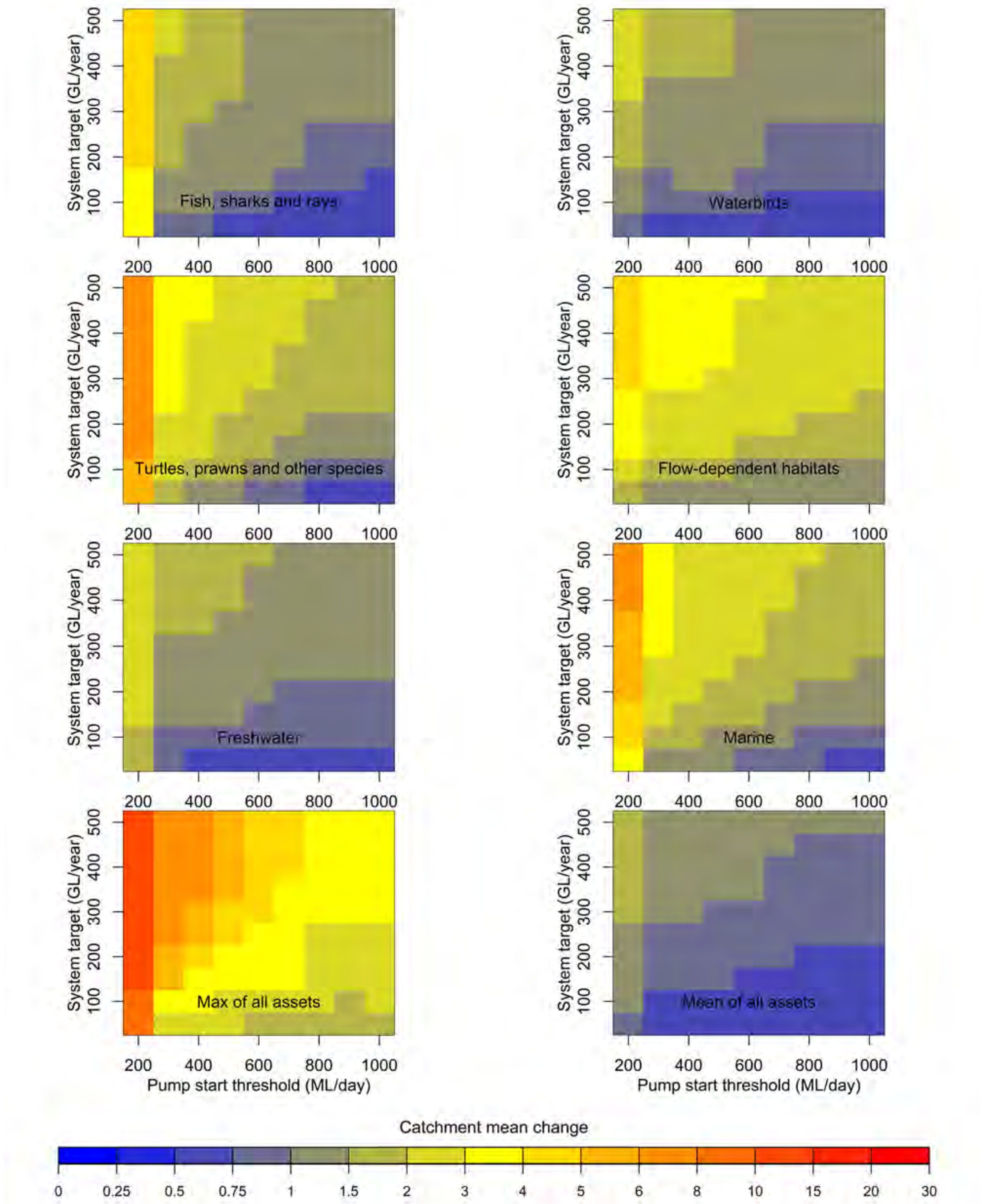

Figure 7-9 Mean change associated with each asset's important metrics across water harvesting increments of system target and pump-start threshold with no annual diversion commencement flow requirement and pump rate of 30 days

Colour intensity represents the mean level of change in important flow dependencies with the scenario given the habitat importance of each node for each asset.

7.4 Biosecurity considerations

7.4.1 Introduction

Biosecurity is the prevention and management of pests, weeds and diseases, both terrestrial and aquatic, to limit the risk of detrimental economic, environmental, social and/or cultural impacts. 'Pests' is a broad term encompassing pest insects, other invertebrates (e.g. nematodes, mites, molluscs) and vertebrates (e.g. mammals, birds, fish). Weeds broadly include invasive plants and algae. Diseases are caused by pathogens or parasites such as bacteria, fungi and viruses.

Any development of the water resources within the catchments of the Southern Gulf for plant industries or aquaculture must take account of biosecurity risks that may threaten production or markets. Development in the study area may also pose broader biosecurity risks to other industries, the environment or communities and these risks must be prevented and/or managed. The catchments of the Southern Gulf extend across Queensland and the NT, so the following sections consider biosecurity policies and regulations for both jurisdictions.

Biosecurity practices to protect the Southern Gulf catchments occur at a range of scales. At the national level, the Australian Government imposes quarantine measures to regulate the biosecurity risks associated with entry of goods, materials, plants, animals and people into Australia. The Queensland and NT governments also have biosecurity legislation to limit the entry of new pests, weeds and diseases into their jurisdictions, and to require the control of certain species that are already established. There can also be requirements at the regional level, such as participating in weed management programs (NT Government, 2021; SGNRM and NWQROC, 2022). At the local scale, individual properties ideally follow routine biosecurity protocols, and work with other similar enterprises in implementing industry-wide biosecurity measures.

While the Southern Gulf catchments are relatively isolated compared with other regions of Australia, they still have physical connections to the neighbouring regions in Queensland and the NT, across northern Australia more broadly, with the rest of the country and with neighbouring countries such as Indonesia. Examples of such connections are the sharing of specialist cropping machinery between agricultural regions, transport of crop products, tourist visits into remote areas, international trade and tourism, mining exploration, shifting cattle between pastoral properties, army training exercises and movements between Indigenous communities. These connections can be pathways for entry of new pests, weeds or diseases.

This section introduces the impacts, spread and management of pests, weeds and diseases of irrigated cropping and aquaculture, as well as invasive species that pose a risk to the Southern Gulf catchments. Given the focus on water-intensive primary industries, biosecurity for terrestrial livestock industries is not included.

Impacts of pests, weeds and diseases

In primary industries, pests, weeds and diseases can cause economic losses by reducing crop yield and product quality, interfering with farm operations and, loss of market access plus the costs of control measures. The national economic impact of established weeds and vertebrate pests on Australian agriculture has been estimated at over $5.3 billion/year (Hafi et al., 2023). Insect pests are also a substantial economic burden nationally (Bradshaw et al., 2021).

The environmental impacts of pests, weeds and diseases, collectively termed 'invasive species', include loss of native plants and animals (from competition, predation and infection), degradation of habitats and disruption of ecosystem processes (e.g. changed fire or moisture regimes). Invasive species are the greatest threat to Australia's threatened flora and fauna (Ward et al., 2021). For example, myrtle rust (*Austropuccinia psidii*) has potential to cause the extinction of some rare, native myrtaceous shrubs and trees (Makinson et al., 2020).

Social impacts of pests, weeds and diseases include loss of public amenity and access to outdoor areas, damage to infrastructure and public safety risks. Cultural impacts include a loss of traditional foods, impaired access for hunting and damage to cultural sites. For example, Gamba grass (*Andropogon gayanus*) is an African grass originally introduced for pasture in the NT and is now a Weed of National Significance (WoNS). WoNS are nationally agreed weed priorities that have been a focus for prevention and improved management (Hennecke, 2012; CISS, 2021). Gamba grass forms tall, dense stands that burn intensely, posing significant risks to public safety, community and primary industries infrastructure, Indigenous heritage sites, native ecosystems and grazing lands (Setterfield et al., 2013).

Pathways of movement

Pests, weeds and diseases spread via movement of adults and juveniles (e.g. vertebrate pests), with movement of their hosts (e.g. infected aquaculture broodstock or nursery stock for planting, harvested produce infested with insect larvae) and by movement of propagules (e.g. fungal spores, insect eggs, weed seeds, viral particles). Such movements provide many pathways by which pests, weeds and diseases could be introduced to the Southern Gulf catchments, potentially causing new outbreaks. Just as importantly, there is also the potential for pests, weeds and diseases from the Southern Gulf catchments to spread to other areas in Queensland and the NT, and elsewhere in Australia.

Human-mediated spread

Human activities are the key means of long-distance and local movement. Pests and propagules, including those within transported soil, can 'hitchhike' on or in vehicles, construction and farm machinery, shipping containers and other equipment brought into a region. The ease of movement on vehicles and machinery means that the road network (including access roads to camping areas, railways, pipelines and powerlines) can be a frequent source of new infestations.

Propagules may contaminate livestock, seed or nursery stock for establishing crops, hay, road base and landscaping supplies (including turf and ornamental plants). Weed infestations can also arise from invasive garden, crop and pasture plants. Aquatic pests and diseases may become established due to deliberate species release into the environment for fishing, inadvertent transport on fishing equipment or vessels, or dumping of aquarium contents.

Incursions of new pests, weeds and diseases from overseas are most likely to occur through contamination of imported goods or containers, or be carried by people (e.g. propagules on shoes or clothing, smuggling of seed or fruit).

Natural spread

Natural dispersal via wind, water and wild animals usually occurs over short distances. Extreme weather events such as floods and cyclones can disperse pests, weeds and diseases over long distances in addition to causing major environmental disturbances that increase the likelihood of invasive species becoming established. Ebner et al. (2020) flagged the floodplain lowlands of the Gulf of Carpentaria as a high risk for pest fish movement due to a natural and relatively regular connectivity of adjacent catchments during periods of torrential rain. Furthermore, irrigation infrastructure such as dams, pipelines and channels may facilitate distant spread via water movements of some aquatic pests, weeds and diseases, within and across catchments. Some animal pests, such as locusts and fall armyworm (*Spodoptera frugiperda*), naturally migrate long distances.

Northern Australia is close to the southern coasts of Indonesia, Timor-Leste and Papua New Guinea (PNG). These neighbouring countries have a range of serious plant pests and diseases that are not present in Australia, including exotic fruit flies and citrus canker (*Xanthomonas citri* subsp. *citri*). The likelihood of their arrival by long-distance wind dispersal is uncertain, particularly with regards to novel atmospheric conditions and extreme weather events occurring under climate change. However, their economic consequences in Australia would be severe were they to establish in Australia. Thus, ongoing biosecurity vigilance in northern Australia through government, industry and community surveillance is vital (DAFF, 2024a; PHA, 2021).

7.4.2 Pest, weed and disease threats to the Southern Gulf catchments

The Southern Gulf catchments principally face biosecurity risks from pests, weeds and diseases already present in the catchment and those that occur in neighbouring regions of northern Australia. However, pests, weeds and diseases could also come from other parts of Australia with similar climates and/or production systems, or from overseas.

Examples of pests, weeds and diseases that pose a risk to the Southern Gulf catchments are highlighted in the following sections. Whether any one of these would have a significant impact at the property level depends on the local environment, land use and agricultural or aquatic enterprise. However, there is a legal requirement to prevent and manage any pest, weed or disease that is formally ‘declared’ under jurisdictional biosecurity legislation, regardless of its local impact. Furthermore, in Queensland there is a general biosecurity obligation (GBO) under the *Biosecurity Act 2014* (Qld) that all persons must take all reasonable and practical steps under their control to not pose a biosecurity risk to others, in all locations (e.g. workplace, home, visiting). This applies regardless of whether a particular pest, weed or disease has been declared as prohibited or restricted matter in Queensland.

Plant industries

The priority pests and diseases for cropping in the Southern Gulf catchments depend on what is grown. Table 7-5 gives examples of high-impact pest and disease threats to particular crops, and their current distribution and legal status under the Queensland Biosecurity Act and the NT *Plant Health Act 2008* (DITT, 2023; Queensland Government, 2022). Information on pests and diseases of plant industries is given on the Queensland and NT governments’ websites (Queensland Government, 2022; NT Government, 2024a). Plant Health Australia is a centralised resource on exotic (i.e. overseas) biosecurity risks to Australia's plant industries. Research and development corporations, including the Grains Research and Development Corporation, the Cotton Research and Development Corporation, AgriFutures Australia and Hort Innovation also provide extension publications on identifying and managing biosecurity threats.

Many pests and diseases have a high host specificity to a particular crop, but there are also generalists that can use many crops as hosts. Local native species can also pose risks of impacts. For example, naturally occurring pathogens of various native wild rices may infect cultivated rice (Chapman et al., 2020) or native animals may graze on crops.

Irrigation brings the potential for year-round cropping, which can provide a 'green bridge' in the dry season to enable pests or diseases, including native insects and diseases, to persist and increase locally, and to potentially spread to other areas.

A significant new generalist pest of cropping is fall armyworm, which has become widely established across northern Australia since a national incursion was detected in 2020. It is likely to be present year round in the Southern Gulf catchments, with a lower incidence in the dry season (PHA, 2020). Fall armyworm caterpillars favour C4 grass crops (e.g. maize, sorghum, rice) and pastures but may also feed on broadleaved crops such as soybean, melon, green bean and cotton. Young crops are most at risk of severe damage and can require immediate insecticide treatment if invaded at levels above the damage threshold.

Cucumber green mottle mosaic virus (CGMMV) infects a wide range of cucurbit crops, including various melons, cucumber, pumpkin and squash, and can also be hosted by a range of broadleaved crop weeds. It causes plant stunting and fruit discolouration, malformation and rotting. CGMMV is present on a few farms in Queensland but is more widespread in the NT. It has also been found interstate. Its presence on-farm can make access to interstate markets more difficult as many jurisdictions have imposed quarantine requirements. Infected plants cannot be treated, so preventive farm biosecurity measures are vital (NT Government, 2024a; Queensland Government, 2019).

Types of weed threats differ between plant industries according to production methods. For example, annual grain and cotton crops tend to have annual weeds (grasses and herbs) and herbaceous perennials which persist and spread vegetatively via underground rhizomes. Perennial horticulture disturbs the soil less, so typically has more perennial grasses and perennial broadleaved weeds. The highest priority weeds in cropping tend to be those that are most difficult to control, such as herbicide-resistant biotypes or species that are otherwise tolerant to routinely used herbicides. For example, some annual grasses that invade cotton crops have developed resistance to certain herbicides, including barnyard grass (*Echinochloa* spp.) and feathertop Rhodes grass (*Chloris virgata*) (CRDC, 2023).

Various native vertebrates may consume grain and horticultural crops that are becoming established and damage tree crops. These vertebrate pests include birds (waterfowl, cockatoos), macropods (kangaroos, wallabies) and rodents. Large flocks of magpie geese (*Anseranas semipalmata*) can be particularly destructive, trampling, grazing and uprooting plants and consuming fruit (Clancy, 2020).

Table 7-5 Examples of significant pest and disease threats to plant industries in the Southern Gulf catchments

Links to further information are current as of March 2024

BIOSECURITY THREAT AND LEGAL STATUS (NT/QLD) For NT: ***Plant Health Act 2008*** – D = declared; nd = not declared For Queensland: ***Biosecurity Act 2014*** – P = prohibited matter; R = restricted matter; FNP = far northern pest; GBO = general biosecurity obligation	CURRENT STATUS	CROPS AT RISK
INVERTEBRATE PESTS		
Asian citrus psyllid ***Diaphorina citri*** nd/P, GBO	Incursion risk from overseas (including Indonesia and PNG)	Citrus
Cluster caterpillar ***Spodoptera litura*** nd/GBO	Widespread in northern Australia	Cotton, pulses, brassicas
Fall armyworm ***Spodoptera frugiperda*** nd/GBO	Widely established across northern Australia following first detection in 2020	Grasses (cereal and fodder), cotton, soybean, melon, green beans
Fruit flies, various species including: Mediterranean fruit fly ***Ceratitis capitata*** D/P, GBO Melon fruit fly ***Bactrocera cucurbitae*** D/P, GBO Oriental fruit fly ***Bactrocera dorsalis*** D/P, GBO New Guinea fruit fly ***Bactrocera trivialis*** D/P, GBO Queensland fruit fly ***Bactrocera tryoni*** D/GBO	Mediterranean fruit fly established in WA. Queensland fruit fly endemic in the NT and Queensland. Melon, oriental, New Guinea and other exotic fruit fly incursion risks from overseas (incl. Indonesia, PNG) and the Torres Strait	Fruit and fruiting vegetable crops
Bollworms ***Helicoverpa*** spp., ***Pectinophora*** spp. nd/GBO	Widespread in northern Australia	Cotton, pulses, brassica, sunflower, forage sorghum, grain sorghum, maize
Guava root-knot nematode ***Meloidogyne enterolobii*** D/GBO	Recent detections in the NT (Darwin region) and Queensland	Cucurbits, solanaceous crops, sweet potato, cotton, guava, ginger
Leaf miners: American serpentine leaf miner ***Liriomyza trifolii*** nd/GBO Serpentine leaf miner ***Liriomyza huidobrensis*** nd/GBO Vegetable leaf miner ***Liriomyza sativae*** D/FNP, GBO	Serpentine and American serpentine leaf miners are recent incursions now present in various locations across Australia. Vegetable leaf miner is present and under control in the far northern biosecurity zone, Queensland	Vegetables, cotton
Mango pulp weevil ***Sternochetus frigidus*** D/GBO	Incursion risk from overseas (including Indonesia)	Mango
Mango shoot looper ***Perixera illepidaria*** nd/GBO	Recent incursion in Queensland and the NT	Mango, lychee
Melon thrips ***Thrips palmi*** D/GBO	Limited presence in the NT north of Alligator River township and in Queensland	Vegetables
Spur throated locust ***Austracris guttulosa*** nd/GBO	Native to northern Australia	Grasses (cereal and fodder), sunflowers, soybeans, cotton
DISEASES		
Alternaria leaf blight ***Alternaria alternata*** nd/GBO	Present in northern Australia	Cotton
Banana freckle ***Phyllosticta cavendishii*** D/P, GBO	Under eradication in the NT	Banana
Brown spot Cochliobolus miyabeanus nd/GBO	Endemic on wild rices in northern Australia	Rice
Citrus canker ***Xanthomonas citri*** subsp. ***citri*** D/P, GBO	Eradicated from the NT and Queensland. Incursion risk from overseas (incl. Indonesia, Timor-Leste and PNG)	Citrus
Cucumber green mottle mosaic virus (CGMMV) nd/R, GBO	Present in certain areas in the NT, Queensland and other states	Cucurbits
Fusarium wilt ***Fusarium oxysporum*** f. sp. ***vasinfectum*** D/GBO	Not present in the NT	Cotton
Huanglongbing ***Candidatus Liberibacter asiaticus*** D/GBO	Incursion risk from overseas (including Indonesia, Timor-Leste and PNG)	Citrus
Panama disease tropical race 4 (Panama TR4) ***Fusarium oxysporum*** f. sp. ***cubense*** D/GBO	Established throughout the NT. Limited distribution in Queensland and mandatory code of practice for its management and control	Banana
Rice blast **Pyricularia oryzae** nd/GBO	Endemic on wild rices in northern Australia	Rice

Aquaculture

A wide range of diseases and parasites are of concern to Australian aquaculture (DAWE, 2020a), including those not known to be in Australia, those now established (i.e. endemic) in Australia and those native to Australian ecosystems.

Barramundi farmers need to consider preventing and managing the biosecurity risks of a range of endemic parasites and viral, bacterial and fungal pathogens that naturally occur in northern Australia (Irvin et al., 2018). In addition, national quarantine measures are vital to prevent exotic disease risks for barramundi from entering Australia (Landos et al., 2019).

Prawn aquaculture in northern Australia is most at risk from white spot syndrome virus (WSSV), for which there have been national incursion responses at prawn farms and hatcheries in south-east Queensland and northern NSW. However, there are also many other exotic crustacean diseases (DAWE, 2020a). Endemic viruses (and endemic genotypes of viruses also found overseas) that occur naturally in Australian waters can also trigger mortalities or reduce productivity (Irvin et al., 2018).

Invasive species

Invasive species, whether pest, weed or disease, are commonly characterised as occurring across multiple land uses in a landscape. Their impacts will vary between land uses, but their coordinated control requires action across all tenures.

Weeds

Table 7-6 lists regional weed priorities in the Southern Gulf catchments and their legal status under the NT Weed Management Act 2001 and the Queensland Biosecurity Act 2014 (NT Government, 2021; SGNRM and NWQROC, 2022). Of those listed, parthenium weed (*Parthenium hysterophorus*), Bathurst burr (*Xanthium spinosum*) and Noogoora burr (*X. occidentale*) are direct competitors and potential contaminants in dryland and irrigated crops. Parthenium weed also poses a health risk to animals and people as a severe allergen. Many species in Table 7-6 are WoNS.

Aquatic weeds can hamper the efficient function of irrigation infrastructure and also cause severe ecological impacts through dense infestations in waterways and wetlands. More-constant water flows from within-stream reservoirs can also change riparian conditions from seasonally ephemeral to perennial, predisposing native vegetation to invasion by weeds that thrive in moist environments.

Terrestrial vertebrate pests

Various large feral herbivores are present in the Southern Gulf catchments, including buffalo (*Bubalus bubalis*), horses (*Equus caballus*), donkeys (*E. asinus*) and pigs (*Sus scrofa*). They can directly affect agricultural production through grazing impacts, severe soil erosion and damaged infrastructure such as fencing and irrigation channels. Feral animal damage to habitats is a key disturbance mechanism that facilitates weed invasion, particularly in riparian and wetland areas. Feral pigs in particular are a major threat to irrigated cropping. Their daily water requirement means that they concentrate during the dry season around watercourses and man-made water supplies (Bengsen et al., 2014).

Cane toads (*Rhinella marina*) are already established in the Southern Gulf catchments (Kearney et al., 2008), but would likely become more abundant around irrigation developments where they could access year-round moisture (Bengsen et al., 2014).

Aquatic pests

Freshwater aquatic pests such as non-native fish, molluscs and crustaceans can affect biodiversity and ecosystem functioning. While these pests may not directly affect irrigated cropping, the associated infrastructure required (e.g. dams, channels, drains) brings increased risk of deliberate release by people for recreational fishing or the disposal of aquarium contents. This infrastructure can also provide enhanced habitat and pathways for the persistence and dispersal of aquatic pests and weeds in the catchment (Ebner et al., 2020).

Table 7-6 Regional weed priorities and their management actions in Southern Gulf catchments

WEED AND LEGAL STATUS	REGIONAL ACTION		HABITATS AT RISK		
WoNS = Weed of National Significance For NT: ***Weed Management Act 2001*** – D = declared; † = has a statutory management plan **under the** Act For Queensland: ***Biosecurity Act 2014*** – P = prohibited matter; R = restricted matter; GBO = only the general biosecurity obligation applies	NT	QLD	AQUATIC (e.g. river, wetland, dam)	WETTER AREAS (e.g. riparian, floodplain, drain)	DRIER AREAS (e.g. grassland, woodland)
AQUATIC/SEMI-AQUATIC HERB					
Cabomba ***Cabomba caroliniana*** WoNS D/R	P	P	✓	✓	
Limnocharis ***Limnocharis flava*** D/R	P	P	✓	✓	
Sagittaria ***Sagittaria platyphylla*** WoNS D/R	P	P	✓	✓	
Salvinia ***Salvinia molesta*** WoNS D/R	P	C ‡	✓	✓	
Water mimosa ***Neptunia plena*** D/R	P	P	✓	✓	
Water hyacinth ***Pontederia crassipes*** WoNS D/R	P	P	✓	✓	
GRASS					
Aleman grass ***Echinochloa polystachya*** -/GBO	P	P	✓	✓	
Gamba grass ***Andropogon gayanus*** WoNS D†/R	E	P		✓	✓
Giant rat's tail grass ***Sporobolu***s spp. -/R	P	P		✓	✓
Grader grass ***Themeda quadrivalvis*** D†/GBO	C	C ‡		✓	✓
Hymenachne ***Hymenachne amplexicaulis*** WoNS D/R	P	P	✓	✓	
Thatch grass ***Hyparrhenia rufa*** D/GBO	P	n		✓	✓
BROADLEAVED HERB					
Bathurst burr ***Xanthium spinosum*** D/GBO	n	C ‡		✓	✓
Devils claw ***Martynia annua*** D/GBO	P	n			✓
Noogoora burr ***Xanthium occidentale*** D/GBO	n	M		✓	✓
Parthenium weed ***Parthenium hysterophorus*** WoNS D/R	P	C ‡		✓	✓
CLIMBER/VINE					
Rubber vine ***Cryptostegia grandiflora*** WoNS D/R	P	C		✓	✓
Ornamental rubber vine ***Cryptostegia madagascariensis*** D/R	P	P		✓	✓
TREE/SHRUB					

WEED AND LEGAL STATUS **WoNS = Weed of National Significance** For NT: ***Weed Management Act 2001*** – D = declared; † = has a statutory management plan **under the** Act For Queensland: ***Biosecurity Act 2014*** – P = prohibited matter; R = restricted matter; GBO = only the general biosecurity obligation applies	REGIONAL ACTION NT	 QLD	HABITATS AT RISK AQUATIC (e.g. river, wetland, dam)	 WETTER AREAS (e.g. riparian, floodplain, drain)	 DRIER AREAS (e.g. grassland, woodland)
Athel pine ***Tamarix aphylla*** WoNS D†/R	E	C ‡		✓	
Barleria ***Barleria prionitis*** D/GBO	n	C ‡		✓	✓
Bellyache bush ***Jatropha gossypiifolia*** WoNS D†/R	C	C		✓	✓
Calotrope ***Calotropis procera***, ***C. gigantea*** D/GBO	M	M			✓
Chinee apple ***Ziziphus mauritiana*** D†/R	C	C ‡		✓	✓
Coffee bush ***Leucaena leucocephala*** -/GBO	M	P		✓	
Lantana ***Lantana camara*** WoNS D/R	P	P			
Madras thorn ***Pithecellobium dulce*** -/R	n	E			
Mesquite ***Prosopis*** spp. WoNS D†/PR	E	C ‡		✓	✓
Mimosa ***Mimosa pigra*** WoNS D†/R	E	P	✓		
Neem ***Azadirachta indica*** D†/GBO	C	C		✓	✓
Parkinsonia ***Parkinsonia aculeata*** WoNS D/R	M	M		✓	✓
Pond apple ***Annona glabra*** WoNS D/R	P	P	✓	✓	
Prickly acacia ***Vachellia nilotica*** WoNS D/R	E	C ‡		✓	✓
Siam weed ***Chromolaena odorata*** D/R	P	P		✓	✓
Sicklepod ***Senna obtusifolia***, ***S. hirsuta***, ***S. tora*** D/R	n	P		✓	✓
Yellow bells ***Tecoma stans*** -/R	n	C ‡		✓	✓
Yellow oleander ***Cascabela thevetia*** -/R	M	C ‡		✓	✓
CACTI/SUCCULENTS					
Bunny ears ***Opuntia microdasys*** WoNS D/R	P	E			✓
Coral cactus ***Cylindropuntia fulgida*** WoNS D/R	P	C			
Engelmann's prickly pear ***Opuntia engelmannii*** WoNS D/P	P	E			
Harrisia cactus ***Harrisia martinii***, ***H. tortuosa***, ***H. pomanensis*** D/R	P	C ‡			
Mother of millions ***Bryophyllum delagoense*** -/R	P	C‡			
Other opuntioid cacti ***Opuntia*** spp., ***Cylindropuntia*** spp., ***Austrocylindropuntia*** spp. WoNS D/PR	P	P			

For regional actions:
- P = alert weed for prevention and early intervention
- E = eradication target (few infestations known)
- C = strategic control target (control and containment of core infestations, eradication of outlier populations, prevention elsewhere)
- M = widely established; regional management focused on protecting assets at risk
- n = not a regional priority in that jurisdiction
- ‡ Restricted to part of catchment only (SGNRM and NWQROC, 2022); otherwise a P

Sources: NT Government (2021); SGNRM and NWQROC (2022); pers. comm. NT and Queensland government officers

Table 7-7 lists examples of high-risk pest fish for the Southern Gulf catchments. Certain species are formally declared as ‘noxious’ under the NT Fisheries Regulations 1992, or as prohibited or restricted matter in Queensland under the Biosecurity Act. Those not declared noxious in the NT are still covered by a general precautionary provision that excludes import into the NT and possession of non-native fish that are not on the Australian Government’s list of permitted live freshwater ornamental fish (DAFF, 2023), or otherwise not listed as a permitted import in Schedule 7 of the Regulations. Those not categorised as prohibited or restricted matter in Queensland are still subject to the general biosecurity obligation.

Table 7-7 High-risk freshwater pest fish threats to the Southern Gulf catchments

PEST FISH AND LEGAL STATUS (NT/QLD)	LEGAL STATUS IF ANY (NT/QLD)	CURRENT DISTRIBUTION
Alligator gar ***Atractosteus spatula***	N/R	Not known to be in the wild in Australia
Black pacu ***Piaractus brachypomus***	E/R	Not known to be in the wild in Australia. Risk of incursion from PNG
Carp ***Cyprinus carpio*** N/R	N/R	Not known to be in the wild in the NT
Cichlids, including tilapia: Giant cichlid ***Boulengerochromis microlepis*** Jaguar cichlid ***Parachromis managuensis*** Pearl cichlid ***Geophagus brasiliensis*** Mozambique tilapia ***Oreochromis mossambicus*** Nile tilapia ***Oreochromis niloticus*** Spotted tilapia ***Pelmatolapia mariae*** Texas cichlid ***Herichthys cyanoguttatus***	 N/R E/GBO E/GBO N/R N/P N/R E/GBO	Jaguar, pearl and Texas cichlid and Mozambique and spotted tilapia present in the wild in Queensland Mozambique tilapia and pearl cichlid also present in the wild in WA. Giant cichlid not known to be in the wild in Australia Nile tilapia an incursion risk from northern Torres Strait
Climbing perch ***Anabas testudineus***	N/R	Risk of incursion from northern Torres Strait
Gambusia (mosquito fish) ***Gambusia holbrooki***	N/R	Not known to be established in the NT (eradicated in Darwin and Alice Springs). Recorded in the wild across Queensland and parts of WA
Guppy ***Poecilia reticulata***	GBO	Recorded in Darwin and Nhulunbuy in the NT. Likely to be present elsewhere
Marbled lungfish ***Protopterus aethiopicus***	N/R	Not known to be in the wild in Australia
Oriental weatherloach ***Misgurnus anguillicaudatus***	N/R	Not known to be in the wild in the NT
Oscar ***Astronotus ocellatus***	GBO	Not known to be in the wild in the NT. Present in the wild in Queensland
Platy ***Xiphophorus maculatus***	GBO	Present in the wild in Darwin and Nhulunbuy in the NT, and in eastern Queensland
Siamese fighting fish ***Betta splendens***	GBO	Established in the Adelaide River catchment in the NT. Not known to be in the wild elsewhere in Australia
Spotted gar ***Lepisosteus oculatus***	N/R	Not known to be in the wild in Australia
Swordtail ***Xiphophorus hellerii***	GBO	Present in the wild in Darwin and Nhulunbuy in the NT, and in eastern Queensland

For NT: Fisheries Regulations 1992 – N = noxious, E = excluded for import and possession
For Queensland: Biosecurity Act 2014 – P = prohibited matter, R = restricted matter, GBO = only the general biosecurity obligation applies
Source: NT Government, 2024a.; Queensland Government, 2023b

Terrestrial invertebrates

Terrestrial invertebrates can also be high-impact invasive species. For example, certain exotic ants can form ‘super colonies’ from which they outcompete native ants, consume native invertebrates, small invertebrates and seeds, and affect people through stinging and infesting buildings. Some ant species ‘farm’ sap-sucking scale insects that are pests of horticultural crops and native plants. Non-native ants can be introduced in pot plants, soil or among other materials.

Yellow crazy ant (*Anoplolepis gracilipes*) is established in parts of eastern Queensland and has also been detected in Darwin and Arnhem Land. Browsing ant (*Lepisiota frauenfeldi*) has been the subject of a national eradication program, including in Darwin and Kakadu in the NT and at the Port of Brisbane. Other national eradication programs continue for red imported fire ant (RIFA; *Solenopsis invicta*) in south-east Queensland and electric ant (*Wasmannia auropunctata*) in far north Queensland (Outbreak, 2024; Environment and Invasives Committee, 2019). The national eradication program for RIFA has cost $596 million (Outbreak, 2023b).

Diseases

Examples of diseases that affect multiple species of native, ornamental and crop plants are myrtle rust and phytophthora (*Phytophthora* spp.). They can cause the death of plants, including established shrubs and trees.

7.4.3 Preventing, responding to and managing biosecurity threats

Biosecurity can be categorised into three broad approaches:

- Prevention - taking measures to stop movement along pathways of spread, whether that be at the international or state border, to and within a catchment, or between and within properties
- Incursion response - undertaking surveillance to detect new pests, weeds or diseases and attempting eradication upon detection, where feasible and cost-beneficial to do so
- Ongoing management – managing a pest, weed or disease that is firmly established in an area (i.e. is not feasible to eradicate), with control measures regularly applied to contain further spread and/or mitigate impacts.

The invasion curve (Figure 7-10) is commonly used as a visual representation of biosecurity actions taken at various stages of pest invasion. It applies at any scale from national down to an individual property. Prevention and eradication generally cost far less than the ongoing management which is needed for widely established species (i.e. containment and impact mitigation), although improved management tools may substantially reduce long-term costs.

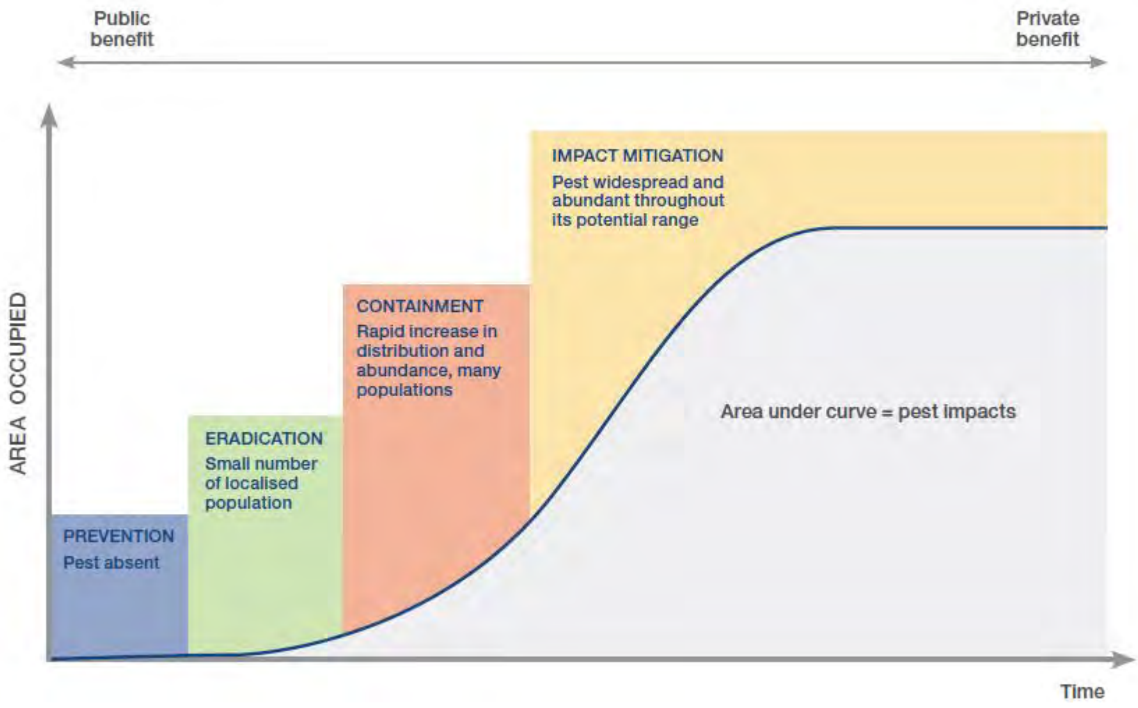

Figure 7-10 The invasion curve with biosecurity actions taken at various stages

Source: J. Virtue

Shared responsibility at all levels

Effective biosecurity requires a collaborative approach between government, industry and community, from the organisational to the individual level. Such 'shared responsibility' includes taking action to limit the risk of entry and spread of new pests, weeds and diseases, routinely looking for biosecurity threats and reporting if and when detected, and collaborating in coordinated control programs across land tenures. Everyone has a duty of care (whether legal or moral) to not pose a biosecurity risk to others, including to not harbour invasive species that may threaten economic, environmental, social or cultural impacts on neighbouring land uses.

The biosecurity systems of Queensland and the NT (NT Government, 2016; Queensland Gov, 2024a) are nested in the national biosecurity system of Australia's border quarantine and states' domestic quarantine and control program arrangements (DAFF, 2022a). Broadly defined, the national biosecurity system consists of the combined Australian, state and territory governments' biosecurity legislative frameworks that seek to prevent pests, weeds and diseases entering, establishing, spreading and having an impact in Australia. It involves cooperation and collaboration between jurisdictions, and working with and supporting industry and community to involve multiple organisations across Australia as biosecurity partners. Various national agreements, plans and governance arrangements drive this shared responsibility ethos.

The following sections describe prevention, incursion response and ongoing management activities for plant industries, aquaculture and invasive species in the Southern Gulf catchments, within local, state and national contexts.

Biosecurity in plant industries

Farm biosecurity planning

In practice, most plant industry biosecurity activities – whether prevention, preparedness, surveillance, elimination, containment or ongoing management – occur at the property level. This level is where the relationship between expenditure on crop protection and maintaining profit-driven productivity and market access is most direct.

Developing and implementing a farm biosecurity plan is an effective means to prevent the introduction and establishment of new pests, weeds and diseases, and to limit the spread and impacts of those which are already established. Standard guidance is available on developing such plans (AHA and PHA, n.d.), which cover hygiene practices for pathways of introduction (e.g. certified seed, machinery and vehicle washdowns, restricted movement of visitors), routine surveillance and quick responses to any on-farm identified biosecurity risks. Associated with implementing these are signage (e.g. Figure 7-11), staff training, mapping, visitor management, record keeping, reporting and annual activity planning.

A farm biosecurity plan is informed by the key biosecurity threats to the crops being grown and broader invasive species risks. A plan should cover both incursion risks and those pests, weeds and diseases already present. It also needs to align with government regulatory requirements and industry standards.

Figure 7-11 Farm biosecurity signage available through www.farmbiosecurity.com.au

Regulatory prevention

Government regulation and policy for plant biosecurity in the Southern Gulf catchments is primarily governed by the Queensland Biosecurity Act or the NT Plant Health Act, depending on where a property is located. It is important to be aware of any differences in legal requirements between the jurisdictions in moving equipment and plant materials across the borders.

In Queensland, plant pests, weeds and diseases may be listed in the Biosecurity Act as ‘prohibited’ (not established in the state) or ‘restricted’ (established in parts of the state and subject to strict controls). There are also declared ‘far northern pests’ that pose a risk of entry into Queensland from PNG, via the Torres Strait and Cape York Peninsula. Both declared and non-declared pests, weeds and diseases are also subject to the Act’s general biosecurity obligation. In Queensland, everyone has a general biosecurity obligation and must take all reasonable and practical steps to prevent or minimise biosecurity risk and to minimise the likelihood of causing an adverse biosecurity event and any harmful effects that risk could have, including not doing anything that could make matters worse.

The *Northern Territory plant health manual* provides a consolidated list of all declared plant pests and diseases in that jurisdiction (DITT, 2023), specifying those which must be reported if detected in the NT.

Each jurisdiction has entry conditions for all commercial and non-commercial movement of plants and plant products and other potential vectors of plant pests and diseases (DITT, 2023; Queensland Government, 2023c).

For example, the NT restricts the entry of maize and soybean seed due to disease risks and the entry of nursery stock due to risk of introducing scale insects and sucking insects. Soil attached to used farm machinery, containers and earth-moving machinery may carry pests or diseases such as nematodes, snails, *Phytophthora* or *Fusarium*. Hence these items are legally required to be clean of soil, and a permit may be required for their entry into NT. In relation to used machinery for cotton production, the NT seeks to retain its ‘area freedom’ status for cotton fusarium wilt (*Fusarium oxysporum* f. sp. *vasinfectum*), which is established in cotton-growing areas in Queensland and NSW (Le et al., 2020).

Examples of Queensland movement restrictions include a hygiene requirement for equipment from interstate that has been used for planting, producing or harvesting a cucurbit crop, to minimise the transmission of CGMMV. There are also restrictions on moving soil or other carriers of RIFA or electric ant (e.g. mulch, compost) out of their respective biosecurity zones within Queensland (Queensland Government, 2023d).

To access interstate markets, produce must meet the respective quarantine specifications and protocols, so as not to inadvertently introduce pests or diseases declared in those jurisdictions. This typically requires an inspection and the issue of a certificate verifying that conditions have been met or that the property is in an area known to be free of a specific pest of concern (DITT, 2023). For example, SA has movement restrictions (as of February 2024) on the entry of melons and other hosts of melon thrips (*Thrips palmi*) from jurisdictions where it is known to occur, including the NT and Queensland (PIRSA, 2024). Current information on moving plant goods interstate is compiled on the Australian Interstate Quarantine website (Subcommittee on Domestic Quarantine and Market Access, 2024).

Exports to overseas markets similarly must meet Australian standards and any additional entry requirements from the importing countries for the product (DAFF, 2024b). This includes certification and supporting documentation relating to area freedom and/or treatments applied for specific pests, weeds and/or diseases. Depending on the country, there also may be maximum residue limits, or even nil tolerances, for specific pesticides. Exports are regulated by the Australian Government through the Commonwealth *Export Control Act 2020* and associated rules for particular produce and products.

Incursion response

Most plant industries have national biosecurity, surveillance and/or preparedness plans for high-risk exotic pests and diseases that pose national incursion risks (PHA, 2024a). Their entry into Australia is prevented by the Australian Government’s pre-border and border quarantine requirements under the Commonwealth *Biosecurity Act 2015*. The Australian Government’s Northern Australia Quarantine Strategy is an ongoing surveillance program that seeks to detect incursions from countries to Australia’s north (DAFF, 2024a).

Plant Health Australia (PHA) is the custodian of the Emergency Plant Pest Response Deed (EPPRD; Anon., 2024), which specifies how governments and affected industries undertake collaborative national eradication responses, including cost sharing and decision making. PLANTPLAN provides accompanying national guidelines for managing responses to emergency plant pest incidents at national, state or territory, and local levels (PHA, 2022). For example, banana freckle (*Phyllosticta cavendishii*) is currently the subject of an EPPRD national eradication program in the NT (Outbreak, 2023a).

Ongoing management

Best management practice guides for control of established pests, weeds and diseases are available through the research and development corporations, other industry organisations and state primary industries departments, with some specific to cropping in northern Australia (e.g. DPIF, 2014; NT Farmers, 2022). These extension materials focus on integrated management approaches that combine a range of control practices (e.g. chemical, physical and biological control methods). The cotton industry has a broader online best management practice assurance system (myBMP, 2024), which includes modules on integrated pest management and pesticide management. Additionally, the Grains Farm Biosecurity Program is an initiative to improve the management of, and preparedness for, biosecurity risks in the grains industry at the farm and industry levels (PHA, 2024b).

Pesticides must be approved for use by the Australian Pesticides and Veterinary Medicines Authority (APVMA) and applied in a manner that aligns with state or territory requirements on the use of such chemicals. This includes minimising spray drift, following label requirements for work health and safety, and ensuring appropriate applicator skills and licences. There are maximum permissible levels for certain pesticides in specified agricultural produce, achieved by following pesticide label (or APVMA permit) requirements regarding approved crops, rates and frequency of application, and withholding periods (NT Government, 2024c; Queensland Government, 2023e).

A key consideration for ongoing management on-farm is ensuring chemical control tools are used tactically to limit the risk of developing insecticide, herbicide and fungicide resistance (Grains Research and Development Corporation, 2024; CropLife Australia, 2021). For example, growers cultivating Bollgard® 3 and Roundup Ready Flex® cotton must follow on-farm stewardship packages (Bayer, 2023).

Growers whose crop production is affected by native animals may require NT Government permits before taking any lethal control measures. On-property storage of harvested grain needs consideration of physical and chemical means to prevent beetle and weevil pests (Grain Storage Extension Project, 2024).

Biosecurity in aquaculture

Plan for prevention

Prevention in aquaculture starts with enterprise-level biosecurity planning. This is vital in protecting aquaculture facilities from disease and parasite risks, which can be difficult to eliminate, let alone manage, once established. Planning guides have been developed for various industries, including barramundi (Landos et al., 2019) and oyster hatcheries. Preventing entry of pathogens into facilities is vital. Growers need to understand the various disease risks and where they could come from. Wild-captured broodstock poses a very high risk of introducing endemic diseases; stock known to be free from specific diseases should be sourced (Cobcroft et al., 2020). Diseases may enter a facility via contaminated equipment, workers handling diseased fish, water harbouring pathogens, or wild animals such as birds entering ponds (Irvin et al., 2018). Untreated source water is a key pathway for disease entry, with pathogen risks coming from wild stocks or, potentially, from a nearby, upstream aquaculture facility (Irvin et al., 2018). Pathogen monitoring should be ongoing, and emergency response plans should be developed to isolate any detected disease occurrence and implement thorough disinfestation procedures.

Commercial aquaculture in the NT is regulated through the NT *Fisheries Act 1998* and the Fisheries Regulations 1992. The Regulations prohibit movement or sale of diseased fish and require reporting of any legally notifiable diseases detected in aquaculture facilities. Movement of all stock is under a permit system, and health assessments are conducted to manage the risk of disease movement through movement of aquaculture stock.

Similar legal provisions apply in Queensland under the Biosecurity Act and *Fisheries Act 1994*. Under the Queensland Biosecurity Act's general biosecurity obligation, aquaculture enterprises are legally obligated to take reasonable and practical measures to minimise the risk and spread of disease. Aquaculture farms are required to have a disease management plan as a standard condition of development approval under the state's *Planning Act 2016*. Approval from Fisheries Queensland is required to move live aquatic animals within the state or interstate, and such movements must comply with a specified health protocol (Queensland Government, 2024b). Actual or suspected disease incidents must be reported.

Incursion response

AQUAPLAN is the national aquatic animal health strategic plan; it aims to improve border, enterprise and regional biosecurity measures, and build surveillance, diagnostic capacity and emergency preparedness (DAFF, 2022b). There is also national policy guidance on minimising the movement of disease when translocating live aquatic animals for aquaculture and other purposes (DAWE, 2020b).

The NT Government can declare a control area in the event of an actual or likely notifiable disease outbreak in an aquaculture facility, providing for limits on further fish movement, halting the release of aquaculture water, and/or requiring mandatory treatment or destruction measures for fish and contaminated equipment. Similar biosecurity emergency restrictions and prohibitions can be applied under the Queensland Biosecurity Act.

Having aquaculture biosecurity plans is not just about protecting the enterprise. There is also a duty of care to protect nearby wild fisheries which may be exposed to disease from discharge waters, escapee infected animals or fish movement via predatory birds. Prompt isolation of affected ponds and preventing water flow from these to the surrounding environment are vital in the event of a disease outbreak. The escape of white spot syndrome virus from prawn farms in south-east Queensland and northern NSW led to restrictions on commercial and recreational fishing of crustaceans in adjacent catchments, with substantial local economic impacts.

Ongoing management

Treatment options are limited for aquatic diseases, particularly viral pathogens. Veterinary medicines, such as antibiotics for bacterial disease in barramundi, are available. However, their use can require veterinary permission in order to manage risks of antimicrobial resistance, both in the aquaculture facility itself and the broader food chain. Fungal and external protozoan pathogens may be able to be suppressed using altered salinity bathing. Most fundamental is the need for a high-quality rearing environment, with optimal water conditions and feed supply, to reduce the risk of stress-induced disease outbreaks (Irvin et al., 2018).

Biosecurity for invasive species

Irrigation development planning

Regional and local irrigation and industry infrastructure development, including road networks, should include prevention and management of invasive species in their environmental planning processes. This includes meeting legal obligations under the various Acts mentioned above, a stocktake of present distribution of declared species, and risk mitigation to limit pathways of introduction of new invasive species during construction and ongoing maintenance. Ongoing monitoring should be implemented for both terrestrial and aquatic pests (vertebrate and invertebrate) and weeds.

Weeds

The Southern Gulf catchments fall within scope of the *Katherine regional weeds strategy 2021–2026* (NT Government, 2021) and the *North West Queensland regional biosecurity plan 2022–2027* (SGNRM and NWQROC, 2022). These define priority declared weed control programs within the study area as coordinated by the NT Government or by local governments in Queensland.

Under the Queensland Biosecurity Act, all landholders are responsible for taking all reasonable and practical steps to minimise the risks associated with invasive plants under their control, as per the general biosecurity obligation. Prohibited plants are not known to be established in Queensland and must be reported. Restricted plants are high-risk weeds that are established in parts of Queensland, and legal requirements are in place to prevent their further spread, including reporting their presence and/or prohibiting their sale, movement and/or cultivation.

Under the NT Weed Management Act, every landholder is legally obliged to take all reasonable measures to prevent land from being infested with a declared weed and to prevent a declared weed from spreading. There are also prohibitions on buying, selling, cultivating, moving or propagating any declared weed, and a legal requirement to notify a declared weed’s presence if it is new to a property. Certain declared plants, such as Gamba grass, neem (*Azadirachta indica*) and bellyache bush (*Jatropha gossypiifolia*), also have statutory management plans (Table 7-6), which require specific management actions to be implemented by all landholders.

The NT Government website and other Australian websites (e.g. www.weeds.org.au) provide best management practice information on how to control declared weeds and other invasive plants, including registered herbicides and biological control agents. In particular, much information is available on management on WoNS (CISS, 2021).

In selecting new crops and pastures for planting in the Southern Gulf catchments, landholders should consider the crops’ weed risks to the surrounding environment. Many northern Australia pasture grasses can be invasive and cause significant biodiversity and cultural impacts in the landscape (DSEWPC, 2012). An example method for considering weed risks is the WA Government’s environmental weed risk assessment process for plant introductions to pastoral lease land (Moore et al., 2022).

Cotton is not considered to pose a significant environmental weed threat in northern Australia (Office of the Gene Technology Regulator, 2024). It has been sporadically recorded across northern Australia on roadsides, near cropping fields, in irrigation drains and adjacent to natural watercourses (Atlas of Living Australia, 2024). However, modern varieties' ability to establish and reproduce is constrained by dense lint around seeds impeding germination, seed predation, seasonal drought, competition from established plants, herbivory and fire (Eastick and Hearnden, 2006; Rogers et al., 2007). Nonetheless, it is recommended that transport of harvested cotton is covered to reduce the likelihood of spread outside cultivation (Addison et al., 2007).

Terrestrial vertebrate pests

Large feral herbivores are controlled through mustering, trapping, baiting and/or aerial or ground shooting programs, depending on the approved humane control methods for particular species (CISS, 2024; NT Government, 2024d; Queensland Government, 2018). For long-term suppression, programs need to be conducted over multiple years at a subregional scale across all infested properties, taking account of animal movements and sub-populations. Ongoing control is then needed to maintain low densities.

7.5 Off-site and downstream impacts

7.5.1 Introduction

Northern Australian river systems are distinctive as they have highly variable flow regimes, unique species composition, low human population densities and, in some cases, naturally high turbidity (Brodie and Mitchell, 2005). Primary influences on groundwater and surface water quality include increased sediment loads associated with land clearing, grazing, agriculture and late dry-season fires, and nutrient pollution from agricultural and pastoral land use (Dixon et al., 2011). These can affect the water quality of not just groundwater and rivers, lakes and wetlands but also estuarine and marine ecosystems.

The principal pollutants from agriculture are nitrogen, phosphorus, total suspended solids, herbicides and pesticides (Lewis et al., 2009; Kroon et al., 2016; Davis et al., 2017). Water losses via runoff or deep drainage are the main pathways by which agricultural pollutants enter water bodies. The type and quantity of pollutants lost from an agricultural system and ultimately the quality of the receiving surface water and groundwater is significantly influenced by a wide range of factors, including environment factors such as climate, hydrology, soils, hydro geochemistry and topography as well as land use and management factors such as crops, cropping system, method of application of irrigation water, tailwater management, quality of source water, location and proximity to drainage lines and conservation and irrigation practices. Due to the high dependency of the location, design, implementation and operation of an irrigation development on water quality predicting water quality impacts associated with irrigated agriculture is very difficult. Rather the influence of these environment and management factors on water quality are discussed in more detail in the companion technical report on water quality (Motson et al., 2024).

Most of the science in northern Australia concerned with the downstream impacts of agricultural development has been undertaken in the eastern-flowing rivers that flow into the Great Barrier Reef lagoon. Comparatively little research on the topic has been done in the rest of northern

Australia and there is need for caution in transposing findings from north-eastern Australia, which is different in terms of climate, geomorphology and patterns of settlement to those parts of northern Australia west of the Great Dividing Range. Nonetheless experience from north-eastern Australia has been that the development of agriculture has been associated with declining water quality (Lewis et al., 2009; Mitchell et al., 2009; De'ath et al., 2012; Waterhouse et al., 2012; Thorburn et al., 2013; Kroon et al., 2016). Pollutant loads in north-eastern Australian rivers (typically those in which agriculture dominates as a land use) are estimated to have increased considerably since European settlement in the 1850s for nitrogen (2 to 9 times baseline levels), phosphorus (3 to 9 times), suspended sediment (3 to 6 times) and pesticides (~17,000 kg) (Kroon et al., 2016).

7.5.2 Managing irrigation drainage

Degraded water quality can cause a loss of aquatic habitat, biodiversity, and ecosystem services. Increased nitrogen and phosphorus can cause plankton blooms and weed infestation, increase hypoxia (low oxygen levels) and result in fish deaths. Pesticides, used to increase agricultural productivity, can harm downstream aquatic ecosystems, flora and fauna. As with fertiliser nutrients, pesticides can enter surface water bodies and groundwater via infiltration, leaching, and runoff from rainfall events and irrigation. These chemicals can be toxic to non-target species, such as aquatic life and humans, affecting nervous systems, immune systems, photosynthesis and growth (Cantin et al., 2007; Kaur et al., 2019; Naccarato et al., 2023). They can be carcinogenic (Mohanty and Jena, 2019) and cause multiple sub-lethal effects that can disrupt the ecological balance of aquatic systems and degrade aquatic communities (Giglio and Vommaro, 2022; Miller et al., 2020; Wang et al., 2022).

Other water quality variables that can have a significant effect on the health of aquatic species, communities and ecosystems include salinity, pH, and suspended sediments. Increased salinity, indicated by increased EC and TDS, can interfere with osmoregulatory processes, harming those species not adapted to saline conditions (Hart et al., 2003). Variations in the pH of a water body can negatively affect an organism's biochemical processes, leading to altered behaviour, functioning, growth, and even survival (US EPA, 2024). In aquatic ecosystems, elevated loads of suspended sediment can smother habitats and benthic invertebrates, affect the feeding and respiratory systems of aquatic species, and reduce light penetration, affecting photosynthetic activity (Chapman et al., 2017). Table 7-8 provides a summary of how changes in key water quality variables affect aquatic ecology and human health.

Table 7-8 Water quality variables reviewed – their impacts on the environment, aquatic ecology and human health

WATER QUALITY VARIABLE		THREATS TO AQUATIC ECOLOGY AND HUMAN HEALTH	REFERENCE
Nutrients	Nitrogen	Forms of nitrogen in freshwater systems include: nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and ammonium (NH_4). In excessive quantities, contributes to eutrophication and algal blooms, which can deplete oxygen and create hypoxic/anoxic conditions harmful to aquatic life. Health threat to humans, particularly infants, and mammals	Carpenter et al. (1998)
	Phosphorus	High concentrations may lead to eutrophication and algal blooms, which can deplete oxygen and create hypoxic/anoxic conditions	Mainstone and Parr (2002)

WATER QUALITY VARIABLE		THREATS TO AQUATIC ECOLOGY AND HUMAN HEALTH	REFERENCE
		harmful to aquatic life	
	Dissolved Organic Carbon	A proxy for dissolved organic matter, affecting water clarity, temperature, biogeochemical processes, food webs and ecosystem productivity. Dissolved Organic Carbon may exacerbate eutrophication and hypoxia in aquatic ecosystems, and cause problems in drinking water treatment processes	Palviainen et al. (2022)
Pesticide groups	Arylurea	Includes pesticides such as Diuron® and tebuthiuron. May inhibit photosynthesis in plants and aquatic species. These pesticides are less soluble in water and better absorbed by the soil	Cantin et al. (2007), Fojut et al. (2012)
	Carbamates	Broad-spectrum pesticides that affect nerve impulse transmission and are highly toxic to vertebrate species. Suspected carcinogens and mutagens. Relatively low persistence; not easily adsorbed to soil particles	Kaur et al. (2019), Rad et al. (2022)
	Chloroacetanilides	Affects cell division, disrupting aquatic plant growth; also toxic to aquatic insects. Persistent. Low binding affinity to soil particles but highly water soluble; therefore, it has a high capacity for leaching into the groundwater and ending up in surface water. Carcinogens with moderate to high chronic toxicity	ANZG (2020), Mohanty and Jena (2019)
	Dinitroanilines	Broad-spectrum herbicides with low water solubility; considered non-mobile in soil. Affect seed germination and root growth in plants. Variable, species-specific toxicity ranging from slightly to highly acute. Hazardous to animals and humans in sub-lethal concentrations. Known bioaccumulation in and acute toxicity to aquatic organisms	Giglio and Vommaro (2022)
	Neonicotinoids	Highly toxic to invertebrates, particularly aquatic insects. Sub-lethal toxicity in fish. High solubility. High chronic risk to global freshwater ecosystems. Suspected to be carcinogenic	Wang et al. (2022)
	Organochlorines	Persistent organic pollutants that can bioaccumulate in fatty tissues. These pesticides are toxic to humans and other animals, and they are highly toxic to most aquatic life	DCCEEW (2021)
	Organophosphates	Broad-spectrum pesticides that control a wide range of pests via multiple functions. Organophosphate insecticides are toxic to both vertebrates and invertebrates, disrupting nerve impulse transmission	Kaur et al. (2019)
	Phenylpyrazole	These pesticides disrupt nerve impulse transmission. Toxic to aquatic organisms and birds. Phenylpyrazole pesticides, such as Fipronil, have been found to degrade stream communities. Moderate water solubility and hydrophobicity. Slightly mobile in soils. Moderate persistence	Gao et al. (2020), Miller et al. (2020)
	Triazine	Inhibits photosynthesis in plants, potentially leading to reduced plant growth and blocks food intake by insect pests. Short to moderate persistence depending on soil pH. Adverse and sub-lethal effects on terrestrial and aquatic non-target organisms, affecting growth and the nervous and immune systems	Naccarato et al. (2023)
Salinity		Can affect osmoregulatory processes of aquatic species, harming aquatic life not adapted to saline water. Significant increases in salinity may compromise the integrity of freshwater ecosystems	Hart et al. (2003)
Other	Total Suspended Solids	Can smother habitats, reduce light penetration (through increasing turbidity), and affect the feeding and respiratory systems of aquatic organisms	Chapman et al. (2017)
	pH	Variations can negatively affect aquatic life stages, affecting their biochemical processes. Preferred pH range of 6.4–8.4 for aquatic species	US EPA(2024)

7.5.3 Impacts of irrigated agriculture on water quality

Fertiliser applications in irrigated agriculture can significantly affect nutrient levels in drainage waters, leading to increased concentrations of total phosphorous and total nitrogen in surface waters during the irrigation season (Barbieri et al., 2021; Mosley and Fleming, 2010). The type of cropping system employed also plays a crucial role in determining groundwater nutrient concentrations. For example, variations in cropping practices, such as mulch-till versus ridge-till systems, can result in substantial differences in nitrate levels, underscoring the importance of adopting best management practices for protecting groundwater quality (Albus and Knighton, 1998).

Surface water quality is similarly affected by nutrient inputs, with concentrations of total phosphorous often decreasing as streamflow increases, suggesting a dilution effect (Skhiri and Dechmi, 2012). However, this relationship can be inconsistent, as dilution effects may not be evident when only storm event streamflow is considered. Instead, total phosphorous concentrations are influenced by a combination of factors, including rainfall duration and intensity, as well as irrigation and fertiliser application practices. The interplay of these factors highlights the complex interactions between rainfall, irrigation, and nutrient management in determining both surface water and groundwater quality outcomes.

Controlled pesticide use is crucial for managing its impact on surface water quality. When pesticide application rates are managed and irrigation schedules are aligned with crop growth stages, their concentrations are typically low. Pesticide-specific application practices also influence runoff concentrations: pesticides that are applied to, and therefore intercepted by, the crop canopy have significantly lower surface water concentrations relative to those applied to bare soil (Moulden et al., 2006).

Seasonal hydrology, particularly 'first-flush' events following irrigation or significant rainfall, plays a critical role in determining water quality (Davis et al., 2013; Yeates, 2016). Studies have shown that pesticide concentrations in runoff are highest following initial irrigation events but decrease in subsequent events (Davis et al., 2013). Despite this dilution, pesticide concentrations in receiving waters can still exceed recommended levels. Similarly, nitrogen concentrations in runoff are often higher following early-season rainfall, when crops have not yet fully absorbed available nitrogen, leading to increased transport in runoff (Yeates, 2016).

These findings underscore the importance of implementing sustainable irrigation management practices and highlight the need for continuous monitoring and adaptive management to mitigate the impacts of agricultural activities on water quality. Ensuring effective management is vital for protecting water resources and maintaining the ecological integrity of aquatic ecosystems and communities amid agricultural intensification.

The potential for irrigated agriculture to cause secondary salinisation is discussed in Section 7.6.

Managing irrigation drainage

Surface drainage water is water that runs off irrigation developments as a result of over-irrigation or rainfall. This is mostly an issue where water is applied using surface irrigation methods (e.g. furrow, flood) rather than spray or micro-irrigation methods (e.g. drip, micro-spray). This excess water can potentially affect the surrounding environment by modifying flow regimes and changing water quality. Hence, management of irrigation or agricultural drainage waters is a key consideration when evaluating and developing new irrigation systems and should be given careful consideration during the planning and design processes. Regulatory constraints on the disposal of agricultural drainage water from irrigated lands are being made more stringent as this disposal can potentially have significant off-site environmental effects (Tanji and Kielen, 2002). Hence, minimising drainage water through the use of best-practice irrigation design and management should be a priority in any new irrigation development in northern Australia. This involves integrating sound irrigation systems, drainage networks and disposal options so as to minimise off-site impacts.

Surface drainage networks must be designed to cope with the runoff associated with irrigation, and also the runoff induced by rainfall events on irrigated lands. Drainage must be adequate to remove excess water from irrigated fields in a timely manner and hence reduce waterlogging and potential salinisation, which can seriously limit crop yields. In best-practice design, surface drainage water is generally reused through a surface drainage recycling system where runoff tailwater is returned to an on-farm storage or used to irrigate subsequent fields within an irrigation cycle.

The quality of drainage water depends on a range of factors including water management and method of application, soil properties, method and timing of fertiliser and pesticide application, hydrogeology, climate and drainage system (Tanji and Kielen, 2002). These factors need to be taken into consideration when implementing drainage system water recycling and also when disposing of drainage water to natural environments.

A major concern with tailwater drainage is the agricultural pollutants derived from pesticides and fertilisers that are generally associated with intensive cropping and are found in the tailwater from irrigated fields. Crop chemicals can enter surface drainage water if poor water application practices or significant rainfall events occur after pesticide or fertiliser application (Tanji and Kielen, 2002). Thus, tailwater runoff may contain phosphate, organic nitrogen and pesticides that have the potential to adversely affect flora and fauna and ecosystem health, on land and in waterways, estuaries or marine environments. Tailwater runoff may also contain elevated levels of salts, particularly if the runoff has been generated on saline surface soils. Training irrigators in responsible application of both water and agrochemicals is therefore an essential component of sustainable management of irrigation.

As tailwater runoff is either discharged from the catchment or captured and recycled, it can result in a build-up of agricultural pollutants that may ultimately require disposal from the irrigation fields. In externally draining basins, the highly seasonal nature of flows in northern Australia does offer opportunities to dispose of poor-quality tailwater during high-flow events. However, downstream consequences are possible, and no scientific evidence is available to recommend such disposal as good practice. Hence, consideration should be given to providing an adequate understanding of the downstream consequences of disposing of drainage effluent, and options must be provided for managing disposal that minimise impacts on natural systems.

7.5.4 Natural processing of water contaminants

While elevated contaminants and water quality parameters can harm the environment and human health, there are several processes by which aquatic ecosystems can partially process contaminants and regulate water quality. Denitrification, for example, is the process of anaerobic microbial respiration which, in the presence of carbon, reduces nitrogen to nitrous oxide and dinitrogen gas (Martens, 2005). Therefore, denitrification is a naturally occurring process that can remove and reduce nitrogen concentrations within a water body. Pesticides can also be naturally removed from water via chemical oxidation, microbial degradation, or ultraviolet photolysis, although some chemically stable pesticides are highly persistent, and their microbial degradation is slow (Hassaan and El Nemr, 2020). Phosphorus, however, does not have a microbial reduction process equivalent to denitrification. Instead, if it is not temporarily taken up by plants, phosphorus can be adsorbed onto the surface of inorganic and organic particles and stored in the soil, or deposited in the sediments of water bodies, such as wetlands (Finlayson, 2006). This phosphorus can be remobilised into solution and re-adsorbed, resulting in 'legacy' phosphorus that can affect water quality for many years (Records et al., 2016).

7.5.5 Water quality considerations relevant to aquaculture

Aquaculture can be impacted by poor water quality and can also contribute to poor water quality unless aquaculture operations are well managed. A summary is provided below, however, for more information see Northern Australia Water Resource Assessment report on aquaculture viability (Irvin et al., 2018).

Chemical contaminant risk to aquaculture and the environment

Hundreds of different chemicals, including oils, metals, pharmaceuticals, fertilisers and pesticides (i.e. insecticides, herbicides, fungicides), are used in different agricultural, horticultural and mining sectors, and in industrial and domestic settings, throughout Australia. Releasing these chemical contaminants beyond the area of target application can contaminate soils, sediments and waters in nearby environments. In aquatic environments, including aquaculture environments, fertilisers have the potential to cause non-point source pollution. Eutrophication is caused by nutrients that trigger excessive growth of plant and algal species, which then form hypoxic 'dead zones' and potentially elevated levels of toxic un-ionised ammonia (Kremser and Schnug, 2002). This can have a significant impact on the health and growth of animals in aquaculture operations, as well as in the broader environment.

Of concern to aquaculture in northern Australia are the risks posed to crustaceans (e.g. prawns and crabs) by some of the insecticides in current use. These are classified based on their specific chemical properties and modes of action. The different classes of insecticides have broad and overlapping applications across different settings.

The toxicity of organophosphate insecticides is not specific to target insects, raising concerns about the impacts on non-target organisms such as crustaceans and fish. Despite concerns about human health impacts and potential carcinogenic risks, organophosphates are still one of the most broadly used types of insecticide globally, and they are still used in Australia for domestic pest control (Weston and Lydy, 2014; Zhao and Chen, 2016). Pyrethroid insecticides have low toxicity to birds and mammals, but higher toxicity to fish and arthropods. Phenylpyrazole insecticides also pose risks to non-target crustaceans (Stevens et al., 2011). Neonicotinoid insecticides are being used in increasing amounts because they are very effective at eliminating insect pests, yet they pose low risks to mammals and fish (Sánchez-Bayo and Hyne, 2014). Monitoring data from the Great Barrier Reef catchments indicate that the concentration of neonicotinoid insecticides in marine water samples is rapidly increasing with widespread use. One significant concern for aquaculture is the risk that different insecticides, when exposed to non-target organisms, may interact to cause additive or greater-than-additive toxicity.

Aquaculture discharge water and off-site impacts

Discharge water is effluent from land-based aquaculture production (Irvin et al., 2018). It is water that has been used (culture water) and is no longer required in a production system. In most operations (particularly marine), bioremediation is used to ensure that water discharged off-farm into the environment contains low amounts of nutrients and other contaminants. The aim is for discharge waters to have similar physiochemical parameters to the source water.

Discharge water from freshwater aquaculture can be easily managed and provides a water resource suitable for general or agriculture-specific irrigation. Discharge water from marine aquaculture is comparatively difficult to manage and has limited reuse applications. The key difference in discharge management is that marine (salty) water must be discharged at the source, whereas the location for freshwater discharge is less restrictive and potential applications (e.g. irrigation) are numerous. Specific water discharge guidelines vary with aquaculture species and jurisdiction. For example, Queensland water discharge policy minimum standards for prawn farming include standards for physiochemical indicators (e.g. oxygen and pH) and nutrients (e.g. nitrogen, phosphorus and suspended solids) and total volume (EHP, 2013).

The volume of water required to be discharged or possibly diverted to a secondary application (e.g. agriculture) is equivalent to the total pond water use for the season minus total evaporative losses and the volume of recycled water used during production.

A large multidisciplinary study of intensive Australian prawn farming, which assessed the impact of effluent on downstream environments (CSIRO, 2013), found that Australian farms operate under world's best practice for the management of discharge water. The study found that discharge water had no adverse ecological impact on the receiving environment and that nutrients could not be detected 2 km downstream from the discharge point.

While Australian prawn farms are reported as being among the most environmentally sustainable in the world (CSIRO, 2013), the location of the industry adjacent to the World Heritage–listed Great Barrier Reef and related strict policy on discharge has been a major constraint to the industry's expansion. Strict discharge regulation, which requires zero net addition of nutrients in waters adjacent to the Great Barrier Reef, has all but halted expansion in the last decade. An example of the regulatory complexity in this study area is the 14-year period taken to obtain approval to develop a site in the Burdekin shire in north Queensland (APFA, 2016).

In a report to the Queensland Government (Department of Agriculture and Fisheries Queensland, 2013), it was suggested that less-populated areas in northern Australia, which have less conflict for the marine resource, may have potential as areas for aquaculture development. The complex regulatory environment in Queensland was a factor in the decision by Project Sea Dragon to investigate greenfield development in WA and NT as an alternative location for what would be Australia's largest prawn farm (Seafarms, 2016).

Today, most farms (particularly marine) use bioremediation ponds to ensure that water discharged off-farm into the environment contains low amounts of nutrients and other contaminants. The prawn farming industry in Queensland has adopted a code of practice to ensure that discharge waters do not result in irreversible or long-term impacts on the receiving environment (Donovan, 2011).

7.6 Irrigation-induced salinity

7.6.1 Introduction

Salts occur naturally in all soils and landscapes. The amount of salt present depends on local climate, salt store in the geology, landscape position, soil type, the depth to the watertable and the quality of the groundwater below the watertable. Naturally occurring areas of salinity, or 'primary salinity', occur in the landscape, with ecosystems adapted to the saline conditions.

Any change to landscape hydrology, including clearing and irrigation, can mobilise salts, resulting in environmental degradation in the form of 'secondary salinity'. Secondary salinity manifests itself in two main forms: irrigation-induced salinity and land clearing induced salinity. In the case of irrigation-induced salinity, an increase in drainage below the root zone following applications of irrigation water can raise watertables and bring salts to the soil surface. Excessive drainage of irrigation water below the root zone tends to more likely occur in coarser-textured soils, (Petheram et al., 2002). In Australia, over-irrigation (or overwatering) due to poor irrigation practices, together with leakage of water from irrigation distribution networks and drainage channels, has caused the watertable level to rise in many irrigated areas. Significant parts of all major irrigation areas have watertables that are now close to the land surface (in the vicinity of 2 to 3 m from the land surface) (Christen and Ayars, 2001). Salts can concentrate in the root zone over time as a result of evaporation, which can be a compounding factor. In addition, the process by which the salts accumulate in the root zone is accelerated if the groundwater has high salt concentrations.

In the Assessment area, some clay soils do have high levels of salt within 1 to 2 m of the surface, depending on their location. Clay soils that have slowly or very slowly permeable subsoils (SGG 9) can accumulate salts in the subsoil over time, even in areas receiving high rainfall during the wet season. Caution should be applied in the irrigation of poorly drained clay soils (SGG 9). The cracking clay soils on the Armraynald Plain, particularly the black soils along the Gregory River backplain, have subsoils that are high in salt and susceptible to irrigation-induced secondary salinity.

No evidence of surface salt was found by this survey or past surveys (Christian et al., 1954; Perry et al., 1964) of the Southern Gulf catchments, apart from on or near the marine plains (Karumba Plains) (see Figure 7-12). However, development of irrigation in the Assessment area is in its infancy.

It should be noted that this section on irrigation-induced salinity provides general information regarding soils suitable for irrigation development. The risk of secondary salinisation at a specific location in the Southern Gulf catchments can only be properly assessed by undertaking detailed field investigations at a local scale.

7.6.2 Potential sources of salt

Salt stores in soils

The salts in the soil and landscape in the Southern Gulf catchments are derived from rainfall, wind, the weathering of primary minerals, and former marine sediments in the substrate. The amount of salt in the landscape ('salt store') depends on the origins of the salts, the degree of geological weathering, the climate (particularly the rainfall and the prevailing wind direction), position in the landscape, landscape permeability (soils and rock), and watertable dynamics.

The Southern Gulf catchments have extensive natural surface salinity, on the extratidal salt plains along the coast of the Gulf of Carpentaria (Karumba Plain; see Section 2.2.2 and Figure 7-12). These plains extend up to 35 km inland and are not considered suitable for irrigation development.

Figure 7-12 An extratidal flat on the Karumba Plain near Burketown, with white salt crystals either side of a shallow natural drainage line. Salt-tolerant samphire and mangrove species can be seen in the background.

Photo: CSIRO

The grey clay soils (SGG 9) north of the Nardoo – Burketown Road on the Armraynald Plain have a high risk of salinity if irrigated, due to their proximity to the salty tidal creeks of the Karumba Plain. Drainage from irrigation could cause the watertable to rise, intercepting some of the tidal creeks and causing a spread of salt beyond the creeks. The risk is much less south of the Nardoo–

Burketown Road. Figure 7-13 shows evidence of surface salinity close to the marine plain already, even without irrigation.

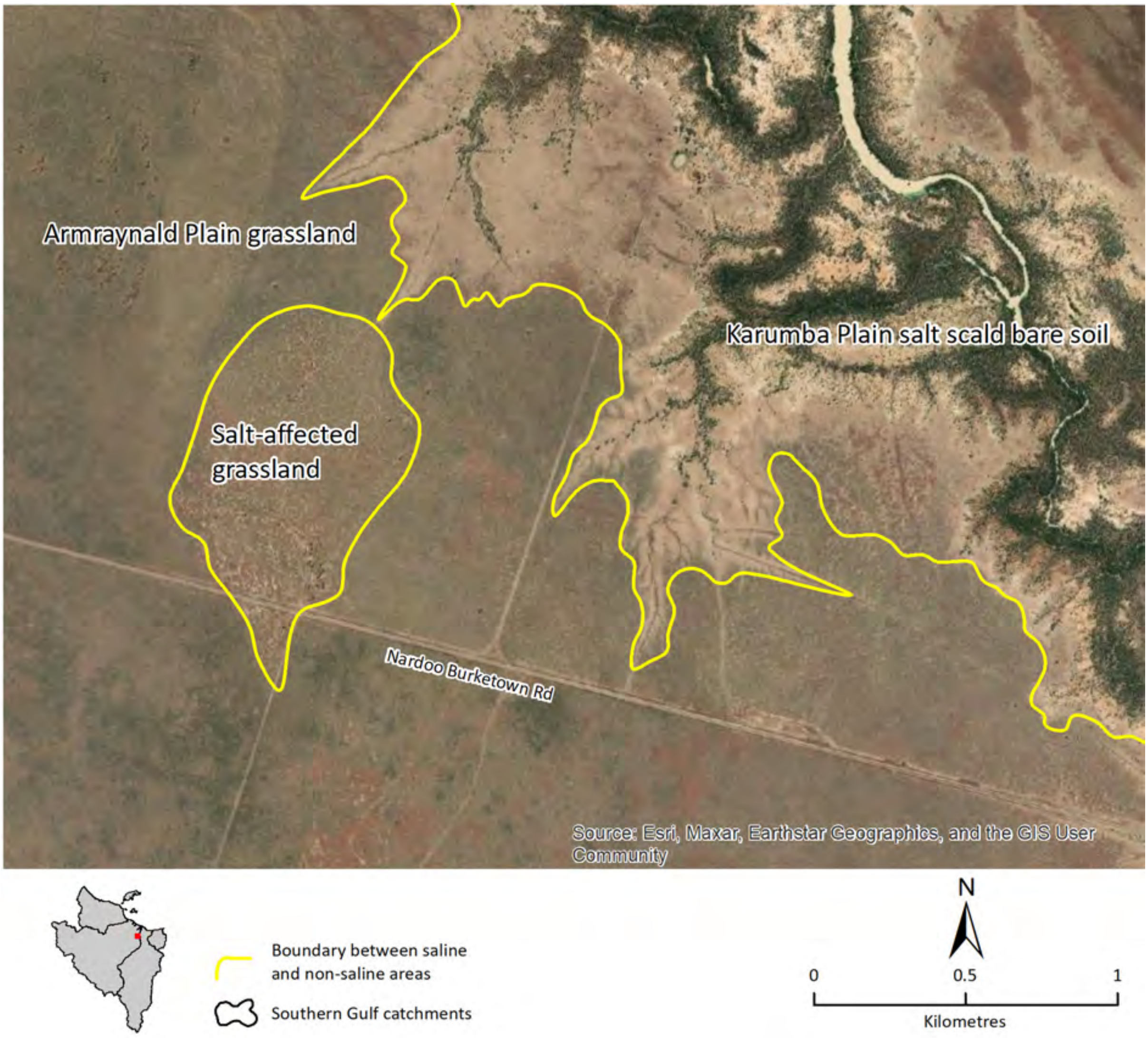

Figure 7-13 Example of salt-affected areas on the northern part of the Armraynald Plain

Photo: Esri, Maxar, Earthstar Geographics, and the GIS User Community

The black clay soils (SGG 9) on the backplain of the Gregory River contain salts at depths of more than 1.5 m. The salts are likely to be derived from the weathering of the underlying Pleistocene marine and terrestrial sediments and from cyclic (rain and wind-blown) sources. If these soils are irrigated, there is a risk that the watertable will rise and carry this salt up to within the plant root zone.

The grey clay soils (SGG 9) around Gregory and the brown clay soils on the east of the Leichhardt River on the Armraynald Plain have much less salt in the subsoil, and thus the risk of irrigation-induced salinity is lower.

The clay soils (SGG 9) on the Barkly Tableland have low subsoil salt levels. Where they are underlain by porous limestone and dolomite, a build-up of salts due to irrigation is not expected.

The sandy soil (SGG 6), loamy soil (SGG 4) and sand or loam over friable brown, yellow and grey clay soils (SGG 1.2) on the Doomadgee Plain also have negligible salts within the soil profile. However, due to other risk factors, care would need to be exercised when clearing the silver box, bloodwood and broad-leaf paperbark savanna landscapes for rainfed or irrigated cropping. Groundwater aquifers contained by underlying ferricrete, the likelihood of soils having variable depths, and the very gently undulating plain make it difficult to manage irrigation water discharge on lower slopes and in drainage depressions, causing salts to accumulate in these areas over time. In places where these soils are shallow, it would be necessary to monitor the depths of rising watertables and manage irrigation rates accordingly. In addition, excessive irrigation rates are likely to have off-site impacts in the long term, as the lateral flow of water can 'wick' from the lower slopes in these landscapes to form scalds. From these scalds, salts can potentially be mobilised towards nearby streams.

Irrigation water as a potential source of salt

In many irrigation developments around the world, poor-quality irrigation water is the source of the salt in secondary salinisation. In the Southern Gulf catchments, however, the river water is relatively fresh, and the aquifers with potential for groundwater resource development are also relatively fresh (see Section 2.5.2), so are unlikely to be a source of salt. However, there is a risk that in some cases certain levels of localised groundwater extraction from aquifers could result in the entrainment of poorer quality water from the surrounding aquifers or aquitards over time, thereby reducing the overall quality of the groundwater applied to crops. The potential for this occurring would require a local, site-specific investigation.

7.6.3 Rise in watertable level and changes in groundwater discharge due to irrigation development

The extent to which the watertable rises close to the surface depends on:

- the initial depth to the watertable
- the amount of groundwater recharge (from root zone drainage)
- the size of the irrigation area (which dictates the total volume of water added to the landscape)
- the lateral distance to rivers (which act as a drainage boundary, thus reducing the height of the groundwater mound under irrigation)
- aquifer parameters, including saturated hydraulic conductivity, aquifer thickness and specific water yield.

Generic modelling results evaluating the risk of watertable rise are documented in the Flinders and Gilbert Agricultural Resource Assessment technical report on surface water – groundwater connectivity (Jolly et al., 2013).

Site-specific assessments need to be undertaken to determine the extent of the secondary salinity risk.

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