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Water resource assessment for the Victoria catchment

A report from the CSIRO Victoria River Water Resource Assessment for the National Water Grid

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Important disclaimer

CSIRO Victoria River Water Resource Assessment acknowledgements

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The Assessment was guided by two committees:

i. The Assessment’s 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 Assessment’s joint Roper and Victoria River catchments Steering Committee: Amateur Fishermen’s Association of the NT; Austrade; Centrefarm; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen’s Association; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; NT Farmers; NT Seafood Council; Office of Northern Australia; Parks Australia; Regional Development Australia; Roper Gulf Regional Council Shire; Watertrust

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 Dr Brian Keating (Independent consultant). Individual chapters were reviewed by Dr Rebecca Doble, CSIRO (Chapter 2); Dr Chris Pavey, CSIRO (Chapter 3); Dr Heather Pasley, CSIRO (Chapter 4); Mr Chris Turnadge, CSIRO (Chapter 5); Dr Nikki Dumbrell, CSIRO (Chapter 6); Dr Adam Liedloff, 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 xxv.

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

The Victoria River is the longest singularly named river in the NT with permanent water. Photo: CSIRO – Nathan Dyer

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

Danial Stratford, Linda Merrin, Simon Linke, Lynn Seo, Rocio Ponce Reyes, Rob Kenyon, Peter R Wilson, Justin Hughes, Heather McGinness, John Virtue, Katie Motson, Nathan Waltham

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.

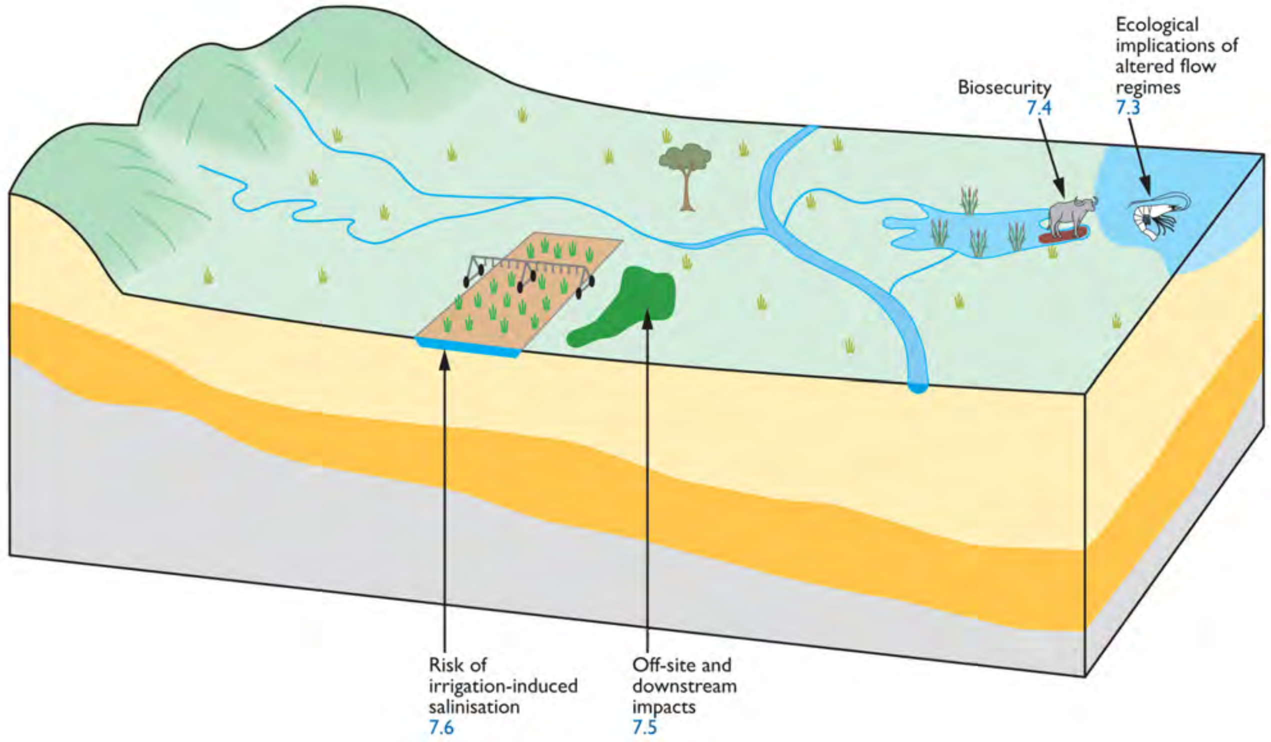

Figure 7-1 Schematic diagram of the environmental components where key risks can manifest during and after the establishment of a greenfield irrigation or aquaculture development, with numbers in blue specifying sections in this report

7.1 Summary

This chapter provides information on the potential ecological, biosecurity, off-site, and downstream impacts, as well as the irrigation-induced salinity risks to the catchment of the Victoria River from greenfield agriculture or aquaculture development. It is principally concerned with the potential impact from these developments on 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 flow regime in northern Australia is highly variable with large seasonal and inter-year variability. The natural flow regime is important for supporting species, habitats and a range of ecosystem functions. Species life-histories are often intricately linked to specific flow conditions considering the magnitude, timing and frequency of flow events. The ecological assets considered in this report represent a range of flow dependencies and have different spatial patterns of occurrence across the catchment. For ecology:

- High flows provide a range of important functions including providing connectivity for movement, increasing productivity and nutrient exchange, providing cues for spawning and migration, and wetting habitat and supporting vegetation growth and persistence. The magnitude, duration and timing of high flows is important in ecological systems.
- Low flows are also an important component of the flow regime with many species adapted to these conditions. Persistent waterholes provide important refuge habitat from environmental conditions and the higher levels of predation that may occur in connected rivers. For many species refuge waterholes function as a source for recolonisation during the wet season. Persistence in low flows during dry periods can help support suitable habitat conditions including thermal and water quality for species in connected rivers and in supporting riparian vegetation and movement and provide a source of water within the broader landscape.
- The timing of flow events is important in supporting life-cycle processes including breeding and migration cues for aquatic species. The timing of flood events and the associated increase in productivity supports function in the river channel and connected marine environments.

Although irrigated agriculture may occupy only a small percentage of the landscape, relatively small areas of irrigation can use large quantities of water, and the resulting changes in the flow regime can have profound effects on flow-dependent flora and fauna and their habitats. Changes in river flow may extend considerable distances downstream and onto the floodplain, including into the marine environment and their impacts can be exacerbated by other changes, including changes to connectivity, water quality and invasive species.

The magnitude and spatial extent of ecological impacts arising from water resource development are highly dependent on the type of development, location, extraction volume and mitigation measures implemented. Ecological impacts, inferred here by calculating change in ecological flow dependency for a range of freshwater-dependent ecological assets.

For water harvesting, impacts accumulate downstream, so ecological assets found near the bottom of the catchment experienced the greatest mean catchment impact. The largest catchment mean changes in flow dependencies for assets was for salt flats, mangroves, floodplain wetlands and banana prawns, all with moderate mean change in flow dependencies across their respective nodes. The largest single-site flow change under water harvesting scenarios were major, for assets including for cryptic waders, threadfin, prawns and floodplain wetlands.

Mitigation strategies that protect low flows and first flows of a wet season are successful in reducing impacts to ecological assets. These can be particularly effective if implemented for water harvesting developments. At equivalent volumes of water extraction, imposing an end-of-system (EOS) annual flow requirement, where water harvesting can only commence after a specified volume of water has flowed past the EOS and into the Joseph Bonaparte Gulf, is an effective mitigation measure for water harvesting. However, the early wet-season streamflow in the Baines River is only moderately correlated with the early wet-season streamflow in the Victoria River, hence assigning an EOS annual flow requirement for each river may result in better ecological outcomes than a single EOS annual flow requirement for the entire catchment. For EOS annual flow requirements greater than 200 GL, additional mitigation measures (e.g. increasing pump-start capacity or decreasing pump rate) have little additional modelled ecological benefit.

A dry future climate has the potential to result in a larger mean change to ecological flow dependencies across the Victoria catchment than the largest physically plausible water resource development scenarios. However, the perturbations to flow arising from a combined drier future climate and water resource development result in greater impacts on ecology–flow dependency than either factor on their own.

For instream dams, location matters, and there is potential for high risks of local impacts. Improved outcomes are associated with maintaining attributes of the natural flow regime with transparent flows (flows allowed to ‘pass through’ the dam for ecological purposes). Potential dams located in small headwater catchments may result in a major change in the ecological flow dependency immediately downstream of the dam. However, impacts reduce downstream with the accumulation of additional tributary flows, so when averaged over the entire catchment or measured at the EOS, the change in ecological flow dependency is minor. Providing transparent flows improves flow regimes for ecology by reducing the mean yield of potential dams. Mean outcomes for fish assets can be improved from minor to negligible, and for waterbirds from moderate to minor, at catchment scales for the scale of scenarios explored.

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 Victoria catchment. 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 of pests, weeds and diseases, to detect and respond to incursions and to manage the impacts of key biological threats.

A variety of current and potential pests, weeds and diseases could have an impact on irrigated cropping in the Victoria catchment. These include fall armyworm (*Spodoptera frugiperda*, which consumes C4 grass crops), cucumber green mottle mosaic virus *(Tobamovirus*), which infects a wide range of cucurbit crops), incursion risks from overseas, such as citrus canker (*Xanthomonas citri* subsp. *citri*), exotic fruit flies, and parthenium weed (*Parthenium hysterophorus*) (as a competitor, 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. There are various high-impact weeds declared in the NT that are present in or threaten to invade the Victoria catchment, 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 diseases (e.g. *Phytophthora* spp.). NT Government legal requirements to control declared 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 their 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. As with fertiliser nutrients, 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 naturally occurring 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 impacted 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 they typically operate under world’s best practice.

Irrigation-induced salinity

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'. Rising groundwater can mobilise 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.

It should be noted 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 (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, 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. 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*), a plant from South America, have become serious weeds of the floodplain wetlands, rendering these wetlands unviable as habitat for most aquatic biota that formerly occurred there (Perna, 2003, 2004; Tait and Perna, 2000).

Thus, there are limitations to the level of advice that can be provided in the absence of specific development proposals, so this section provides general advice on those considerations or externalities that are 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 1%) 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.

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 Victoria catchment 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 diseases, pests and weeds, and the risks new agriculture or aquaculture enterprise in the Victoria catchment 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 7.5 Irrigation-induced salinity: briefly discusses the risk of irrigation-induced salinity to an irrigation development and the downstream environment in the Victoria catchment.

It should be noted that the discussions in section 7.4 to 7.5 are more generalised in nature than the material presented in Section 7.3, as the actual risks tend to be highly scenario- and location-specific, and appropriate data are typically missing.

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)
- the movement of aquatic species and loss of connectivity (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 the 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 between communities and government, and subsequent decisions.

It is important to note that this chapter primarily focuses on key risks resulting from irrigated agriculture and to a lesser extent aquaculture, although the section on biosecurity considers both risks to the enterprise and risks emanating from the enterprise into the broader environment. Additional 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 and reservoir inundation (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).

The material within this chapter is largely based on the companion technical reports on ecology asset analysis (Stratford et al., 2024a) 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, with species broadly adapted to the prevailing conditions under which they occur. Flow-dependent flora, fauna and habitats are defined here as those sensitive to changes in flow and those sustained by either surface water or groundwater flows or a combination of these. In rivers and floodplains, the capture, storage, release, conveyance and extraction of water alters the environmental template on which the river functions, and 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 act during both wet and dry periods to change the magnitude, timing, duration and frequency of flows (Jardine et al., 2015; McMahon and Finlayson, 2003). Impacts on fauna, flora and habitats associated with flow regime change often extend considerable distances downstream from the source of the impacts and into near-shore coastal and marine areas as well as onto floodplains (Burford et al., 2011; Nielsen et al., 2020; Pollino et al., 2018). Water resource development can also result in changes to water quality (see Section 7.5).

The environmental risks associated with water resource development are complex, and particularly so in northern Australia. This is in part because of the diversity of species and habitats distributed across and within the catchments and the near-shore marine zones, and because water resource development can produce a broad range of direct and indirect environmental impacts. These impacts can include changes to flow regime, 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). Storages 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 and Faggotter, 2021; Burford et al., 2016; Tockner et al., 2010). Further, even minor instream barriers can disrupt migration and movement pathways, causing loss of essential habitat for species that need passage along the river at key times, and fragmentation of populations (Crook et al., 2015; Pelicice et al., 2015). With water resource development and irrigation comes increased human activity. This can add additional pressures, including changes in fire regimes, additional harvesting pressures, and biosecurity risks associated with invasive or pest species transferring into new habitats or increasing their advantage in modified habitats (Pyšek et al., 2020).

Section 7.3 of this report analyses the risks to flow-dependent freshwater, estuarine and near-shore marine assets, as well as terrestrial systems, resulting from changes in the flow regime change in the catchment of the Victoria River. See the companion technical report on water storages (Yang et al., 2024) for more details on the impacts of habitat loss within potential dam impoundments and connectivity loss due to the development of new instream barriers. Refer to the companion technical report on ecological asset descriptions in the Victoria catchment by Stratford et al. (2024a) for more details on the flow ecology of the Victoria catchment and its ecological values. The asset description report (Stratford et al., 2024a) also qualitatively examines existing and potential threatening processes for freshwater-dependent ecological assets, including possible influences of synergistic impacts. For more details of the ecological asset analysis and details of analysis for all assets, see Stratford et al. (2024b).

7.3.2 Ecology of the Victoria catchment

The comparatively intact landscapes of the Victoria catchment hold significant ecological and environmental values and are important for the ecosystem services they provide, including recreational activities, tourism, fisheries (Indigenous, recreational and commercial), military training, and agricultural production (notably cattle grazing on native pastures). The Victoria River is a large river originating to the south of the Judbarra National Park. At over 500 km in length, it is the second longest rivers in the NT with permanent water. The catchment area of 82,400 km^2 makes it one of the largest ocean-flowing catchments in the NT, with flows that enter the south-eastern edge of the Joseph Bonaparte Gulf. The catchment and the surrounding marine environment contain a rich diversity of important ecological assets, including species, ecological communities, habitats, and ecological processes and functions. The ecology of the Victoria River is maintained by its flow regime, shaped by the catchment’s complex geomorphology and topography, and driven by patterns of seasonal rainfall, evapotranspiration, and groundwater discharge.

The protected areas located in the Victoria catchment include one gazetted national park (Judbarra), a proposed extension to an existing national park (Keep River), the Commonwealth Joseph Bonaparte Gulf Marine Park, two Indigenous Protected Areas and two Directory of Important Wetlands in Australia (DIWA) sites. The two DIWA sites are the Bradshaw Field Training Area and the Legune Wetlands (Figure 7-2). The freshwater sections of the Victoria catchment include diverse habitats such as intermittent and perennial rivers, anabranches, wetlands, floodplains, and groundwater-dependent ecosystems (GDEs). The diversity and complexity of the habitats, and the connections between the habitats within a catchment, are vital for providing the range of habitats needed to support both the aquatic and terrestrial biota (Schofield et al., 2018).

In the wet season, flooding connects rivers to floodplains. This exchange of water means that floodplain habitats support higher levels of primary and secondary productivity than surrounding terrestrial areas with less frequent inundation (Pettit et al., 2011). Infiltration of water into the soil during the wet season and along persistent streams enables riparian habitats to form an important interface between the aquatic and terrestrial environments. While riparian habitats often occupy a relatively small proportion of the catchment, they frequently have a higher species richness and abundance of individuals than surrounding habitats. The riparian habitats that fringe the rivers and streams of the Victoria catchment have been rated as having moderate to high cover and structural diversity of riparian vegetation (Kirby and Faulks, 2004). These riparian habitats comprise a *Eucalyptus camaldulensis* overstorey with *Lophostemon grandiflorus*, *Terminalia platyphylla*, *Pandanus aquaticus* and *Ficus* spp understorey. The dominant overstorey across many parts of the catchment includes *Acacia holosericea* and *Eriachne festucacea* (Kirby and Faulks, 2004). Further away from the creeks and rivers, the overstorey vegetation in the Victoria catchment becomes sparser, opening up into savanna woodlands and various grasslands.

In the dry season, biodiversity is supported by perennial rivers, wetlands and the inchannel waterholes that persist in the landscape. In ephemeral rivers, the waterholes that remain become increasingly important as the dry season progresses; they provide important refuge habitat for species and enable recolonisation into surrounding habitats upon the return of larger flows (Hermoso et al., 2013). Waterholes provide habitat for water-dependent species, including fish, sawfish and freshwater turtles, and also provide a source of water for other species more broadly within the landscape (McJannet et al., 2014; Waltham et al., 2013).

The mouth and estuary of the Victoria River is up to 25 km wide and includes extensive mudflats and mangrove stands (Kirby and Faulks, 2004). Although mangroves and mudflats are prominent along the coastal margins (Department of Climate Change, Energy, the Environment and Water, n.d.), the mangrove communities along the estuary are recognised as being low in species richness, with approximately ten plant species recorded. Of these, the dominant mangrove species in the catchment is *Avicennia marina*, which is largely confined to the estuary (Kirby and Faulks, 2004). The Legune (Joseph Bonaparte Bay) Important Bird and Biodiversity Area can support over 15,000 waterbirds across mudflats, salt flats, and seasonally inundated wetlands (BirdLife International, 2023). Marine habitats in northern Australia are vital for supporting important fisheries, including banana prawn (*Fenneropenaeus merguiensis*), mud crab (*Scylla* spp.) and barramundi (*Lates calcarifer*), as well as for supporting biodiversity more generally, including waterbirds, marine mammals and turtles. In addition, the natural waterways of the sparsely populated catchments support globally significant stronghold populations of endangered and endemic species that often use a combination of both marine and freshwater habitats (e.g. sharks and rays).

7.3.3 Scenarios of hypothetical water resource development and future climate

This ecology analysis used modelled hydrology to explore the potential ecological risks of water resource development in the Victoria catchment through a series of hypothetical scenarios. It used a purpose built river model for the Victoria catchment – for more detail, see the companion technical report on river model calibration in the Victoria catchment by Hughes et al. (2024a). The scenarios were designed to explore how different types and scales of water resource development might affect selected water-dependent ecosystems across the Victoria catchment.

The hypothetical developments assessed included instream infrastructure (i.e. large dams) and water harvesting (i.e. pumping river water into offstream farm-scale storages). In evaluating the likelihood of a development scenario occurring, Section 1.2.2, which discusses the plausibility of development pathways, should be consulted. Broad scenario definitions used in the Assessment are described in Section 1.4.3, with Table 7-1 providing a summary of the specific scenarios used in the ecology analysis. Figure 7-2 shows the location of the river system model nodes used in the ecology analysis and the location of hypothetical water resource developments. Further details of the river system model simulations are provided in the companion technical report on river model simulation (Hughes et al., 2024b). The river models were also used to explore the ways in which dry future climate conditions may have an impact on water-dependent ecosystems (i.e. Scenario C), as well as the interactions between water resource development and a potential dry climate future (i.e. Scenario Ddry).

Key terms used in Section 7.3

Water harvesting – an operation where water is pumped or diverted from a river into an offstream storage, assuming there are no instream structures

Offstream storages – usually fully enclosed circular or rectangular earthfill embankment structures situated close to major watercourses or rivers so as 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. In the Victoria catchment, most hypothetical dams were assumed to be concrete gravity dams with a central spillway (see companion technical report on water storage) (Yang et al., 2024)

Annual diversion commencement flow requirement (DCFR) – also known as an end-of-system requirement, the cumulative flow that must pass the most downstream node (81100000) during a water year (1 September to 31 August) before pumping can commence. It is usually implemented as a strategy for mitigating the ecological impact of water harvesting

Pump-start threshold – a daily flow rate threshold above which pumping or diversion of water can commence. It is usually implemented as a strategy for mitigating 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, the end use is not necessarily limited to 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, the end use is not necessarily limited to irrigation. Users could also be involved in aquaculture, mining, urban, or industrial activities

Transparent flow – a strategy for mitigating 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 the flow regimes, due to differences and interactions between rainfall and upstream catchment sizes, inflows, the attenuation of flow through the river system (including accumulating inflows with river confluences), and the many ways in which each hypothetical water resource development is implemented. These scenarios were not analysed because they are considered likely or recommended by CSIRO; rather, they were selected to explore some of the interactions between location and the types and scales of development, to provide insights into how different types and scales of water resource development may influence ecology outcomes across the catchment.

Some of the hypothetical scenarios listed in Table 7-1 do not provide dedicated environmental provisions and have been optimised for water yield reliability, without considering policy settings or additional restrictions that may help mitigate the impacts to 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). Further, as an artefact of the scenario assumptions, modelling hypothetical dam development assumed water from the reservoir was released via a pipe or channel rather than releasing water for irrigation into the downstream river channel. Consequently, the river model calculates and removes the extractive take at the dam node. Furthermore, many of the scenarios explored, while technically feasible, exceed the level of development that would be likely to reasonably occur and are modelled without regulatory requirements and management to mitigate ecological impacts. These scenarios were included as a stress test of the system and can be useful for benchmarking or contrasting various levels of change and different mitigation options.

The development scenarios are hypothetical and are for the purpose of exploring a range of options and issues in the Victoria catchment. 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 Map of the Victoria catchment and the marine region showing the locations of the river system modelling nodes at which flow–ecology dependencies were assessed (numbered) and the locations of hypothetical water resource developments

Nodes are the locations at which flow–ecology dependencies were assessed and are marked as purple or orange circles. The hypothetical modelled dam locations are shown by the triangles marked A and B, and the water harvesting extraction locations are shown by orange circles. The flow ecology of the ecological assets was assessed in the subcatchments in which they occur, downstream of the river system nodes. The locations of ecological assets across the catchment for modelling are documented in Stratford et al. (2024b).

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

Descriptions of the river system modelling scenarios are provided in Hughes et al. (2024b). DCFR = annual diversion commencement flow requirement. FSL = full supply level. GCM = general circulation model. na = not applicable.

SCENARIO	DESCRIPTION	TRANSPARENT FLOW	ANNUAL TARGET EXTRACTION VOLUME / YIELD (GL)	DCFR (GL)	PUMP-START THRESHOLD (ML/D)	PUMP CAPACITY (D)
Scenario A	**Historical climate and current levels of development**					
A	Historical climate and no development	No	0	0	na	na
Scenario B	**Historical climate and hypothetical future development**					
B-D_{LC}	Single dam on Leichhardt Creek	No	60‡	na	na	na
B-D_{VR}	Single dam on Victoria River	No	500‡	na	na	na
B-D_2	Two hypothetical dams, LC, VR	No	560‡	na	na	na
B-W_V, E_F, P_T, C_R	Water harvesting with varying target extraction volume (V), DCR requirements (F), pump-start threshold (T), and/or pump rate (R)	na	V = 40, 80, …, 960, 1000‡	F = 0, 200, 500, 700, 1000	T = 200, 300, …, 900, 1000	R = 10, 20, 30, 40, 50
Scenario C	**Future climate and current level of development**					
Cdry	Dry GCM§ projection (see Section 2.4.5)	No	0	na	na	na
Scenario D	**Future climate and hypothetical future development**					
D-D_2	Two hypothetical dams (same as B-D_2), for each Scenario C climate (clim = dry)	No	591‡	na	na	na
D-D_{2T}	Two hypothetical dams (same as B-D_2), for each Scenario C climate (clim = dry) with transparent flows	Yes	591‡	na	na	na
D-$W_{150,F,600,c}$	Water harvesting under Scenario C climate (clim = dry)	na	680‡	0	200	30

‡Target extraction volume applies to water harvesting scenarios. Yield applies to hypothetical dam scenarios and is the amount of water that could be supplied by the dams reservoir in 85% of years.

7.3.4 Ecology outcomes and implications

The ecology activity used an asset-based approach for analysis and built upon work presented in Pollino et al. (2018) and Stratford et al. (2024c). For the Victoria catchment, 18 ecological assets were selected for analysis (Table 7-2) across 41 nodes, including the end-of-system node for marine assets (Figure 7-2). Both the ecology asset descriptions technical report (Stratford et al., 2024a) and the ecology asset analysis technical report (Stratford et al., 2024b) should be consulted in conjunction with the material provided here.

The selected ecological assets spanned freshwater, marine and terrestrial habitats and included species, species groups, and habitats that depend on river flows. Eighteen assets (shown in Table 7-2) were modelled to investigate the effects of changes to river flow resulting from hypothetical water resource development and a projected dry future climate (as a potential worst-case projected climate scenario). Assets were included if they were distinctive, representative, describable and significant within the catchment. The flow–ecology interactions of the assets, including important flow linkages and relationships, and assessment locations in the catchment were documented in Stratford et al. (2024a), as were species and habitat distribution maps, including species distribution models developed for many of the species. Each asset had different requirements of, and linkages to, the flow regime and was distributed across particular parts of the catchment or the near-shore marine zone. Understanding the flow–ecology interactions of assets and their locations across the catchment was important for identifying the potential risks caused by changes in catchment hydrology.

Table 7-2 Ecological assets used in the Victoria Water Resource Assessment

Eighteen ecological assets were modelled in the ecology analysis. A description of the ecological assets, their flow ecology, and their distribution is provided in Stratford et al. (2024a). Assets marked with an asterisk are presented in this report. The analyses and interpretations for all assets are provided in Stratford et al. (2024b).

ASSET GROUP	ASSET	SYSTEMS
Fish, sharks and rays	Barramundi (*Lates calcarifer*)*	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
Turtles, prawns and other species	Banana prawns (*Penaeus indicus*)	Marine
	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
	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 a suite of asset-specific hydrometrics, with metrics based upon those in 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). As a basis for selecting asset hydrometrics, Stratford et al. (2024a) 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 node under 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 A, calculated over the Assessment period (i.e. 1 September 1890 to 31 August 2022). The hydrometric index of change is calculated as:

$$Percentile\ change = \frac{x - scenario\ median}{scenario\ median} \times\ 100$$

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 catchment 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 Stratford et al., 2024b 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 the assets' 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 the results, larger values represent greater change in the parts of the flow regime and across sections of the catchment that are important for the asset, with qualitative descriptors provided in Table 7-3 considering the habitat weighted value of each reach for each asset. At a single location as the values are percentile change from the median of the distribution of Scenario A, the assets flow dependency values can be referenced against this historical variability. For example, a value of 25 for a metric at a single location 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 Descriptive qualitative values for the flow dependencies modelling as 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 Stratford et al. (2024b).

VALUE	RATING	IMPLICATION
>0–2	Negligible	The median for the assets' metrics under the scenario is negligible change, as considered against the modelled historical conditions, and is well within the normal experienced conditions at the model node. The assets' hydrometrics are within the 2nd percentile of the historical Scenario A median
2–5	Minor	The change is minor, with the median for the assets' metrics for the scenario outside the 2nd and within the 5th percentile of Scenario A and the historical distribution of the hydrometrics
5–15	Moderate	The change is moderate, with the median for the assets' metrics under the scenario outside 5th and within the 15th percentile of Scenario A and the historical distribution of the hydrometrics
15–30	Major	The change is major, with the median for the assets' metrics for the scenario outside the 15th and within the 30th percentile of Scenario A and the historical distribution of the hydrometrics
>30	Extreme	The change is extreme, with the median for the assets' metrics under the scenario being extreme change, as considered against the modelled historical conditions, with metrics occurring well outside typical conditions at the modelled node or exceeding that of historical variability. The scenario median is outside the 30th percentile from the historical Scenario A median (or equivalent to the new mean, being typical of the outside 20% of observations from the historical sequence across the metrics important to the asset)

In addition to quantifying change relative to the historical variability under Scenario A for each asset, an existing analogue of change in asset–flow dependencies is compared using the level of change in the hypothetical scenarios with models of the Ord River below Lake Kununurra (with and without the Ord River Dam and the Ord Diversion Dam (i.e. Lake Kununurra)), near the end-of-system. This analogue considers the modelled changes in river flow associated with the construction of Lake Kununurra, Ord River Dam and Ord River Irrigation Scheme. In addition to the Ord scheme analogue, three natural periods of low-flow conditions are used as benchmarks and plotted alongside the hypothetical developments and climate scenario values. For the Victoria catchments, these were the periods with the lowest 30-year flow (1905–1934), lowest 50-year flow (1890–1939) and lowest 70-year flow (1890–1959) across the historical climate (Scenario A). These are benchmark comparisons, so flow conditions and outcomes of change in flow dependencies 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.

It is important to note that this ecological 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 the production of potentially novel outcomes. The understanding of freshwater ecology in the Victoria catchment and northern Australia more generally is still developing.

Provided below is a sample of outcomes for three representative assets for the Victoria catchment: barramundi; shorebirds; and mangroves. For more details and for results on other assets see Stratford et al. (2024b).

Barramundi

Barramundi are large opportunistic, predatory fish that inhabit riverine, estuarine and marine waters in northern Australia, including those in the Victoria catchment. Adults mate and spawn in the lower estuary and coastal habitats near river mouths during the late dry season and early wet season. Small juveniles migrate upstream from the estuary to freshwater habitats, where they grow and mature before emigrating downstream to estuarine habitats as adults, where they reside and reproduce. In the Victoria catchment, barramundi occupy relatively pristine habitats in both the freshwater and estuarine reaches, as well as in the coastal marine waters. Their life history renders them critically dependent on river flows (Tanimoto et al., 2012) as new recruits move into supra-littoral estuarine and coastal salt flat habitats, and freshwater riverine reaches and wetland habitats occupied as juveniles (Crook et al., 2016; Russell and Garrett, 1983, 1985).

Barramundi are sensitive to changes in flow regime in Australia’s tropical rivers where critical requirements for growth and survival include riverine–wetland connectivity, riverine–estuarine connectivity, passage to spawning habitat, and volume of flood flows (Crook et al., 2016; Roberts et al., 2019).

Barramundi are an ecologically important fish species capable of modifying the estuarine and riverine fish and crustacean communities throughout Australia’s wet-dry tropics (Blaber et al., 1989; Brewer et al., 1995; Milton et al., 2005). It is targeted by commercial, recreational and Indigenous fisheries. Barramundi is an important species for Indigenous Peoples in northern Australia, both culturally (Finn and Jackson, 2011; Jackson et al., 2011) and as a food source (Naughton et al., 1986).

The analysis here considers change in flow regime and related habitat changes. For consideration of the addition or loss of potential habitat associated with the creation of a dam impoundment or instream structures see Yang et al. (2024).

Flow dependencies analysis

Barramundi were modelled across a total of 1918 km of assessment reaches in the Victoria catchment and in the marine region, with contributing flows from a total of 41 model nodes (see Stratford et al. (2024b)). Some of the key river reaches for barramundi within the catchment were modelled downstream of nodes 81100070, 81100000 and 81100002. The locations for modelling barramundi in the Victoria catchment were based upon species distribution models (Stratford et al., 2024a).

Hypothetical water resource development in the Victoria catchment resulted in varying levels of change to important flow dependencies for barramundi. When considering mean change in flow dependencies across all 41 barramundi reaches and nodes, the effects under the hypothetical dam scenarios ranged from negligible (0.5) to minor (3.2) under scenarios B-D_{LCT} and B-D_2, respectively, while for water harvesting the effects were negligible (0.1 to 1.0) under scenarios B-$W_{v80t200r30f500}$ and B-$W_{v800t200r30f0}$ (Figure 7-3). Scenario Cdry resulted in moderate change (5.1) for barramundi. The resulting spatial change in flow dependencies associated with dam, water harvesting and climate scenarios varied as a result of the different spatial patterns, including the extent and magnitude of flow change across different parts of the catchment, as illustrated in Figure 7-4.

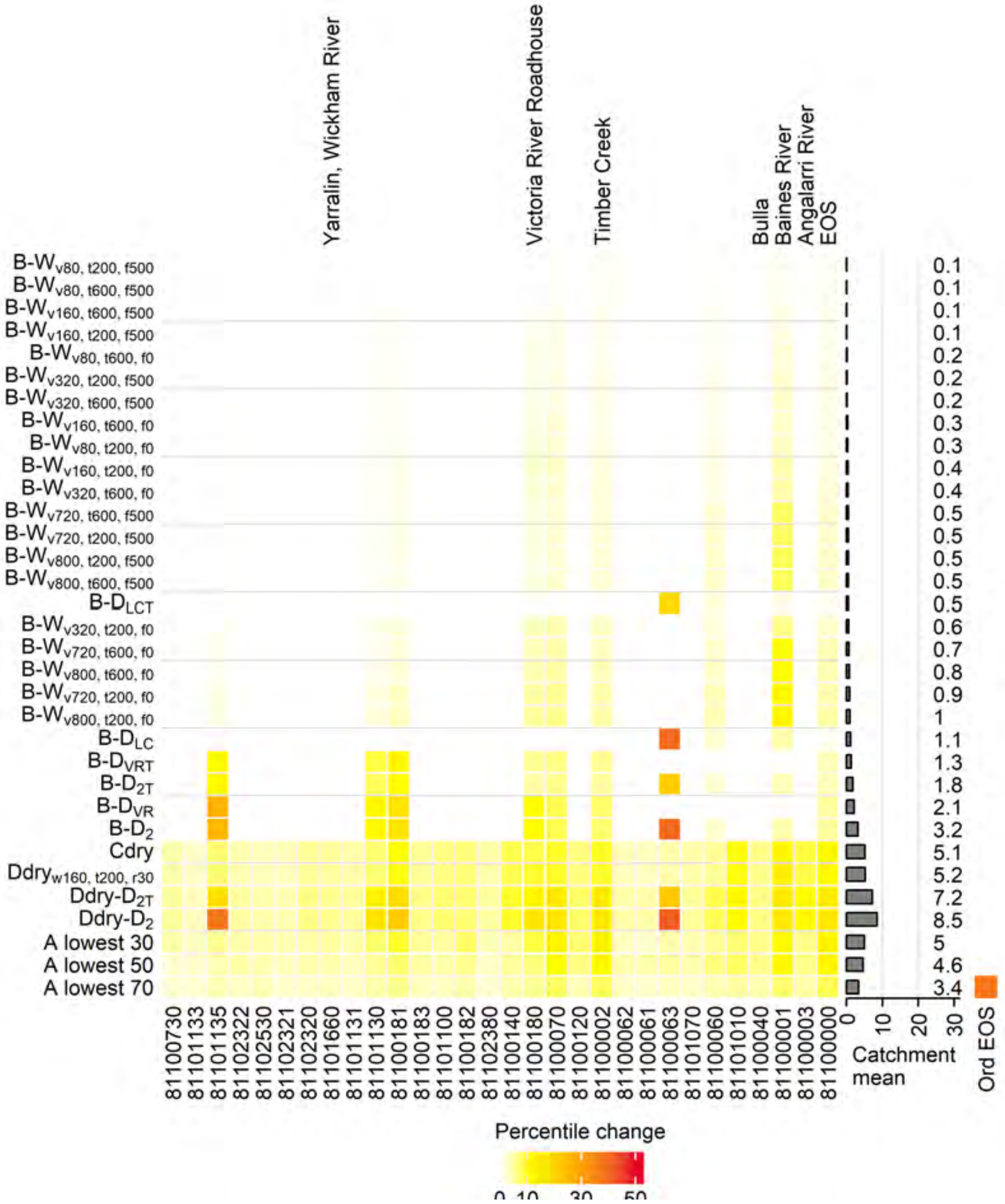

Figure 7-3 Habitat weighted change in important flow dependencies for barramundi by scenario across model nodes

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 barramundi. 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. EOS = end-of-system.

The mean change in important flow dependencies for barramundi across the Victoria catchment for the lowest 30-year, 50-year and 70-year flows in the historical record are 5, 3.6 and 3.4 respectively.

Under Scenario B-D_{LC}, (i.e. a potential dam on Leichhardt Creek without transparent flows) there was a negligible mean change in important flow dependencies (1.1) across the 41 barramundi assessment nodes. When transparent flows were provided to support environmental functions (i.e. Scenario B-D_{LCT}), the change in important flows for barramundi was reduced, remaining negligible (0.5). Under Scenario B-D_{VR} greater change relative to Scenario B-D_{LC} was calculated, with a minor (2.1) mean change in flow dependencies. This was reduced to negligible (1.3) with the provision of transparent flows under Scenario B-D_{VRT}. Under Scenario B-D_2, which includes both the B-D_{LC} and B-D_{VR} dams, a minor (3.2) mean change in flow dependencies occurred across the catchment without transparent flows. This was reduced to negligible (1.8) with the provision of transparent flows. Under Scenario B-D_2 with multiple dams, there was a greater mean change in flow dependencies across the catchment, relative to either of the single dam scenarios. This was due to the combined effects on flows downstream of the confluence of the two dams and the change in flows affecting a larger portion of the catchment from which flows would be impounded. At the end-of-system node 81100000 the mean impact under the hypothetical dam scenarios in the Victoria catchment was considerably less than at the end-of-system in the Ord.

Under Scenario B-D_{2T}, habitat-weighted flow changes for barramundi were greatest at node 81100063 (Figure 7-3), with a major (20.6) change in flow dependencies at this single node. Nodes directly downstream of the dams under scenarios B-D_{LC} and B-D_{VR} resulted in extreme (39.9) and major (26.6) change, respectively. These changes were reduced to major (18.8) and moderate (11.4) with the provision of transparent flows. This reflects a combination of the higher level of change in flows directly downstream of dams, the benefits associated with the provision of transparent flows for riverine resident species, and the importance for barramundi of the habitat at these locations. In years of natural low flows, or flows reduced by anthropogenic activity, the range of facultative habitat and ecosystem processes available to barramundi is reduced, reducing growth and survival (Blaber et al., 1989; Brewer et al., 1995; Milton et al., 2005).

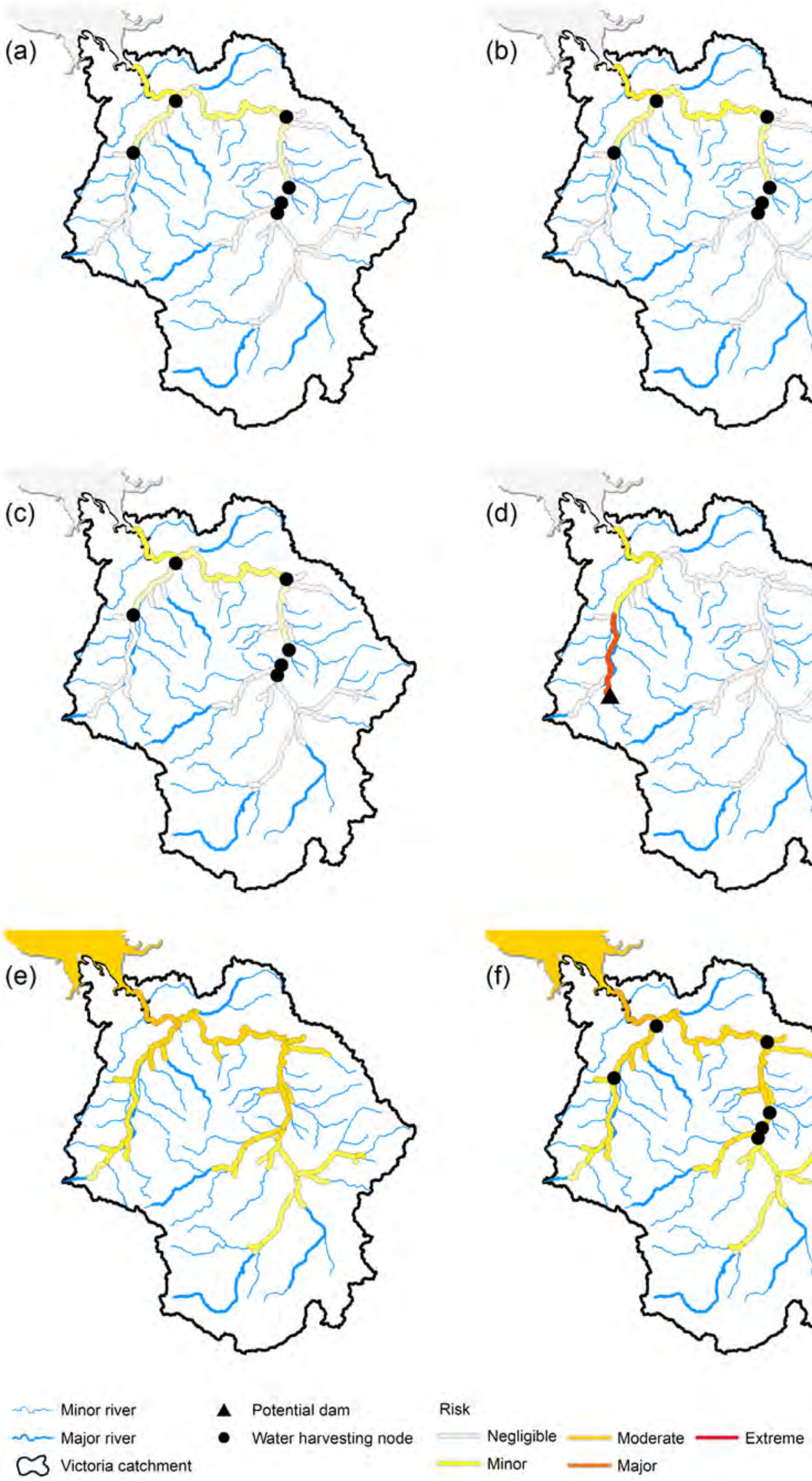

Figure 7-4 Spatial heatmap of change in important flow dependencies for barramundi, considering their distribution across the catchment

Scenarios are: (a) B-W$_{\text{v80t200r30f0}}$, (b) B-W$_{\text{v160t200r30f0}}$, (c) B-W$_{\text{160t60r20f0}}$, (d) B-D$_{\text{LC}}$, (e) Cdry and (f) D-dry$_{\text{w160t200r30}}$. See Table 7-1 for a description of the scenarios. River shading indicates the level of flow change of important metrics, weighted by the habitat value of each reach for barramundi.

Under the hypothetical water harvesting scenarios, there was a negligible (0.1 to 1.0) mean change in flow dependencies across the barramundi assessment nodes for B-W$_{\text{v80t200r30f500}}$ and B-W$_{\text{v800t200r30f0}}$, respectively. Under the water harvesting scenarios the greatest mean change occurred at node 81100001, with a moderate (11.8) change occurring at this node under Scenario B-W$_{\text{v800t200r30f0}}$. The change in barramundi flow dependencies with water harvesting varies according to the extraction targets, pump-start thresholds, pump rates, and locations (Figure 7-3). With a low extraction target of 80 GL under Scenario B-W$_{\text{v80t200r30f0}}$, the mean weighted change across the catchment was negligible (0.3), only increasing to 1.0 with the larger extraction target of 800 GL under Scenario B-W$_{\text{v800t200r30f0}}$. Increasing the pump-start threshold from 200 to 600 ML per day (scenarios B-W$_{\text{v160t200r30f0}}$ and B-W$_{\text{v160t600r30f0}}$) with a target extraction volume of 160 GL maintained a negligible change with the mean weighted change reduced from 0.4 to 0.3 (Figure 7-3). Increasing the pump-start threshold protected the low flows that are important for barramundi ecology, such as habitat connectivity and pool refugia water quality, particularly at the end of the annual dry season (Arthington et al., 2005; Crook et al., 2022).

The effects of water harvesting were strongly influenced by the node location, relative to the extraction. Nodes downstream of multiple water harvesting locations often had large changes in important flow dependencies (see node 81100001 compared with node 81101135 in Figure 7-5). The benefits associated with having a low system allocation target can be seen when changes in flow dependencies are increased with greater allocation targets (see also nodes 81100001 and 81100180 in Figure 7-5, where change is increased along the plot's *y*-axis). Similarly, reductions in change can be seen in association with having higher pump-start thresholds (see node 81101135, where the change in flow dependencies is reduced along the plot's *x*-axis). Figure 7-5 demonstrates the large spatial variability in risks associated with water harvesting across the catchment, and that mitigation strategies can be used to reduce flow change, although their success may have local considerations.

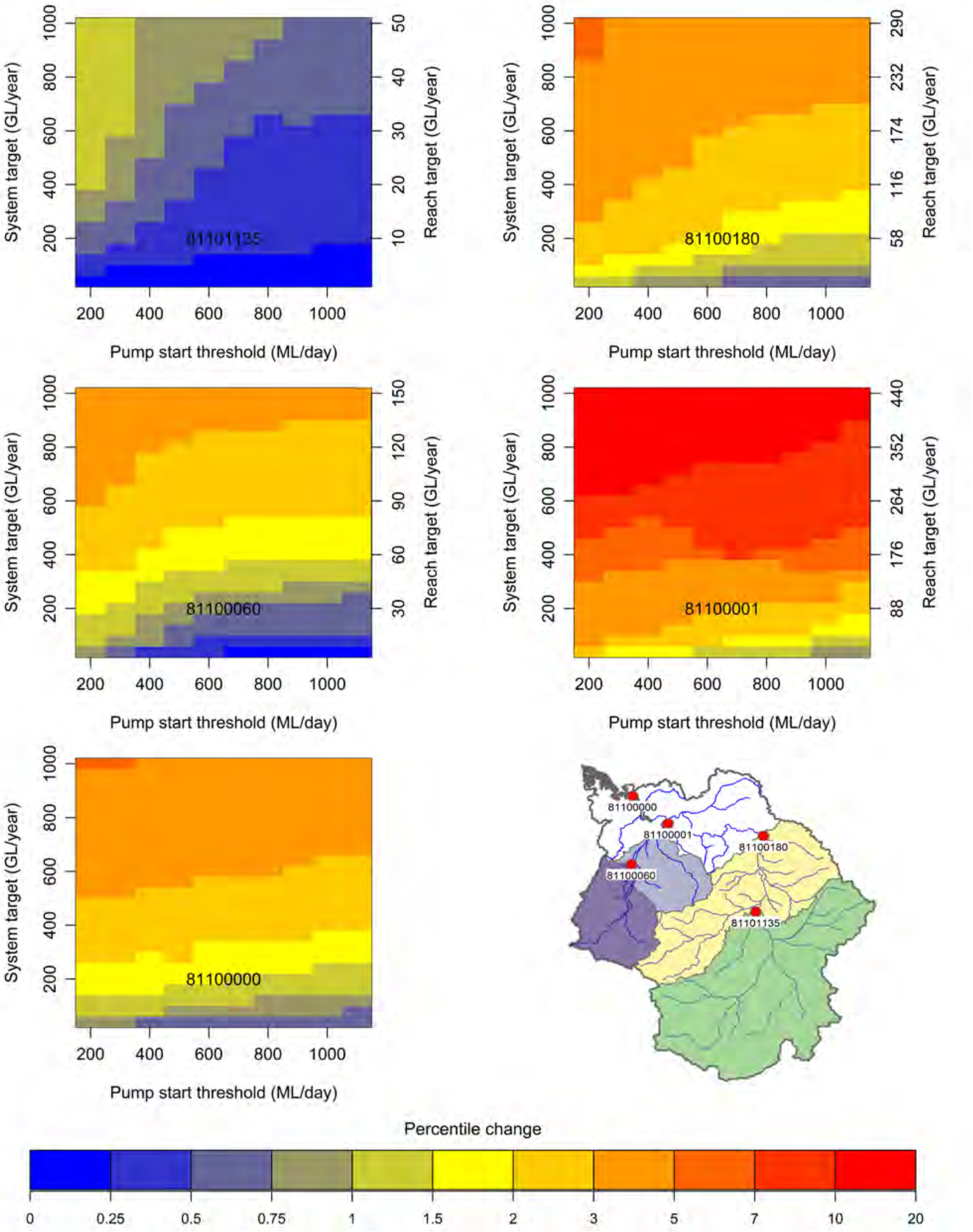

Figure 7-5 The change in barramundi flow dependencies under the various water harvesting scenarios at sample nodes across the catchment, showing response to system targets and pump-start thresholds

Colour intensity represents the level of change occurring in the barramundi's important flow metrics under the scenarios at the important nodes. The results incorporate the habitat-weighted change under each scenario relative to the distribution under Scenario A, with results for no end-of-system (EOS) requirement and a pump rate of 30 days.

Scenario Cdry resulted in a moderate mean change in flow dependencies (5.1) for barramundi across the 41 barramundi assessment nodes (Figure 7-3). This level of change accrued, as the new median conditions under this scenario were equivalent to the lowest 30-year flow analogue period for barramundi (Figure 7-3). This analysis indicates that under Scenario Cdry and under the lowest 30-year, 50-year and 70-year flow periods there were on average across all catchment nodes greater changes to mean asset flow dependencies than under scenarios B-D_{2T} (negligible; 1.8) and B-$W_{v160t200r30f0}$ (negligible; 0.4). However, it is important to note that local changes under some water resource development scenarios can be considerably higher. Under scenarios $D_{clim-D2T}$ and Ddry$_{-Wv160t200r30}$, there were moderate (7.2 and 5.2) changes, respectively, when weighted across all barramundi assessment nodes. These values were higher than any of the analogue low-flow periods. This shows that the combined impacts under scenarios $D_{clim-D2T}$ or Ddry$_{-Wv160t200r30}$ were greater than under Scenario Cdry or under either scenarios B-D_2 or B-$W_{v160t200r30}$ alone.

Barramundi populations depend on habitat connectivity being maintained throughout the catchment. Access to riverine habitats due to the physical barriers of instream infrastructure (particularly under scenarios B-D_{VR} or B-D_2) would limit access to some habitats (see Yang et al. (2024)). Access to upstream habitats and estuarine supra-littoral habitats would be reduced if water harvesting or dam scenarios reduced the inundation level, frequency or duration of overbank flows. High river flows expand the extent of wetland and estuarine-margin habitats, increase connectivity, deliver nutrients from terrestrial landscapes, create hot spots of high primary productivity and food webs, increase prey productivity and availability, and increase migration within the river catchment (Burford and Faggotter, 2021; Burford et al., 2016; Leahy and Robins, 2021; Ndehedehe et al., 2020, 2021). Reduced flow levels under a future drier climate would reduce wetland habitat connectivity and productivity. A wetter climate would likely increase wet-season flow levels and increase wetland–riverine–estuarine connectivity, and it could ameliorate the effects of possible anthropogenic flow reduction compared with current conditions.

The difference in flow effects of single dams (negligible or minor) or two dams (minor) are expected, as the single potential dam on Leichhardt Creek has minimal impact on flow at the catchment scale, as it does not affect the majority of subcatchments of the Victoria River. A much larger area of the river catchment is located above the dam on the hypothetical Victoria River (B-D_{VR}). The extent to which the construction of dam infrastructure will reduce barramundi habitat by reducing longitudinal connectivity varies depending upon the potential dam location (see Yang et al. (2024) for changes associated with instream structures). A potential dam on a small headwater catchment such as Leichhardt Creek has minimal impact on longitudinal connectivity of assets compared toa a potential dam on the Victoria River. Across the entire catchment, water extraction of between 80 and 800 GL (i.e. under scenarios B-$W_{v80t200r30f0}$ to B-$W_{v800t200r30f0}$) causes a negligible change in flow dependencies for barramundi, including both wet-season high-level flows and low-level flows during September to March prior to the wet season.

Barramundi growth and year-class strength are enhanced by large wet-season flows during the wet-season months of January to March (Crook et al., 2022; Leahy and Robins, 2021). Larger flows both preceding and following the wet-season peak flows also enhance barramundi growth and recruitment. Previous studies have shown that reducing high flows lowers the growth rates of barramundi: a model of flow–growth estimates a 12% reduction in barramundi growth under an 18% reduction in the natural flow regime (Leahy and Robins, 2021). Recent research on monsoon-driven habitat use by barramundi has shown that, during drier years with lower river flows, a large proportion of the juvenile barramundi migrate upstream from estuarine spawning habitat to freshwater habitats, probably seeking out riverine and palustrine productive hot spots (Roberts et al., 2023). Hence, maintaining low-level flows would be critical. Negligible change in seasonal flow levels due to water harvesting maintains the natural seasonality of flow patterns and would support barramundi populations within the Victoria River catchment. While two dams within the catchment are modelled to result in a minor change to barramundi flows, mitigation actions (such as transparent flows) can reduce the level of change to negligible. The impacts on barramundi populations from modifying the level and seasonality of flows would be greater under a future dry climate and greatest with water resource development under a dry climate, with results similar to those modelled in other tropical Australian catchments (Plagányi et al., 2024).

Shorebirds

The shorebirds group consists of waterbirds with a high level of dependence on end-of-system flows and large inland flood events that provide broad areas of shallow-water and mudflat environments (see Stratford et al. (2024a) for a species list). Shorebirds are largely migratory and mostly breed in the northern hemisphere (Piersma and Baker, 2000). They are in significant decline and are of international concern (Clemens et al., 2010; Clemens et al., 2016; Nebel et al., 2008). Shorebirds depend on specific shallow-water habitats in distinct geographic areas, including northern hemisphere breeding grounds, southern hemisphere non-breeding grounds, and stopover sites along migration routes such as the East Asian–Australasian Flyway (Bamford, 1992; Hansen et al., 2016). In northern Australia, this group comprises approximately 55 species from four families, including sandpipers, godwits, curlews, stints, plovers, dotterels, lapwings and pratincoles. Approximately 35 species are common regular visitors or residents. Several species in this group are Endangered globally and nationally, including the bar-tailed godwit, curlew sandpiper (*Calidris ferruginea*), eastern curlew, great knot (*Calidris tenuirostris)*, lesser sand plover (*Charadrius mongolus*) and red knot (*Calidris canutus*). An example species from this group is the eastern curlew, which is listed as Critically Endangered and recognised through multiple international agreements as requiring habitat protection in Australia. Eastern curlews rely on food sources along shorelines, mudflats and rocky inlets, and also need roosting vegetation (Driscoll and Ueta, 2002; Finn et al., 2007; Finn and Catterall, 2022). Developments and disturbances, such as recreational, residential and industrial use of these habitats, have restricted habitat and food availability for the eastern curlew, contributing to population declines.

The intertidal mudflats and coastal flats provide important habitat for shorebirds, as do the large open shallow wetlands (Chatto, 2006). Shorebirds rely on the inundation of shallow flat areas such as mudflats and sandflats during seasonal high-level flows to provide invertebrates and other food sources. Without inundation events, these habitats cannot support high densities of shorebird species, and lack of food can increase mortality rates both on-site and during and after migrations (Barbaree et al., 2020; Canham et al., 2021; Durrell, 2000; Kozik et al., 2022; van der Pol, et al., 2024; West et al., 2005). The analysis considers change in flow regime and related habitat changes, and does not consider the addition or loss of potential habitat associated with the creation of a dam impoundment (see Yang et al. (2024) for effects of dam impoundments).

Flow dependencies analysis

Shorebirds were modelled across a total of 1918 km of assessment reaches in the Victoria catchment and in the marine region, with contributing flows from a total of 41 model nodes, using eastern curlew as a representative species for understanding distribution patterns (see Stratford et al. (2024a)). Some of the key river reaches for shorebirds within the catchment were modelled downstream of nodes 81100180, 81100000 and 81100140, based upon species distribution modelling. The mean change in important flow dependencies for shorebirds across the Victoria catchment for the lowest 30-year, 50-year and 70-year flows in the historical record are 5, 4.5 and 3.6 respectively.

Hypothetical water resource development in the Victoria catchment resulted in varying levels of change in flow dependencies for shorebirds that did not exceed any of the analogue low-flow periods from the historical series (Figure 7-6). The mean change in flow dependencies across all 41 shorebird analysis reaches and nodes under the hypothetical dam scenarios ranged from negligible (0.5) to minor (2.9) under scenarios B-D$_{\text{LCT}}$ and BD$_{2}$, respectively, while under water harvesting it was negligible, ranging from 0.2 to 1.5 under scenarios B-W$_{\text{v80t600t30f500}}$ and B-W$_{\text{v800t200r30f0}}$, respectively (Figure 7-6). Under Scenario Cdry, there was minor change (4.3) for shorebirds. The resulting spatial change in flows under the dam and water harvesting, varied due to the scale, location and nature of the hypothetical developments. Projected climate scenarios resulted in changes to asset flow dependencies across the entire catchment.

Under the hypothetical water harvesting scenarios, there was a mean negligible change in flow dependencies across the shorebirds assessment nodes, ranging from 0.2 to 1.5 under scenarios B-W$_{\text{v80t600t30f500}}$ and B-W$_{\text{v800t200r30f0}}$, respectively. Under the water harvesting scenario with the largest change (B--W$_{\text{v800t200r30f0}}$), the single node with the highest change in flow dependencies was 81100001, with major (16.2) change. The change in important flow dependencies for shorebirds under water harvesting scenarios varies by the extraction targets, pump-start thresholds, pump rates, and location (Figure 7-6). With a low extraction target of 80 GL under Scenario B-W$_{\text{v80t200r30f0}}$, the mean weighted change across the catchment was negligible (0.4), increasing slightly (1.5) with an extraction target of 800 GL under Scenario B-W$_{\text{v800t200r30f0}}$. Increasing the pump-start threshold from 200 ML per day (under Scenario B-W$_{\text{v160t200r30f0}}$) to 600 ML per day (under Scenario B-W$_{\text{v160t600r30f0}}$) with a target extraction volume of 160 GL reduced the level of change in shorebird flow dependencies across the assessment nodes from 0.6 to 0.4.

Under Scenario Cdry, there were minor mean changes (4.3) for shorebirds across the 41 shorebirds assessment nodes, with a median value that was equivalent to the analogue low-flow time periods (Figure 7-6). This indicates that under the dry climate scenario, there were on average across all catchment nodes greater changes than under scenarios B-D$_{\text{2T}}$ (negligible; 1.6) and B-W$_{\text{v160t200r30f0}}$ (negligible; 0.6). However, it is important to note that local changes under some water resource development scenarios can be greater. Under scenarios D$_{\text{clim-D2T}}$ and Ddry$_{\text{-Wv160t200r30}}$, there were moderate (6.4) and minor (4.6) changes in important flows, respectively, when weighted across all shorebirds assessment nodes. This shows that the combined changes under scenarios D$_{\text{clim-D2T}}$ and Ddry$_{\text{-Wv160t200r30}}$ were greater than under Scenario Cdry or either of scenarios B-D$_{2}$ or B-W$_{\text{v160t200r30}}$ alone.

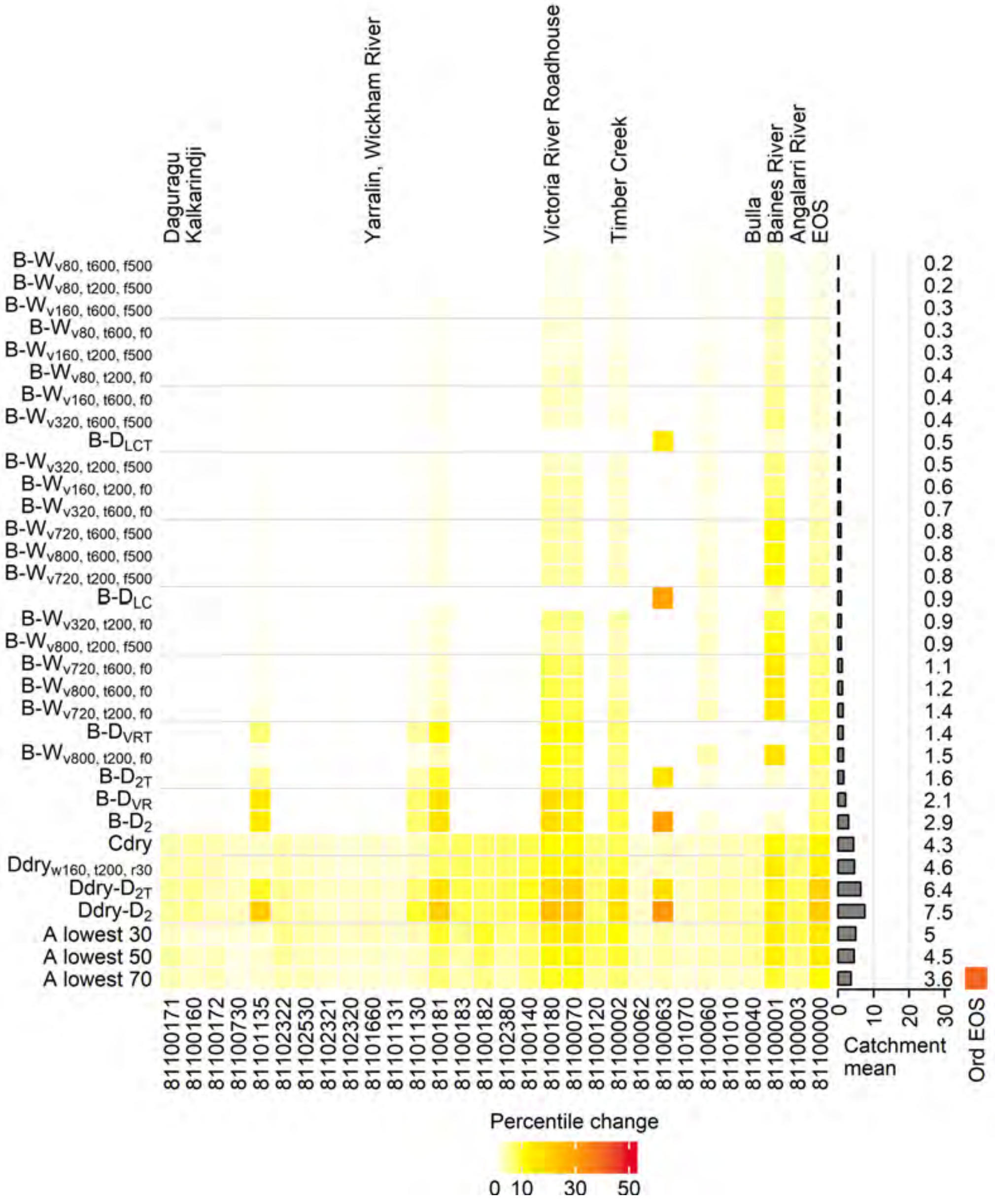

Figure 7-6 Habitat weighted change in important flow dependencies for shorebirds under the various scenarios across the model nodes

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 shorebirds. 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. EOS = end-of-system.

Mangroves

Mangroves forests include species of shrubs and trees that occupy a highly specialised niche within the intertidal and near-supra-littoral zones along tidal creeks, estuaries and coastlines (Duke et al., 2019; Friess et al., 2020; Layman, 2007). Mangroves are an important and prolific habitat-forming species group in the Victoria River estuary and coastal littoral habitats. Mangrove forests provide a complex habitat that offers a home to many marine species, including molluscs

(McClenachan et al., 2021), crustaceans (Guest et al., 2006; Thimdee et al., 2001), reptiles (Fukuda and Cuff, 2013), birds (Mohd-Azlan et al., 2012) and numerous fish species, when connected to coastal waters. During periods of inundation at high tide, species including crustaceans access mangrove forests, which provide settlement substrates and shelter against predation, using the mangroves' trunks and prop-roots as refugia during postlarval and benthic juvenile phases (Meynecke et al., 2010). Fish and crustaceans also access mangroves and their epiphytes for food (Layman, 2007; Skilleter et al., 2005). Despite occupying saline habitats, mangroves require freshwater inputs from precipitation, groundwater or overbank inundation to thrive (Duke et al., 2017), so reduced flood flows and an increased frequency and duration of no-flow periods or other impacts on hydro-connectivity are key threats to mangroves.

Flow dependencies analysis

Mangroves were modelled in the marine region with one model node at the end-of-system. The locations for modelling mangroves in the Victoria catchment were based upon habitat maps (see Stratford et al. (2024b)). Hypothetical water resource development in the Victoria catchment resulted in varying levels of change in important flow dependencies for mangroves. The levels of change ranged from negligible (0.8) to moderate (7.4) under hypothetical dam scenarios B-D_{LCT} and B-D_2, respectively, while the levels of change in important flow dependencies ranged from negligible (0.7) to moderate (5.7) under the water harvesting scenarios B-$W_{v80t600t30f500}$ and B-$W_{v800t200r30f0}$, respectively. Under Scenario Cdry, there was moderate change in flows (11.3) for mangroves (Figure 7-8). The mean change in important flow dependencies for mangroves across the Victoria catchment for the lowest 30-year, 50-year and 70-year flows in the historical record are 15.7, 14.3 and 10.1 respectively.

Figure 7-7 Waterhole fringed by boab trees, Victoria catchment

Photo: CSIRO – Nathan Dyer

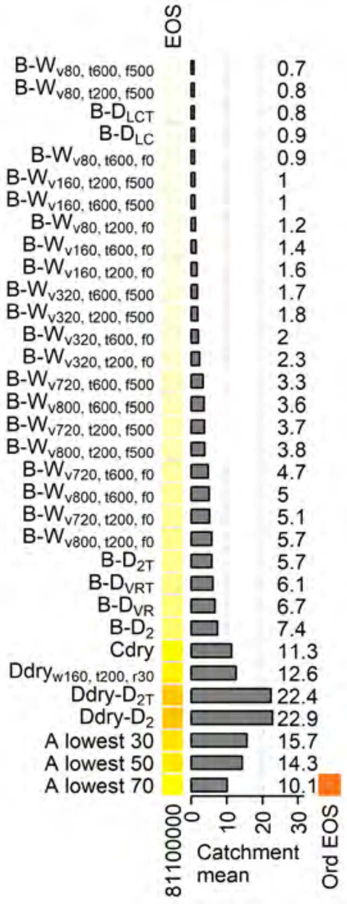

Figure 7-8 Change in important mangroves flow dependencies under the various scenarios

Colour intensity represents the level of change occurring in important flow metrics as percentile change from the historical conditions for mangroves. 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. 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. EOS = end-of-system.

The hydrological requirements for mangroves are complex: they are influenced by tidal inundation, rainfall, soil water content, groundwater seepage, and evaporation, all of which influence soil salinity, which can have profound effects on mangrove growth and survival. Mangroves require access to fresh water via their roots, though many species occur at their upper salinity threshold (Robertson and Duke, 1990). Sediment delivered to the coast during flood flows helps to sustain mangrove forests, supports their expansion (Asbridge et al., 2016) and increases the accumulation of carbon in sediments (Owers et al., 2022). An overall reduction in freshwater inputs into mangrove systems could contribute to mangrove stress and potentially dieback, as has occurred in the Gulf of Carpentaria (Duke et al., 2019).

Under scenarios B-D$_{LC}$ and B-D$_{VR}$ flow-modification changes were negligible and moderate respectively, and under Scenario B-D$_2$ there were moderate flow-modification changes to mangrove flow (Figure 7-8). Water harvesting resulted in moderate negative risks to freshwater service provision to mangroves via flow modification during the year. One dam on a small headwater tributary had little effect in terms of overall catchment flows, in contrast to a potential dam in the mid-reaches of the Victoria River itself, which was associated with a reduction in flow volumes compared to the natural flow regime. Incorporating transparent flows in the potential dam operations only slightly reduced the change in flow dependency for mangroves. Under Scenario B-D_{VRT}, the change in important flow dependency continued to result in a moderate risk to the habitat-forming species group. High-level flows are important for inundating the mangrove forests during the wet season and replenishing the soil water. Water harvesting would extract water during wet-season flows, potentially reducing the magnitude of high flows at the critical period of wet-season ecological replenishment in the wet-dry tropics. In addition, reduction of sediment loads under flow regime change that results in lower flows would be detrimental due to lower levels of coastal deposition to maintain estuarine soils for the benefit of the mangrove community (Asbridge et al., 2016).

Overview of the impacts of water resource development on ecology

This section provides a high-level overview of the aggregated results (means of assets) arising from the hypothetical development and climate change scenarios and discusses specific differences in the spatial pattern and magnitude of change. Outcomes for specific assets vary depending upon water needs and flow ecology and are discussed with implications and interpretation of results in Stratford et al. (2024b). The values associated with the means include, but do not show, the range in outcomes across assets, where change in flow dependencies for individual assets or at specific locations can be considerably higher or lower than the mean but provide an overview of the potential range of outcomes that may occur.

Hypothetical dams and water harvesting resulted in different changes in flows, affecting outcomes for ecology by different magnitudes of change across different parts of the catchment, and in different ways (Figure 7-10 and Figure 7-11). Under a water harvesting scenario, Scenario B-$W_{v800t200r30f0}$ (Figure 7-11), the largest catchment mean changes in flow dependencies for assets was for cryptic waders, threadfin, banana prawns and floodplain wetlands, all with moderate mean change in flow dependencies across their respective nodes. The largest single-site flow change under water harvesting scenarios were major, for assets including for floodplain and riparian vegetation, floodplain wetlands, shorebirds and colonial and semi-colonial wading waterbirds. Under Scenario B-D_2, 89 nodes were rated as having moderate mean change across all the assets (out of a total potential of 419 asset nodes representing 21%), compared with 43 (10%) under Scenario B-$W_{v800t200r30f0}$. Under Scenario B-D_2, across all assets there were a total of 16 asset nodes (4%) with extreme levels of change in flow dependencies, which was reduced to none under Scenario B-$W_{v800t200r30f0}$.

Under Scenario B-D_2 with two dams, the largest catchment mean change in flow dependencies for assets were for threadfin, cryptic wading waterbirds, banana prawns and mangroves, each with moderate mean change in flow dependencies across all their assessment nodes. Considering the mean of all assets, the change in flow dependencies under the largest water resource development scenario modelled (B-D_2) was lower than that for all three of the benchmark low-flow time periods (Figure 7-11), although individual assets may have differing outcomes (see Stratford et al. (2024b)). Under scenarios with dams, the largest site-based changes in flow for assets were often directly downstream of hypothetical dams and resulted in node impacts with up to extreme change for assets, including floodplain wetlands, colonial and semi-colonial wading waterbirds, grunter and sawfish at these impacted downstream nodes (e.g. Figure 7-11d for downstream dam impacts).

Under Scenario Cdry, flow regime change impacts on ecology occurred largely across the catchment (Figure 7-10e), and cumulative impacts of water resource development in combination with dry future climate often led to the greatest catchment-level changes in flow ecology (Figure 7-10f showing D-dry$_{w160t200r30}$ and Figure 7-11).

Under the largest hypothetical development scenarios for water harvesting (e.g. B-W$_{v800t200r30f0}$) and instream dam (Scenario B-D$_2$) developments, the impacts at the end-of-system node alone were greater under water harvesting than dams for sawfish, shorebirds and salt flats, and inversely greater under dams for mullet, threadfin, barramundi and mangroves. The flow changes under scenarios with a single dam ranged from negligible to moderate at the end-of-system for the mean across assets (negligible under Scenario B-D$_{LC}$ and minor to moderate under Scenario B-D$_{VR}$). While some assets have extreme change at some nodes downstream of dams, as unimpacted tributary inflows increasingly dominate streamflow patterns with distance downstream from the dam the impact is reduced.

Figure 7-9 Riverine landscape, Victoria catchment

Photo: CSIRO – Nathan Dyer

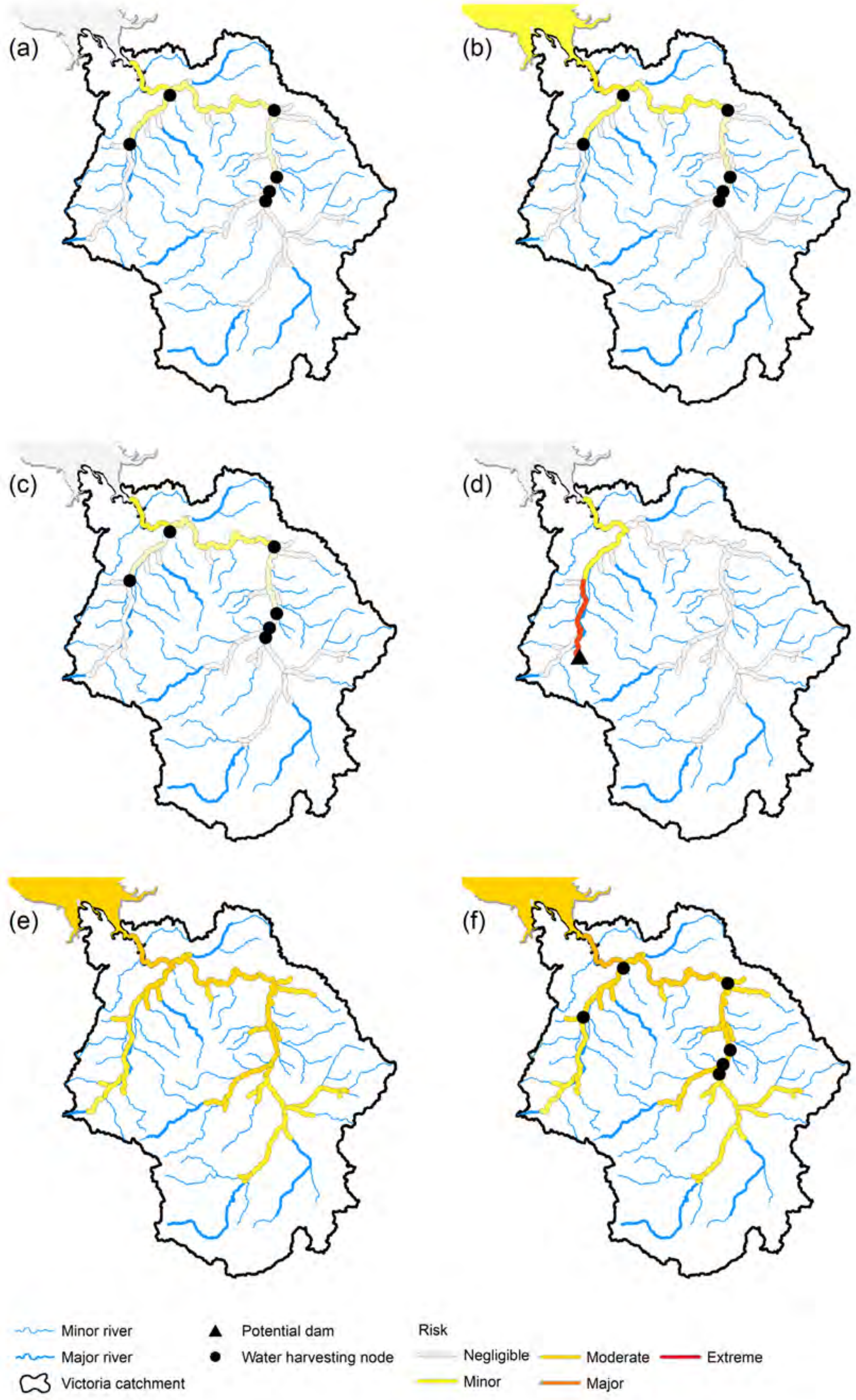

Figure 7-10 Spatial heatmap of change to asset–flow dependencies across the Victoria catchment, considering change across all assets in the locations in which each of the assets was assessed

Scenarios are: (a) B-W$_{v80t200r30f0}$, (b) B-W$_{v160t200r30f0}$, (c) B-W$_{160t60r20f0}$, (d) B-D$_{LC}$, (e) Cdry and (f) D-dry$_{w160t200r30}$. See Table 7-1 for descriptions of scenarios. River shading indicates the mean level of flow change of important metrics weighted by the habitat value of each asset for each reach.

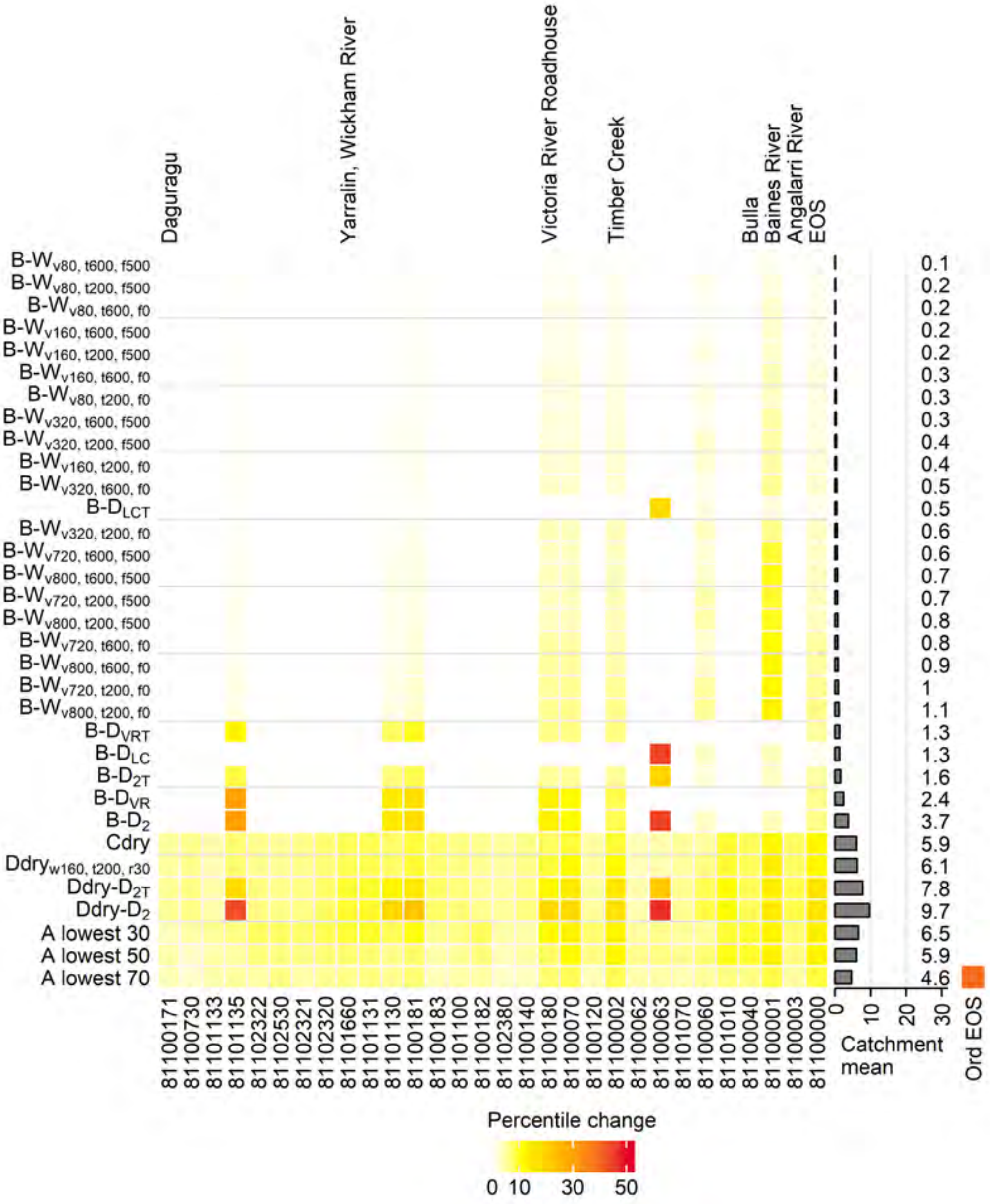

Figure 7-11 Mean change to assets' important flow dependencies across scenarios and nodes

The scenarios (see Table 7-1) are listed on the left vertical axis. The *x*-axis lists river system model nodes (i.e. locations). Colour intensity represents the mean level of change occurring in the assets' important flow metrics under the various scenarios, given the habitat importance of each node for each asset. See Table 7-1 for descriptions of the scenarios and Figure 7-2 for a map of the gauge locations. Heatmap shading indicates the mean level of flow change of important metrics, weighted by the habitat value of each asset for each reach. EOS = end-of-system. Horizontal grey bars and number correspond to the mean change across all model node locations.

Water harvesting and mitigation of impacts

For water harvesting scenarios, measures to mitigate the risks of extraction include limiting the system target thereby reducing extraction across the catchment, providing a pump-start threshold by limiting pumping of water from the river during periods of low river flows, providing an end-of-system requirement for a volume of water to pass the last node in the river system before pumping is allowed to commence that water year, and limiting the pump rate that water can be extracted from the river (see Hughes et al. (2024b) simulation report for more details).

Providing reduced limits on system targets improves outcomes for ecological flow dependencies compared with larger targets (Figure 7-12 *y*-axis); this applies broadly across all asset groups and throughout the range of explored irrigation targets. Larger extraction volumes resulted in increases in mean changes in flow dependencies across asset groups up to moderate change across the catchment's ecological assets. Some assets, including flow-dependent habitats, the 'other' species group and marine assets experienced higher changes in important flow dependencies at some system targets (Figure 7-12). While improvements are likely to occur in conjunction with providing either minimum flow thresholds or end-of-system requirements, greater extraction equates to a greater level of risk due to changes in important ecological flow metrics.

Providing minimum flow pump-start thresholds improved ecological flow dependencies across increasing pump-start threshold levels (Figure 7-12 *x*-axis). Modelled minimum flow thresholds varied incrementally from 200 to over 1000 ML/day and are provided by requiring that flow volume in the river exceeds required thresholds before pumping commences. Increasing pump-start threshold to 1000 ML/day results in a significant reduction in modelled mean change in important flow dependencies compared with only 200 ML/day (Figure 7-12). Increasing the pump-start threshold above 600 ML/day results in incremental improvements to ecological flows with reduced rate of relative improvement to levels of change in important flow dependencies above about 900 ML/day (Figure 7-12). The benefit of higher pump-start thresholds was largest in scenarios with no or low EOS requirements, as the benefit of having higher pump-start thresholds was reduced in combination with scenarios that had greater EOS requirements. This is likely because large flows have already passed the system to the EOS node before the pump-start threshold is triggered.

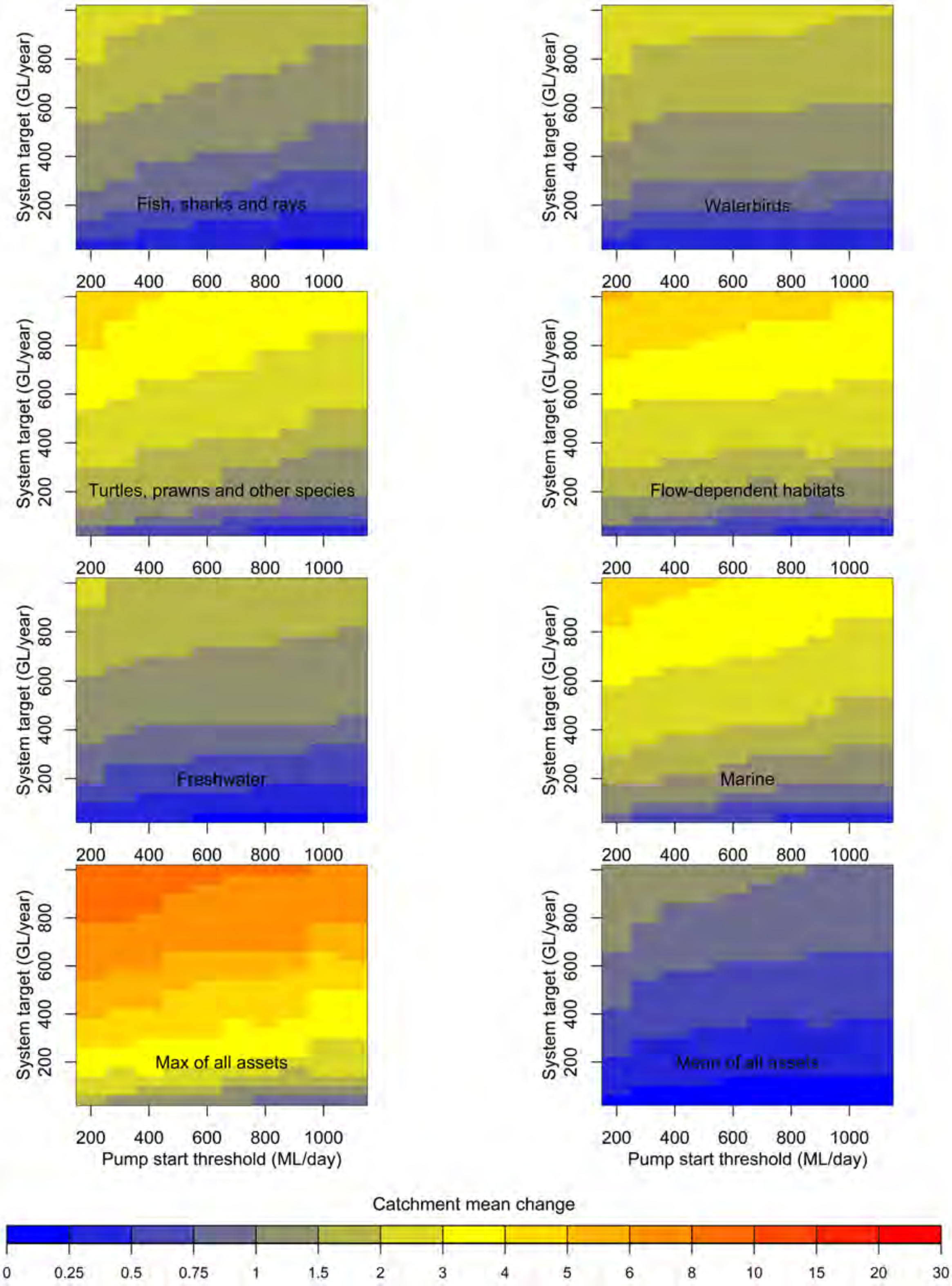

Figure 7-12 Mean change to assets' important flow dependencies across water harvesting increments of system target and pump-start threshold, with no end-of-system (EOS) requirement and a pump rate of 30 days

Colour intensity represents the mean level of change occurring in the assets' important flow metrics under the various scenarios, given the habitat importance of each node for each asset.

Instream dams with and without transparent flows

Two hypothetical locations for instream dams were selected (Leichhardt Creek and Victoria River) for modelling and analysis (Yang et al., 2024) and simulated following the hydrology modelling approach outlined in Hughes et al. (2024b). The locations are shown in Figure 7-2. The goal of this analysis was to test the effect of different dam locations and configurations on changes to streamflow, to understand the effect on downstream ecology. These hypothetical dams were modelled individually, as well as two dams together, to better understand cumulative impacts. In addition, the hypothetical dams were also modelled incorporating transparent flows. 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 risks on downstream flow associated with instream dams are explored here across broad asset groups, and the results are presented 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 flow–ecology relationships are discussed in more detail for each asset in Stratford et al. (2024b).

Assessment of the individual dams found varying levels of impact on ecology–flow dependencies (Table 7-4). None of the scenarios resulted in changes greater than minor averaged for all assets across the catchment, although local impacts were often considerably higher. The dams varied in size, inflows, and capture volumes, and the location within the catchment, all of which influenced the outcome. Impacts directly downstream of modelled dams can often be high and may cause extreme changes in ecology–flow dependencies. Areas further downstream have contributions from unimpacted tributaries that help support natural flow regimes. Dams further up the catchment may affect a larger proportion of streams and river reaches when considering flow regime change, but they may have lower impacts associated with connectivity. Impacts 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.

Table 7-4 Scenarios of different hypothetical instream dam locations showing end-of-system (EOS) flow and mean changes in 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 Stratford et al. (2024b)). Some assets are considered in multiple groups, in which cases 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	HYPOTHETICAL DAM SCENARIO DESCRIPTION	ALL-ASSET MEAN	FISH	WATER BIRDS	OTHER SPECIES	HABITATS	FRESHWATER ASSETS	MARINE ASSETS
B-D$_{LC}$	Leichhardt Creek	1.1	1.0	1.0	0.9	1.2	1.2	0.9
B-D$_{LCT}$	Leichhardt Creek with transparent flows	0.6	0.4	0.6	0.6	0.8	0.5	0.7
B-D$_{VR}$	Victoria River	3.6	3.2	3.1	4.3	4.0	2.5	4.5
B-D$_{VRT}$	Victoria River with transparent flows	2.6	1.9	1.9	3.3	3.5	1.4	3.7
B-D$_2$	Both Leichhardt Creek and Victoria River dams	4.5	4.1	4.1	4.9	5.1	3.7	5.2
B-D$_{2T}$	Both Leichhardt Creek and Victoria River dams with transparent flows	2.7	2.0	2.2	3.1	3.9	1.8	3.6

The cumulative change in flow dependencies due to multiple dams (Scenario B-D_2) is greater than the change in flow dependencies due to individual dams, considering both change in flow volumes and ecology–flow dependencies (Table 7-4). Cumulative change in flow ecology may be associated with the combination of a larger portion of the catchment being affected by changes in flows across larger parts of the catchment, and residual flows being lower due to the overall greater level of abstraction (Table 7-4).

Measures to mitigate the risks of large instream dams, such as transparent flows resulted in reduced ecological change in flows broadly across all assets compared with no transparent flows (Table 7-4). Particularly strong benefits from transparent flows were found for fish (Table 7-4). Instream dams capture inflows and change downstream flow regimes. Transparent flows are a type of environmental flow provided as releases from dams that maintain some aspects of natural flows. Inflow thresholds used in the transparent flows analysis are conceptually similar to the commence-to-pump thresholds used in water harvesting, facilitating comparison. Transparent flows are provided across both dams under Scenario B-D_2 (Hughes et al., 2024b).

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 Victoria catchment for plant industries or aquaculture must take account of biosecurity risks that may threaten production or markets. Development in the region may also pose broader biosecurity risks to other industries, the environment or communities, and these risks must be prevented and/or managed.

Biosecurity practices to protect the Victoria catchment 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 NT Government also has biosecurity legislation to limit the entry of new pests, weeds and diseases into the jurisdiction, and to require the control of certain species already established within the NT. There can also be requirements at the regional level, such as participating in weed management programs (NT Government, 2021). 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 Victoria catchment is relatively isolated compared with other regions of Australia, it still has physical connections to the rest of 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 Victoria catchment. 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 that is now a Weed of National Significance (WoNS). WoNS are nationally agreed weed priorities that have been a focus for prevention and improved management (CISS, 2021; Hennecke, 2012). 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 by 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 Victoria catchment, potentially causing new outbreaks. Just as importantly, there is also the potential for pests, weeds and diseases from the Victoria catchment to spread to other areas in 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. Irrigation infrastructure such as dams, pipelines and channels may facilitate distant spread via water movements of some 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 Victoria catchment

The Victoria catchment principally faces 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 Victoria catchment 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 pests, weeds or diseases that are formally ‘declared’ under the NT’s biosecurity legislation, regardless of its local impact.

Plant industries

The priority pests and diseases for cropping in the Victoria catchment depends on what is grown.

Table 7-5 includes some examples of high-impact pest and diseases threats to particular crops, and their current status. The NT Government website provides local plant pest and disease management information (NT Government, 2024a), while the NT Plant Health Manual lists all declared pests and diseases (NT Government, 2023). 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 certain 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 Victoria catchment, 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 number of farms in the NT and 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).

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 that persist and spread vegetatively through underground rhizomes. Perennial horticulture disturbs the soil less, so typically has more perennial grasses and perennial broadleaved weeds. The highest priority weeds 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, by trampling, grazing, uprooting and consuming fruit (Clancy, 2020).

Table 7-5 Examples of significant pest and disease threats to plant industries in the Victoria catchment

BIOSECURITY THREAT	CURRENT STATUS	CROPS AT RISK	FURTHER INFORMATION
INVERTEBRATE PESTS			
Asian citrus psyllid *Diaphorina citri*	Incursion risk from overseas (including Indonesia and PNG).	citrus	www.agriculture.gov.au/biosecurity-trade/policy/australia/naqs/naqs-target-lists/pests_of_plants_asian_citrus_psyllid
cluster caterpillar *Spodoptera litura*	Widespread in northern Australia.	cotton, pulses, brassicas	www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/biosecurity/plants/insects/field-crop/cluster-caterpillar
fall armyworm *Spodoptera frugiperda*	Established across northern Australia, following first detection in 2020.	grasses (cereal and fodder), cotton, soybean, melon, green beans	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/fall-armyworm
fruit flies, various species including: Mediterranean fruit fly *Ceratitis capitata* melon fruit fly *Zeugodacus cucurbitae* oriental fruit fly *Bactrocera dorsalis* New Guinea fruit fly *B. trivialis* Queensland fruit fly *B. tryoni*	Mediterranean fruit fly established in WA. Queensland fruit fly endemic in NT. Melon, oriental, New Guinea and other exotic fruit fly incursion risks from overseas (including Indonesia, PNG) and the Torres Strait. Various species declared.	fruit and fruiting vegetable crops	www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/fruit-flies-australia www.agriculture.gov.au/biosecurity-trade/policy/australia/naqs/naqs-target-lists/fruit-flies
Bollworms *Helicoverpa* spp. *Pectinophora* spp.	Widespread in northern Australia.	cotton, pulses, brassica, sunflower, sorghum, maize	www.crdc.com.au/publications/cotton-pest-management-guide
guava root-knot nematode *Meloidogyne enterolobii*	Recent detection in Darwin region. Declared.	cucurbits, solanaceous crops, sweet potato, cotton, guava, ginger	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/guava-root-knot-nematode
Leafminers American serpentine leafminer *Liriomyza trifolii* serpentine leafminer *L. huidobrensis* vegetable leafminer *L. sativae*	Serpentine and American serpentine leafminers are recent incursions now present in various locations across Australia. Vegetable leafminer an incursion risk from overseas and Torres Strait and is declared in NT.	vegetables, cotton	www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/biosecurity/plants/priority-pest-disease/serpentine-leafminer www.agriculture.gov.au/biosecurity-trade/policy/australia/naqs/naqs-target-lists/vegetable_leaf_miner
mango pulp weevil *Sternochetus frigidus*	Incursion risk from overseas (including Indonesia). Declared.	mango	www.agriculture.gov.au/biosecurity-trade/policy/australia/naqs/naqs-target-lists/mango-pulp-weevil
mango shoot looper *Perixera illepidaria*	Recent incursion in Queensland and NT. Not declared.	mango, lychee	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/mango-shoot-looper
melon thrips *Thrips palmi*	Limited presence in NT north of Alligator township.	vegetables	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/plants-and-quarantine/travelling-within-the-nt

BIOSECURITY THREAT	CURRENT STATUS	CROPS AT RISK	FURTHER INFORMATION
spur-throated locust *Austracris guttulosa*	Native to northern Australia.	grasses (cereal and fodder), sunflowers, soybeans, cotton	www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/locusts/about/spur-throated
DISEASES			
Alternaria leaf blight *Alternaria alternata*	Present in northern Australia.	cotton	www.crdc.com.au/publications/cotton-pest-management-guide
banana freckle *Phyllosticta cavendishii*	Under eradication in NT. Declared.	banana	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/banana-freckle
brown spot *Cochliobolus miyabeanus*	Endemic on wild rices in northern Australia.	rice	www.agrifutures.com.au/product/rice-growing-guide-north-queensland
citrus canker *Xanthomonas citri* subsp. *citri*	Eradicated from NT and Queensland. Incursion risk from overseas (including Indonesia, Timor-Leste and PNG). Declared.	citrus	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/citrus-canker
cucumber green mottle mosaic virus	Present in certain areas in NT and other states.	cucurbits	www.nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/cucumber-green-mottle-mosaic-virus
Fusarium wilt *Fusarium oxysporum* f. sp. *vasinfectum*	Not present in NT. Declared.	cotton	www.crdc.com.au/publications/cotton-pest-management-guide
Huanglongbing *Candidatus Liberibacter asiaticus*	Incursion risk from overseas (including Indonesia, Timor-Leste and PNG). Declared.	citrus	www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/plant/huanglongbing
Panama TR4 *Fusarium oxysporum* f. sp. *cubense*	Established throughout NT. Declared.	banana	www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/biosecurity/plants/priority-pest-disease/panama-disease
rice blast *Pyricularia oryzae*	Endemic on wild rices in northern Australia.	rice	www.dpi.nsw.gov.au/biosecurity/plant/insect-pests-and-plant-diseases/rice-blast

Declaration status is under the *Plant Health Act 2008* (NT), derived from NT Government (2023). Links to further information are current as of March 2024. PNG = Papua New Guinea.

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 Victoria catchment (NT Government, 2021). All of these weeds are currently declared under the Northern Territory *Weed Management Act 2001*, other than other than coffee bush (*Leucaena leucocephala*), giant rat's tail grass (*Sporobolus* spp.) and yellow oleander (*Cascabela thevetia*). Many in Table 7-6 are WoNS. These are nationally agreed weed priorities that have been a focus for prevention and improved management (CISS, 2021; Hennecke, 2012). For example, the parthenium weed (*Parthenium hysterophorus*), one of the WoNS, is a direct competitor to and contaminant in dryland and irrigated crops, and poses a health risk to animals and people as a severe allergen.

Aquatic weeds can hamper the efficient function of irrigation infrastructure and cause severe ecological impacts through dense infestations in waterways and wetlands. More-constant water flows from within-stream reservoirs can 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 Victoria catchment, including feral buffalo (*Bubalus bubalis*), horses (*Equus caballus*), donkeys (*E. asinus*), pigs (*Sus scrofa*) and camels (*Camelus dromedarius*). 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 Victoria catchment (Kearney et al., 2008), but would likely become more abundant around irrigation developments, where they could access year-round moisture.

Aquatic pests

Freshwater aquatic pests such as non-native fish, molluscs and crustaceans can affect biodiversity and ecosystem function. While these pests may not directly affect irrigated cropping, the associated infrastructure (e.g. dams, channels, drains) brings increased risk of deliberate release by people for recreational fishing or in 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 the Victoria catchment

Source: NT Government, 2021; NT Government officers, pers. comm.

LIFEFORM AND WEED	REGIONAL ACTION		HABITATS AT RISK:	
		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***†	P	✓	✓	
limnocharis ***Limnocharis flava***	P	✓	✓	
sagittaria ***Sagittaria platyphylla***†	P	✓	✓	
salvinia ***Salvinia molesta***†	P	✓	✓	
water hyacinth ***Pontederia crassipes***†	P	✓	✓	
water mimosa ***Neptunia plena***	P	✓	✓	
GRASS				
buffel grass *Cenchrus ciliaris, C. pennisetiformis*	§			✓
gamba grass ***Andropogon gayanus***†‡	E		✓	✓
giant rat's tail grass ***Sporobolus*** spp.	P			✓
grader grass ***Themeda quadrivalvis***‡	C			✓
hymenachne ***Hymenachne amplexicaulis***†	P	✓		
thatch grass ***Hyparrhenia rufa***	P			✓
BROADLEAVED HERB				
devil's claw ***Martynia annua***	E			✓
Parthenium weed ***Parthenium hysterophorus***†	P		✓	✓
CLIMBER/VINE				
rubber vine ***Cryptostegia grandiflora***†	P		✓	✓
ornamental rubber vine ***C. madagascariensis***	P		✓	✓
TREE/SHRUB				
Athel pine ***Tamarix aphylla***†‡	E		✓	
bellyache bush ***Jatropha gossypiifolia***†‡	C			✓
calotrope ***Calotropis procera*, *C. gigantea***	M			✓
Chinese apple ***Ziziphus mauritiana***‡	C		✓	✓
coffee bush ***Leucaena leucocephala***	M		✓	
lantana ***Lantana camara***†	P			
mesquite ***Prosopis*** spp.†‡	E		✓	✓
mimosa ***Mimosa pigra***†‡	E	✓		
neem ***Azadirachta indica***‡	C		✓	
parkinsonia ***Parkinsonia aculeata***†	M		✓	
pond apple ***Annona glabra***†	P	✓	✓	
prickly acacia ***Vachellia nilotica***†‡	E			✓
Siam weed ***Chromolaena odorata***	P		✓	✓
yellow oleander ***Cascabela thevetia***	M		✓	✓
OTHER				
rope cactus *Cylindropuntia* spp.†	P			✓

† On the Weeds of National Significance (WoNS) list.

‡ Have statutory management plans under the *Weeds Management Act 2001* (NT).

§ Declared in 2024 and thus not categorised for management action in the current regional weed management plan (NT Government, 2021).

C = strategic control target (control and containment of core infestations, eradication of outlier populations, prevention elsewhere).

E = eradication target (few infestations known).

M = widely established; regional management focused on protecting assets at risk.

P = alert weed for prevention and early intervention.

Table 7-7 includes examples of high-risk pest fish for the Victoria catchment. Certain species are formally declared as noxious under the Northern Territory Fisheries Regulations 1992. However, those not declared noxious 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.

Table 7-7 High-risk freshwater pest fish threats to the Victoria catchment

Source: Australian Government and NT Government, n.d.; Queensland Government, 2023

PEST FISH	LEGAL STATUS (IF ANY)	CURRENT DISTRIBUTION
alligator gar *Atractosteus spatula*	N	Not known to be in the wild in Australia.
black pacu *Piaractus brachypomus*	E	Not known to be in the wild in Australia. Risk of incursion from PNG.
carp *Cyprinus carpio*	N	Not known to be in the wild in NT.
cichlids, including tilapia:		Giant cichlid not known to be in the wild in Australia. 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. Not known to be in the wild in NT. Nile tilapia an incursion risk from northern Torres Strait. All tilapia species noxious.
giant cichlid *Boulengerochromis microlepis*	N	
jaguar cichlid *Parachromis managuensis*	E	
Mozambique tilapia *Oreochromis mossambicus*	N	
Nile tilapia *O. niloticus*	N	
pearl cichlid *Geophagus brasiliensis*	E	
spotted tilapia *Pelmatolapia mariae*	N	
Texas cichlid *Herichthys cyanoguttatus*	E	
climbing perch *Anabas testudineus*	N	Risk of incursion from northern Torres Strait.
gambusia / mosquito fish *Gambusia holbrooki*	N	Not known to be established in NT (eradicated in Darwin and Alice Springs). Recorded in the wild across Queensland and parts of WA.
guppy *Poecilia reticulata*		Recorded in Darwin and Nhulunbuy in NT. Likely to be present elsewhere.
marbled lungfish *Protopterus aethiopicus*	N	Not known to be in the wild in Australia.
oriental weatherloach *Misgurnus anguillicaudatus*	N	Not known to be in the wild in NT.
oscar *Astronotus ocellatus*		Not known to be in the wild in NT. Present in the wild in Queensland.
platy *Xiphophorus maculatus*		Present in the wild in Darwin and Nhulunbuy in NT, and in eastern Queensland.
Siamese fighting fish *Betta splendens*		Established in the Adelaide catchment in NT. Not known to be in the wild elsewhere in Australia.
spotted gar *Lepisosteus oculatus*	N	Not known to be in the wild in Australia.
swordtail *Xiphophorus hellerii*		Present in the wild in Darwin and Nhulunbuy in NT, and in eastern Queensland.

E = excluded for imports into and possession in the NT.
N = noxious under the Northern Territory Fisheries Regulations 1992.
n.d. = no date.

Terrestrial invertebrates

Terrestrial invertebrates can be high-impact invasive species. For example, certain exotic ants form ‘super colonies’ from which they outcompete native ants, consume native invertebrates and seeds, and affect people by stinging them 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*) has 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. Other national eradication programs continue for red imported fire ant (*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 red imported fire ant has cost $596 million (Outbreak, 2023a).

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 7-13) 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.

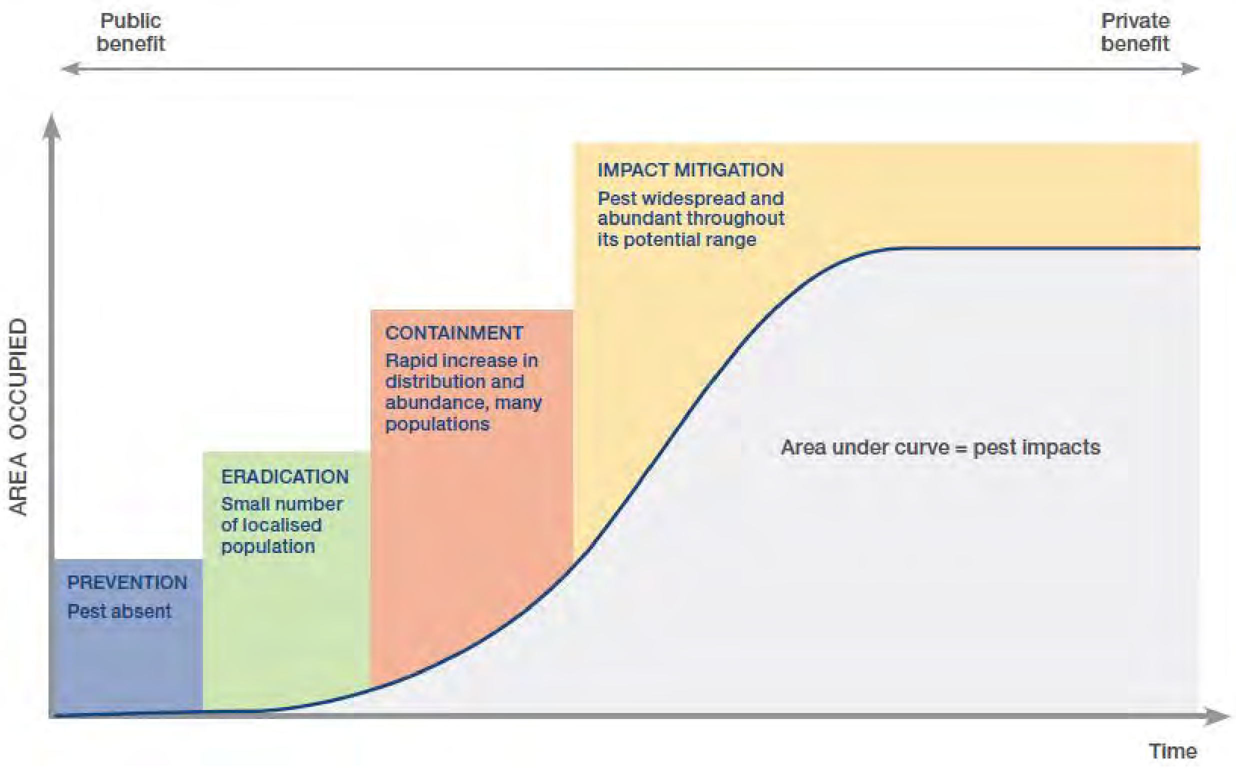

Figure 7-13 The invasion curve with biosecurity actions taken at various stages

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 incursions and reporting high-risk species 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 to neighbouring land uses.

The NT's biosecurity system (NT Government, 2016) is nested in the national biosecurity system of Australia's border quarantine and states' and territory's 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 Victoria catchment, within local, NT 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 that 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 7-14), 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.

VISITORS

PLEASE RESPECT
FARM BIOSECURITY

Please phone or visit the office before entering

☎ ____________________

Do not enter property without prior approval
Vehicles, people and equipment can carry weed seeds, pests and diseases

animalhealth AUSTRALIA farmbiosecurity Plant Health AUSTRALIA

Figure 7-14 Farm biosecurity signage available through www.farmbiosecurity.com.au

Regulatory prevention

Government regulation and policy for plant biosecurity in the Victoria catchment are primarily governed by the Northern Territory *Plant Health Act 2008*. Specific legal requirements are summarised in the *Northern Territory plant health manual* (NT Government, 2023), which lists currently declared pests and diseases (and those that must be reported if detected in the NT), and associated entry conditions for all commercial and non-commercial movement of plants and plant products.

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).

To access interstate markets, produce must meet the respective quarantine specifications and protocols, so that pests or diseases declared in those jurisdictions are not inadvertently introduced. 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 (NT Government, 2023). For example, South Australia has movement restrictions (as of March 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 (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 must meet Australian standards and any additional entry requirements from the importing countries for the products (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's *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). Entry of these pests and diseases 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, 2023b).

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. NT Government, 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 also 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 requirements of the NT's *Agricultural and Veterinary Chemicals (Control of Use) Act 2004*. 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 requirements (or a Australian Pesticides and Veterinary Medicines Authority permit) regarding approved crops, rates and frequency of application, and withholding periods (NT Government, 2024c).

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 diseases and parasites, 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 through contaminated equipment, workers handling diseased fish, water that is 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, 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 is regulated through the Northern Territory *Fisheries Act 1998*, and the Northern Territory 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.

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.

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 Queensland and 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 fundamentally 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 already mentioned, 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 terrestrial and aquatic pests (vertebrate and invertebrate), and weeds.

Weeds

The Victoria catchment is within the scope of the Katherine Regional Weeds Strategy (NT Government, 2021) which collates the priority declared weed control programs, as coordinated by the NT Government. Under the Northern Territory *Weeds Management Act 2001* every landholder is legally obliged to take all reasonable measures to prevent land 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.

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 Victoria catchment, landholders should consider their crops’ weed risks to the surrounding environment. An example method for considering weed risks is the Western Australian Government’s environmental weed risk assessment process for plant introductions to pastoral lease land (Moore et al., 2022). Many northern Australia pasture grasses can be invasive, and cause significant biodiversity and cultural impacts in the landscape (Australian Government, 2012).

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). 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 subpopulations. 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 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 Impacts of changes in water quality on aquatic ecosystems

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 (U.S. 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 harmful to aquatic life	Mainstone and Parr (2002)
	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	Naccarato et al. (2023)

WATER QUALITY VARIABLE		THREATS TO AQUATIC ECOLOGY AND HUMAN HEALTH	REFERENCE
		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	
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	U.S. E.P.A (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 (TP) and total nitrogen (TN) 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 TP 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, TP 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, 2022). 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 region 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

Salinity is the presence of soluble salts in soils or water. Salinity is the result of the complex interactions of geophysical and land use factors such as landscape features (geology, landform), climate, soil properties, water characteristics and land management. Salinity becomes a land use issue when the concentration of salts adversely affects plant establishment growth (crops, pastures or native vegetation) or degrades soil or affects water quality (Department of Natural Resources, 1997).

The salts in the landscape are derived from salts delivered through rainfall, weathering of primary minerals and origin of the geology such as marine sediments. Most salinity outbreaks result from the imbalances in the hydrological systems of a landscape, including secondary salinity due to man related activities such as clearing of native vegetation, cropping and irrigation.

Naturally occurring areas of salinity or ‘primary salinity’ occur in the landscape with ecosystems adapted to these conditions. In a dryland salinity (non-irrigated) hazard mapping of the NT, Tickell (1994) determined that the dryland salinity hazard over most of the NT is low, predominantly due to relatively low salt storages occurring in the landscape were mainly due to small salt inputs from rainfall.

Natural salinity in the Victoria catchment is confined to the freshwater springs originating from the dolomites on Kidman Springs; on shales in the West Baines catchment; and on the marine plains at the mouth of the Victoria River which are subject to tidal inundation. The springs and associated discharge areas on Kidman Springs have very high salt concentrations (mainly calcium salts) on the soil surface and are unsuitable for development. All moderately deep to very deep soils developed on the Proterozoic shales in the West Baines catchment are naturally high in subsoil salts with minor natural salinity in scarp retreat areas below quartz sandstone hills and plateaux.

In Australia, excessive root-zone drainage through poor irrigation practices, together with leakage of water from irrigation distribution networks and drainage channels, has caused the watertable level to rise under many intensive irrigated areas. Significant parts of all major intensive irrigation areas in Australia are currently either in a shallow watertable equilibrium condition or approaching it (Christen and Ayars, 2001). Where shallow watertables containing salts approach the land surface (in the vicinity of 2–3 m from the land surface), salts can concentrate in the root zone over time through evaporation. The process by which salts accumulate in the root zone is accelerated if the groundwater also has high salt concentrations.

In the case of irrigation-induced salinisation in the Victoria catchment, the landscapes suitable for irrigation development but at risk of secondary salinisation are restricted to the extensive Cenozoic clay plains (SGG 9); and the gently undulating plains with Sodosols (SGG 8), Chromosols (SGG 1) and Dermosols (SGG 2) developed on shales in the West Baines catchment. Clay soils (SGG 9) on the alluvial plains overlying the shales may also be at risk. These soils with heavy clay subsoils are naturally high in soluble salts in the subsoils. Irrigation may cause excessive deep drainage and raised watertables resulting in secondary salinisation. Other soils are generally not at risk from irrigation-induced salinity.

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).

Further investigations on salinity processes and monitoring of watertables are necessary if these areas are to be developed.

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