A Vulnerability Assessment for the Great Barrier Reef

Australian Government

Great Barrier Reef Marine Park Authority

Freshwater wetlands

Information valid as of Sep 2016

Summary

Diversity

Freshwater wetlands are diverse environments that permanently or periodically contain static or flowing water and include a wide range of associated plant communities. There are four main classes of freshwater wetland ecosystems classified by the Queensland Wetland Program. These are Riverine (rivers, creeks), Lacustrine (lakes, dams), Palustrine (vegetated swamps) and Subterranean (aquifers, caves).

This vulnerability assessment covers the three surface freshwater ecosystem classes: riverine, lacustrine and palustrine wetlands.

Susceptibility

The key elements for the maintenance of freshwater wetlands include:

- appropriate hydrological regimes delivered via rainfall or connectivity to other sources of water
- management of catchment sediment, nutrient and other contaminant loads within ecosystem thresholds
- maintenance of appropriate physio-chemical conditions including optimal temperature ranges
- minimal natural and human disturbance including that associated with domestic stock, invasive species and extreme weather events.

Tolerances to changes in these elements and the impacts associated with such changes will vary spatially within wetlands and between wetland ecosystem types. The health and vulnerability of freshwater wetlands is largely determined by the extent of biophysical changes, including non-native species, within them and their contributing catchment areas.

Wetlands occur in relatively low lying parts of the landscape and receive run-off and contained sediment, nutrient and other material loads exported from contributing catchment areas. These biophysical linkages between a wetland and its contributing catchment mean the susceptibility of a wetland to environmental impact is mediated by the condition of its catchment.[1] More intensive forms of land use such as agricultural, industrial and urban development present some of the greatest threats to wetlands, particularly when these sources of potential disturbance and pollution occur in close proximity.

Major pressures

Freshwater wetlands are facing major pressures from:

- catchment development and land use intensification, which results in both direct physical impacts on wetlands (for example, vegetation clearing, filling, drainage, bunding, channel straightening, road crossings) and indirect impacts via altered biophysical processes (flow paths, connectivity, run-off hydrology) and elevated contaminant loads)
- catchment run-off containing elevated sediment, nutrient and other contaminant loads and waste water discharges causing poor water quality
- water resource development including infrastructure and extractive use altering catchment hydrology including flow patterns, connectivity and groundwater behaviour
- grazing and associated physical impacts (for example, vegetation trampling, bank compaction and erosion)
- invasive plant and animal species
- altered fire regimes
- climate change driving elevated temperatures and extreme weather including droughts, cyclones, storm surges and destructive floods
- sea level rise.

Cumulative pressures

Cumulative pressures facing freshwater wetlands arise from the combination of site-based direct impacts and indirect impacts driven by the pattern of land use and land use change within contributing catchment areas. The 2009 and 2014 Great Barrier Reef Outlook Reports[2,3] identified an extensive loss of coastal ecosystems across the Great Barrier Reef catchment since European settlement and their replacement with non-remnant vegetation and land uses that do not provide the same ecosystem services to downstream ecosystems ultimately including the Reef. The historic and continuing loss of catchment ecosystem services

Freshwater wetland in the Russell River catchment that provide sediment and nutrient regulation and landscape water balance are primary sources of cumulative pressures affecting freshwater wetlands.

Site physical impacts such as the loss of riparian vegetation or other disturbances, for example channel straightening, bund wall construction, or installation of infrastructure, often undermine the natural resilience of wetlands to further disturbance pressure. The relationship between cumulative pressure and wetland impact is often not linear. Once site disturbance and/or catchment development thresholds are exceeded, cumulative pressures can operate synergistically to increase impacts exponentially. For example, the loss of riparian vegetation simultaneously exposes a wetland to elevated water temperatures, decreased dissolved oxygen carrying capacity and increased nutrient and sediment inputs. It also leads to secondary impacts associated with weed infestation, algal blooms and water quality deterioration.

The disturbance to wetlands associated with cumulative impacts is most severe when direct physical modification is coupled with indirect sources of impact from contributing catchment areas such as agricultural run-off, sedimentation from soil erosion or exposure to industrial pollutants. Where a wetland’s contributing catchment is subject to ongoing development and/or degradation pressure (for example, soil erosion associated with grazing) there is a strong likelihood that cumulative pressures affecting the receiving wetland will continue to increase. More substantive impacts occur once catchment development thresholds are surpassed, that is where changes in catchment conditions (for example, percentage of vegetation cover, intensive land use or water use) result in nonlinear increases in catchment sediment, nutrient and contaminant exports and/or loss of landscape water balance.

Studies within the Great Barrier Reef catchment have shown freshwater wetlands with the least pressure are those contained within relatively undisturbed catchments with lower intensity land uses and/or less extensive patterns of development.[1,4] Such wetlands are often located in upper catchment areas less suited to development and/or catchments within a national park or other protected area offering a similar level of protection. In disturbed basins, better condition wetlands are associated with patterns of catchment development comprised of less extensive areas of intensive land use and/or variegated landscapes that retain protective buffers such as vegetated riparian zones and contributing catchment areas.

Climate change represents a major emerging driver of cumulative pressure on freshwater wetlands. This is because it affects climatic and hydrologic regimes which are primary determinants of freshwater wetland condition.[5] Changes in these regimes also amplify the individual and collective impact of existing pressures.[6,7] For example, more extreme variability in rainfall due to climate change, reflected in more frequent droughts and intense rainfall events, will exacerbate existing hydrological impacts associated with water resource development and elevate sediment and nutrient loads exported from stressed catchments. Elevated temperatures due to climate change alter biogeochemical processes which also exacerbate existing stresses, for example low dissolved oxygen levels which increase the solubility and hence availability of metal contaminants and nutrients. The latter also promotes eutrophication, algal blooms and weed infestation.[7,8]

Water lilly flower, Haughton basin

Management in the Great Barrier Reef catchment

A range of legislative instruments and policy documents impact directly or indirectly on freshwater wetland management within the Great Barrier Reef catchment which occurs in a complex jurisdictional environment operating at international, national, state and local levels. Australia is a signatory to a number of international conventions which support wetland protection by providing a head of power to domestic legislation to affect development controls. In addition, such conventions provide an opportunity for raising awareness and enhanced visibility for specific wetlands, ecological communities synonymous with wetlands, and species of flora and fauna which inhabit and depend on wetlands.

A range of Commonwealth statutory tools, programs and policy documents apply to the management of freshwater wetlands including the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The EPBC Act provides a mechanism for protecting wetlands of international importance (Ramsar wetlands) and for the listing of nationally threatened native species, ecological communities, and native migratory species.

The *National Water Quality Management Strategy* provides policies, national guidelines and a structured process for water quality management including the development of water quality improvement plans for regional areas. The main policy objective of the strategy is to achieve sustainable use of water resources, by protecting and enhancing their quality, while maintaining economic and social development. The Australian Government is implementing the strategy in collaboration with states and territories by developing water quality improvement plans to reduce pollution inputs to aquatic ecosystems with high ecological, social and/or recreational values.

A range of Queensland Government statutory tools, programs and policy documents apply to the management of freshwater wetlands. The key legislative tools within the state jurisdiction include five acts and two policies.

The *Coastal Protection and Management Act 1995* has the objective of providing for the protection, conservation, rehabilitation and management of the coast including its natural resources and biological diversity. The Act requires the water quality of wetland systems to be considered when assessing development in the coastal zone including how water quality will be monitored and maintained in relation to an application for construction of an artificial waterway. The Act also specifically requires information relating to the coastal zone to be incorporated into the State of the Environment report.

The *Water Act 2000* directly regulates access to and use of water resources in Queensland. The Act affects the management of freshwater wetlands by regulating works that take or interfere with water in a watercourse, lake, spring, aquifer or from overland flow. Such works may include pumps, diversion channels, weirs, dams, or bores. Section 35 of the Act requires the provision of information for planning purposes; regularly measuring and keeping publicly available records of the volume and quality of water, the water requirements of, and impacts of water management on natural ecosystems and information about future water requirements.

The *Vegetation Management Act 1999* contributes to freshwater wetland management by regulating the clearing of native vegetation in Queensland which is classified as or in proximity to freshwater wetland. Amendments in 2012 allow for self-assessment for many vegetation clearing codes, including regrowth and to improve operational efficiency of existing agriculture.

The *Fisheries Act 1994* provides for the use, conservation and enhancement of the community's fisheries resources and fish habitats in a way that seeks to apply and promote ecologically sustainable development. The Act impacts directly and indirectly on the management of freshwater wetlands through the declaration of protected Fish Habitat Areas and by regulating fishery matters such as: size limits and bag limits; closed seasons; closed waters and protected areas; gear restrictions; noxious fish; protected species and sexes; and through regulating development related activities that damage declared fish habitat areas and marine plants.

The *Environmental Protection Act 1994* aims to protect Queensland's environment while allowing for development in ways that maintain ecological processes. The Act may affect the management of freshwater wetlands in a variety of ways including: the development and implementation of environment protection policies; development approval processes integrated into the Sustainable Planning Act 2009 (Qld) for Environmentally Relevant Activities; environmental impact assessment requirements for mining and petroleum activities; defined environmental offences; special measures to reduce water pollution from agricultural Environmentally Relevant Activities; and a legislated general environmental duty of care and duty to notify of environmental harm.

The Environmental Protection (Water) Policy 2009 seeks to achieve the object of the Environmental Protection Act for Queensland waters "to protect Queensland's waters while allowing for development that is ecologically sustainable". Queensland waters include water in rivers, streams, wetlands, lakes, aquifers, estuaries and coastal areas. This purpose is achieved within a framework that includes: identifying environmental values for aquatic ecosystems and for human uses (for example, water for drinking, farm supply, agriculture, industry and recreational use); and determining water quality guidelines and water quality objectives to enhance or protect the environmental values.

The Queensland Government's State Planning Policy 4/11: Protecting Wetlands of High Ecological Significance in Great Barrier Reef Catchments (SPP 4/11) is a statutory instrument enacted in 2009. It seeks to ensure development in, or adjacent to wetlands of high ecological significance in Great Barrier Reef catchments is planned, designed, constructed and operated to prevent the loss or degradation of wetlands and their environmental values, or enhances their values. Local government planning schemes are required to ensure they reflect the elements outlined in SPP 4/11. In the case of discrepancy between a local planning scheme and SPP 4/11, the latter will operate to override the planning scheme.

Existing management actions

The primary focus of actions to protect wetlands, aside from applying those tools identified above, is to improve water quality and wetland resilience. Activities that build wetland resilience include:

- revegetation of riparian vegetation and up-stream catchments
- controlled grazing in weed affected areas and grazing exclusion for sensitive or relatively undisturbed areas
- provision of fish passage
- removal of bund walls
- removal of redundant dams and weirs
- weed control

- management of fire regimes
- constructed wetlands
- rural and urban water sensitive urban design
- water quality improvements through enhanced uptake of improved management practices.

The *Reef Water Quality Protection Plan 2013* sets targets for improvement and is supported by the resources of the Australian and Queensland governments, as well as significant industry investment to implement change and monitor progress. Other programs, such as Reef Guardians, include education, awareness and action plans on what individuals can do to minimise their impacts on the environment.

Weed choke in a creek in the Haughton basin that functions as a barrier for migrating fish

In addition to the Queensland Government, many regional natural resource management bodies, along with local government, industry and community groups, also conduct waterway monitoring programs, restoration works, weed management, bund wall removal, fire regime management, water sensitive urban design. They also conduct revegetation at paddock and catchment scales to support water quality improvement plans, systems repair programs (to reinstate ecological processes) and other initiatives for catchment and Reef health.

Healthy Water Management Plans are now established under the Environmental Protection (Water) Policy 2009 (Qld) as a key planning mechanism to improve the quality of Queensland waters. Key matters to be addressed in a Healthy Water Management Plan include identifying: waters to which the plan applies; issues affecting water dependent ecosystems, drinking water and natural flows; waterway uses and values ('environmental values'); management goals and water quality objectives to protect identified environmental values; ways to protect the environmental values for the water; and ways to monitor and assess the effectiveness of the protection.

Vulnerability assessment: High

Providing a single vulnerability assessment for freshwater wetlands across the entire Great Barrier Reef catchment area is difficult due to the:

- geographical scale, landform and climatic diversity of the catchment
- associated diversity and variable resilience of freshwater wetland types
- varying levels of catchment development reflected in different patterns and intensity of land and water resource use
- variability of pressures that freshwater wetlands experience.

Freshwater wetlands that occur in landscapes dominated by intensive land uses such as irrigated agriculture or urban development are some of the most vulnerable due to associated impacts to supporting ecological services in their contributing catchment areas usually in combination with site-based disturbances. More intensively developed catchments also have higher levels of water resource use which increases wetland exposure to pressures associated with infrastructure and altered flow impacts on hydrological processes and connectivity.[9] In addition, site and catchment-based disturbances affecting wetlands in more developed basins facilitate secondary impacts associated with aquatic and terrestrial weeds, one of the most significant threats to wetland condition within the developed Reef catchment.[10] The 2014 Outlook Report[2] identified that most Reef catchment river basins south of Cairns are characterised by extensive patterns of development, particularly on the coastal lowlands that contain the greatest density of freshwater wetlands. The developed status of these and other Reef catchments is not static. Population growth and proposals for further agricultural, water resource, mining and coastal development all contribute to the spectre of further cumulative pressure being exerted on freshwater wetlands in catchments subject to further development. While freshwater wetlands in catchments with less intensive development are usually in better ecological condition due to fewer operating pressures, their overall vulnerability is still assessed to be high. This is due to the range of pervasive threats that operate even in relatively unpopulated and less developed catchments. These include total grazing pressure, soil erosion, feral animals, weeds, fire regime and climate change. Examples of these pressures affecting the condition of wetlands via direct site impacts or indirectly via catchment process linkages have been documented within even the most remote Reef catchment river basins in eastern Cape York.[11,12]

On current projections, unchecked climate change which is also a driver of sea level rise, would by itself be sufficient cause to assess the vulnerability of freshwater wetlands as high. This is because climatic and hydrologic regimes affected by climate change are two of the primary determinants of freshwater wetland condition, and changes in these regimes will amplify the individual and collective impact of all existing pressures.[5,6] In the case of freshwater wetlands near coastal areas — that are now subject to unavoidable sea level rise through the 21st century and beyond — their vulnerability to condition impacts is extreme. This is regardless of catchment development status or other operating pressures.[7]

Freshwater wetlands are arguably some of the most threatened and degraded ecosystems in the Great Barrier Reef catchment, considering the range of pressures they are operating under. Human-induced disturbance has now affected Great Barrier Reef catchment wetlands particularly across most coastal lowlands.

The increasing pressures on wetlands are inhibiting their ability to function in a healthy state, resulting in a reduction in the quality of ecosystem services they provide to downstream environments including the Great Barrier Reef World Heritage Area.[2,13] Resources to support the regulation and management of freshwater wetlands are limited, and currently do not allow for remediation of all wetlands. In addition, while the loss of area of wetlands is measurable, the loss of wetland function and health is more difficult to quantify.

Suggested actions to address vulnerabilities:

Catchment run-off

The most important action required to improve the resilience of freshwater wetlands at the scale of the Great Barrier Reef catchment is to reduce the load of sediment, nutrients and other contaminants they currently receive from contributing catchment areas. There are two aspects to achieving this. One is the reduction of contaminant loads at source via improved land and farm management practices (currently the focus of Reef Water Quality Protection Plan)[14]; the other is increased interception and retention of loads within catchment via maintenance and reinstatement of ecosystem services that regulate contaminant loads and transport (currently the focus of the Queensland Wetlands Program[15]). Current management efforts are starting to address water quality, although ongoing effort will need to continue to reach goals.[14] Catchment hydrology, particularly the detention of run-off, is integral to the provision of these ecosystem services and an important focus for management, as are actions that improve catchment condition including ground cover, waterway stability, and riparian and wetland vegetation buffers.

For more densely populated areas, point source pollution is also significant and continued implementation of wastewater management remains important including:

- tertiary treatment technology and recycling where absent
- urban storm water management where absent

East Barratta Ck – Haughton Basin Circa 1970's

East Barratta Cks – Haughton Basin 1999

Two photographs of Barratta Creek, Haughton basin showing the changes in water clarity between the 1970s and 1999. © Jim Tait

Water sensitive urban design in new urban land development and equivalent re-instatement of catchment function in existing urban development is also critical for wetland health in more developed catchments. Systems repair and reinstatement of catchment function is also required where other forms of intensive land use (for example, agriculture) has exceeded development thresholds, that is it has surpassed the capacity of remnant ecosystems to provide contaminant load and run-off regulating services.

Continued implementation of the Australian and Queensland governments' Reef Plan, which is working to reduce pollutants released to receiving waters from diffuse sources, is an important and proven path toward these management outcomes across the Reef catchment. Queensland's Healthy Waterway Management Plans are also an important planning vehicle for delivering water quality objectives and protecting environmental values at the sub-basin scale. Given the importance of biophysical linkages to surrounding areas, wetland management outcomes are best served by catchment-based management and planning frameworks. While continued significant management effort is required to reduce existing loads of contaminants, the importance and effectiveness of land use planning for preventing inappropriate development generating new load sources must also be recognised (see catchment development). Catchment-based protective management for wetlands can be delivered where controls on development protect important catchment places and processes. Places requiring protection include wetlands and their natural buffer systems, but also land that is sensitive to degradation and that poses catchment condition risks if developed.

Catchment development

The legacy of existing patterns of land and water resource development within the Reef catchment includes the loss and disturbance of substantial areas of freshwater wetland and impairment of catchment ecosystem services underpinning the condition of remnant ones.[3] Further development and intensification of land and water resource use represents an ongoing source of vulnerability for freshwater wetlands. While legislative initiatives (such as SPP 4/11 *Protecting Wetlands of High Ecological Significance*) limit direct impacts to wetlands, ongoing catchment development has the potential to add to cumulative pressures affecting them via further impacts to catchment condition, elevation of contaminant loads and impairment of catchment ecosystem services. Managing pressures associated with catchment development is integral to maintaining and improving freshwater wetland condition in the Reef catchment.

To effectively address the impact risks posed to freshwater wetlands by new development, managers require access to a range of planning and legislative tools including:

- catchment-based planning frameworks that identify the location of freshwater wetland assets and important contributing catchment areas, including areas sensitive to development
- protective mechanisms for remnant wetlands, associated buffer areas and biophysical process linkages within contributing catchment areas
- planning policies that recognise cumulative impacts and catchment development thresholds and promote land use patterns and intensity do not exceed the capacity of regulating and supporting ecosystem services within catchments
- a system of development offsets for where, after careful assessment and consideration wetland disturbance cannot be avoided, compensatory system repair works or protective management efforts are implemented to net positive benefit for Great Barrier Reef freshwater wetlands.

Given the prospect of continuing and unavoidable sea level rise through the remainder of this century and beyond, another specific area warranting enhanced controls on development is the immediate near coastal zone. In developed areas, accommodating the landward migration and re-establishment of coastal wetland mosaics, including freshwater wetlands, is essential. The establishment of appropriate development setback controls for areas subject to sea-level rise is an important planning consideration to reduce Reef ecosystem vulnerabilities and protect future assets. The Queensland government Coastal hazards adaptation program (Qcoast2100) has committed $12 million towards helping councils and their communities plan and prepare for storm tide, coastal erosion and rising sea levels resulting from climate change.[16]

Ecological condition and function

Given the history of disturbance and ongoing pressures that affect most freshwater wetlands within the Great Barrier Reef catchment, degraded ecological condition and function is often a constraint on their ability to provide ecosystem services to downstream systems including the World Heritage Area. While pressures from catchment run-off (above) is a primary driver of condition impacts, management intervention on other site and catchment-based pressures is also required to reinstate wetland condition and function across Great Barrier Reef river basins.

Weeds, both aquatic and terrestrial, are recognised to be one of the most significant threats to wetland condition and function in developed Reef catchments. [10] They impact a range of biophysical functions affecting water quality, primary productivity, nutrient assimilation and cycling, biota connectivity and habitat resource availability. Given the magnitude of wetland weed infestations, intensive control methods are often cost and resource prohibitive and beyond the remit of individual land holders. In recent decades, strategic, collaborative, cost-shared and catchment-based wetland weed management approaches, including weed harvesting, boat and aerial-based spraying programs, have demonstrated the capacity to recover aquatic ecosystems from collapsed states associated with major weed infestations. The use of broadacre weed management methods, such as controlled grazing and burning regimes for fire sensitive exotic pasture weeds, have also been successfully trialed and developed in different Reef catchment contexts.[17]

The development of broadacre management approaches is also important for reducing cost prohibitions associated with improving wetland condition by revegetation. While intensive revegetation methods are viable in more intensive land use settings and warranted for stabilising drainage lines and consolidating riparian buffers, the use of broadacre tools, including controlled grazing and burning and direct seeding to promote natural vegetation succession and recruitment, offers the best promise for catchment-scale system repair.

Altered hydrology and connectivity are another pair of often related wetland pressures significant across the Reef catchment that are an important focus for system repair activities.[18,19] Notwithstanding social constraints, altered hydrology associated with local catchment-scale infrastructure (for example, bunds, levees and tide gates) can technically be more readily rectified than that associated with water resource development and commitments at a basin scale. They can also produce major dividends in wetland ecosystem service delivery.[20] Where hydrological change results from basin scale water resource commitments, wetland system repair opportunities lie with improved commitment to managing regulated systems to emulate natural processes and in meeting environmental flow requirements.[19]

Biota connectivity impacts are commonly associated with water resource (dams, weirs) or other instream infrastructure (such as road crossings) but can also arise from modified hydrology (reduced flows) and reach conditions (sediment slugs, weed infestation). The cause of biota connectivity impacts can be remotely located from affected wetlands and may exert limited if any hydrological impacts on affected wetlands. With the increased availability of effective bio passage designs (for example fish ladders) for instream infrastructure across a range of catchment development contexts, addressing biota connectivity impacts has become more feasible and widely implemented across the Reef catchment in recent decades.[21 22] Further supporting these types of works represents a cost effective investment for re-instatement of wetland biotic processes that directly underpin biodiversity values and associated ecosystems services (that is, fish and fisheries) important to the Reef ecosystems and appreciated by the catchment community.

Successful management intervention aimed at improving freshwater wetland condition and function across the Reef catchment needs to be progressed by adaptive management approaches underpinned by good science, with the gained management insights shared and communicated across the region. This necessitates taking current understanding of Reef freshwater wetlands beyond mapping and inventory towards improved assessment and understanding of condition and function (below). Recognition that ideal wetland condition may not be some historical undisturbed baseline but a healthy system capable of delivering ecosystem services within its particular catchment development context is a keystone to progressing effective management objectives and outcomes.

Informing improved management and ecosystem health outcomes

Effective management of freshwater wetland vulnerability across a region as large as the Great Barrier Reef catchment needs to be underpinned by good science and an effective monitoring and research program. In the last decade the Queensland Wetland Program, jointly sponsored by the Queensland and Australian governments, has been responsible for major advances in understanding of freshwater wetland ecosystems within the Reef catchment. This has included region-wide mapping and classification, generation of management profiles for different wetland types, compilation of conceptual models on wetland condition pressures and establishment of a web based wetland information portal http://wetlandinfo.ehp.qld.gov.au/wetlands/.

To capitalise on this foundation of information it is important that further investments in monitoring and research are made and targeted to progress wetland resource inventory into improved management knowledge. Key areas include:

- effective monitoring approaches to assess wetland condition and status trends
- quantifying the wetland ecosystem services delivered by different wetland types
- understanding of the ecological function and impairment of wetlands based on their catchment development context
- research to underpin more effective management of catchment and site pressures and system restoration approaches.

Climate change

Climate change represents a major emerging pressure on freshwater wetlands. Affected climatic and hydrologic regimes are primary determinants of freshwater wetland condition and function. Changes in these regimes also amplify the individual and collective impact of existing pressures.[6,7] To effectively address threats posed by climate change, emissions abatement and impact adaptation actions need to be investigated. While the broader national and global initiatives required to address emissions abatement are not considered here, it is pertinent to note the effectiveness of adaptive management measures in the longer term is ultimately tied to the effective implementation of global emissions control. Even in the shorter term they are likely to only be effective at the lower end of the emissions scenarios promoted by the Intergovernmental Panel on Climate Change (IPCC). [23] Current emissions trends and global temperature and atmospheric carbon dioxide concentrations recorded in 2016[24] are consistent with the most extreme of the Representative Concentration Pathways modelled by the IPCC.[25,26,27] This presents the spectre of a global climate trajectory progressing beyond target levels of 1.5–2 degrees Celsius and into the realm of dangerous climate change, with accompanying extreme risks for freshwater and other ecosystems of the Great Barrier Reef catchment before the turn of the century.[28]

Assuming that progress on global emissions controls will be achieved, improving wetland resilience to climate change associated pressures represents the most prudent path forward for securing wetland ecosystem services within the Reef catchment. Given most potential impacts associated with climate change will be realised by exacerbation of existing pressures, recommended management responses largely entail reducing existing pressures (as discussed in preceding sections). More specific adaptive management needs that have been identified include:

- protective management of higher integrity wetlands and catchments
- identification and protection of key aquatic refugia
- targeted restoration of waterways and other catchment ecosystems that regulate quantity and quality of run-off
- protection and re-instatement of environmental flows including by dedicated operation of water infrastructure in regulated basins
- enhancing habitat connectivity
- pre-emptive control of invasive species favoured by climate change
- appropriate planning consideration of ecological risks posed by water resource development proposals within the context of climate change.[6,7]

Another specific risk posed by climate change is that of unavoidable sea level rise. For freshwater wetlands within the near coastal zone, little can be done to provide resilience against projected impacts.

Accommodating the landward migration and re-establishment of coastal wetland mosaics, including freshwater wetlands via appropriate development setback controls from areas subject to sea level rise, is likely to provide the best opportunity for maintaining ecosystems services associated with these coastal wetland complexes.[7]

Background

Brief description of freshwater wetlands

There are six main classes of wetland ecosystem classified by the Queensland Wetland Program. These are marine (oceans), estuarine (estuaries), riverine (rivers, creeks), lacustrine (lakes, dams), palustrine (vegetated swamps) and subterranean (aquifers, caves). This vulnerability assessment concerns the three classes of surface freshwater ecosystems: riverine, lacustrine and palustrine wetlands.

These freshwater wetlands are diverse environments that permanently, periodically or intermittently contain static or flowing freshwater that support plants or animals that are adapted to and dependent on living in wet conditions. By definition, wetlands are underlain by undrained, permanently or periodically anaerobic soils or other water-saturated substrates. Freshwater wetlands support a wide range of associated plant communities, including algae, submerged, floating and emergent aquatic vascular plants, fringing riparian communities and seasonally inundated swamp forests. Palustrine wetlands, commonly referred to as 'vegetated swamps', are classified by the Queensland Wetlands Program as primarily vegetated non-channel environments of less than eight hectares. They include some billabongs, swamps, bogs, springs, and soaks that have more than 30 per cent of their area dominated by emergent vegetation.[29]

Lacustrine wetlands commonly referred to as 'lakes' are larger, open, water-dominated systems that are greater than eight hectares in area. This definition includes modified systems such as dams and river weir pools, which share the same characteristics as natural lakes for example deep, standing or slow-moving waters.[29]

Riverine wetlands include rivers and creeks and all wetlands and deep-water habitats within a channel. This can include artificial as well as natural channels that periodically or continuously contain moving water, or connect two bodies of standing water.[29]

Given the seasonality of the climate across the Great Barrier Reef catchment and its links to the hydrology of freshwater wetlands, wetland classes are not mutually exclusive or fixed in time or space. For example, wet season flooding and inundation can create seasonal open water lakes or lacustrine habitats that experience receding water levels during the dry season and that become dominated by emergent vegetation forming palustrine habitats. Similarly, floodplain distributary streams, which are connected riverine systems conveying flowing water in the wet season, can form isolated palustrine and/or lacustrine systems during the dry season.

The climate and associated hydrologic regime are key determinants of the nature and condition of freshwater wetlands. For some wetlands to be healthy there needs to be a cycle of wetting and drying. Wetlands that dry out periodically are often more biologically diverse.[30] Biophysical process linkages (such as water run-off) between wetlands and their contributing catchment area mean wetland condition is often mediated by that of its catchment. Riparian vegetation fringing freshwater wetlands is integral to freshwater wetland health.[13]

Spatially, wetlands can occur as a single class type site or as contiguous or disjunct aggregations comprised of a single class or complex of wetland classes, including non-freshwater or subterranean wetlands.[31]

Seasonal wetlands dry out, resulting in cracked clay. These cracks trap the 'first flushes' of water, protecting the Reef from contaminants contained within.

Geographical distribution

Freshwater wetlands are distributed across all river basins comprising the Great Barrier Reef catchment. Riverine wetlands are associated with the drainage lines within these river basins. They originate as low order streams in uppermost catchments and conflux to form larger, higher order main tributary stems and river channels in lower catchment areas. Ultimately, they discharge directly or indirectly via floodplain distributaries to the sea as estuarine systems. The density, gradient, perenniality and associated fringing vegetation communities of these drainage lines are determined by basin geology, climate and associated hydrology and landform. The greatest density of riverine wetland systems is associated with the higher rainfall areas of the Wet Tropics, while the largest occur in the largest basins (that is, the Fitzroy and Burdekin).

Palustrine and lacustrine wetland distribution is not as uniform as riverine systems, but is also controlled by catchment hydrology and landform. They typically form on silts, mud or humic loams in low-lying parts of floodplains, alluvial flats, drainage depressions, back swamps, lagoons, and in back-barrier landforms where floodplains adjoin coastal sand plains. These are typically flat, low-lying, alluvial landforms where water from local catchment run in and/or overbank flows from adjoining riverine systems are retained. Lacustrine wetlands also form in these settings but are less common than palustrine wetlands and many are associated with human modification of the landscape (dams). The greatest density of palustrine wetlands occurs on coastal floodplains particularly those associated with larger river systems (such as the Burdekin and

Fitzroy). These larger river systems also have aggregations of palustrine wetlands associated with inland floodplains of lower gradient tributary systems. This is a feature not observed in smaller, steeper coastal river basins.

In 2005, 1241 square kilometres of wetlands were mapped across the Great Barrier Reef catchment. The current extent of wetlands is shown in Figure 1.

Current status in the Great Barrier Reef catchment

Assessment of the status of freshwater wetlands across the Reef catchment is limited by a lack of dedicated monitoring. The most quantitative information available is for the areal extent of wetlands, and has been compiled by Queensland Herbarium mapping of the remnant extent of regional ecosystems, including those associated with wetlands across Queensland. This mapping uses a combination of satellite imagery, aerial photography and fieldwork, and can be used to provide a spatial representation of the pre-clearing and current extent of freshwater wetlands and other regional ecosystems types within the Great Barrier Reef catchment (Figure 1). The comparison of these layers provides a reporting mechanism for monitoring changes in the area of freshwater wetlands within the Reef catchment through time.

This mapping indicates that up to 86 per cent of the original extent of freshwater wetlands remains within the Reef catchment.[32] However, this high proportion is not consistent across river basins or wetland types. Within the Wet Tropics and Mackay Whitsunday regions, where coastal lowlands have been intensively developed to agriculture, only 40 per cent of the original extent of freshwater wetlands remains and only approximately 50 per cent remains within the Burnett region. In the larger Burdekin region, some 83 per cent remain, while in the Fitzroy region greater than 100 per cent of the original extent of freshwater wetland occurs, with individual basins such as the Styx recording a 400 per cent increase in areal extent of freshwater wetland. This increase in wetland area in these basins is attributable to the creation of ponded pastures via bund wall construction on the coastal plain. Ponded pastures, albeit artificially constructed, are mapped as palustrine wetland and contribute to the high freshwater wetland retention values in the Burdekin. Other basins in these regions lacking ponded pastures have lower freshwater wetland retention values (for example, 56 per cent for the Don in the Burdekin region and 50 per cent for the Boyne in the Fitzroy region). Freshwater wetland retention values of 99 per cent for the eastern river basins of the Cape York region reflect its relative undeveloped status.

In the case of individual freshwater wetland classes, the Queensland State of the Environment assessments (2011) indicate 40–70 per cent of palustrine wetland area has been lost across most Great Barrier catchment river basins south of Cairns. Individual basins have recorded greater than 70 per cent loss (such as the Barron River basin within the Wet Tropics) and a few have greater than 85 per cent loss (for example Bowen (within the Burdekin Region), Boyne (within the Fitzroy region) and Kolan and lower Burnett river basins (within the Burnett region)) (Figure 2). Palustrine wetlands are generally comprised of shallow basins that are only seasonally inundated, making them susceptible to agriculture development via drainage and land levelling and filling. Given their lower suitability for development, riverine wetlands have experienced lower rates of loss than palustrine systems, though rates of 20–40 per cent loss per river basin have still been mapped across much of the Reef catchment. Some individual basins within the Wet Tropics, Mackay–Whitsunday, Fitzroy and Burnett regions have experienced higher rates of 40–70 per cent loss, while two basins within the Burnett Region (upper Burnett and Barker and Barambah Creek basins) have greater than 70 per cent loss of riverine wetland (Figure 3).

It is prudent to note that the spatial estimates of the total area of freshwater wetland cleared in the Great Barrier Reef catchment is likely to be understated. This is due to the mapping scale used by the Queensland Herbarium which does not include wetlands of less than one hectare in area. These smaller freshwater wetlands are often the most vulnerable to development or degradation. Smaller wetlands also often provide important habitat connectivity linkages through the landscape, changes in which may not be captured by current mapping scales.

A limitation of current wetland extent mapping for conducting assessments of freshwater wetland status is that it provides no indication of wetland condition or level of degradation. Consequently, the loss of ecological functions provided by freshwater wetlands throughout Reef catchments may be much greater than that indicated by the mapping of remnant extent. Given the extensive area of Reef catchment river basins now dominated by non-remnant vegetation, including intensive agricultural land uses (Figure 1), many remnant freshwater wetlands have contributing catchments that lost ecosystem services provided by the pre-clear mosaic of forests and other regional ecosystem types.[32] The implications of these catchment land-use changes have been demonstrated throughout the Reef catchment through elevated sediment, nutrient and other contaminant loads up to more than 100 per cent greater than natural levels[32] and by monitored water quality that regularly exceeds guidelines for the maintenance of aquatic ecosystems health.[9,32] Case studies within more intensively developed sub-catchments confirm the ecosystems health of remnant freshwater wetlands is being overwhelmed by the loss or regulating ecosystems services in contributing catchment areas[13].

Numerous other regional and thematic studies and basin-scale condition assessments, including those prepared for water resource planning, indicate that in addition to catchment contaminant loads the condition and function of remnant freshwater wetlands across developed basins are commonly impaired by a range of pressures including:

- aquatic and terrestrial weeds [10]
- infrastructure and reach condition impacts to flow and biota connectivity[19, 20]
- water resource development and altered catchment hydrology[9,13,33,34,35,36]
- altered fire regimes[17]
- grazing[37]
- feral animals. [11,38]

The lack of wetland condition monitoring across the Reef catchment not only limits the ability to quantify condition impacts or functional impairment affecting remnant freshwater wetlands but also system improvements attributable to management intervention. Since the advent of Landcare and subsequent community-based natural resource management organisations, the community and governments have made significant investment in freshwater wetland management within the Reef catchment over the last 30 years. The primary management activities have included:

- improved land use practices in contributing catchments
- riparian revegetation management and restoration
- aquatic and terrestrial weed control programs
- feral animal control
- reinstatement of hydrology
- provision of fish passage
- construction of artificial wetlands
- controlled grazing and burning regimes.

While the spatial extent of these activities remains limited relative to the overall Great Barrier Reef catchment, resulting improvements in the status of freshwater wetland condition and function has been demonstrated at site to local catchment scales.

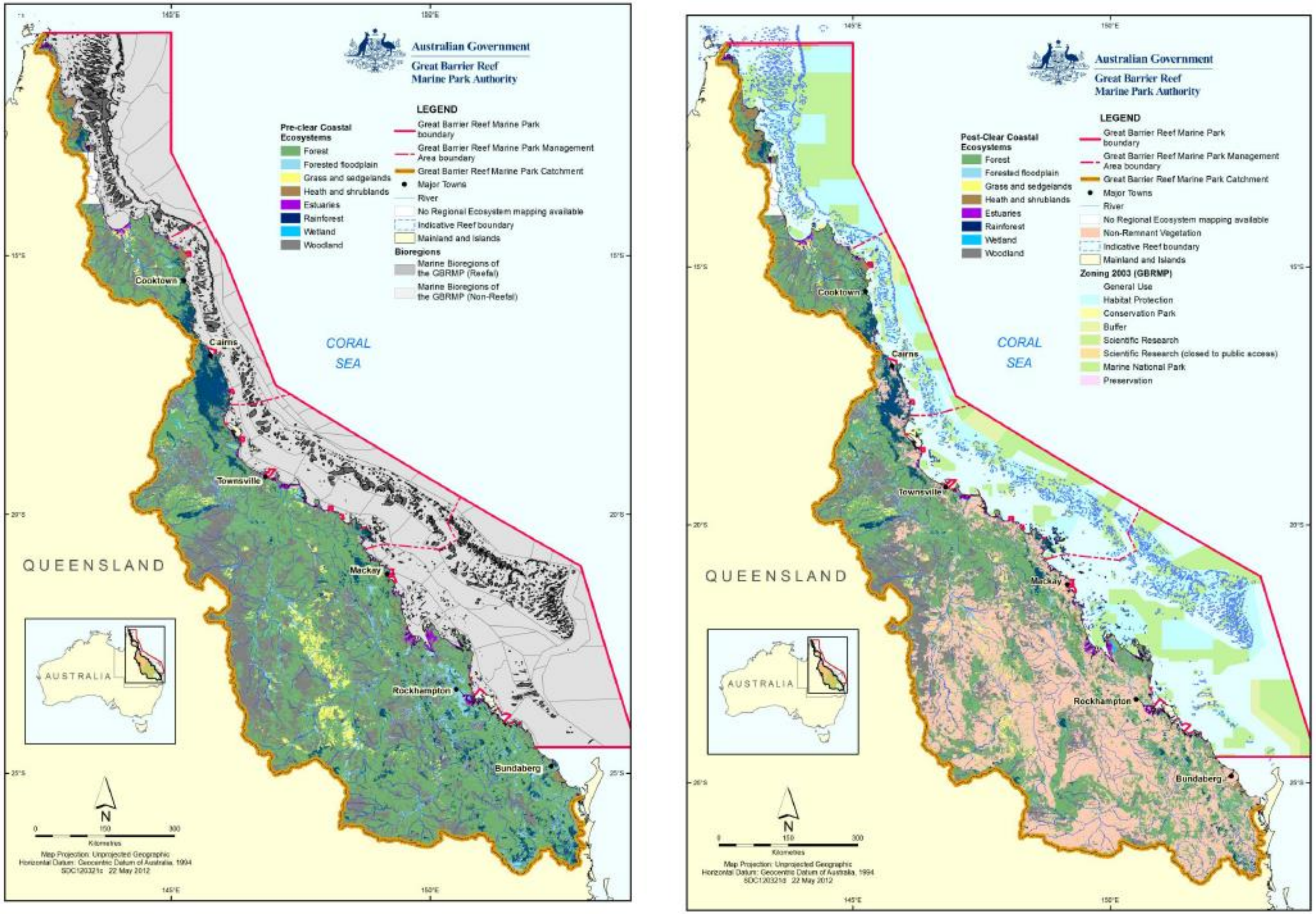

Figure 1: Pre-clear and post-clear extent of coastal regional ecosystems within the Great Barrier Reef catchment

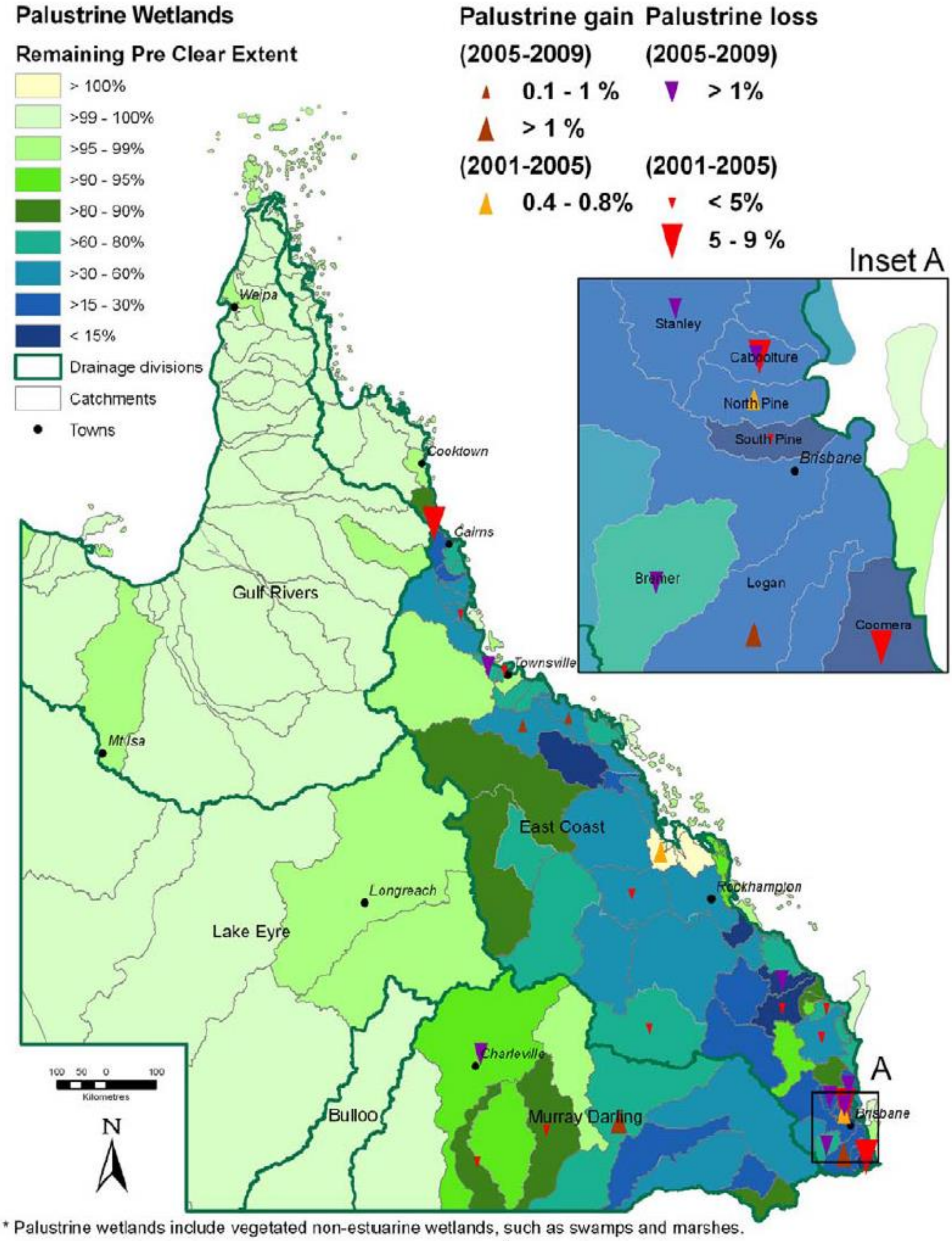

Figure 2: Change in the extent of palustrine wetlands compared to pre-clearing extent and loss of palustrine wetlands over 2001–2005 and 2005–2009 in Queensland. Source: Queensland State of the Environment Report. Department of Environment and Heritage Protection, http://www.ehp.qld.gov.au/state-of-the-environment/report-2011/

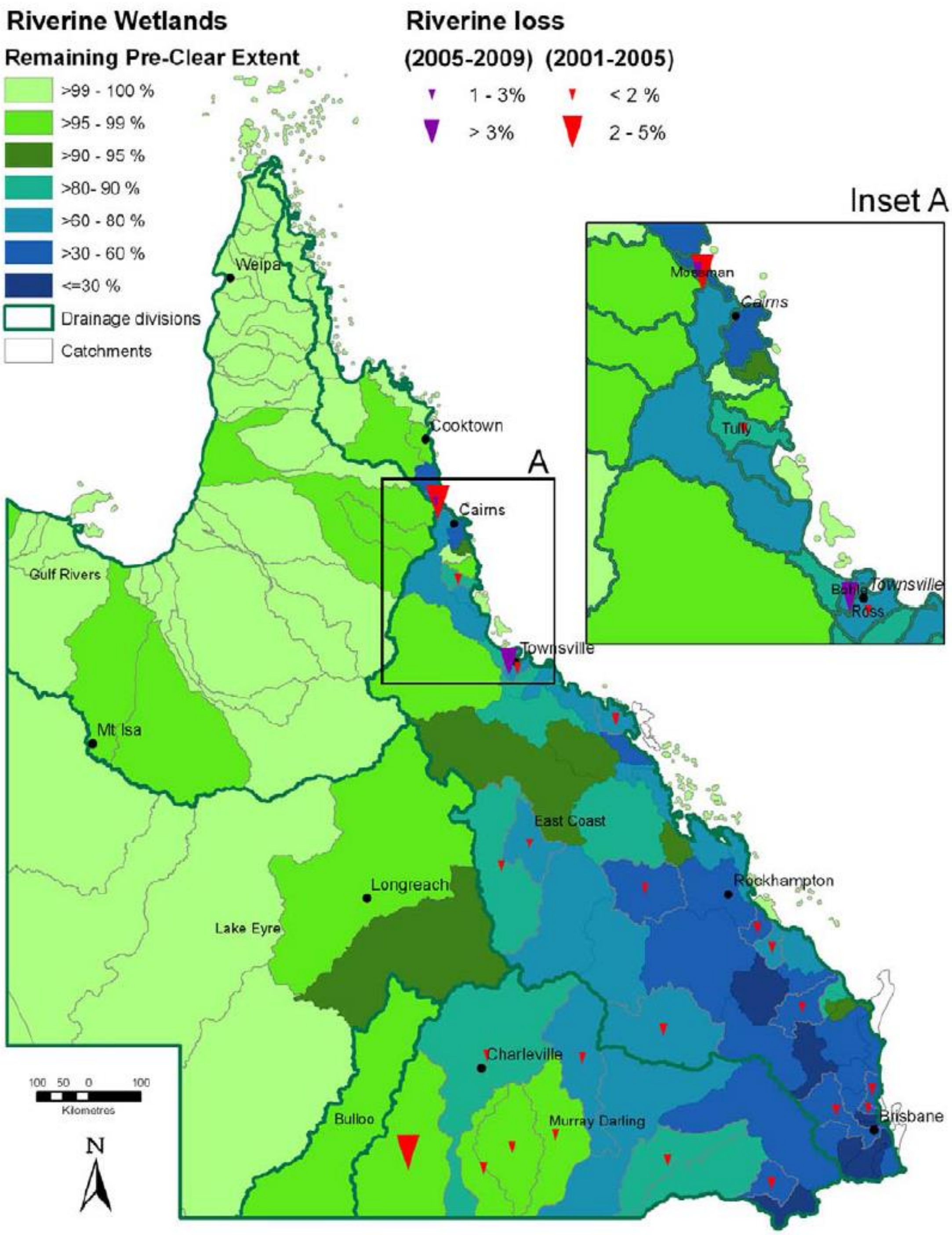

Figure 3: Change in the extent of riverine wetlands compared to pre-clearing extent and loss of riverine wetlands over the 2001–2005 and 2005–2009 periods for Queensland. Source: Queensland State of the Environment Report. Department of Environment and Heritage Protection, http://www.ehp.qld.gov.au/state-of-the-environment/report-2011/

Ecosystem role and function:

At a macro scale, all wetland classes within a river basin form a hydrologically linked, catchment-bound, aquatic ecosystem that extends from upper catchment streams and aquifer recharge and discharge areas to lowland rivers, floodplain wetlands, aquifers, estuaries and receiving marine systems. The catchment-to-coast hydrological and associated biophysical process linkages underpin why freshwater wetlands are an integral part of the Great Barrier Reef ecosystem. They perform a wide range of ecological functions and provide critical ecosystem services to the Great Barrier Reef that are pivotal to its long-term health and resilience. These services include regulating catchment water flows, loads of sediment, nutrient and other materials and hence water quality, and providing habitat for species with life cycle linkages to the Great Barrier Reef.

Freshwater inflow is one of the most influential coastal processes affecting biological community structure and function in coastal lagoons, estuaries and deltas of the world.[39] A significant proportion of the material lost from the land during flood events invariably finds its way via river discharges to the Great Barrier Reef lagoon.[40] Most of the transport of materials from land to sea is via river systems and the natural and anthropogenic changes to catchment habitats and processes can have major impacts on the quantities of sediment, nutrients and water entering coastal seas.[41]

As a natural process, freshwater flow and the downstream movement of nutrients is one of the primary controls of the productivity of estuarine systems, coastal seas and the Great Barrier Reef.[41] However, excessive nutrient delivery to the Reef has been identified as a threat to its ecological integrity.[42] Maintenance and reinstatement of ecosystems services provided by freshwater wetlands to the Reef are recognised as important ways to reduce this threat[3,32]

Why are wetlands important?

Wetlands are a critical part of our natural environment. They protect our shores from wave action, reduce flood impacts, absorb pollutants and improve water quality. They provide habitat for animals and plants, and many contain a wide diversity of life, supporting plants and animals that are found nowhere else.

Freshwater wetlands also provide numerous ecosystems services to people within the Great Barrier Reef catchment and to the broader Australian community. These wetland ecosystems services support values that extend across ecologic, economic, social and cultural classes. They include:

- habitat provisioning services that support economic and cultural values associated with commercial, recreational and traditional fisheries
- hazard regulation services that protect infrastructure and agricultural production
- cultural services that provide inspiration, recreation and a sense of identity particularly for Indigenous people
- supporting services that contribute to ecological functions, for example primary production, nutrient cycling that supports all other ecosystems services and intrinsic values associated with the maintenance of biodiversity and evolutionary processes. [32,43]

Ecosystem goods and services:

Ecosystem goods and services category	Services provided by freshwater wetlands and underpinning ecological processes and functions
Provisioning services (e.g. food, fibre, genetic resources, biochemicals, fresh water)	• Provision and storage of water resources used for domestic, industrial and agricultural use (dependent upon water quality and quantity regulating services (below) • Provision of pasture resources for domestic stock within palustrine wetlands and via flooding based productivity on floodplains • Production of fishes that support recreational, commercial and traditional fisheries, e.g. provide nursery areas commercially and recreationally important species such as barramundi and mangrove jack • Production of plant and animals resources used by Indigenous people
Cultural services (e.g. spiritual values, knowledge system, education and inspiration, recreation and aesthetic values, sense of place)	• Recreational services via provision of opportunities for nature based recreation including swimming, boating, camping, fishing and nature appreciation • Spiritual and inspirational services provided by places that provide a source of inspiration and/or cultural identity • Traditional Owner cultural resource values including via provision of habitat for culturally significant animals • Aesthetic services by provision of places of aesthetic beauty • Educational services via opportunities for formal and informal education • Employment opportunities associated with fishing and other forms of nature based tourism • Riverine system provision of opportunities for transportation and recreational boating
Supporting services (e.g. primary production, provision of habitat, nutrient cycling, soil formation and retention, production of atmospheric oxygen, water cycling)	• Soil formation via sediment retention and accumulation of organic matter • Storage recycling, processing and acquisition of nutrients • Food chain linkages to downstream ecosystems, e.g. spawning of freshwater species with marine larval development is a source of food for inshore marine species.[44] Riparian vegetation provides food for aquatic systems via both terrestrial primary and secondary production and high aquatic primary and secondary production instream. [45,46] Woody material acts as substrate and habitat for aquatic fauna and microalgae.[45] Freshwater shrimp graze upon benthic algae and provide food for predatory fish species • Provide habitat and a pathway for fish migration/recruitment, i.e. connectivity between habitats • Riverine systems mediate river channel direction and morphology[45] and act as a conduit for sediment transport • Wetlands exchange organic and inorganic material between terrestrial and aquatic systems[45] • Provide refuge during dry periods for aquatic species that have connections with the Reef[47] • Provides habitat that sustain bird species including some with connections to the Reef [48]
Regulating services (e.g. invasion resistance, herbivory, pollination, climate regulation, disease regulation, natural hazard protection)	• Water quantity / flow / flood regulation via groundwater recharge / discharge. Riparian vegetation stores run-off [45] and recharges groundwater. Groundwater may also be discharged into wetlands, forming the base flow in some streams. Riparian vegetation reduces overland flow velocity. [49,50] Palustrine and lacustrine wetlands act as detention areas for surface run-off • Water quality regulation via retention, recovery and removal of excess nutrients and other pollutants inkling via filtering of sediments and phosphorus uptake and cycling [46,51,52]. Riparian vegetation controls nutrients [46] and maintains water quality [45,50] including nitrate removal.[53] Riparian vegetation moderates stream temperatures through evapotranspiration and shading. [45,46] Where water is retained in wetlands (lacustrine, palustrine) nutrient cycling regulates load transported to Great Barrier Reef but limited in riverine wetlands as most transport occurs during flood events.[54] • Climate regulation via influencing local and regional temperature, precipitation and other climatic processes and by acting as source and sinks for greenhouse gasses • Erosion regulation via retention of soils and sediments. Riparian vegetation stabilises banks and sediments [45,46] • Regulate pollination services via provision of habitat for pollinators (bats, birds, insects)

Pressures influencing freshwater wetlands in the Great Barrier Reef catchment

Pressures

Major pressures affecting freshwater wetlands within the Great Barrier Reef catchment include catchment land and water resource use and development, catchment run-off and invasive species. Although described individually, these pressures are not mutually exclusive in terms of their definition or operation. These pressures interact to produce synergistic and cumulative effects and influence key drivers that impact the condition and function of freshwater wetlands. For example, land and water resource development are a major source of catchment run-off pressure which in turn can create favourable conditions for invasive species. Key drivers for freshwater wetlands include:

- hydrological regime, including patterns of connectivity
- water quality (sediments, nutrient and other contaminants, temperature, salinity, dissolved oxygen, pH)
- physio-chemical conditions including optimal temperature ranges
- physical disturbance (natural and anthropogenic).

Climate change and associated sea level rise are also emerging as significant pressures which, if unmitigated, have the collective potential to severely impact the condition and function of wetland ecosystems across the entire Reef catchment. While climate change presents unique threats associated with extreme weather, sea level and temperature rise, many impacts associated with it will be realised by exacerbation of existing pressures.

Freshwater wetlands are receiving environments that are biophysically linked to their contributing catchment area by run-off inflows and carried material loads. The amount of catchment run-off and the nature of exported material loads are mitigated by climate and catchment condition including vegetation cover and drainage network integrity. Across the broader Reef catchment there are a wide range of climatic zones, land-use patterns and practices, and associated catchment conditions. Consequently the suite of pressures and individual pressure exposure levels a freshwater wetland experiences also varies significantly across the Reef catchment.
Generally, the extent of intensive land or water use within a river basin or contributing catchment area is strongly correlated with the level of pressure experienced by downstream wetland ecosystems[1] Undeveloped river basins such as those in western Cape York host some of the best condition freshwater wetlands, while catchments dominated by intensive land use, such as the lower Burdekin, host some of the most disturbed.[13] This is because extensive development reduces the extent of natural catchment ecosystems and the supporting and regulating services they provide to downstream systems.[3] In some instances this correlation may not hold where catchment development has by default or design retained or reinstated catchment functions underpinning ecosystem services, or alternatively where low intensity land use (for example rangeland grazing) on sensitive land types has set in train extensive land degradation.

A summary of the assessment of pressures affecting freshwater wetland across the Reef catchment is tabled below. For a detailed assessment and explanatory notes see Appendix 1.

Pressure (vulnerability) assessment matrix

The *Great Barrier Reef Outlook Report 2009*[3] identified a number of commercial and non-commercial uses of the Marine Park, as well as climate change, coastal development and poor water quality from catchment run-off as the key pressures reducing the resilience of the ecosystem.

From this report, it was considered that pressures such as climate change, coastal development, catchment run-off and direct use were the key factors that influence the current and projected future environmental, economic and social values of the Great Barrier Reef. To conduct this vulnerability assessment for freshwater wetlands it has been necessary to move the focus of the assessment area away from the Great Barrier Reef and primarily to its contributing catchment area which is comprised of 35 river basins extending from Jacky Jacky River basin in Cape York to the Burnett River basin in southeast Queensland. The suite of pressures that needed to be considered were also distinct from those previously used for the Marine Park and marine ecosystems and was based on those that can impact directly and/or indirectly on freshwater habitats, species and groups of species to reduce their resilience. Pressures associated with the commercial and non-commercial uses of the Marine Park were not considered due to limited significance for freshwater wetlands. Additional catchment-based pressures that were identified include: invasive species, grazing, altered fire regimes and water resource development. Coastal development was retitled as catchment development recognising a broader inland focus and sea level rise was separated from climate change in recognition of the more specific nature and extent of its impact potential.

Using the vulnerability assessment framework adapted by Wachenfeld and colleagues[82], this assessment aims to provide an integration of social, ecological, economic and governance information. For each key pressure in the Great Barrier Reef, exposure and sensitivity is assessed in relation to each other to reach a level of potential impact. The potential impact is then reassessed having considered the level of natural adaptive capacity that freshwater wetlands have to respond to the pressure and the adaptive capacity that management has, or can apply, to reduce the potential impact from the pressure. This provides managers and stakeholders with an understanding of the key elements that each pressure can impose on the habitat, to reach a final assessment of the overall residual vulnerability of freshwater wetlands to that particular pressure. This allows for suggested actions to be formulated to minimise the impact of the pressures to which freshwater wetlands are most vulnerable.

Pressure assessment matrix summary

		Exposed to source of pressure	Degree of exposure to pressure source	Sensitivity to source of pressure	Adaptive capacity – natural	Adaptive capacity – management	Residual vulnerability	Level of confidence supporting evidence
Pressures	**Invasive species**	Yes; Great Barrier Reef catchment wide. Greater weed pressure developed basins greater feral animal pressure in less developed basins	Low – undeveloped basins, low feral populations	Low – small spatial/ temporal scale stress but no longer term strain	Good – structure/ function relatively unmodified, no secondary pressures	Good – spatially constrained, declared pests, broadacre control	High	Good
			Medium – moderate development and/or feral populations	Medium – greater scale strain, with impacts wetland structure / function	Moderate – structure/ function changes, periodic secondary pressures	Moderate – large spatial scales, long-term chronic infestations, catchment coordination delivering functional baseline outcomes.		
			High – high development levels and/or feral populations	High to very high – large scale chronic strain, structure/function altered	Poor – structure/ function highly altered, chronic secondary pressures			
	Grazing	Yes; Great Barrier Reef catchment wide with localised exclusions	Low – areas where grazing excluded	Low – exposure low, resilient type or grazing improves condition	Good–medium pressure, relatively unmodified no secondary pressures	Good – supportive landholders, moderate-good natural capacity	Medium	Good
			Medium – managed total grazing pressure, fencing controlled	Medium – exposure medium, type or condition vulnerable	Moderate–medium–high pressure, resilient type, few secondary pressures	Moderate – socio-economic constraints, secondary pressures limit natural capacity, significant investment required, limited human resources		
			High – high total grazing pressure, no fencing controls	High – high exposure, highly vulnerable type / context, good condition	Poor – high pressure, degraded state, chronic secondary pressures			
	Altered fire regime	Yes; Great Barrier Reef catchment wide but variable exposure	Low – ecological fire management, natural or managed suppression	Low – seasonal tropics, fire adapted, no floristic /structural changes	Good – recuperation between low frequency impacts, no secondary pressures	Good – low frequency impacts, limited secondary pressures on fuel load	Medium	Good
			Medium – insensitive fire management, invasive species impacts fuel loads	Medium – fire sensitive juxtaposed fire adapted or fuel changes in latter	Moderate – infrequent impacts, resilient, few fuel/structure changes	Moderate – natural adaptive capacity, limited land use conflicts		
			High – antagonistic fire management, high fuel loads, seasonally dry,	High – fire sensitive or adapted with structural and fuel load changes	Poor – frequent impact, sensitive type, fuel load and structural changes	Poor – private land, high exposure and sensitivity, antagonistic practices		
	Water resource development	Yes; Localised. Higher pressure in developed river basins	Low – little resource development and/or wetlands upstream	Low – where exposure low and changes within natural variability	Good – key flows/function retained, impacts mitigated, no secondary pressure	Good – water resource plans for flows, impacts infrastructure mitigated	High	Good – Knowledge of relationship between water resource development thresholds and key flow driven processes requires further development.
			Medium – wetlands downstream water extraction/ infrastructure,	Medium – some condition / function changes, secondary pressures	Moderate – some impact mitigation, key functions not lost, secondary pressures	Moderate – exposure, sensitivity, resource commitments high, infrastructure impacts,		

		Exposed to source of pressure	Degree of exposure to pressure source	Sensitivity to source of pressure	Adaptive capacity – natural	Adaptive capacity – management	Residual vulnerability	Level of confidence supporting evidence
			High to very high – major flow / infrastructure impacts wetland function	High to very high – permanent condition / function changes, secondary pressures	Poor – permanent local or basin scale impact, key function/flows lost	functional flows lost, secondary pressures established		
	Catchment development	Yes; Great Barrier Reef catchment wide. Greater pressure is associated with existing and proposed more intensive development	Low – protected area, low intensity use, limited built infrastructure	Low – exposure low, condition and function unimpaired	Good – small spatial/ temporal scale impacts, condition/ function good	Good – exposure, sensitivity, low, land use intensification controlled	Low – for undeveloped basins and low intensity use without soil erosion	Moderate – Further research required for cumulative impact assessment and catchment development threshold relationships to biophysical process integrity and ecosystem service delivery.
			Medium – variegated land use, infrastructure impacts, intensification	Medium – some, condition / function changes, secondary pressures	Moderate – secondary pressures non-permanent, some habitat resetting function	Moderate – exposure, sensitivity high, natural capacity/ space limited, resource intensive reinstatement function/ condition	High – intensive agricultural lowland areas, population centres and proximal coastal plains / hinterlands	
			High to very high – Intensive land use, built infrastructure dominates	High – permanent condition / function changes, secondary pressures	Poor – permanent impact site/catchment functions, chronic secondary pressure			
	Catchment run-off	Yes; Great Barrier Reef catchment wide. Pressure related to catchment development, land use practices and land degradation. Comprised of contaminant loads and altered run-off hydrology	Low – protected, low intensity use, erosion and use intensification	Low – water quality, hydrology in ecosystem health guidelines	Good – low exposure sensitivity, impacts small condition/ function good	Good – medium exposure, economic and legislative incentives	Low – for undeveloped basins and low intensity use without soil erosion	Moderate – Knowledge required: Load transport pathways; thresholds of tolerance to pollutants; effectiveness of strategies to minimise run-off from agricultural lands.
			Medium – variegated land use, some erosion and use intensification	Medium – sometimes outside guidelines, some secondary pressure stress	Moderate – secondary pressures non-permanent stress, periodic habitat resetting	Moderate – exposure, sensitivity, medium economic incentive (best management practices)	Medium – variegated land use which retains ecosystem services	
			High to very high – Land use intensive, poor practices, high erosion	Very high – permanently outside guidelines, long-term secondary pressure strain	Poor – high exposure and sensitivity, chronic strain big departure baseline	Poor – high exposure and sensitivity, intensive use, degradation extensive	High – intensive land use and/or extensive areas of land degradation	
	Climate change	Yes; Great Barrier Reef catchment wide	High – for freshwater wetlands across the Reef catchment-based on greenhouse emissions and RCP scenarios	Low – undeveloped basin, few secondary pressures, distributed rainfall, groundwater	Moderate – resilience not impacted by secondary pressures, climatically diverse large basins, secure aquatic refugia, higher rainfall regions	Moderate – moderate natural capacity, protective management options, resources for secondary pressures, capacity environmental flows	High – wetlands in relatively undeveloped larger basins / catchments with higher rainfall and limited other pressures	Poor – High uncertainty surrounds predictions for the magnitude or rate of climate change impacts that will be experienced by Great Barrier Reef catchment wetlands.
				Medium – some secondary pressures, more seasonal rainfall				
			Very high – seasonally arid and immediate near coastal sites	Very high – seasonally arid, extreme climates, high no. secondary pressures	Poor – high exposure, sensitivity, bioclimatic boundaries, secondary pressures	Poor – poor natural capacity, remote, limited human, other resources	Very high – developed basins, seasonally arid, established secondary pressures	
	Sea level rise	Yes; Localised to near coastal lowlands with potential for regional and basin wide significance	Low – outside inundation area with no biotic linkages to it.	Low – low exposure	Good – low exposure sensitivity, outside inundation area	Moderate – higher gradient, rainfall coast, resource intensive bunding / barraging high value assets, assisted migration wetlands	Very high	Poor – High uncertainty surrounds predictions on the rate and ultimate extent of sea level rise and of natural or
			Medium – margin of inundation zone and/or significant biotic linkages	Medium – medium exposure	Moderate – inland margin inundation zone, slope/ aquifer buffers			

		Exposed to source of pressure	Degree of exposure to pressure source	Sensitivity to source of pressure	Adaptive capacity – natural	Adaptive capacity – management	Residual vulnerability	Level of confidence supporting evidence
			Very high – within sea level inundation zone	Very high – high exposure	Poor – in sea level inundation zone, marine/ estuarine transformation	Poor – low gradient coasts, sea level rise fast, development landward		managed adaptive capacity of coastal wetland complexes.

Key concerns: Pressures generating high to very high residual vulnerability

Catchment development

Development of land and water resources for human use is the primary pressure that has changed the Great Barrier Reef catchment's condition and its capacity to deliver ecosystem services to receiving environments including freshwater wetlands and ultimately the Reef.[32] Ongoing growth in human population and the material economy will drive further development in the catchment. While statutory planning and management frameworks now provide a good capacity for managing potential impacts associated with new development, existing and future catchment development still generates a high residual vulnerability for freshwater wetland ecosystems.

Much existing development occurred before there was a societal appreciation of catchment process linkages to downstream systems or for ecological sustainability generally. The legacy of more intensive development patterns, such as built urban or irrigated agriculture-dominated catchments, has been the loss of natural ecosystems and the supporting and regulating ecosystem services they provide which mitigates the hydrological regime and contaminant loads experienced by downstream wetlands. In many instances, ecosystems heavily disturbed or lost to development have included freshwater wetlands.

In this intensive catchment development context, the condition and function of freshwater wetlands will be perennially impaired because their contributing catchment area — which in effect represents their extended functional boundary — is permanently impaired in terms of condition and function. The creation of secondary pressures, such as weeds and water quality decline, amplify the impact of development on receiving wetlands. It also moves pressure from periodic or extended stress to long-term chronic strain.

To address the pressure from existing intensive development on freshwater wetlands, adaptive management needs to reinstate catchment functions and processes that underpin the provision of regulating ecosystem services. This resource-intensive management can take the form of natural ecosystem repair or re-establishment in remnant undeveloped areas. Alternatively, it could involve approaches that seek to retrofit areas of intensive development with equivalent functions and processes, or both, subject to land use constraints. Current management efforts are often focused on restoring the condition of remnant wetlands downstream of development, without appreciating the extent to which their functional capacity is overwhelmed by the lack of regulating services in their contributing catchment area.[13]

A catchment ecosystem service approach to reinstating freshwater wetland condition and function, and ultimately their capacity to provide ecosystem services, to the Great Barrier Reef has not yet been widely developed or promoted in intensive land use areas of the Reef catchment. This approach could offer much promise if progressed in conjunction with existing programs that target remnant wetlands and property management practices. A catchment ecosystem service provision approach could also be used to improve the management of new development, particularly if it is applied to recognising catchment development patterns and thresholds at which ecosystem service provision is undermined and associated cumulative impact risks exacerbated.

Water resource development

Water resource development is another form of catchment development that usually (but not always) occurs in conjunction with the development of land resources but more directly affects catchment hydrological behaviour. The pressure posed on wetlands by water resource development includes flow and infrastructure impacts which can operate synonymously, collectively or exclusively. Water resource development also acts as a driver for other pressures and impacting processes including catchment run-off, invasive species, loss of connectivity and water quality decline.

Contemporary planning processes for new water resource development are also based on ecological sustainability principles and seek to meet the water allocation needs of flow-dependent ecological assets and to mitigate connectivity impacts associated with instream infrastructure. Nonetheless, existing and potential water resource development generates a high residual vulnerability for freshwater wetland ecosystems.

Reasons underpinning the high vulnerability assessment include: the general sensitivity of wetland physical habitat and biota to changes in hydrologic regimes; the permanence; sub-basin scale and functional significance of flow and connectivity impacts associated with large, often dated, on-stream infrastructure (dams); the role of water resource development as a driver of secondary pressures; the limitations of understanding and monitoring underpinning the management of flow-based ecosystem impacts; and the potential for increased consumptive demands and/or climate change to further undermine existing environmental flow allocations.[6,55]

Several areas of improved adaptive management can be identified to address the residual vulnerability of freshwater wetlands to water resource development including:

- substantive investment to address unmitigated connectivity impacts associated with older water resource infrastructure (dams, weirs) with a commitment to develop nature-like bypass channels where possible, in contrast to 'fish ladder' solutions which often fail to pass large and threatened fish species and non-fish biota[13]
- improved commitment by infrastructure operators to manage secondary pressures (weed infestation, water quality decline) that emerge where important functional flow processes have been impacted by water resource development, including by dedicated flow allocations and infrastructure operation where possible and applicable
- ensuring assessment of proposals for any further development of water resources include reference to ecological risks across all ecological and socio-economic dimensions with due reference to impacts on other industries and external costs
- committing sufficient ongoing resources to aquatic ecosystem research and monitoring to ensure the best possible system understanding is used to underpin flow allocation decision making and that the determined needs of flow-dependent assets, including freshwater wetlands, are reflected in binding commitments in water resource operation plans.

Catchment run-off

Catchment run-off pressures on freshwater wetlands are intimately linked to catchment development and land use. These provide the source of contaminants conveyed in run-off and affect the transport and retention capacity of contaminant loads within the catchment by impacts to catchment ecosystem components that provide regulating ecosystem services. Water resource development can also provide a major contributing source of pressure to catchment run-off where irrigation development results in significant tail-water volumes leaving farms as run-off. [56]

While catchments dominated by intensive land use generally present greater catchment run-off risks, this correlation may not always apply. Some intensive uses, such as urban settlement, can sometimes be associated with small contaminant loads particularly of sediment, while some low intensity land uses, such as rangeland grazing on native pastures, can generate large contaminant loads from land types that are susceptible to erosion in highly seasonal climates.[12,32] The limitations of existing water quality regulatory frameworks for dealing with contaminant loads from diffuse point sources conveyed in catchment run-off, and the chronic impact strain such loads and altered run-off hydrology can generate, results in a high residual vulnerability for freshwater wetland ecosystems in relation to this pressure.

Catchment run-off has been the primary focus of the joint Australian and Queensland governments Reef Plan which is working to reduce pollutants released to receiving waters from diffuse sources. Targeting improved land management practices to reduce contaminant loads at source has been a key strategy by which this plan has sought to reduce the pressure posed by catchment run-off. While significant water quality improvements have been made, substantive challenges remain. Additional initiatives are required to achieve improved water quality outcomes for receiving environments.

As identified in the discussion concerning catchment development (above), a significant opportunity exists in the reinstatement of catchment hydrological functions and components that provide regulating ecosystem services where these have been lost to intensive development or extensive land use pressure. Where the area of a wetland's contributing catchment area, dominated by intensive land use or other diffuse load generating sources such as soil erosion, exceeds the functional capacity of remnant catchment ecosystems, adoption of best management land use practices on production areas alone will not prevent receiving wetlands being overwhelmed by contaminant loads and other run-off pressures.

Addressing run-off pressures posed by existing intensive patterns of development and the associated loss of regulating ecosystem services from contributing catchment areas requires relatively intensive management interventions. These need to deliver natural ecosystem repair and re-establishment in remnant undeveloped areas, or alternatively or additionally, approaches that retrofit areas of intensive development with equivalent catchment functions and processes. Recognition of the importance of catchment ecosystem service provision for mitigating catchment run-off pressure not only has application in the restoration of wetland condition and function in catchments impacted by development or land use pressure, but also in the protective management of wetlands in catchments subject to land use intensification. Ensuring all catchment ecosystem components and functions that underpin regulating ecosystem service provision are recognised by regulatory planning frameworks, along with development thresholds that impinge upon catchment capacity to provide such services, represents a potentially effective means for mitigating catchment run-off pressures affecting freshwater wetlands and the Reef.

Invasive species

Invasive species include aquatic and terrestrial plants and feral animals. The feral animals include terrestrial species, such as pigs, and aquatic species such as fish. Major weed infestations are often symptomatic of disturbed environments or catchment processes. Some feral animal species such as fish, which owe their origins to human introductions and distribution, are also associated with more populated and disturbed catchments. Other species, such as pigs, proliferate in more remote relatively undisturbed basins free of significant human interaction. The capacity of invasive species, particularly weeds, to completely alter the structure, composition and function of freshwater wetlands and to form apparently insurmountable, ecosystem collapsing infestations, results in the high residual vulnerability assessment for freshwater wetlands in relation to this pressure.

Control of wetland invasive species is resource intensive. Where infestations are symptomatic of other pressure disturbances, such as altered hydrology and elevated nutrient loads, the prospect of reinfestation after control events is high and undermines the incentive for management. While many (but not all) invasive species of wetlands are declared under pest management legislation, thereby invoking statutory control requirements, the capacity of individual landholders or stakeholder groups to deliver effective control outcomes — particularly in chronic long-term infestations — is often inadequate. This results in management neglect. The ecological cost of such neglect across the Great Barrier Reef catchment is enormous in generating secondary pressures such as water quality decline, loss of habitat connectivity and declined fisheries productivity.[10,13,19]

Although significant investment of resources is required to address neglected infestations of wetlands from invasive species, experience gained in recent decades shows wetland condition and function dividends can be significant if control efforts are strategic and sustained. Gaining industry, government and community acceptance that investment in invasive species control programs represents a maintenance cost of using natural ecosystems for economic and social benefit is integral to securing sufficient management resource commitments.

Broader adoption of management knowledge gained through successful programs across the entire catchment region will help ensure the vulnerability of wetlands to invasive species and associated secondary pressures created by them — all of which are likely to be exacerbated by climate change — can be reduced. Elements underpinning more effective catchment-scale invasive species management programs have included:

- engagement of multiple stakeholders (government, industry, community) and landholders in formal catchment-based working groups and cost-sharing arrangements over multi-year programs
- catchment-based control strategies including recognition of infestation and population refugia and control fronts
- successional weed control programs that progress from intensive mechanical approaches for neglected infestations through to chemical control maintenance and revegetation (where appropriate)
- integrated feral animal control programs that use multiple methods, such as baiting, trapping, shooting
- maintenance of active monitoring efforts to support timely control interventions
- capitalisation on natural events, such as droughts (for feral animals), flood spates (aquatic weds) to gain control advantages
- reinstatement of catchment functions to remove dysfunctional conditions promoting invasive species, for example overbank flood flows via levee removal, tidal ingress via coastal bund removal, seasonal wetland drying via aseasonal flow isolation
- use of cost effective broadacre control methods, for example controlled grazing and burning

- multi-party shared acquisition of expensive capital equipment and associated establishment and maintenance of human resource capacity, for example Land and Sea Ranger programs in remote areas
- management objectives based on functional wetland outcomes that reflect the contemporary development context of catchments rather than pre-development baselines. [10,13,19,20]

Climate change

Ecosystems impacts of climate change associated with anthropogenic global warming are emerging globally and nationally, most recently in the form of an unprecedented extensive and severe coral bleaching event across the northern region of the Great Barrier Reef.[27] Freshwater wetlands are also exposed to pressures associated with climate change — impacts are predicted to increase into the foreseeable future.[6,7] While wetland type, climatic setting, condition and catchment development context will differentiate the sensitivity and rate of exposure of Reef catchment freshwater wetlands to climate change impacts, vulnerability of wetlands across the catchment is assessed to be high to very high over decadal timescales. This assessment is based on the quality and persistence of freshwater aquatic habitats being heavily dependent on the climatic and hydrologic regimes impacted by climate change[5] and on the fact that global greenhouse gas emissions are currently tracking[24] in line with the worst case representative concentration pathway (RCP 8.5) scenarios modelled by the IPCC.[25,26,27] This presents the spectre of global warming going beyond the targets of 1.5–2 degrees Celsius, creating climate and sea level impacts that will potentially be detrimental for many wetland ecosystems.[28]

While it is beyond the scope of this assessment to examine current or required national and international management efforts to abate greenhouse gas emissions, it must be reiterated that the effectiveness of adaptive management measures in the longer term is ultimately tied to the effective implementation of global emissions control. Even in the shorter term, actions are likely to only be effective at the lower end of the emissions scenarios promoted by the IPCC.[23] In addition, carbon removal technology, as yet unproved, needs to be developed on an industrial scale to deliver the representative concentration pathways scenarios to climate stabilisation modelled by the IPCC.[27]

Considering current greenhouse gas emission trajectories, and accepting the premise that national and global initiatives to address catastrophic risks posed by climate change will become effective within the next decade, adaptive management strategies that build resilience and reduce vulnerabilities of freshwater wetland habitats will be increasingly crucial to their prognosis. While these have been described in more detail in Appendix 1, the key strategies include:

- reducing other non-climate change pressures impacting the condition and function of freshwater wetlands
- using catchment-based protective management approaches to secure high integrity wetlands, free-flowing rivers and catchment components and processes that underpin regulating and supporting ecosystems services for aquatic ecosystems
- considering climate change and ecological risks and external costs across all ecological and socio-economic dimensions and applying a global perspective in land and water resource planning and development decision making.

Sea level rise

Near coastal wetland complexes include significant freshwater components and represent some of the most important wetland ecosystems within the Great Barrier Reef catchment. They provide intrinsic biodiversity values and habitat for migratory birds. They are also seasonal productivity hotspots that support regionally significant populations of waterbirds, and nursery habitat for fisheries, while providing ecosystems services to downstream systems including the Great Barrier Reef.[17,32,57] These systems are highly exposed to projected sea level rise through to the turn of the century. Sea level rise is predicted to range from conservative estimates in the order of a metre[27] to potential multi-metre levels based on the most recent ice shelf melting data.[58]

Defining the likely amount and rate of sea level rise the coastline will experience is an area of ongoing scientific investigation. Current research suggests that IPCC (2014) projections of ~1m rise by 2100 are overly conservative due to the omission of Greenland and Antarctic ice shelf contributions, with contributions from the former alone projected to add a metre of sea level rise by 2100[58]. Historical evidence throughout the Holocene indicates 2.3 m sea level rise can be expected for every degree Celsius of global warming.[59]

For inundated freshwater wetlands, impacts will result in complete transformation to highly disturbed estuarine or marine systems. Wetlands on the immediate landward margin of sea level inundation areas will also be subject to potentially high levels of disturbance via saltwater intrusion of aquifers, landfall of cyclones and storm surge events.[7] High uncertainty surrounds predictions on the rate or ultimate extent of sea level rise and of the natural or managed adaptive capacity of near coastal wetlands to the pressures from sea level rise. Given the extremely high value of near coastal freshwater wetlands, and the prospect of their total degradation and loss due to sea level rise, a very high residual vulnerability for freshwater wetlands is assessed for this pressure.

Existing statutory planning frameworks may have some capacity to address adaptive management needs in relation to sea level rise, however there has been little application of them trialled within the Great Barrier Reef catchment. Research and development of sea level rise management approaches for freshwater wetlands and ecosystems generally within the near coastal zone is a priority. While options may be limited they could include: planned retreat of land use and built infrastructure to facilitate the landward migration of coastal wetland complexes; facilitated migration or establishment of coastal wetlands via landscape manipulation; and protective management of higher value wetland assets via works including constructed bunds on coastal plains or barrages on riverine systems. Each option carries some associated risks and warrants specific site and asset assessment.

Management of freshwater wetlands in the Great Barrier Reef catchment

The responsibility for the management of wetlands in the Reef catchment is with the Australian, state and local governments, landholders and the wider community. These responsibilities are formalised in laws and through international obligations. Various government agencies manage the wetlands through application of a range of laws, policies and programs.

These are often changing and up-to date information can be found at Wetland*Info* http://wetlandinfo.ehp.qld.gov.au/wetlands/management/policy-legislation/

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	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
Exposed to source of pressure **(Yes/No)**	Yes; Great Barrier Reef catchment wide. Pressure temporal dimension varies from long chronic strain to periodic stress. Usually greater pressure from weeds in more developed basins and due to feral animals in less developed basins.	Yes; Great Barrier Reef catchment wide with localised exclusions from urban, agricultural, protected and rainforest areas. Exposure to pressure depends on land management practices and wetland landscape context.	Yes; Great Barrier Reef catchment wide but variable exposure. Lower in higher rainfall Wet Tropics, and more intensively developed urban and agricultural, areas. Exposure to pressure depends upon land management practices and interacts with other pressures including invasive grass species and grazing.	Yes; Localised. Higher pressure in developed river basins from Cairns south, particularly those that support irrigated agriculture and/or major population centres and for wetlands downstream of major infrastructure. Pressure associated with both infrastructure and flow impacts.	Yes; Great Barrier Reef catchment wide. Greater pressure is associated with areas of both existing and proposed more intensive development, (i.e. within river basins from Daintree south and predominantly on the near coastal lowlands within these basins). Pressure is associated with land use intensity, and pattern and both direct site impacts on freshwater wetlands (including instream infrastructure) and indirect impacts via disturbance on catchment biophysical processes and contribution to contaminant loads in catchment run-off.	Yes; Great Barrier Reef catchment wide. Pressure temporal dimension varies from long chronic strain to periodic stress. Pressure closely related to catchment development pattern, land use practices and entrained land degradation processes. Catchment run-off pressure is comprised of both contaminant loads and altered run-off hydrology.	Yes; Great Barrier Reef catchment wide. Long temporal scale chronic pressure.	Yes; Localised to near coastal lowlands. Potential for regional and basin wide significant impacts as a result to changes to dependent ecological processes and species.

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
Degree of exposure (low, medium, high)	Variable: Low to High **Low:** Where basins are undeveloped (retain natural hydrology and remnant vegetation cover) and feral animal populations are not large. **Medium:** Where river basins have moderate levels of land and water resource development and catchment contaminant loads remain predominantly below ecosystem health thresholds and/or feral animal populations are moderate. **High:** Where basins have high levels of land and water resource development and catchment	Variable: Low to High **Low:** Where wetlands occur in areas where grazing usually excluded e.g. urban, agricultural, protected and rainforest areas. **Medium:** Where stock total carrying capacity managed in relation to seasonal forage and/or fencing/ seasonal grazing used to reduce site impacts or landscape context of wetlands reduces stock access or site impact levels. **High:** Where stock total carrying capacity high and/or not managed in relation to seasonal forage and/or wetland forage resources significant relative	Variable: Low to High **Low:** Where: • fire regime actively managed for ecological objectives, (e.g. some protected areas and Traditional Owner managed lands) • wetlands occur in areas where fire naturally suppressed /infrequent (e.g. Wet Tropics or in areas where fire actively supressed such as more intensively developed urban and agricultural, areas including sugarcane growing areas using green cane harvesting) Noting that the complete suppression of fire also presents potential fire regime impact	Variable: Low to Very High Depends on the level of water resource development within the basin and the wetland location in relation to it. **Low:** Where wetlands occur: • in basins with little or no water resource development. • upstream of infrastructure and flow impacts in developed river basins • downstream of water resource development but infrastructure impacts are not significant and flow regime changes and extraction levels remain below thresholds that lead to changes in ecosystem function and condition.	Variable: Low to Very High **Low:** Where: • wetlands occur in protected or relatively undeveloped basins /catchments • built infrastructure is limited and land use intensity is low (i.e. traditional use or rangeland grazing on unimproved native pastures and there is no proposed intensification of land use). **Medium:** Where wetlands occur: • in basins /catchments with mixed land uses including more intensive agricultural development or areas of settlement but overall land use	Variable: Low to Very High **Low:** Where: • wetlands occur in protected or relatively undeveloped basins • land use intensity is low (i.e. traditional use or rangeland grazing on unimproved native pastures) and land management practices provide for retention of adequate ground cover during rainfall periods; and have avoided extensive development of land degradation (particularly alluvial gully and waterway bank erosion); and there is no proposed intensification of land use. **Medium:**	Variable: High to Very High Freshwater wetland exposure to climate change impacts is increasing with time. Wetland type, condition and catchment development context will differentiate the sensitivity and rate of exposure of freshwater wetlands to climate change impacts. Exposure of freshwater wetlands across the board is assessed to be high to very high over decadal timescales. This assessment is made on the basis that the quality and persistence of freshwater aquatic habitats depends	Variable: Low to Very high Exposure depends on amount of sea level rise experienced before global atmospheric greenhouse gas stabilisation is achieved, and wetland location in relation to the marine inundation zone (i.e. wetland proximity to coast, elevation and hydrological connectivity to estuarine / marine systems). For wetlands outside the inundation zone, exposure will also occur on the basis of dependent biotic linkages with it (e.g. freshwater fish species with coastal freshwater / estuarine nursery habitats).

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
	contaminant loads predominantly exceed ecosystem health guidelines and/or large populations of feral animals occur.	to surrounding landscape and fencing configurations do not support conservative grazing management.	risks). **Medium:** Where fire regime management /controlled burning conducted but not primarily for ecological objectives (e.g. where wetlands occur within pastoral properties and burning regime inappropriate in terms of season or frequency) and/or where controlled burns are conducted but excessive fuel load conditions are created by invasive grass species. **High:** Where wetlands are: • subject to frequent and/or too hot fire regimes includes remnant areas where fuel load excessive due to invasive	**Medium:** Where wetlands occur: • in basins downstream of water resource development and infrastructure and flow regime changes and extraction levels are sufficient to generate some changes in wetland function and condition • upstream of major water infrastructure that represents a partial connectivity barrier that has altered wetland community species composition and basin population levels. **High:** Where wetlands occur in basins downstream of major water resource development and	pattern is variegated with intensive use areas occurring as nodes on suitable land types and most drainage lines and off stream wetlands retained within contiguous areas or corridors of remnant vegetation or within areas of less intensive use • in areas with currently low exposure but are being subject to land use intensification • in relatively undeveloped basins but built infrastructure that generates direct site impacts on wetlands (e.g. bund walls, dams, road crossings) is common. **High – very high:**	Where wetlands occur: • in basins with mixed land uses (including more intensive agricultural development or areas of settlement) but overall land use pattern is variegated (with intensive use areas occurring as nodes on suitable land types and most drainage lines and off stream wetlands retained within contiguous areas or corridors of remnant vegetation or within areas of less intensive use) • in areas with relatively low exposure but are being subject to land use intensification • in basins with predominantly extensive (compared with	heavily on the climatic and hydrologic regimes impacted by climate change[5,25,59] and on the fact that global greenhouse gas emissions are currently tracking[24] in line with the worst case representative concentration pathway (RCP 8.5) scenarios modelled by the IPCC[25,26,27] This presents the spectre of global warming going beyond 1.5 – 2 degrees Celsius which will create climate and sea level impacts that will last for millennia and risks taking the global climate system into the realm of dangerous uncontrollable climate change[28].	**Low:** Where wetlands occur outside of the ultimate sea level rise inundation zone and are not hydrologically connected to it (including via flood and storm surges) and do not host significant populations of biota with dependent linkages to this zone. **Medium:** Where wetlands occur on the inland boundary of the ultimate sea level rise inundation zone and have some periodical hydrological connectivity to it (i.e. via stream flow, flood inundation levels or storm surges) and/or occur outside the inundation zone but host

	Pressures							
	Invasive species	Grazing	Altered fire regimes	Water resource development	Catchment development	Catchment run-off	Climate change	Sea level rise
			pyrophytic grasses and or exclusion of grazing (including protected areas adjoining regularly burnt pastoral areas) • more intensively developed seasonally dry urban and agricultural areas extend suppression / too infrequent burning, which results in realised wildfire risks • sugarcane growing areas use burnt cane harvesting resulting in remnant wetlands exposure to regular unintentionally burning • or where wetlands are intentionally	infrastructure and flow regime changes (including both reduced flows or additional / aseasonal flows) and extraction levels move system across thresholds that generate major changes in wetland function and condition or wetland occurs upstream of major water infrastructure that represents a complete connectivity barrier and wetland community species composition and basin population levels has been altered. **Very high** Where wetland is the site for water resource infrastructure development e.g. riverine, lacustrine wetland	Where wetlands occur: • in basins /catchments dominated by more intensive agricultural or urban / industrial development with overall land use pattern predominantly monotypic intensive use with remnant vegetation areas occurring as isolated patches, drainage lines as narrow discontinuous and/or degraded riparian vegetation corridors and off stream wetlands retained as isolated remnants often lacking riparian vegetation within intensively developed contributing catchment areas • in areas with currently	intensive) land use (e.g. rangeland grazing on unimproved native pastures) but extreme weather events droughts/floods significantly impact catchment condition • in basins that past or current land management practices have not ensured for the retention of adequate ground cover during rainfall periods, and there has also been significant development of land degradation (particularly alluvial gully and waterway bank erosion) • In areas where cumulative impact of catchment condition changes and/or irrigated farm /		significant populations of biota with dependent linkages to it. **Very high** Where wetland occurs within the sea level rise inundation zone. Will ultimately experience complete transformation to highly modified / novel estuarine – marine system.

	Pressures							
	Invasive species	Grazing	Altered fire regimes	Water resource development	Catchment development	Catchment run-off	Climate change	Sea level rise
			burnt as part of farm fire risk management [13]	developed to dam, weir, holding storage.	medium exposure but are being subject to land use intensification or wetlands occur in moderately developed basins but built infrastructure that generates direct site impacts on wetlands (e.g. bund walls, dams, road crossings) is extensive.	point source discharges results in some hydrological changes in receiving aquatic ecosystems. **High – very high** Where wetlands occur in basins : • with a predominantly extensive land use pattern but there has been significant current or historical development of land degradation (particularly alluvial gully and waterway bank erosion) and some impairment of regulatory ecosystems services controlling contaminant load retention/ transport. • with a variegated pattern of land use but land use practices result in significant off		

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
						site export of contaminant loads and regulatory ecosystems services controlling contaminant load retention/transport have been impaired • with a land use pattern dominated by more intensive agricultural or urban / industrial development with overall land use pattern predominantly monotypic intensive use with remnant vegetation areas occurring as isolated patches, drainage lines as narrow discontinuous and/or degraded riparian vegetation corridors, and off stream wetlands retained as isolated remnants (often lacking riparian		

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
						vegetation) within intensively developed contributing catchment areas • with currently medium exposure to run-off pressures but are being subject to land use intensification • receiving point source waste water discharges or extreme weather events droughts/floods significantly impact catchment condition • where moderate to high exposure to catchment run-off already exists • where the cumulative impact of catchment condition changes and/or irrigated farm / point source discharges results in major sustained hydrological		

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
						changes in receiving aquatic ecosystem.		
Sensitivity to source of pressure **(low, medium, high, very high)**	Variable: Low to Very High. **Low:** Where degree of exposure results in small spatial or temporal scale impact stress but no longer term strain. **Medium** where degree of exposure results in greater temporal and/or spatial scale impacts the strain of which changes wetland structure or function. **High to Very High** where degree of exposure results in large scale temporal and/or spatial scale impacts generating chronic strain which completely alters wetland structure	Variable: Low to High. **Low:** Where degree of exposure to pressure is low to medium, and/or where wetland type is resilient to pressure, or wetland condition relatively improved by pressure exposure (e.g. where pasture grass weeds and/or fire fuel loads reduced by grazing). **Medium:** Where degree of exposure to pressure is medium, and/or wetland type or landscape context increase its vulnerability to pressure, or existing disturbed wetland condition has reduced	Variable: Low to High. Dependent upon wetland type and nature of altered fire regime e.g. frequency, season Low where wetland occurs within seasonal tropics and supports fire adapted (sclerophyll) vegetation and has not been subject to other pressures resulting in structural or floristic changes. **Medium:** Where wetland supports fire adapted (sclerophyll) vegetation but has been subject to other pressures (invasive species, development) resulting in some structural or	Variable: Low to Very High. **Low:** Where wetland exposure to pressure is low and effects on wetland condition or function fall within range of natural variability and system resetting capacity provided by key natural flow regime components remains. **Medium:** Where wetland exposure to pressure is sufficient to affect condition (including community or habitat composition) or function (connectivity, refugia, baseflow) of wetland in some years and	Variable: Low to High. Dependent upon exposure to pressure and temporal dimension of associated impacts (e.g. short term stress versus longer term strain). Sensitivity in also influenced by wetland type and contrast between baseline conditions and those created by development e.g. closed versus open canopy, seasonal versus perennial flows etc). **Low:** Where exposure to development pressure is low and condition and functional processes of	Variable: Low to High. Dependent upon exposure to pressure and temporal dimension of associated impacts (e.g. short term stress versus longer term strain). Sensitivity in also influenced by wetland type and contrast between baseline conditions and those created by catchment run-off pressure e.g. clearwater system versus turbid, oligotrophic versus eutrophic etc, and by the occurrence and frequency of extreme weather events (droughts / floods). **Low:**	Variable: Low to Very High. Sensitivity to exposure will ultimately depend upon the level of pressure generated by climate change before and if and when mitigation efforts become effective. Unmitigated climate change is recognised as having the potential to ultimately generate catastrophic impacts to all contemporary ecosystems including freshwater wetlands[28]. In this context described sensitivity is relative and based on the premise	Variable: Low to Very High. **Low:** Where wetland lies outside of sea level rise inundation zone **Medium – high** where wetlands occur on the inland boundary of the sea level rise inundation zone and have some periodical hydrological connectivity to it (i.e. stream flow, flood inundation levels or storm surges) and hosts significant populations of biota with dependent linkages to it. In wet tropics environments with higher rainfall shallow freshwater aquifers may provide enhanced

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
	and function.	sensitivity to further potential grazing associated impacts. **High:** Where degree of exposure to pressure is high, and/or wetland type or landscape context make it highly vulnerability to pressure, or a wetland's relatively undisturbed/pristine condition increase relative sensitivity of wetland to potential grazing associated impacts.	floristic changes that impact fire fuel load or behaviour or wetland occurs within wet tropics and supports fire sensitive (broad leaf) vegetation and is juxtaposed with fire adapted vegetation subject to too hot/frequent fire regime. **High:** Where wetland supports: • fire adapted (sclerophyll) vegetation but has been subject to other pressures (invasive species, development, grazing) that have resulted in major structural and floristic changes that have totally alter fire fuel load and/or behaviour • fire sensitive (broad leaf)	wetland habitat conditions moves from original state and has increased vulnerability to other pressures in some years (e.g. water quality decline, weed infestation). **High – very high:** where wetland is exposed to high / very high pressure and condition (including community or habitat composition) and function (connectivity, refugia, nutrient cycling) of wetland in modified in all years and wetland habitat condition moves to degraded state with synergistic realisation of other pressure risks (e.g. water quality decline, weed infestation). **High** sensitivity occurs when the component of flow	wetland have not been impaired. **Medium:** Where development pressure has resulted in some impairment of wetland condition or functional processes by either direct site impacts (e.g. encroachment onto riparian vegetation, or instream /flow path structures or works altering hydrology / connectivity or via off site impacts to catchment hydrological processes via hard panning, groundwater recharge reductions etc). Also operates in concert with run-off contaminant loads (discussed separately). **Medium** sensitivity occurs	Where exposure to catchment run-off pressure is low, weather conditions are not extreme and contaminant loads and flows received from catchment run-off result in ambient water quality conditions within ecosystem health guidelines and no significant alteration of wetland hydrology. **Medium** where exposure to catchment run-off pressure is medium and flows and contaminant loadings from the catchment periodically result in ambient water quality conditions exceeding ecosystem health guidelines for one or more parameters and/or some significant alteration of wetland	that national and global initiatives to address risks posed by climate change will become effective within the next decade. **Low:** Where wetlands are in good condition and occur: • in undeveloped and/or protected catchments outside of the immediate coastal zone (cyclone landfall, storm surge areas) • in wet tropics regions with high and evenly distributed rainfall, • in areas that receive significant baseflow contributions from deeper groundwater aquifers with	resilience against salt water intrusion impacts than in seasonally dry tropics. **Very high:** Where wetland occurs within the sea level rise inundation zone.

	Pressures							
	Invasive species	Grazing	Altered fire regimes	Water resource development	Catchment development	Catchment run-off	Climate change	Sea level rise
			vegetation but has been subject to other pressures (invasive species, development, grazing) that have resulted in structural and floristic changes that have introduced fire into the wetland and make it prone to ongoing burning.	regime affected by water infrastructure development or extraction e.g. peak overbank flood flows reduced by dams, are key drivers of wetland functions (e.g. connectivity) and habitat condition (e.g. channel scouring).	where impacts result in short or extended term stress but not long-term chronic strain, generating altered but still functional wetlands. Secondary pressures (weeds, water quality decline) can establish during stressful periods which are often mitigated by climatic conditions, with stress occurring during more extreme weather and being reduced by habitat resetting events (e.g. flushing flood events, extended base flows) under better weather conditions. **High – Very High:** Where exposure to development pressure is high and wetland has been impacted by	hydrology, resulting in the establishment of some secondary pressures (weeds, water quality decline and condition and function impacts associated with short or extended term stress but not long-term chronic strain, generating altered but still functional wetlands. Sensitivity to such stressful periods are often mitigated by climatic conditions, with stress occurring during more extreme weather and being reduced by habitat resetting events (e.g. flushing flood events, extended base flows) under better weather conditions. Extreme weather events droughts/floods	limited other pressures (e.g. catchment run-off, invasive species, water resource development) operating. **Moderate** sensitivity will be experienced by wetlands that fall within the range of conditions described for low (above) or High (below) sensitivity. This will include wetlands in higher, evenly distributed rainfall regions but with greater levels of other operating pressures that can be exacerbated by climate change or alternatively wetlands in more seasonal climatic regions but with less or few other pressures operating that can be exacerbated by climate change.	

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
					the combination of permanent site (changes in channel form, riparian vegetation structure) and off site impacts (flow paths, connectivity, run-off hydrology, groundwater discharge) which have facilitated the establishment of secondary pressures (weeds, water quality decline, floristic changes) creating long-term chronic strain which persists in the absence of habitat resetting and recuperative processes. **High** sensitivity occurs where wetland conditions under development pressure represent a major departure from baseline e.g. seasonal versus perennial, closed canopy versus	that significantly impact catchment condition can also result in medium sensitivity in catchments where exposure to pressure is otherwise low. **High – Very High** Where the following occur in unison and result in long- term chronic strain, generating highly modified and dysfunctional wetlands: • high exposure to catchment run-off • flows and contaminant loadings from the catchment result in ambient water quality conditions permanently exceeding ecosystem health guidelines for one or more parameters • sustained alteration of wetland	**High-very high:** Where wetlands: • occur in the near coastal zone (cyclone landfall, storm surge areas) occur in highly seasonal climates, where biota are seasonally exposed to critical conditions (including waterhole stratification and/or temperatures nearing their thermal maxima) • or depend on a small number of functional aquatic refugia to sustain obligate aquatic biota through dry seasons • are dependent on groundwater discharge from shallow aquifers • are exposed to existing pressures that are exacerbated by higher temperatures	

	Pressures							
	Invasive species	Grazing	Altered fire regimes	Water resource development	Catchment development	Catchment run-off	Climate change	Sea level rise
					open, brackish versus permanent fresh, scoured versus un-scoured, sandy versus muddy substrate.	hydrology, • establishment of multiple secondary pressures (weeds, water quality decline) Sensitivity to such stressful periods is often mitigated by climatic conditions, impacts exacerbated during more extreme weather and being reduced by habitat resetting events (e.g. flushing flood events, extended base flows) under better weather conditions. Extreme weather events droughts/floods that significantly impact catchment condition can also result in high sensitivity in catchments where exposure to pressure is otherwise medium.	and extreme climate events increasing due to climate change (e.g. poor/degraded catchment condition, eutrophication, chronic weed infestations, water resource development / altered flow regimes, hot fire regimes, high sediment and other contaminant loads and flow or reach condition based connectivity impacts).	

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
Adaptive capacity natural (Poor, moderate, good)	**Variable**. **Poor** if structure and function of wetland modified and other pressures contributing to invasive species success (e.g. catchment run-off, water resource development) remain unaltered. **Moderate** if structure and function of wetland not completely modified and there are no other operating pressures or changes in catchment processes driven by other pressures associated with catchment run-off, water resource development are within ecosystem health thresholds and/or retain habitat resetting functions (e.g.	**Variable**. **Poor** if exposure to pressure has been high and sustained or wetland type or landscape context make wetland highly sensitive to pressure and structure and function of wetland have been modified to degraded condition state which lacks recuperative capacity or which is maintained by other operating pressures. **Moderate** if exposure to pressure has been sustained medium or episodic high or wetland type or landscape context provide wetland with resilience to pressure and modified structure and function of wetland not beyond	**Variable**. Depends on the fire sensitivity and condition of the wetland and whether the altered fire regime is sustained. **Poor** if the altered fire regime is sustained and associated impacts frequent and wetland is a fire sensitive community and other pressures have altered its structure and fuel load characteristics or if the wetland is a fire adapted community but other pressures have cause major alteration in structure, elevated fire fuel loads and frequent fire impacts undermine its recuperative capacity. **Moderate** if frequency of fire	**Variable**. Adaptive capacity depends on level of exposure to pressure, sensitivity of system and level of functional change. **Poor** where water resource infrastructure is located on the wetland and/or flow impacts are sustained/ permanent or operate at large basin scales (e.g. large dams in upper catchment, weir barriers in lower catchment) and effect key flow or connectivity associated ecological processes and functions (e.g. overbank flood flows, seasonal water level draw down, perenniality, baseflow, channel scouring) and	**Variable**. **Poor** where exposure and sensitivity is high, including where wetland conditions under development pressure represent a major departure from baseline and development associated site and off site impacts including to catchment processes and wetland functions are permanent and secondary pressures have established creating long-term chronic strain. **Moderate** where exposure and sensitivity is medium and only some impairment of wetland condition or functional processes has occurred resulting in short or extended term	**Variable**. **Poor** where exposure and sensitivity is high, including where wetland conditions created by runoff pressure represent a major departure from baseline conditions and changes in wetland condition and function are sustained due to long-term chronic strain. **Moderate** where exposure and sensitivity is medium and only some impairment of wetland condition or function has resulted from short or extended term stress but not long-term chronic strain associated with the permanent establishment of dominating secondary pressure and	**Poor - Moderate** The capacity for adaptation is not well understood and as for preceding comments on pressure exposure, degree and sensitivity, capacity can only be described in a relative sense within the premise that climate change mitigation will become effective within the nearer term to avoid its full catastrophic potential. **Poor** natural adaption capacity will be associated with wetlands that occur in regions that naturally have relatively extreme climatic conditions (i.e. highly seasonal, low rainfall and temperature regimes near the thermal maxima for biota).	**Variable**. The capacity for adaptation is sea level rise rate and extent determinant and the upper boundaries for these are not yet resolved. Therefore the capacity is described for wetlands outside of, on the boundary of or within the sea level rise inundation zone. **Poor** where wetland occurs within the sea level rise inundation zone. Will ultimately experience complete transformation to highly modified / novel estuarine – marine system. **Moderate** where wetlands occur on the inland boundary of the ultimate sea level

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
	flood spates). **Good** where structure and function of wetland relatively unmodified and there are no other significant operating pressures or changes in catchment processes associated with catchment run-off, water resource development pressures are within ecosystem health thresholds.	recuperative capacity which is not retarded by significant other pressures (weeds, altered hydrology). **Good** if exposure to pressure has been only sustained low or episodic medium or wetland type or landscape context are resilient to pressure and structure and function of wetland have not been modified and no other pressures are operating or significant.	impacts associated with altered fire regime is medium and wetland is a fire sensitive community but has not experienced structural changes due to other pressures or is a fire adapted community but has experienced only some structural or floristic changes that impact fire fuel loads/ behaviour and recuperative capacity. **Good** if wetland is a fire sensitive or fire adapted community that has not experienced structural changes due to other pressures and fire impacts associated with altered fire regime occur less frequently than the time required	result in synergistic secondary pressures (e.g. weed infestation, water quality decline, structural and composition changes) that perpetuate degraded condition state. **Moderate** where water resource infrastructure impacts are partially mitigated (e.g. fish passage, environmental releases) and/or flow impacts are not experienced in all years and some key flow or connectivity associated ecological processes and functions (e.g. overbank flood flow habitat resetting) still occur albeit possibly at a lesser frequency or magnitude, reducing opportunities for	stress but not long-term chronic strain and there has been no permanent establishment of dominating secondary pressures and periodic habitat resetting events still occur. **Good** where exposure and sensitivity is low and condition and functional processes of wetland have not been significantly impaired despite small spatial or temporal scale impacts associated with development pressure.	where periodic habitat resetting events (flushing flood flows, extended baseflows) still occur. **Good** where exposure and/or sensitivity is low and condition and functional processes of wetland have not been significantly impaired despite small spatial or temporal scale impacts associated with catchment run-off pressures.	Increased temperatures and climatic variability in such regions is likely to result in the extirpation of biota and the loss of or increased external pressure (e.g. from grazing stock) on aquatic refugia upon which obligate aquatic biota depend in highly seasonal aquatic ecosystems. Where wetlands (and their contributing catchment areas) have existing condition impacts that can be exacerbated by greater climatic variability (e.g. soil erosion, weed infestations, poor water quality e.g. low dissolved oxygen, eutrophication associated with high catchment contaminant loads), natural adaption capacity	rise inundation zone and have some periodical hydrological connectivity to it (i.e. via stream flow, flood inundation levels or storm surges). In wet tropics environments with higher rainfall shallow freshwater aquifers may provide enhanced resilience against salt water intrusion than in seasonally dry tropics allowing freshwater riparian communities to persist longer providing a more stable environment for colonisation by tidal mangrove communities. Adaptive capacity will also be mediated by extreme weather event frequency particularly

	Pressures							
	Invasive species	Grazing	Altered fire regimes	Water resource development	Catchment development	Catchment run-off	Climate change	Sea level rise
			for each of these community types to recover.	longer term system stain emerging in relation to secondary pressures (e.g. weed infestation, water quality decline, structural and composition changes). **Good** where water resource infrastructure connectivity impacts are avoided or fully mitigated (e.g. off stream storage, biota bypass channels) and/or flow / extraction impacts are below thresholds that drive ecosystem change including via targeting components of natural flow regime that allow for maintenance of key flow or connectivity associated ecological processes and functions (e.g. baseflows,			will also be poor. Where wetlands occur on the edge of wet tropical or upland biogeographic / climatic boundaries and climate change pushes these sites into drier, hotter climatic settings with different flow regimes e.g. wet tropics to seasonal dry tropics the adaptive capacity of the existing communities particularly to novel; pressures such as fire and flow cessation will be poor. **Moderate** natural adaption capacity to climate change will be associated with: • wetlands that have not had their resilience undermined by other site or catchment	cyclones and storm surges. **Good** where wetlands occur outside of the sea level rise inundation zone or in the longer term on inland boundary of the ultimate sea level rise inundation zone once sea level rise reduces to median historical rates or stabilises.

	Pressures							
	Invasive species	Grazing	Altered fire regimes	Water resource development	Catchment development	Catchment run-off	Climate change	Sea level rise
				overbank flood flow habitat resetting) and the establishment of secondary pressures (e.g. weed infestation, water quality decline, structural and composition changes) have been avoided.			condition pressures. • wetlands that occur in areas that naturally have moderate levels of climatic variability in which biota have preadapted to seasonal stresses that will be enhanced under climate change. This capacity will be enhanced where flow regimes are partially supplied by groundwater contributions (that maintain flows and/or refugia) - particularly those associated with deeper aquifers (not as readily impacted by seasonal rainfall changes). • wetlands that occur in large hydrologically connected catchments that extend across climatic zones and contain a	

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
							range of associated flow regimes • wetlands with community members that have broader flow, water quality, temperature and fire regime tolerances.	
Adaptive capacity- management (Poor, moderate, good)	Moderate to Good. **Moderate** where significant investment of resources and catchment based management co-ordination is required where invasive species dominate systems on a large spatial scale, represent long-term chronic infestations or occur in remote areas with limited human resources. However management models developed within the Reef catchment in	Moderate to Good. **Moderate** where: • social /economic constraints limit opportunities to reduce high total grazing pressure • medium to high grazing pressure has been sustained for long periods • landscape context or type of wetland have made it susceptible to pressure and/or structure and function of wetland has been modified to	Poor to Good. Varies in relation to wetland community fire sensitivity, wetland condition and land use context. **Poor** where levels of wetland disturbance from other pressures (invasive grasses, climate change) create permanent changes in fuel load dynamics, and associated wild fire risks and have undermined natural recuperative capacity, and/or wetlands occur	Moderate to Good. **Moderate** where the following apply: • large scale older water infrastructure involved and/or wetlands are used as part of supply infrastructure • high levels of flow allocation are committed to consumptive uses • key flow and connectivity associated processes and	Moderate to Good. **Moderate** where the following apply: • Where wetland exposure and/or sensitivity to development pressures has been high • intensive land use in contributing catchments and abutting and into wetland boundaries is extensive • catchment development	Poor to good. Through integrated coastal management decision making, policies and legislation there is potential to explicitly recognise the intrinsic value of freshwater wetland habitat and implement protection. Significant actions are already underway to halt and reverse the decline in water quality entering the Great Barrier Reef including implementation of	Poor to Moderate. The extent and persistence of impacts from climate change will depend on the success of international efforts to curb the rate of accumulation of greenhouse gases in the atmosphere, and on the resilience of the ecosystem to the changes in climate that manifest over coming decades. Given current trajectories of greenhouse gas emissions,	Poor to Moderate The capacity to adaptively manage Reef catchment freshwater wetland assets in the face of pressures presented by sea level rise is not tried or tested. While this is an important area for research and development most suggested approaches remain largely theoretical and draw on experience gained on the creation and maintenance

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
	recent decades (stakeholder cost sharing, catchment based control and Land and Sea Ranger programs) have demonstrated that at least moderate outcomes can be achieved with sufficient resources. A key underpinning of the value of such investment is recognition that a functional albeit modified freshwater wetland condition although not representative of an unmodified baseline condition does provide an ecosystem service dividend. Legislative capacity underpinning declared weed species management is good but resource constraints of	degraded state • recuperative capacity is retarded by other operating pressures • wetland occurs in remote area with limited human resources, requires significant investment of resources in educational extension, provision of fencing materials, project coordination and labour. **Good** where • private landholders are supportive of wetland management goals • there are opportunities to reduce high total grazing pressure and/or financial	predominantly on private land, and land use conflicts limit ability to deliver appropriate burning regimes, and/or there is a lack of human resources with a capacity to deliver fire regime outcomes or alternatively entrenched burning practices are for objectives which conflict with wetland ecological outcomes. **Moderate** where levels of wetland disturbance from other pressures have not created permanent or major changes in fuel load dynamics and associated wild fire risk and wetlands retains some natural recuperative capacity and land use conflicts are limited providing default	functions have been lost from the system for an extended period • secondary pressures have become well established (e.g. water quality decline, weed infestation and community structural and compositional changes). Significant investment of resources and catchment based management co-ordination, including statutory tools provided by Water Resources legislation is required to deliver adaptive management via retrofitting impact mitigating design features to infrastructure (e.g. bio passage), reallocating water to meet environmental	thresholds have been exceeded to where biophysical process integrity and associated ecosystem service provision has been undermined. In this development context much natural adaptation capacity has generally been lost and secondary pressures (weeds, water quality decline, altered hydrology) have established. Required adaptive management in this context is resource intensive though can usually draw upon greater human and financial resources than management needs in less developed basins and is predicated on the recognition	the *Reef Water Quality Protection Plan* and development and implementation of Healthy Waters Management Plans. Waste water discharge quality is legislated. A degree of uncertainty surrounds several elements of water quality management including thresholds, models of run-off, and effectiveness of strategies to minimise run-off from agricultural lands. **Poor** where exposure and sensitivity to run-off pressure is high and impacts to wetland condition and function have emerged as a result of long-term chronic strain.	strategies that build resilience and reduce vulnerabilities of freshwater wetland habitats will be increasingly crucial to their prognosis. Considering that most potential impacts of climate change on freshwater wetlands operate via exacerbation of existing pressures, recommended adaptive management responses largely represent consolidation of existing pressure management approaches. In summary the key wetland management responses nominated[6],[7] for climate change include: (1) Minimising the	of freshwater resources in tidal interface zones via protective bunding or barrages or alternatively on the coastal erosion management approach of planned retreat. Against the spectre of accelerating rates of sea level rise both of these approaches are likely at best to provide only a moderate management capacity. In many instances site or resource constraints will provide only a poor adaptive management capacity. **Poor** capacity will occur where: • rates of sea level rise are high and/or

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	individual landholders remain an impediment. **Good**: where • infestations are spatially constrained, detected early, occur in relatively undeveloped or protected catchments • wetlands retain healthy ecosystem functions • species of concern are controlled by broadacre control methods or natural event (grazing, fire, tidal intrusion, flood spates) • subject to well resourced, catchment co-ordinated longer term control programs.	material incentives are available to support on ground management activities, and/ or high total grazing pressure has not been for sustained for long periods • wetland type or landscape context of wetland provide it with resilience to pressure and/or structure and function of wetland has not been modified to degraded state and/or subjected it to significant other pressures and/or substantive resources (human, financial, material) are available for management.	opportunities for more appropriate burning regimes and/or human resources with a capacity to deliver fire regimes for wetland ecological outcomes are available subject to resourcing and educational extension. **Good** where the following apply to wetlands: • they are less disturbed by other pressures • have not experienced substantive structural or floristic changes • retain natural recuperative capacity • where there are limited land use conflicts associated with maintaining appropriate burning regimes	flow requirements (including to emulate natural flow events and to mitigate critical events) and specific ancillary programs are implemented to address secondary pressures that have emerged in response to water resource development (e.g. water quality decline, weed infestations, community structural and compositional changes). A key underpinning of the value of such investment is the recognition that a functional albeit modified freshwater wetland condition although not representative of the unmodified baseline condition does provide an ecosystem service	that a functional albeit modified freshwater wetland provides an ecosystem service dividend. Required management interventions include reinstating and retrofitting catchment process functions (connectivity, run-off detention, groundwater recharge) and addressing the secondary pressures (weeds, water quality decline, floristic and structural changes) that have established due to development impacts and associated loss of catchment functions. Private land ownership and limited spatial opportunities present adaptive management	Adaptive management capacity is particularly limited where the following occur together: • contributing catchment areas are dominated by intensive development that is associated with high contaminant loads (e.g. irrigated agriculture) • natural catchment buffers (e.g. vegetated drainage lines and detention areas) associated with the provision of ecosystem services that regulate the retention and transport contaminant loads have been lost or degraded • development	impact of non-climate change pressures to increase wetland resilience and reduce overall pressure they face as climate changes (2) Increasing catchment scale ecosystem resilience by protecting free flowing rivers and tributaries wherever possible (3) Increasing gazettal of comprehensive adequate, representative and efficient aquatic ecosystem protected areas to provide focus nodes for management of rivers and wetlands and ensure existing legislative commitments for protected areas (i.e. Ramsar wetlands) are met	freshwater wetlands occur on low gradient, flat coastal lowlands • site occurs in seasonal dry tropics and seasonally lacks freshwater discharge and/or freshwater aquifer levels can maintain a hydraulic head against sea water intrusion • there are high levels of hydraulic connectivity via channels or groundwater with estuarine/marine areas • areas landward of coastal wetlands are intensively developed limiting opportunities (including via hard walling) for inland migration

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			• there are dedicated human resources with a capacity to deliver ecological fire regime outcomes (some protected areas, Traditional Owner lands).	dividend. **Good** Where the following apply: • water infrastructure is off stream or if on stream is not large scale and has connectivity impacts mitigated by biopassage • statutory Water Resource Planning has ensured flow allocations to meet the needs of flow dependent ecological assets including (via the retention of flow regime elements that drive important ecological functions) • the condition of system has been managed to avoid establishment of secondary	constraints in such intensively developed catchments. **Good** Where the following apply: • wetland exposure and/or sensitivity to development pressures has been low to moderate • catchment land use patterns are variegated retaining a mix of intensive and extensive land uses with remnant vegetation • catchment development levels have not undermined the integrity of all biophysical process and the associated capacity for ecosystem service provision.	status has generated permanent changes in catchment run-off hydrology (e.g. hard panning, laser levelling) • where land tenure is predominantly freehold • development density presents limited spatial opportunities for reinstatement of buffer and detention functions. In less intensively developed basins widespread land degradation e.g. subsoil exposure/ gully erosion can also contribute to poor adaptive management capacity. Other constraints include where: • secondary	(4) Protecting and restoring functionally important catchment ecosystem elements such as riparian zones and other catchment vegetation cover to increase receiving freshwater ecosystem resilience (5) Moving beyond current environmental flows to restoration of flow regimes (including flow manipulation in highly regulated systems) that efficiently focus on key ecosystems and processes, protected areas and significant sites (6) Reducing anthropogenic impacts on aquatic refugia, gain an improved understanding of their spatial and temporal extents	of coastal interface wetland complexes • the site is remote and available human resources are limited. **Moderate** capacity will occur where: • rates of sea level rise are low-medium • freshwater wetlands occur on higher gradient, relatively elevated sloping coastal lowlands • site occurs in wet tropics where sustained freshwater discharge or aquifer levels maintain a hydraulic head against sea water intrusion • there are low levels of

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				pressures.	Good adaptive management is also supported where good-moderate natural adaptation capacity has been retained and few secondary pressures have established. Adaptive management in this development context needs to address pressures associated with both existing and potential future development. This requires a mix of asset protection for high integrity wetlands and important functional processes, threat management to address and prevent secondary pressures (weeds, bank stability etc.) and system restoration for where existing development	pressures (e.g. weeds) have become entrenched • natural adaptive management capacity has been lost • cultural practice and economic pressures are an impediment to adoption of Best Management Practices on farm • where the climate is highly seasonal and tending toward more frequent extreme events. Moderate where exposure and sensitivity to run-off pressure is medium and catchment land use, condition, functional process integrity and natural adaptive management capacity lies between that	and increase their recognition in policy frameworks (7) Improving governance and adaptive management including use of catchment management frameworks, legislation that supports the resilience of rivers and wetlands, integration of aquatic ecosystem conservation management responsibilities at a catchment scale and adaptive management based on (1) set management objectives, (2) identified action thresholds and (3) monitoring. Considering these management approaches: **Poor** adaptive management capacity will	hydraulic connectivity with estuarine/ marine areas • areas landward of coastal wetlands are undeveloped providing opportunities for inland migration of coastal interface wetland complexes • the site is served with sufficient human and other resources to deliver more intensive management options including bunding / barraging of high value assets, creation of managed brackish mixing zones, assisted landward migration / creation of freshwater wetland habitats within the coastal plain.

	Pressures							
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					pressure has impaired functions (hydrology, connectivity). Through integrated state and local government development decision making, policies and legislation there is potential to explicitly recognise the intrinsic value of wetland habitat and implement protection during new development. Developments are subject to assessment, licensing and conditions that can protect freshwater wetlands. Codes of practice and water sensitive urban design are in place to manage stormwater in local areas.	described for poor (above) and good (below). **Good** where exposure and sensitivity to run-off pressure is low and existing impacts to wetland condition and function have emerged as a result of short term or spatially limited stress rather than long-term strain. Adaptive management capacity is best where contributing catchment areas have limited intensive development associated with high contaminant loads and natural catchment buffers remain or are capable of being repaired/ reinstated and catchment run-off hydrology behaves similar to baseline	generally be associated with wetlands that retain only poor natural adaption capacity (described above), particularly where they occur in remote areas with entrenched land use pressures and limited human or other resources to address other operating pressures. **Moderate** adaptive management capacity will be associated with wetlands that retain moderate natural adaption capacity (described above) particularly where they occur in relatively undeveloped high integrity basins with higher rainfall and climatic regions less exposed to seasonal	

	Pressures							
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					Erosion and sediment control plans are legislated requirements during construction phases of development. Penalties apply for non-compliance. Cumulative impacts are however difficult to assess.	conditions in terms of flow duration curves and land degradation is limited. Management capacity is also enhanced by an absence of entrenched secondary pressures (e.g. weeds) where: • natural adaptive management capacity remains • there are economic and/or legislative incentives to support adoption of Best Management Practices on farm • and where the climate is less seasonal and extreme events infrequent.	extremes. In more developed basins, a moderate adaptive management capacity could be achieved through higher levels of investment in addressing other existing pressures on catchment and wetland condition including through dedicated flow regime management in more highly regulated basins predicated on the recognition that a functional albeit modified freshwater wetland provides an ecosystem service dividend.	

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Residual vulnerability (Low, medium, high)	**High**	**Medium**	**Medium**	**High**	**Low** for undeveloped basins, extensive land use (grazing) areas and protected areas. **High** for intensive agricultural lowland areas, population centres and proximal coastal plains / hinterlands. Cumulative impacts are difficult to assess and manage. There are issues with capacity to limit development within contributing catchments to prevent it exceeding thresholds that result in loss of biophysical functional integrity and associated ecosystem service provision.	**Low** for undeveloped basins dominated by extensive land use (grazing) where it is not associated with significant soil erosion, and protected areas. **Medium** for basins with a variegated land use pattern and which retain catchment ecosystems services which regulate contaminant loads and transport and **High** for catchments dominated by intensive land use and or containing extensive areas of land degradation particularly gully erosion. Addressing the poor water quality /high contaminant loads in Great Barrier Reef catchment run-off	**High–very high** This vulnerability recognises the current status of global emissions trajectories and likely response time to as yet unimplemented mitigation strategies. Wetlands in relatively undeveloped larger basins / catchments with higher rainfall and limited other pressures affecting site or catchment condition have the lowest vulnerability to climate change associated impacts.	Very high

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						is not a short-term problem with a simple solution. It will take many years to improve practices that generate contaminant loads throughout Reef catchments and also to allow for the targeted repair and reinstatement of catchment ecosystems services that regulate their transport and retention.		
Level of confidence in supporting evidence (Poor, moderate, good)	**Good.**	**Good**	**Good.**	**Good.** Knowledge of relationship between water resource development thresholds and	**Moderate**. Cumulative impacts are difficult to assess. Knowledge of catchment	**Moderate.** Knowledge of end of catchment loads good but transport pathways uncertain.	**Poor.** High uncertainty surrounds predictions for the magnitude or rate of climate change impacts that will	Poor High uncertainty surrounds predictions on the rate and ultimate extent of sea level rise and of the

	Pressures							
	Invasive species	**Grazing**	**Altered fire regimes**	**Water resource development**	**Catchment development**	**Catchment run-off**	**Climate change**	**Sea level rise**
				key flow driven processes requires further development.	development threshold relationships to biophysical process integrity and ecosystem service delivery requires further research.	Knowledge of thresholds of tolerance to pollutants, as well as light limitations is poor. A degree of uncertainty surrounds effectiveness of strategies to minimise run-off from agricultural lands.	be experienced by Reef catchment wetlands.	natural or managed adaptive capacity of coastal wetland complexes to sea level rise.

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