

Chapter 7

Performance indicators and monitoring programs

The purpose of this chapter is to identify quantitative indicators for monitoring the status of the identified ecological assets.

Table 6-1 provides potential indicators of ecological values and mechanisms for monitoring ecological outcomes of water resource management. The following section provides a summary of the key monitoring elements, with particular reference to flow monitoring, that could be undertaken for the purposes of the Water Resource Plan.

7.1 High-integrity low-order stream reaches of upper catchments

7.1.1 Timing of first filling of channel pools

This is an indicator that surface runoff patterns have not been impacted such that the timing of initiation of colonisation and pool community development has been substantially delayed.

While ecologically relevant and directly flow related, this would be difficult to measure via ground access in isolated headwater streams, especially during rainy conditions. Aerial photography could prove a cost-effective method to rapidly survey pool infilling during the early wet season, weather and cloud cover permitting. This would also enable broad coverage of little or no impact areas and potentially impacted areas to provide statistical power for what will be a naturally highly variable response in low order streams.

7.1.2 Duration of base flow beyond wet season

The persistence of pools in these upper-catchment areas after the wet season, when soil moisture is falling, will provide for completion of the aquatic life stages of a wider range of pool flora and fauna in intermittent pools than would be possible for pools that only persist during the wet season. This is important for maintaining the aquatic community biodiversity in the local region. Also, persistent pools will provide services for riparian flora and fauna and ecotonal fauna as soil moisture falls and alternative sources of drinking water fail. This persistence of base flow once rainfall-driven surface flows have ceased will be dependent upon connection to and maintenance of levels of the upper-catchment fractured rock aquifers.

Ground access to selected pools could be used to monitor this feature, but again aerial photography is likely to be a cost-effective tool that would allow assessment of more pools for a given budget.

7.1.3 Recession rate of pools

This is linked to the issues discussed in Section 7.1.2 above, but also incorporates evaporative, seepage and extraction losses from the pools. Water extraction from isolated pools can be directly managed under a water resource plan, but alteration of other losses would be difficult to relate to water resource use. Anthropogenic influences could include factors such as removal of riparian vegetation, increasing insolation and wind, enhancing

evaporation, and disruption of clay or rock pool beds, enhancing seepage losses, and increasing stock watering. These would not be directly related to water resource use, but could be related to land-use changes associated with altered water resource usage.

Similar monitoring to that recommended in Section 7.1.2 above could be used, as could water-level loggers at selected representative pools could be used.

7.1.4 Riffle presence or persistence

This indicator is related to pool persistence and recession rate indicators discussed in 7.1.2 and 7.1.3 above, but refers to riffle habitat. However, riffles require flow, so rainfall-driven surface flows and base flows are required for them to persist. Therefore, the key parameter is extent and persistence of flows.

It would not be feasible to establish gauging stations across the upper catchments, but this may be feasible in selected upper-catchment streams. Again, riffles can be readily identified in aerial photography, so the late wet season and dry season photographic runs that could be used to assess pool persistence would also be suitable for assessing riffle persistence.

7.1.5 Depth of pools and channel bed form

These are indicators that flood flow scour is sufficient to maintain key habitat features through periodic transportation of sediment. Note that access to the upper catchment during flood flows is likely to be extremely restricted.

The suggested monitoring tools of photo point monitoring of selected reaches or pools is likely to provide a valuable record of changes to channel form and pool size that would in future allow geomorphic assessment of changes or fluctuations over an extended timeframe and to depict abrupt changes after major flow events in a very cost-effective manner. Periodic surveys of pool morphometry could be used to provide supplementary, more precise data, but would require substantially greater effort to achieve comparable geographic coverage.

7.2 Deepwater habitats of middle reaches of the Proserpine River

7.2.1 Dissolved oxygen and nutrient status of selected pools

Low dissolved oxygen through the Proserpine catchment, particularly mid to lower reaches, has been identified as a potential water quality issue in the catchment and possibly related to patterns of water use for irrigation. Also, nutrient alterations by below-thermocline releases from the Peter Faust Dam, the influence of cropping in the catchment, particularly associated with irrigation, and effluent inputs from the Proserpine STP have been shown to affect nutrient status in the waters of this catchment. The interactions between the altered flow regimes of the catchment and in-channel macrophyte masses, particularly exotic aquatic grasses, and these water quality parameters in the catchment is not known and constitutes a key knowledge gap.

These processes and their implications may require targeted research to better understand (see Section 8.13). However, better understanding and management could be derived from monitoring of the patterns of dissolved oxygen and nutrient concentrations in selected pools in these reaches. Dissolved oxygen monitoring should be stratified by season, depth

and time of day, as these factors are all known to naturally influence oxygen concentrations. Surface water spot measurements, particularly at variable times of day, are minimally informative except in extreme circumstances. Similarly, nutrient monitoring should be seasonally stratified, as within-year patterns of water flows, water use and temperature driven changes to rates of nutrient consumption and release will strongly affect the observed concentrations.

7.2.2 Extent of coverage of channel by macrophytes

The absence of flood flows in the Proserpine River since the building of Peter Faust Dam has removed a key part of the flow regime for scouring and removal of macrophytes (both native and exotic). Overgrowth of macrophytes, particularly exotic aquatic grasses, has been identified as potentially affecting the habitat quality, water quality and water-transport characteristics of the Proserpine River.

Photo point monitoring of selected pools would provide a cost-effective method to monitor channel and water surface coverage by macrophytes over time, requiring only sufficient time at each site to access the nominated photography point and take a photograph. Visual assessment of photographic time series at each site would readily identify problem sites and overall trends.

7.2.3 Pool depth

The reduction in flood peak associated with the current water resource management in the Proserpine River is likely to affect the sediment transport capacity of flows. This may result in a tendency for pools to infill without periods of time sufficient to reset the pool depth profile. This would then lead to the reduced extent of these habitats in the river.

The photo point monitoring suggested above would also provide a temporal record of pool extent and morphology. Additional direct monitoring of channel morphology and depth profiles of selected pools would provide more quantitative data.

7.2.4 Organic composition of sediments

The combination of overgrowth of macrophytes and reduced frequency or absence of scouring flows is likely to lead to increased deposition of organic matter in pool bed sediments. This would alter the habitat characteristics of the bed sediments, and potentially act as a source of increased oxygen consumption and exacerbation of low dissolved oxygen concentrations.

This issue would be readily monitored by collection of bed sediments for measurement of organic carbon content. Collection of inorganic particle size distribution (PSD) data from the same sediment samples would provide additional useful data on sediment fining, and by inference patterns of sediment transportation in the catchment.

7.3 Riffles and waterholes in middle reaches

7.3.1 Number, distribution, depth and drawdown rates of waterholes

Waterholes are critically important refugial habitats for many aquatic biota during the dry season. Reduction in their abundance, both overall and within tributaries and reaches, would adversely affect the standing stocks of such organisms. Reduction in the extent of deepwater (more than one metre) habitat would reduce the extent of thermal refuge

availability and the ability of some organisms to avoid surface predators. Increased drawdown rates of these waterholes, directly through increased extraction or indirectly through reduced base flow or increased seepage or evaporative losses (see 7.1.3 above) would reduce the persistence of the habitats, reduce the duration of deepwater habitat and, if it were to lead to substantial reduction of the number of waterholes that persisted through the dry season, reduce the ability of populations of organisms without mechanisms to survive pool loss to survive the dry season, at least on a local basis.

As for upper-catchment pools (see 7.1.2 and 7.1.3), aerial photography would potentially provide a cost-effective method to achieve widespread coverage of the persistence of these habitats within the plan area. However, as the middle reaches are more readily accessible than the upper-catchment areas, ground surveys would be relatively more cost effective. A stratified design to access representative reaches and waterholes could provide more quantitative data of fauna and flora presence and status, depth profiles and recession rates.

7.3.2 Riffle distribution, extent and persistence

Riffles are key habitats for a suite of aquatic flora and fauna, and the current populations and assemblages of these are determined by the current patterns of riffle distribution, extent and persistence. Persistence will be an important factor, as some taxa will be better able than others to maintain recruitment during periods of riffle absence, via refuge in other habitats or via resistant stages. Some taxa and assemblages may require perennial riffles for maintenance. As riffles are by definition shallow habitats, they are sensitive to small changes in flow volumes, and particularly during the dry season when natural and water resource use pressures on base flows are greatest.

As for waterholes, riffle distribution may be monitored in a broad sense by use of aerial photography, particularly during the later stages of the dry season. However, not all riffles will show clearly on aerial photography, and subtle changes to riffle size may not be possible to measure. Additionally, the composition of riffle assemblages would require physical surveys to assess. Therefore, ground surveys of the persistence, extent and flora and fauna of selected riffles should be conducted, particularly during the mid to late dry season. Surveys at the start of the dry season could be used to assess maximum non-flood condition extent.

7.3.3 Groundwater levels in fluvial and Tertiary aquifers

The extent and persistence of waterholes and riffles, and most other aquatic habitats and flow-linked riparian ecosystems are related to the extent and persistence of flow from or level of windows to the groundwater systems that provide water to those systems once surface runoff flows have ceased. Alteration of groundwater levels in the fluvial and Tertiary aquifers of the mid reaches of most streams in the plan area, particularly in the O'Connell and Andromache river catchment, through increased extraction or reduction of infiltration through capture of surface flows or runoff could have a direct and rapid influence on the extent and persistence of water holes and riffles.

This could be monitored directly by measurement of water levels in monitoring bores into appropriate aquifers, and more indirectly by analysis of base flows from gauging station hydrographic records.

7.4 Goorganga Plain wetland habitat complex

7.4.1 Recession rates and aerial extent of perennial freshwater pools

The presence of perennial fresh waterholes within the main stream channels of the Goorganga Plain wetland is a key contributor to its wetland values. While these waterholes draw down naturally during the low rainfall dry season, the rate at which they draw down is affected by base flow inputs from tributary streams and connected shallow aquifers. Use of surface and groundwater resources within the catchment of the Goorganga Plain wetland, including regulated flow discharges, has the potential to alter the seasonal depth and persistence characteristics of these waterholes and associated aquatic habitats.

Establishing the dry season recession (drawdown) behaviour of a representative suite of channel waterholes through seasonally stratified and regular recording of water levels would provide a means of defining baseline behaviour against which potential impacts associated with excessive ground or surface water extraction or regulated flow discharges may be identified. As the variability in recession rates between seasons and waterholes is likely to be large and potentially affected by localised geomorphology and water use patterns, a number of waterholes would need to be monitored for successive years before any general behaviour could be established. Aerial photography captured by seasonally stratified low altitude flyovers of perennial waterholes would provide another means of capturing water level data simultaneously for a large number of floodplain waterholes. However, due to the steep sided banks of many of the channel hosted waterholes, depth discrimination possible through remote sensed data will be limited and will need to be supplemented by actual depth measurements at selected sites. Recession rate data would need to be examined in conjunction with base flow and groundwater level data to identify the relative contribution of each in observed waterhole behaviour.

To gain maximum ecological information, other habitat data, such as water quality (DO, temperature and nutrients) and macrophyte abundance, should ideally be recorded in conjunction with water level monitoring to provide the opportunity to identify habitat-quality thresholds associated with water level depth recession.

7.4.2 Flow volumes of tributary streams

The base flow characteristics of tributary streams is a key driver of the seasonal water levels and recessions rates in channel hosted waterholes of the Goorganga Plain wetland. Base flows can be measured by stream gauging. Catchments of the Goorganga Plain wetland are currently too poorly served by flow gauging stations to be able to assess potential base flow impacts associated with surface and groundwater resource use. Establishing baseflow characteristics of tributary systems through seasonally stratified stream gauging on all of the major tributaries of the Goorganga Plain wetland would be a prudent means of establishing the relationship between base flow and waterhole persistence and recession, and would serve the management of any future water resource development in the catchments of the Goorganga Plain wetland.

7.4.3 Flow height and duration in channels

The height and duration of flood flows within a floodplain habitat complex such as Goorganga is a primary driver of channel and floodplain geomorphology and associated habitat structure. Land and water use, including tree clearing, laser levelling, overland flow capture and vegetation condition within the catchments of the Goorganga Plain wetland and the adjoining Proserpine River, which historically inundated parts of the Goorganga Plain wetland, has the potential to impact the character of flood flows experienced within

the Plain wetland. To establish contemporary flood height and duration characteristics, stream water level data need to be collected for as many streams of the wetland as possible. Pragmatically such data are difficult to collect as the required sampling period coincides with limited accessibility to the floodplain. While automated data loggers can overcome this problem, the resources needed to establish such monitoring are unlikely to become available. The establishment of flood height gauging stations on all of the main Bruce Highway crossings of tributary streams of the Goorganga Plain wetland provides the most likely opportunity for gathering contemporary flood height and duration data. Historical records of road closures due to flooding and gauging data available for the one tributary stream of the system that is gauged (Lethe Brook) provide an opportunity to assess how the contemporary flooding behaviour of the floodplain compares with pre-development patterns.

7.4.4 Channel depth and form near natural and allowed to naturally alter

Floodplains are dynamic environments and undergo 'resetting' of physical characteristics when exposed to major flood flow events, which usually occur annually in the seasonal, tropics of north Queensland. Changes in the frequency or magnitude of flood flow events would drive directional changes in floodplain channel form and long term behaviour. The nature of floodplain channel form changes and whether they exhibit directional or dynamic equilibrium characteristics can be monitored by reference to long term data compiled through regular (one to five years) aerial photography based mapping of channel locations and surveys of stream channel cross-sections. Modern tools such as GPS linked depth sounders provide the opportunity to conduct longitudinal surveys of waterhole bathymetry. If such data were collected in conjunction with stream channel cross sections, the statistical power to detect changes in channel depth would be increased. Long term data sets would generally need to be compiled to identify significant changes in channel form, depth and behaviour, which may be driven by land use changes as well as water resource use.

7.4.5 Seasonal macrophyte cover and composition

Macrophyte cover and composition is another feature of the floodplain environment that is reset by flood flows. Accumulated submerged and emergent macrophyte masses are often stripped and scoured from floodplain channels and drainage depressions by flood flows, leaving open water areas for post-flood succession of macrophyte communities. In the absence of the resetting provided by peak flow events, floodplain macrophyte communities will often become dominated by a reduced number of species and directional changes in the overall diversity of species and relative areal extent of species will occur. To capture data to the extent that inferences can be made concerning the role of flood peak flows in resetting the macrophyte community, high resolution and low altitude aerial photography collected by annual flyovers immediately post-wet season would be required. Interpretation of the role of flood flows in driving observed changes to macrophyte cover would be confounded where there were land use or other factors (e.g., hymenachne invasion and establishment) that were contributing to changes to the relative dominance and cover of macrophyte species.

In near coastal areas, macrophyte composition and relative dominance is also driven by salinity gradients influenced by tidal inflows. As per flood flows, major tidal inflow events (i.e., spring-tide events) have the potential to reset macrophyte communities in the lower tidally influenced reaches of the floodplain wetland. The general response is that of the replacement of freshwater submerged and emergent macrophytes (including aquatic

grasses) with more brackish dependent sedge species. Longer terms changes are also typically apparent in terms of the relative dominance of freshwater species versus marine couch and halophyte communities. Identification of the relative dominance and catchment position of tidally dependent and brackish water associated macrophyte communities in remote sensed data (low altitude aerial photography) provides a means of monitoring tidal flow changes and influences on the Goorganga Plain wetland.

7.4.6 Groundwater depth and salinity

The height of shallow freshwater aquifers within the Goorganga Plain wetland has a major influence on their ecological and hydrological functions in terms of their base flow contribution to surface water bodies, their accessibility to dependent vegetation communities and their role in maintaining a hydraulic head against the potential landward migration of the seawater wedge in near-coastal areas. Seasonally stratified monitoring of groundwater depth and salinity in monitoring bore networks established across the floodplain, including near-coastal margins, provides the means by which these important functions of shallow groundwater aquifers can be identified and monitored for potential impacts associated with water resource use or other factors such as tidal-channel constriction, changes in recharge behaviour or sea-level rise. To be able to interpret the potential impact of groundwater levels on surface water features and groundwater dependent ecosystems, good topological data would be required for the floodplain and its drainage channels.

7.4.7 Tide-induced water-level variation in lower stream reaches

Water levels in the near-coastal lower reaches of streams draining the Goorganga Plain wetland will vary under tidal influence subject to the tidal prism experienced in adjoining estuaries, tide height and tidal-channel access. Monitoring of water-level fluctuations in response to tides, including the landward extent of such influence, provides a means of monitoring the hydraulic connectivity of the lower drainage network with the estuary. This may be more important in terms of identifying the potential impacts of changes in tidal influence on water resources rather than vice versa.

7.4.8 Salinity of lower stream reaches of floodplain network

Seasonally stratified measurement of salinity regimes in the lower reaches of the floodplain drainage network provides a direct measure of water resource condition that may be associated with either water resource use or hydraulic connectivity with the estuary (described above). Water resource use has the potential to increase the landward intrusion of higher salinity water where upstream surface or groundwater extraction levels reduce the downstream hydraulic gradient. Salinity values may also decrease where regulated flows discharge higher seasonal volumes of freshwater to lower reaches. The influence of tidal bunds and channel constrictions generated by aquatic weed chokes also need to be assessed in interpreting the observed salinity regimes.

7.5 Proserpine and O'Connell river estuarine and coastal complex

7.5.1 Seasonal salinity profile within estuarine reach

Freshwater base flow volumes have an important influence on the salinity regimes experienced seasonally within an estuarine habitat complex. These in turn have important ecological functions and influences. To monitor salinity responses to base flow inputs

within an estuary requires seasonally and depth stratified monitoring of tidal cycle salinity regimes at fixed points distributed through an estuary. Concurrently recorded base flow data would be required to identify interactions between base flow inputs and the observed salinity regimes and responses of these to water resource use patterns.

7.5.2 Mangrove-community composition and structure

Mangrove species have habitat preferences in terms of salinity regimes and the energetic setting of the geomorphic environment. Quantitative surveys of mangrove community composition and distribution within an estuary provides a mechanism for monitoring long-term changes in estuarine salinity regimes that may be associated with impacts to seasonal base flows due to water resource use. Potentially confounding drivers of mangrove distribution and abundance include sea-level rise and modification of surface water flows associated with changes in channel form and bunding. These need to be considered concurrently in the interpretation of any observed changes in mangrove community distribution and abundance.

7.5.3 Flood hydrograph in upper estuary and channel

The recording of flood hydrographs in the upper reaches of an estuarine system provides a 'bottom of (catchment) system' method of identifying potential changes in catchment runoff characteristics potentially impacted by water resource development, particularly over-land flow capture and stream channel impounding. Key indicators include the magnitude, duration and frequency of wet season flood peaks. Significant changes in these indicators would result in changes to associated sediment and nutrient loads and freshwater plumes into and from the estuary during the wet season. Recorded and modelled flood hydrographs and historically observed changes in estuarine channel form measured through aerial photography interpretation provide a basis for interpreting the relationship between catchment flood flows and estuary form and the potential longer term consequences of existing (i.e., Peter Faust Dam) and any future water resource development that has the potential to impact flood flow discharges to the bottom of the catchment.

7.5.4 Geomorphology within estuary

Estuaries are dynamic geomorphic environments in which the competing influences of river, tide and wave energy determine resultant form and function. In the highly seasonal tropics, wet season flood flows have a dominating influence on estuary geomorphology although such influences are reworked during the non-wet season period by tides and waves. Aerial photography based mapping of the sediment facies within an estuary would provide a snapshot of the estuary form. To monitor potential changes in the influence of flood flows on estuary form, aerial photography for sediment facies interpretation and mapping would need to be captured at approximately the same time of year post-wet season in subsequent years. Given the inherent variability of estuarine systems, data would need to be collected for long-term periods (~10 years) before directional changes in geomorphology could be identified. Historical aerial photography interpretation provides a means of establishing the range of natural dynamic changes in the estuary's form.

7.5.5 Landward extent of tidal inflows

The landward extent of tidal inflows is a measure of the continued influence of tidal flows on near-coastal aquatic habitats. Tidal influence is a critical driver of near-coastal

environments and creates habitats (e.g., brackish sedge swamps) that are critical to estuarine crocodile breeding, waterfowl nesting and fish recruitment (e.g., barramundi). The landward extent of tidal inflows can be impacted by structures such as bunds, water extraction and sea-level rise. Monitoring to establish the landward extent of tidal inflows needs to identify the inland extent of tidal influence on surface water levels under a range of tide heights and the salinity regime of lower stream reaches. These measures would provide the means to establish the tidal influence on near-coastal habitats, including the landward extent of tidal inflows.

7.6 Diverse and native-dominated macrophyte communities

7.6.1 Distribution, abundance and assemblage structure of macrophytes

Despite a very limited available dataset, it is clear that the macrophyte assemblages in many parts of the plan area were notable in their diversity, extent and assemblage structure health. The generally low abundance of weed species, apart from exotic grasses, was also indicative of high integrity macrophyte assemblages. Such healthy macrophyte assemblages are valuable ecological assets in their own right, but they also provide key habitat values for a range of other aquatic and riparian fauna and flora. Macrophytes in stream systems are sensitive to flow alteration (e.g., Mackay and Thompson 2000), and can be both favoured and disfavoured by flow alteration, depending on the nature of the flow alteration and the species present in the system. Macrophyte assemblages will naturally develop, mature, senesce and be scoured out during the course of annual flow variation in the seasonal tropics. An appropriate time to assess annual maximum extent and structural complexity will be some time after the scouring of flood flows in the wet season and before low water levels and potentially stressful water quality conditions develop in drying pools late in the dry season (where this occurs). Nominally, mid dry season would be a suitable compromise for a standardised time of year to assess these characteristics.

Direct survey of macrophyte extent, diversity, abundance and assemblage structure would not only address this as a potential indicator of flow-related response of the ecological asset, but would also help to fill the data gaps in knowledge of these vegetation assemblages in the plan area (see Section 8.3).

7.6.2 Groundwater levels, base flows and base flow periods

The persistence and health of macrophyte assemblages are linked to the persistence of water to support them, as discussed for the pool and riffle habitats, which support macrophytes, discussed in 7.3 above. Key features are the maintenance of groundwater levels, base flows and base flow periods, after allowance for natural rainfall-derived variability in these factors.

Monitoring of base flows and base flow persistence using hydrographic records from stream gauges would be an appropriate mechanism to monitor these factors. Groundwater levels could be assessed directly by measurement of water levels in monitoring bores into appropriate aquifers, and more indirectly by analysis of base flows.

7.6.3 Number, distribution and depth fluctuation or recession of perennial pools

Perennial pools are key habitats for macrophytes, particularly submerged macrophytes. The continued availability of these habitats could be monitored as indicated above in 7.3.1.

7.7 Fish fauna without exotics and with migratory species

7.7.1 Absence of exotic fish

The current apparent rarity of exotic fish in the plan area and absence from the O'Connell and Andromache river catchment is highly unusual in eastern Australia, and certainly a notable ecological asset. However, its links to water resource use are not clear. In part they are related to maintenance of suitable habitat for the native fish fauna, and through this suppression of exotic species population development. Monitoring of flow-related impacts to these key habitats are discussed above in 7.1, 7.2, 7.3 and 7.6.

7.7.2 Distribution and abundance of migratory fishes

Fish are very sensitive to flow alterations that affect the ability of fishes to migrate between feeding, breeding, nursery and refugial habitats within the stream-channel network and between it and estuarine, coastal and floodplain habitats. In order to migrate fish need surface water connections between habitats, and for most Australasian species these connections must provide contiguous flows of generally less than 1 m.s^{-1} and minimal vertical rises. A number of potential fish passage barriers have already been identified in Section 4.6.4, but this list was only from the brief field inspections of the TAP. Flows adequate to permit fish passage past these, and any as yet unidentified barriers, will be required to allow continued recruitment of migratory fishes to the current, and preferably to the natural range limits within the plan area, and to maintain access to key breeding and foraging areas.

This could be monitored by direct assessment of migratory fish species distributions, particularly of juveniles (young of the year) during the dry season. Indirect assessments that may help with data interpretation and prediction of possible fish movements would include assessment of flood flow frequency and comparison of measured flows with that predicted from rainfall-runoff relationships. These assessments should also be extended to consideration of the duration of flows of sufficient height to flood out artificial passage barriers, as determined from surveys of the structures and modelling of flows.

7.7.3 Persistence of pools greater than one metre deep

Deep pools are critical refugial habitats for many fish species, particularly larger species and species susceptible to surface predation. Monitoring of the persistence of this subset of pools could be incorporated into the general pool habitat monitoring discussed in 7.3.1.

7.8 At-risk fringing regional ecosystems

These regional ecosystems comprise semi-deciduous notophyll or mesophyll vine forest fringing watercourses on alluvial plains [RE 8.3.1 and 8.3.1a].

This vegetation type is understood to rely to a great extent on the occurrence of perennial base flows fed by Tertiary terrace aquifers. The condition and health of this vegetation represents a potential indicator of the effects of water resource use. However, a wide range of other factors, such as adjoining land use, fire regime, weed infestation and natural climatic variability, could also affect vegetation condition. The potentially most effective physical indicator for these ecosystems would be the condition and trend of the Tertiary terrace aquifers and streamflow monitoring for base flow condition.

Effective monitoring of the Tertiary terrace aquifer would require, in the first instance, a baseline survey comprising a series of seasonal measurements of aquifer level to establish the current condition of the aquifers. Subsequent seasonal monitoring and evaluation of the data against known aquifer utilisation would provide an indication of the potential occurrence of effects of resource use on these ecosystems. This of course requires that the current utilisation of Tertiary terrace aquifers by water resource consumers is known, which is not the case for all parts of the plan area.

Monitoring of base flow conditions in key reaches under the influence of fractured rock aquifers in mid to upper catchment areas is recommended. The periodicity of base flows would be the critical parameter to monitor, as this indicates the availability of moisture to the ecosystems through the dry season, when the reliance of the vegetation on stream flow is greatest.

7.9 At-risk frontage regional ecosystems

These regional ecosystems comprise:

- *Corymbia clarksoniana* + *Lophostemon suaveolens* + *Eucalyptus platyphylla* woodland, or *E. platyphylla* woodland on alluvial plains [RE 8.3.5]
- *Eucalyptus tereticornis*, *Corymbia intermedia* and *Lophostemon suaveolens* (or *C. tessellaris*-dominant) open forest on alluvial levees and lower terraces [RE 8.3.6 and 8.3.6a].

The key physical indicator for these ecosystems would be the occurrence of overbank flow events. In particular, the occurrence of flows above ARI 10 years would be a useful indicator of whether these floodplain and terrace ecosystems are receiving the overbank flow events required to maintain and sustain the communities. Such data would of course need to be interpreted with reference to prevailing rainfall conditions. As an alternative to this, streamflow monitoring and detailed hydrological models of predicted overbank flow regimes under different water resource use scenarios would also provide an indication of the potential effects of water resource development on frontage regional ecosystems.

7.10 At-risk frontage regional ecosystems in near-coastal areas

These regional ecosystems are comprised of *Eucalyptus tereticornis* and/or *Corymbia tessellaris* and/or *Melaleuca* spp. open woodland to open forest on alluvial and old marine plains, often adjacent to estuarine areas [RE 8.3.13 a,c,d].

These ecosystems are particularly sensitive to the substrate conditions determined by the interaction between mainland freshwater aquifers and saltwater intrusion. Wet season flow characteristics will be significant in terms of recharge of coastal aquifers and maintaining the status quo of saline and fresh groundwater systems.

A key indicator of the persistence of these flow conditions would be wet season flows in the lower end of the Proserpine, Lethe Brook and O'Connell catchments. Monitoring of flows to this part of the catchment would be difficult given the complex network of distributaries and inter-catchment linkages. A more direct indicator of the condition of near-coastal aquifers may be required and would be provided by seasonal salinity regimes and level fluctuations in shallow near-coastal aquifers. This indicator could be monitored by a network of monitoring bores located in shallow near-coastal aquifers, which would be

used to monitor seasonal and inter-annual water and salinity level fluctuations.

The extent and condition of these regional ecosystems could also be monitored directly via vegetation mapping. RE mapping is updated periodically using contemporary aerial imagery but does not provide an indication of the condition or trend of vegetation and does not provide particularly accurate indications of the spatial extent of vegetation due to the mapping scale of 1:100 000. RE mapping alone cannot provide the level of detail required to gauge potential impacts on at-risk regional ecosystems from water resource use. However, more detailed mapping based on high-resolution aerial imagery with minimal ground-truthing represents a cost-effective monitoring approach. These coastal ecosystems lend themselves to mapping via aerial imagery, as the potential changes wrought on woodland vegetation by modification of the fresh–saline groundwater balance would be readily apparent in aerial imagery.

Evaluation of monitoring data would need to take account of the fact that the construction and operation of levees, drains and bunds could modify surface flows and shallow aquifer recharge characteristics, and in turn affect the habitat conditions and distribution patterns for these ecosystems.

7.11 At-risk frontage regional ecosystems incorporating wetlands

These regional ecosystems comprise:

- *Melaleuca viridiflora* woodland often with emergent eucalypts and grassy or herbaceous ground layer, on seasonally inundated alluvial plains with impeded drainage [RE 8.3.2]
- *Melaleuca* sp. aff. *viridiflora* closed forest to woodland in broad drainage areas (wetlands) [RE 8.3.11].

The key physical indicator for these ecosystems would be the occurrence of overbank flow events. In particular, the occurrence of flows above ARI 10 years would be a useful indicator of whether these floodplain and terrace ecosystems are receiving the overbank flow events required to maintain and sustain the communities. Such data would of course need to be interpreted with reference to prevailing rainfall conditions. As an alternative to this, stream-flow monitoring and detailed hydrological models of predicted overbank-flow regimes under different water resource use scenarios would also provide an indication of the potential effects of water resource development on frontage regional ecosystems.

The absence of in-stream storages on the Andromache and O’Connell suggests that the return interval and extent of higher flow events will not be affected by current modes of water extraction.

7.12 At-risk frontage regional ecosystems incorporating wetlands in near-coastal areas

These regional ecosystems are comprised of *Melaleuca dealbata* woodland with grassy understorey, occurring on swampy marine or alluvial plain adjacent to mangroves.[RE 8.3.13b].

These ecosystems are particularly sensitive to the substrate conditions determined by the interaction between mainland freshwater aquifers and saltwater intrusion. Wet season flow characteristics will be significant in terms of recharge of coastal aquifers and maintaining

the status quo of saline and fresh groundwater systems.

A key indicator of the persistence of these flow conditions would be wet season flows in the lower end of the Proserpine, Lethe Brook and O'Connell catchments. Monitoring of flows to this part of the catchment would be difficult given the complex network of distributaries and inter-catchment linkages. A more direct indicator of the condition of near-coastal aquifers may be required and would be provided by seasonal salinity regimes and level fluctuations in shallow near-coastal aquifers. This indicator could be monitored by a network of monitoring bores located in shallow near-coastal aquifers, which would be used to monitor seasonal and inter-annual water and salinity level fluctuations.

The extent and condition of these regional ecosystems could also be monitored directly via vegetation mapping. RE mapping is updated periodically using contemporary aerial imagery but does not provide an indication of the condition or trend of vegetation and does not provide particularly accurate indications of the spatial extent of vegetation due to the mapping scale of 1:100 000. RE mapping alone cannot provide the level of detail required to gauge potential impacts on at-risk regional ecosystems from water resource use. However, more detailed mapping based on high-resolution aerial imagery with minimal ground-truthing represents a cost-effective monitoring approach. These coastal ecosystems lend themselves to mapping via aerial imagery as the potential changes wrought on woodland vegetation by modification of the fresh–saline groundwater balance would be readily apparent in aerial imagery.

Evaluation of monitoring data would need to take account of the fact that the construction and operation of levees, drains and bunds could modify surface flows and shallow aquifer recharge characteristics, and in turn affect the habitat conditions and distribution patterns for these ecosystems.

7.13 At-risk grasslands on alluvium regional ecosystems

These regional ecosystems are comprised of grassland on alluvial and old marine plains [RE 8.3.12].

The key physical indicator for these ecosystems would be the occurrence of overbank flow events. In particular, the occurrence of flows above ARI 10 years would be a useful indicator of whether these floodplain and terrace ecosystems were receiving the overbank flow events required to maintain and sustain the communities. Such data would of course need to be interpreted with reference to prevailing rainfall conditions. As an alternative to this, streamflow monitoring and detailed hydrological models of predicted overbank flow regimes under different water resource use scenarios would also provide an indication of the potential effects of water resource development on frontage regional ecosystems.

The absence of in-stream storages on the Lethe Brook and Thomson Creek suggests that the return interval and extent of higher flow events will not be affected by current modes of water extraction.

7.14 At-risk estuarine regional ecosystems

These regional ecosystems comprise:

- samphire open forbland to isolated clumps of forbs on saltpans and plains adjacent to mangroves [RE 8.1.2]

- *Sporobolus virginicus* grassland on marine sediments; estuarine wetland [RE 8.1.3]
- *Paspalum* spp. and *Fimbristylis ferruginea* sedgeland or grassland (estuarine wetland); includes areas of deep open water with clumps of *Schoenoplectus littoralis* ± *Eleocharis dulcis* [RE 8.1.4]
- *Melaleuca* spp. and/or *Eucalyptus tereticornis* and/or *Corymbia tessellaris* woodland to open forest (estuarine wetland) with a ground stratum of salt-tolerant grasses and sedges, usually in a narrow zone adjoining tidal ecosystems [RE 8.1.5].

These ecosystems are particularly sensitive to the substrate conditions determined by the interaction between mainland freshwater aquifers and saltwater intrusion. Wet-season flow characteristics will be significant in terms of recharge of coastal aquifers and maintaining the status quo of saline and fresh groundwater systems.

A key indicator of the persistence of these flow conditions would be wet season flows in the lower end of the Proserpine, Lethe Brook and O'Connell catchments. Monitoring of flows to this part of the catchment would be difficult given the complex network of distributaries and inter-catchment linkages. A more direct indicator of the condition of near coastal aquifers may be required and would be provided by seasonal salinity regimes and level fluctuations in shallow near-coastal aquifers. This indicator could be monitored by a network of monitoring bores located in shallow near-coastal aquifers, which would be used to monitor seasonal and inter-annual water and salinity level fluctuations.

The extent and condition of these regional ecosystems could also be monitored directly via vegetation mapping. RE mapping is updated periodically using contemporary aerial imagery but does not provide an indication of the condition or trend of vegetation and does not provide particularly accurate indications of the spatial extent of vegetation due to the mapping scale of 1:100 000. RE mapping alone cannot provide the level of detail required to gauge potential impacts on at-risk regional ecosystems from water resource use. However, more detailed mapping based on high-resolution aerial imagery with minimal ground-truthing represents a cost-effective monitoring approach. These coastal ecosystems lend themselves to mapping via aerial imagery as the potential changes wrought on these types of vegetation by modification of the fresh–saline groundwater balance would be readily apparent on aerial imagery.

Evaluation of monitoring data would need to take account of the fact that the construction and operation of levees, drains and bunds could modify surface flows and shallow aquifer recharge characteristics, and in turn affect the habitat conditions and distribution patterns for these ecosystems.

7.15 Wetland birds

The current wet season flow regime maintains the complex system of lower-catchment wetland habitats that support these species. A large number of threatened and migratory species occur in the wetland bird communities in the study catchment.

The wetland ecosystems that support wetland birds are particularly sensitive to surface water conditions determined by the interaction between mainland freshwater flows, and saltwater intrusion. Wet season flow characteristics will be significant in maintaining the status quo of saline, brackish and freshwater wetland systems.

A key indicator of the persistence of these flow conditions would be wet season flows in the lower end of the Proserpine, Lethé Brook and O'Connell catchments. However, monitoring of flows to this part of the catchment would be difficult given the complex network of distributaries and inter-catchment linkages.

The regular mapping of coastal ecosystems using aerial imagery, as proposed for coastal at-risk regional ecosystems, would provide useful monitoring of the potential for wetland birds to respond to changes to the array of saline, brackish and fresh wetlands. Evaluation of monitoring data would need to take account of the fact that the construction and operation of levees, drains and bunds could modify surface flows and shallow aquifer recharge characteristics, and in turn affect the habitat conditions and distribution patterns for these ecosystems.

Direct monitoring of wetland bird congregations in key coastal wetlands would also provide valuable information. Informal monitoring of wetland bird populations may already be occurring via local ornithologists. The establishment of a systematic, targeted wetland bird monitoring program may be achievable at little cost by co-coordinating existing bird monitoring resources in the study catchment.

7.16 Receiving marine ecosystem assets

These assets include:

- inter-tidal habitat for EPBC protected waders and shorebirds
- Proserpine River estuary crocodile population
- threatened marine fauna such as turtles and cetaceans
- Great Barrier Reef Marine Park
- Northern Repulse Bay Dugong Protection Area.

These marine assets are dependent on the maintenance of coastal and marine geomorphological and primary productivity regimes, which are inextricably linked to river basin sediment and nutrient export characteristics.

There are physical indicators that could be used to monitor the potential effects of water resource use on these assets. The spatial extent, duration and water quality characteristics of wet season river discharge plumes to the marine environment represent physical indicators of the potential effect of water resource use on the drivers of coastal processes. Another potential could be provided by monitoring seasonal salinity regimes and level fluctuations in shallow near-coastal aquifers. This indicator could be monitored by a network of monitoring bores located in shallow near-coastal aquifers, which would be used to monitor seasonal and inter-annual water and salinity level fluctuations.

The spatial extent of marine habitat features, including seagrass beds, inter-tidal flats and banks, and mangrove communities, provides an indicator of the persistence and availability of key habitat features for these marine assets (apart from the GBRMP). These habitat features lend themselves to mapping via aerial imagery as the potential changes wrought on these features by modification of coastal geomorphological and productivity regimes would be readily apparent in aerial imagery.

Interpretation of changes to the distribution and extent of these habitat features would need to be undertaken with consideration of the dynamic nature of coastal geomorphology in tropical Queensland. Although changes to shoreline, tidal and nearshore habitats may be

caused by a range of factors not necessarily related to water resource use upstream, the detection of any significant changes would prompt investigation of the extent to which water resource use was contributing to the change.

7.17 Black ironbox (*Eucalyptus raveretiana*)

Because the exact relationship between changes to flow regime and health of black ironbox is not known, the only useful monitoring approach for the wellbeing of the species would be direct monitoring of the species in catchments where water resource use has modified the flow regime. If changes to flow regime occur in the O'Connell and Horse Creek systems the areas where black ironbox reportedly occur in stands on the floodplain should be target areas for monitoring.

Monitoring of the condition of the species would be achieved by establishing monitoring sites with a range of stream type, flow type (aquifer and non-aquifer fed) and water resource use characteristics, and conducting seasonal assessments of the health and vigour of both mature and juvenile individuals.

7.18 Relatively extensive riparian habitat corridors with high functionality for fauna movement and fauna refugial values

Because these riparian corridors may include both fringing (banks) and frontage (levees and floodplain) ecosystems, key flow characteristics for these ecosystems comprise base flow and overbank flow. The periodicity of base flows and frequency and extent of overbank flow events represent potential indicators for these habitat corridors, and can be monitored by stream-flow measurements. It is also recommended that periodic monitoring (every five years) of riparian habitat corridor condition at representative sites down the system would calibrate and strengthen the utility of the stream-flow data for gauging potential effects on key habitat corridors.

Monitoring of habitat corridors should include the condition and vigour of all vegetation strata (i.e., ground, understorey and canopy) and focus on the persistence of natural canopy density.

7.19 Springs and seepage areas fed from Tertiary terrace aquifers

The perennial availability of moisture provided by these springs and seeps supports a characteristic vegetation assemblage comprising denser, moisture dependent vegetation types. The persistence of year-round base flows from aquifers will be critical to the maintenance of these ecosystems.

The potentially most effective physical indicator for these ecosystems would be the discharge characteristics of springs or the condition of the Tertiary terrace aquifers from which the springs are derived. Significant departure from the natural flow conditions would be likely to lead to adverse effects on the ecosystems.

Effective monitoring of the Tertiary terrace aquifer would require, in the first instance, a baseline survey comprising a series of seasonal measurements of groundwater level to establish the current condition of the aquifers. Subsequent seasonal monitoring and evaluation of the data against known aquifer utilisation would provide an indication of the potential occurrence of effects of resource use on these ecosystems. This of course requires that the current utilisation of Tertiary terrace aquifers by water resource consumers is

known. However, at present this does not appear to be the case. It is also recommended that periodic monitoring (every five years) of spring vegetation condition would calibrate and strengthen the utility of the spring discharge or Tertiary aquifer data for gauging potential effects on the spring ecosystems.