RETROFITTING STORMWATER INFRASTRUCTURE TO ENHANCE THREATENED FISH HABITAT

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Abstract

This paper presents a case study demonstrating how retrofitting stormwater treatment devices can target the protection of specific aquatic ecosystems.

Oxleyan Pygmy Perch (OPP) (*Nannoperca oxleyana*) is an endangered fish species that is at risk of becoming critically endangered or even extinct without protection. Impacts from urban stormwater runoff have the potential to degrade important OPP habitat including wallum wetlands and other shallow waterways surrounding the Evans Head urban area.

In 2006, GeoLINK was engaged by Richmond Valley Council (RVC) to:

- design urban and roadside habitat regeneration works that reflect and enhance OPP habitat; and
- design stormwater works that complement the habitat regeneration works while providing all necessary drainage and treatment functions.

Covering three distinct areas, the works have improved OPP habitat by reducing high flows, reducing sediment and nutrient inputs through facilitating infiltration, stabilising channel banks to prevent erosion and revegetating with species preferred by OPP.

A combination of stormwater management features were incorporated into existing developed lands cognisant of the hydrogeology of the study area to improve habitat conditions required by OPP. Features included check dams, swales, submerged weirs and infiltration basins at the outlets of the existing stormwater systems. Implementation of these environmentally sensitive controls, coupled with appropriate educational initiatives, was critical to the success of the stormwater improvement project.

The treatment effectiveness of the proposed measures was assessed using the MUSIC water quality modelling software, with the results indicating that the proposed works will substantially reduce the annual sediment and nutrient loads, thus ensuring that the concentrations of key parameters are within the range targeted for OPP habitat. Contributing to the improvement in discharged stormwater quality is a significant increase in the amount of stormwater infiltrated to groundwater directly benefiting downstream habitat for threatened fish species.

Retrofitting an appropriate mix of stormwater management features into existing developments can minimise some impacts of development on key fish habitats including seagrass beds, saltmarsh and industries such as oyster farming and fishing.

Introduction

Impacts from urban stormwater runoff have the potential to degrade important fish habitat. Oxleyan Pygmy Perch (OPP) habitat includes wallum wetlands and shallow waterways surrounding the Evans Head urban area. OPP is a small freshwater fish species that is at risk of becoming critically endangered or even extinct without protection. It is listed as endangered under the NSW *Fisheries Management Act 1994* and the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999.* OPP have a very limited distribution, being confined to a small number of swamps, streams and lakes of lowland, coastal 'wallum' heaths of coastal north-east NSW and south-east Queensland and have been recorded within the wallum heath communities that surround the urban area of Evans Head (Knight 2000).

Evans Head is located on the Far North Coast of NSW, approximately 100 km north of Grafton, 30 km south of Ballina, within the Richmond Valley Council (RVC) local government area.

With known populations of OPP within the shallow waterways and vegetation surrounding the Evans Head urban area, impacts from increased stormwater runoff caused by urbanisation have the potential to further degrade the remaining OPP habitat.

In 2006, GeoLINK was engaged by RVC to:

- design urban and roadside habitat regeneration works that reflect and enhance OPP habitat; and
- design stormwater works that complement the habitat regeneration works while providing all necessary drainage and treatment functions.

The works involved a range of stormwater management initiatives. Implementation of the retrofitted end-of-pipe treatment controls, coupled with appropriate educational initiatives were critical to the successful implementation of the project.

A detailed analysis of the recommended stormwater management works was undertaken using stormwater modelling software MUSIC and DRAINS to model the treatment effectiveness and hydraulic capacity of the proposed measures. The proposed works aim to improve stormwater runoff water quality from urban and industrial areas of Evans Head prior to discharge into habitats used by OPP.

OPP Habitat Requirements

The initial step in the project was to understand the habitat requirements of the subject species in order to develop water management objectives that would specifically target the particular requirements of the species.

OPP is similar in appearance to other pygmy perch species and to juveniles of other perch-like species (refer to **Plate 1**). Individuals are usually light brown to olive in colour (darkest on its back and paler on its sides) and mottled, with a whitish belly and three to four patchy, dark brown bars extending from head to tail. The opercular flap has a blue iridescence and there is a conspicuous round dark spot with an orange margin at the base of the tail. The scales have dusky margins and the fins are mainly clear. There is a blue ring around the eye. During breeding, the dorsal, pelvic and anal fins darken and the lateral stripes and tail turn scarlet (DPI 2002).

Plate 1Oxleyan Pygmy Perch

(Source: Pat Tully., http://www.dpi.nsw.gov.au/fisheries/species-protection/species-conservation/what-current/endangered-species/oxleyan-pygmy-perch)

Detailed information on the OPP is found within the *OPP Recovery Plan* (Department of Primary Industries: Fisheries 2005).

Pygmy perch are generally found at sites with a high level of in-stream vegetation cover (60-80%) and with limited to no visible in-stream flow (Knight 2000). Department of Primary Industries (DPI 2005) identified higher abundances of OPP near steep/undercut banks, snags, leaf litter and aquatic vegetation. Catches were also greater in shallower, sandy habitats than in habitats with deeper water and mud/detritus substrates. Knight (2000) identified that no fish were found in areas with high flow.

OPP have been recorded within some of the constructed, open channel drainage systems that RVC maintains as part of its stormwater management activities.

Even within areas of known habitat, OPP distribution is patchy, and despite extensive searching the species has only been found in a relatively small numbers. Knight (2000) recorded specific habitat preferences including tannin-stained, acidic (pH 3.32-5.10) fresh waters (90-320 uS/cm) where it frequented low flow environments (<0.298 m/sec) in moderate water depths (<1.3 m). They can occur in very clear to dystrophic water, amongst submerged and emergent vegetation and occasionally woody debris (Thompson *et al*. 2000). It is therefore evident that OPP has very specific habitat requirements. The works attempted to incorporate these environmental attributes whilst improving the stormwater quality and reducing flows by encouraging infiltration within the study area.

Illustration 1 provides a visual representation of the ‘known’ and ‘potential’ OPP habitat areas within the Evans Head and Woodburn catchment areas.

Illustration 1 Known and potential OPP habitat in the Evans Head area

Source: Data derived from surveys by J.Knight and from NSW DPI databases

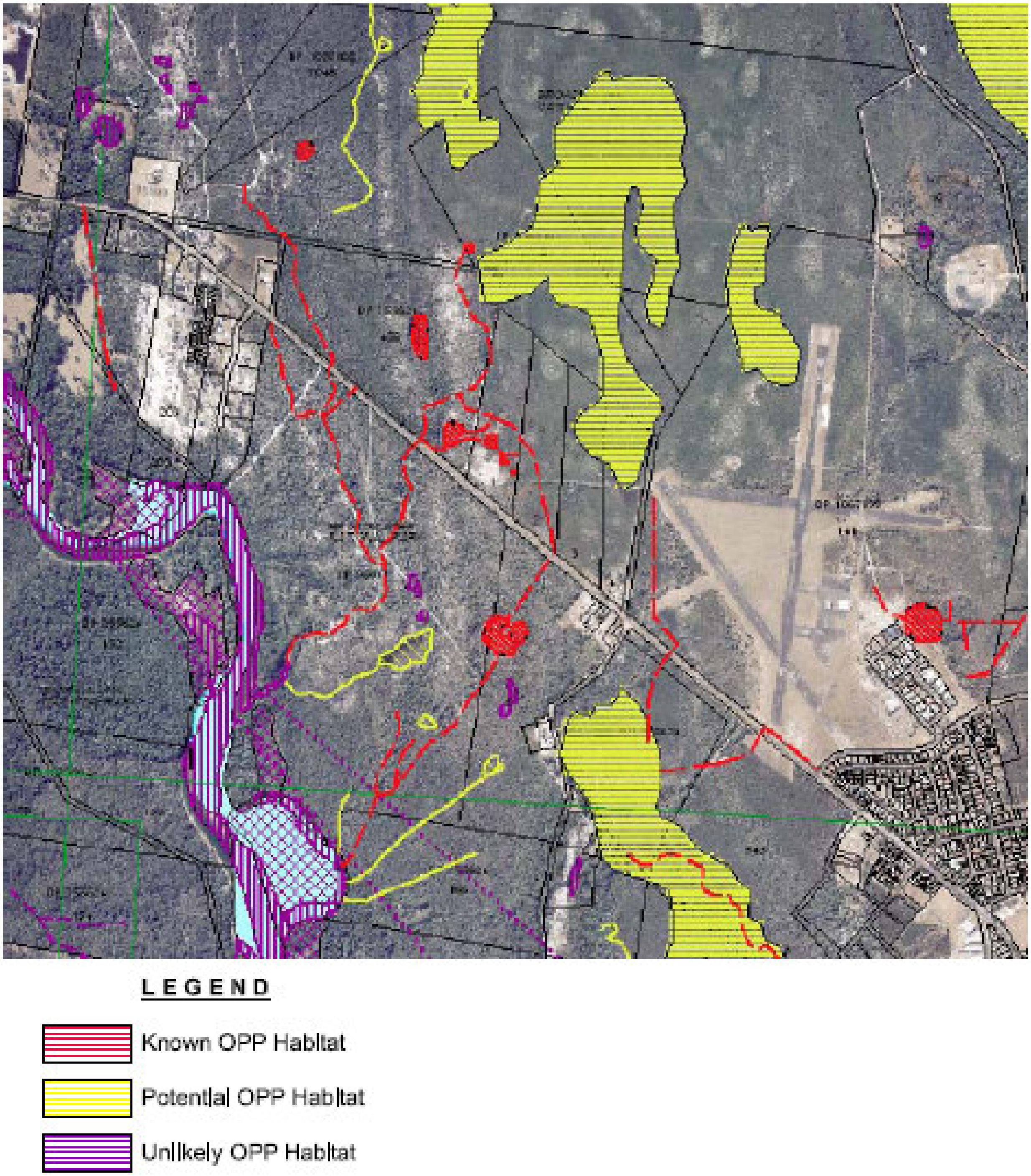


Table 1 indicates the parameters of typical OPP habitat.

Table 1 Habitat Preferences of Oxleyan Pygmy Perch

Water Quality Parameter	*Mean (n=82)*	*Range*
Temperature (deg C)	17.3	11.7 – 29.7
pH	4.39	3.32 – 6.96
Conductivity (uS/cm)	171	90 – 830 (8860)
Dissolved Oxygen (mg/L)	6.29	2.15 – 10.02
Turbidity (NTU)	13	0 – 51
Water Colour	N/A	Clear to dark tannin
Other Parameters		
Nutrients	Low nutrients	
Sediment	Low sediments	
Water Velocity	No visible or very low flows	
Vegetation	Frogsmouth (*Philydrum lanuginosum*) emergent and submerged sedges (*Lepironia articulata, Schoenus brevifolius, Restio pallens, Eleocharis* spp., *Gahia* sp., *Juncus* sp.), water lilies (*Nymphaea* sp.), bladderworts (*utricularia* sp), mosses (eg *Sphagnum falcatulum*) and algae (*Chara* sp., *Cladophora* sp., *Batrachospermum* sp.).	

Source: DPI (2005)

Breeding periods for OPP typically occur in the warmer months of the year between October and May when water temperatures exceed 20°C (Wager 1992; Arthington 1996 in Knight 2000). OPP is a serial or batch spawner, with females laying a few eggs daily during the breeding season (Wager 1992 in Knight 2000). It is unknown how many times an OPP spawns in one season, with spawning frequency potentially being a function of the timing and duration of optimal environmental conditions. Eggs sink and are deposited onto the substrate or vegetation at the bottom of the water body in which mating occurred. The eggs of aquarium-reared fish hatch in three to four days and begin feeding within another day or two. Knight (2000) suggests that eggs deposited amongst well structured habitats such as dense macrophytes and fringing vegetation could provide protection from predators and harsh environmental conditions such as fast flowing water.

The OPP is at threat from habitat degradation and loss, the introduced *Gambusia holbrooki* and the illegal capture for aquariums. *Gambusia holbrooki* was observed by GeoLINK staff within all three work areas (refer to **Illustration 2**). Housing development and road construction projects pose major habitat threats and need to be carefully managed to avoid or minimise impacts. Habitat degradation poses the biggest threat to OPP as development can be rapid and broad scale with little regard for the specific environmental habitat parameters of the OPP.

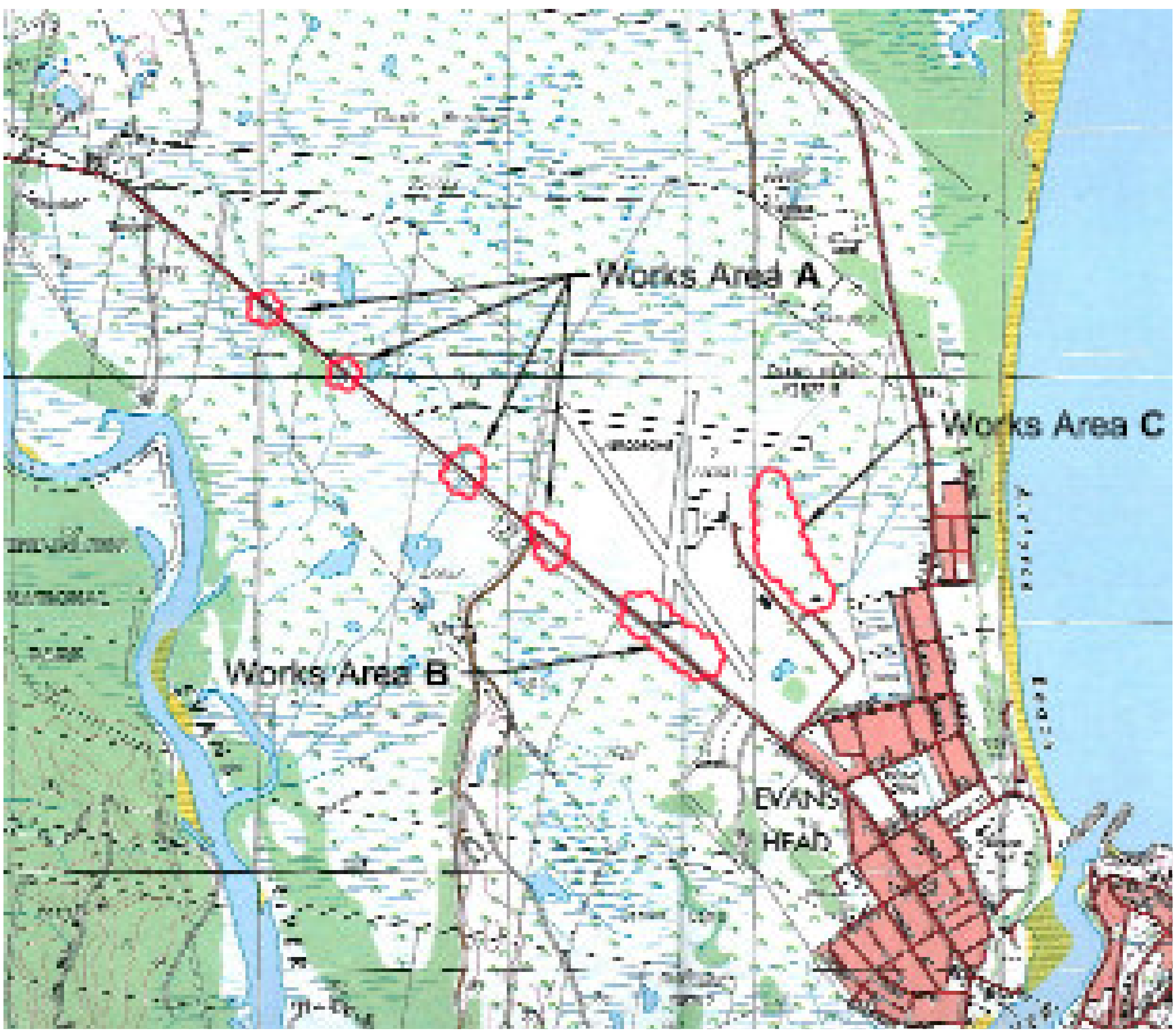
The wallum heath that provides habitat for OPP is characterised by sandy soils and high water tables. The predominantly flat topography of this landscape results in a poorly defined surface drainage pattern that increases infiltration and deep drainage to the water table. Groundwater is typically found within 1 m of the surface. Wetlands occur within the low lying depressions that intersect the water table. Thus the habitat for OPP is groundwater dependent.

After prolonged rainfall that typically occurs during the wet season, the water table can rise to the surface. Hydrologic modelling of the long term water balance of these types of landscapes indicates that only 10% of the rain that falls on the site becomes surface runoff, whereas approximately 45% of the rainfall on the site is lost by deep percolation into the groundwater. The remaining 45% is lost to the atmosphere by evapotranspiration.

However, the traditional urban stormwater system and the accompanying predominance of impermeable surfaces within the urban landscape create a significantly different hydrological regime. This is because urbanisation often reduces the opportunity for infiltration. The stormwater system results in the concentration and channelling of flows, thereby increasing stormwater velocities and volumes and producing sharper peaks in the runoff hydrograph. These more concentrated, short duration, higher intensity flows increase the likelihood that stormwater will find its ways into any nearby estuary. It can be concluded therefore that the urbanisation at Evans Head has most likely increased direct runoff and reduced groundwater recharge.

Manipulation of hydrology of the urbanised catchment to provide an outcome that more closely matches the natural hydrology of the wallum landscape was therefore an important objective in addressing the habitat requirements of this species. Creating water quality conditions that closely match that of the OPP habitat was also a key objective.

Illustration 2 Work Areas A, B and C



Site Characteristics

It was critical in the early stages of the project to obtain a thorough understanding of hydrogeology of the study area. This project focused on three main areas (Work Areas A, B and C).

<u>Work Area A</u> is that area which drains the low lying wetlands and shrub land between Evans Head and Woodburn. There is limited development within this area, which primarily comprises large rural residential blocks with frontage to the Woodburn-Evans Head Road. The roadside drainage network consists of a series of grass swales constructed to convey stormwater runoff from the road pavement into the natural drainage lines. The road crosses a number of natural drainage lines where culverts have been provided to allow waters from large upstream wetland areas to drain into the Evans River to the south.

It is not known whether OPP pass through these culverts; however *Gambusia holbrooki* were observed by GeoLINK staff. OPP habitat mapping (data derived from surveys by J.Knight and NSW DPI databases) identifies some of the deeper roadside drainage channels and the natural watercourses either side of the road as likely habitat. In addition, Knight (2000) reports significant OPP catches from within these natural watercourses.

<u>Work Area B</u> has an estimated catchment area of approximately 88 ha and includes areas of urban development, the Evans Head Memorial Aerodrome (the aerodrome), a portion of the Woodburn-Evans Head Road and an area designated for future urban expansion. Work Area B drains to a single outlet being the culvert under the Woodburn-Evans Head Road adjacent to the aerodrome.

An existing drainage system collects runoff from the residential areas of Acacia Street, Bottlebrush Crescent, Banskia Street, Lilly Pilly Place, Palm Place, Rosewood Place, and the western section of Currajong Street via kerb and gutter and a piped stormwater network. The stormwater drainage network that collects runoff from this existing residential catchment discharges via a gross pollutant trap (GPT) located at the corner of Currajong Street and the Woodburn-Evans Head Road.

GPTs are a stormwater quality device used to provide treatment of stormwater. The subject GPT is a proprietary product called a 'CDS off-line unit'. GPTs are typically designed to remove coarse sediment and litter from stormwater runoff, and generally provide limited removal of other common pollutants such as suspended solids and nutrients. The GPT is located at the end of the piped drainage system, within a section of 1,050 mm diameter reinforced concrete stormwater pipe. Immediately downstream of the GPT, stormwater discharges into a large open drain, known as the 'airfield drain'.

The airfield drain, which flows north-west along the south-western side of the aerodrome parallel to the Woodburn-Evans Head Road, has been identified as OPP habitat. The majority of works within Work Area B are confined to the airfield drain. The drain has a headwall constructed at the downstream end with a large diameter outlet pipe which discharges to the natural drainage channel on the southern side of the Woodburn-Evans Head Road. The airfield drain is, on average, 20 m wide from top of bank to top of bank. Due to the low water velocities within the channel, suspended solids, leaf litter and heavier sediments such as sand tend to accumulate within the channel. A survey of the channel indicated that a significant build up of sediment within the lower sections had created a negative fall on the channel bottom. Therefore this channel was acting more as a basin rather than a free flowing drainage channel.

Due to a combination of the poor natural drainage of this channel, the low flows, the large hydraulic capacity and the extensive grass and reed growth within the channel, it was considered likely that the majority of sediments and gross pollutants are retained within the channel while nutrients are taken up by the vegetation.

Work Area C is that area which drains the industrial area accessed off Currajong Street and incorporates the existing industrial area and the proposed expansion of the industrial area to the north-east. The existing industrial area and the proposed expansion of the industrial area were identified as the main pollution sources within this catchment. The existing industrial estate covers an area of approximately 6.5 ha and is expected to increase in size to 11.2 ha once future land is developed. The industrial area drains directly to a large area of known OPP habitat via overland flow, a network of inlet pits and pipes and a series of shallow informal open channels. There are no stormwater controls provided within the existing drainage network servicing the industrial area.

Stormwater Management Initiatives

A variety of stormwater management initiatives were recommended, each with different methods of achieving improved stormwater quality whilst addressing specific OPP habitat requirements. Table 2 outlines the stormwater management features and states their applicability / issues associated with retrofitting.

Table 2 Retrofitting Stormwater Management Features

Stormwater Management Feature/ Improvement	***Benefits to OPP***	***Considerations for Retrofitting***
Check Dam	▪ removes sediment and attached nutrients from flow ▪ increases infiltration into groundwater ▪ assists groundwater recharge which is important for retaining open water wetland areas and reducing flow velocities that limit the suitability of some habitats for OPP.	▪ Small footprint; ▪ low cost; ▪ only appropriate for some sites; ▪ requires ongoing maintenance; ▪ ease of construction; ▪ only suitable for grades in the range of 0.5-5%
Swale	▪ removes nutrients from stormwater flow; ▪ decreases water velocity (when compared to piped network or concrete channel).	▪ Moderate footprint; ▪ sometimes difficult to incorporate into existing developments where multiple private properties are involved; ▪ only suitable for grades in the range of 0.5-5%; ▪ easy maintenance (by mowing).
Weir	▪ Captures sediment; ▪ encourages infiltration ▪ increases groundwater	▪ Instream / online structures are generally not supported due to impacts on fish

Stormwater Management Feature/ Improvement	Benefits to OPP	Considerations for Retrofitting
	recharge.	populations but an effective tool to isolate existing detention basins etc. from natural habitats and avoid fish kills and improve water quality treatment.
Infiltration Basin	▪ Encourages infiltration; ▪ Can be planted with suitable vegetation for OPP.	▪ Moderate footprint; ▪ requires ongoing maintenance; ▪ requires suitable soils or importation of suitable soils.
Revegetation	▪ increases nutrient uptake; ▪ stabilises banks which reduces erosion and turbidity.	▪ requires ongoing maintenance.

Stormwater Management Initiative 1 Check Dams

It was recommended that a number of small check dams be constructed across each swale at the outlet where the swale discharges into the natural drainage line. These small check dams allow greater retention of pollutants and also hold back and retain the stormwater to allow infiltration through the base and sides of the swales during low intensity (less than 18 mm/hr) rainfall events, while allowing more significant stormwater flows, containing fewer pollutants, to overtop the check dams. The check dams also help to capture any chemical spills that might result from road accidents, thereby limiting any impacts on receiving waters.

Check dam construction involves the use of 100 mm diameter aggregate mounded to approximately 300 mm in height at the outlet of each swale. Soil permeability must be confirmed prior to installation. To increase nutrient uptake, the base of each swale is planted with endemic species for a distance of 5 m upstream from the check dam.

Annual maintenance involves litter collection and mowing of the road verge. The planted endemic species within the base of the swale require little maintenance.

Stormwater Management Initiative 2 Submerged Weir and other Improvements to the Airfield Drain

To facilitate the effective capture of sediments, encourage infiltration and increase groundwater recharge, a submerged weir was constructed across the airfield drain to create a new infiltration/sedimentation basin. The weir was constructed approximately 85 m downstream of the box culverts under Currajong Street, using a sand fill core and finished with a gabion mattress to minimise erosion and facilitate access for plant and equipment. The weir provides sufficient upstream storage volume for the accumulation of the expected annual sediment load and to retain a three month average recurrence interval (ARI) storm event. Storm events of greater magnitude will overtop the weir and flow into the downstream receiving environment via the gabion lined spillway.

The computer simulation model DRAINS was used to model the hydraulic effect of placing a weir within the channel. The computer modelling indicated that during a 1 year ARI event, the weir would overtop by approximately 100 mm, while in a 100 year ARI event the weir would overtop by 330 mm. For the 1 year ARI and the 100 year ARI rainfall events, the estimated flow velocities over the weir were 0.5 and 1.0 m/s respectively. The DRAINS model indicated that the weir will cause no adverse impacts on the upstream drainage system because the backwater effects would be minimal.

A MUSIC model was used to estimate pollutant loads at the outlet from the new infiltration/sedimentation basin. Total nutrient loads are expected to be reduced by approximately 65%, while suspended solids will be reduced by approximately 70%. The proposed measures can also be expected to capture and retain close to 100% of gross pollutants. Water quality at the outlet of the airfield drain has been estimated using MUSIC and, on average, suspended solid concentrations of approximately 24 mg/L, phosphorous concentrations of approximately 0.06 mg/L and total nitrogen concentrations of 0.51 mg/L are expected. This is within the range targeted to suit the OPP.

The existing northern bank of the airfield drain, in parts, appeared to be too steep to allow vegetation to naturally establish. As a result, the sandy embankment was unstable and susceptible to erosion. To stabilise the bank and reduce sedimentation within the base of the channel, it was proposed that erosion control matting be placed in these areas. The effected areas would then be landscaped using endemic vegetation.

Initially the entire length of the airfield drain prior to the proposed works was identified as 'known' OPP habitat (J. Knight and DPI Databases) as OPP have been recorded from the drainage line downstream of where the drain passes under the Evans – Woodburn Road into Bundjalung National Park and protection of the upstream habitats of this highly mobile species is desirable. The existing culvert under the road however forms a substantial barrier to the regular movement of OPP upstream into the airfield drain. Following consultation with the Threatened Species Unit within the then DPI Fisheries it was agreed that construction of the weir within the airfield drain was acceptable. While creating a barrier within the airfield drain the weir would contribute to improvements in water quality for downstream habitats and OPP populations. To facilitate future management, the airfield drain is unlikely to remain as OPP habitat.

The piped system that drains the aerodrome discharges into the airfield drain at four separate locations. One of these outlets is located upstream of the weir and therefore any sediment/pollutant loads are treated within the new infiltration/sedimentation basin. The three remaining discharge pipes have the potential to introduce sediment and nutrients into the OPP habitat within the airfield drain. It was therefore proposed that these three piped outlets would be directed into a separate offline infiltration basin to allow nutrient removal, sediment capture and groundwater recharge. This offline infiltration basin however, to date, has not been constructed.

Stormwater Management Initiative 3 Infiltration Basins

While a significant part of Work Area C has been covered with imported clayey soils, the underlying natural sandy soils were utilised to promote infiltration into the groundwater. This was achieved by providing a series of infiltration areas at the outlets of the existing stormwater system after the previously imported impervious material was removed. Where areas of clay fill were encountered within the proposed infiltration area, they were excavated and replaced with sand extracted from a nearby area.

Work Area C did not contain identified OPP habitat, therefore, the proposed works which involved disturbance to a significant area of land, were not expected to impact on OPP habitat.

At the end of Winjeel Drive a relatively small grassed depression was provided to allow for the capture of sediments and gross pollutants as well as allow infiltration of stormwater to groundwater for more regular rainfall events having less than a 3 month ARI. During more extreme events, the grassed infiltration area fills up and overtops a weir into the adjacent large volume infiltration area where additional treatment and infiltration occurs.

The existing drainage channel was modified by realigning and increasing the width to allow for reduced velocity to promote infiltration. Additionally the three stormwater discharge points were directed to a single outlet point at the eastern end of the industrial estate. As pollutant loads from industrial areas are generally higher than those from residential areas, the large infiltration area has been designed to retain a six month ARI storm event while also allowing sufficient storage for sediment deposition over time. A rock bund with a small weir was provided at two separate locations to retain the first flush runoff of all storm events and promote infiltration.

More extreme storm events are designed to overtop the weir and freely discharge to the receiving environment.

The results of the MUSIC modelling indicate that the retrofitted end of pipe works reduce the annual suspended solids, nitrogen and phosphorous loads by more than 95%. The measures therefore result in a significant increase in the amount of stormwater infiltrated to groundwater and a substantial improvement in discharged stormwater quality. GeoLINK estimated that the quality of discharged stormwater produced is in the order of 37 mg/L for suspended solids, 0.01 mg/L for phosphorous and 0.1 mg/L for total nitrogen, which is within the range targeted for the OPP habitat.

The infiltration area was landscaped using endemic species, grasses and shrubs. The vegetation planted within and around the infiltration area promotes the uptake of nutrients and water.

The landscaping allows for the future development of a public walkway connecting Currajong Street to the industrial area and a public park for use by workers at the industrial estate.

Any maintenance activities, such as de-silting, slashing and chemical application, are programmed not to occur during the OPP breeding period between October and May.

Monitoring of the Operational Phase

The works were largely completed by mid 2008 therefore following an establishment phase, it is an appropriate time to monitor the operation phase to assess the effectiveness of the retrofitted management measures. It is our understanding that Council will implement this monitoring program.

Routine checks and maintenance, above that specified in the Operational Management Plan (OMP), will be undertaken on the main components of the proposed works to ensure that they are operating satisfactorily.

Water sampling to assess the existing water quality has been undertaken. In order to assess the efficacy of the constructed measures water quality monitoring will also be undertaken post construction. Future sample locations will be developed and located as part of the maintenance work and council will carry out sampling. Water samples collected will be analysed for pH, turbidity, total nitrogen, total phosphorous and dissolved oxygen. These results can then be used to assess the effectiveness of the proposed works when compared to results obtained before construction.

Conclusion

Many urban developments result in the degradation of the quality of stormwater runoff and changes to catchment hydrology. Increasing new developments are subject to conditions to adopt techniques to minimise the impacts of stormwater runoff. There remains a legacy of ongoing impacts from developments approved prior to consideration of stormwater impacts. This case study demonstrates that there are considerable opportunities to reduce the impacts of existing development by retrofitting stormwater management features. The presence of threatened aquatic species, key fish habitats such as seagrass or important industries such as aquaculture (oyster farming) or commercial fishing can be key catalysts to initiating these changes. In the case of the OPP, it was recognised that one of the important aspects of its habitat is its dependence on groundwater.

Urbanisation inevitably results in a significant proportion of the catchment area being covered with impermeable surfaces. However, by providing opportunities for stormwater runoff to be captured so that is can slowly infiltrate into the soil, groundwater dependent aquatic habitats can be sustained. By planting these infiltration areas with appropriate species, the water quality can be significantly enhanced through the uptake of nutrients by plants and the filtration of particulate matter by the soil medium.

This project highlights the importance of understanding both the hydrology and the water quality requirements of the local aquatic ecosystems and the identification of measures that are best suited to achieving those objectives.

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