alluvium

FINAL REPORT

Assessment of the Kings Hill development impacts on the hydrology and vegetation of Irrawang Swamp and Coastal Wetland 803

December 2019

Document history

Revision:

Revision no.	04
Authors	Mark Wainwright, David Carew, Liam Nicholson
Checked	Mark Wainwright, David Carew
Approved	

Distribution:

Revision no.	04
Issue date	4/12/19
Issued to	Chris Piper (Northrop Consulting Engineers)
Description:	This report outlines an assessment of the impacts on the Irrawang Swamp hydrology and vegetation resulting from changes to hydrology associated with the proposed Kings Hill development

Contact:

Name	Alluvium Consulting Australia Pty Ltd
ABN	76 151 119 792
Contact person	Mark Wainwright
Ph.	0417 208 130
Email	mark.wainwright@alluvium.com.au
Address	Suite 9, 744 Hunter Street, Newcastle West

Ref:
U:\Work\2019\022_Irrawang_Swamp_Assessment\10_Project\1_Deliverables\Final\P619022.02 Irrawang Swamp ecohydrology assessment 191204.docx

Contents

Figures

Tables

1 Executive summary

Kings Hill Developments Pty Ltd (KHD) is proposing to develop residential rezoned land in the Kings Hill Urban Release Area (Kings Hill) located north of Raymond Terrace. The land would be developed over multiple stages across a 10 to 15 year period for residential and other mixed use development. Kings Hill includes three main catchments that each currently drain to separate receiving environments. Kings Hill South drains to Irrawang Swamp (Coastal Wetland 804) which is located between New Line Road and the Pacific Highway. Kings Hill West drains to an unnamed wetland (Coastal Wetland 803) located adjacent to New Line Road to the north of Irrawang Swamp. Kings Hill East currently drains to Grahamstown Dam and runoff from this catchment is proposed to be diverted to Irrawang Swamp to protect water quality in the dam. Irrawang Swamp and Coastal Wetland 803 are both mapped coastal wetlands under SEPP (Coastal Management) 2018 (SEPP 2018).

Each wetland contains a number of species that are susceptible to impacts from altered hydrological regimes. The vegetation communities will be most susceptible to changes in the drying hydrology that typically occurs in the critical warmer September to March period. The dominant risks to the vegetation in the wetlands from hydrological changes include:

- extended periods of increased inundation depth; and
- reductions in seasonal drying patterns

If these are realised, retention of diversity in the Seasonal Swamp Meadow vegetation would be compromised within Irrawang Swamp and the ability for the woody plants to regenerate would be reduced. The hydrological analysis indicates that these risks are unlikely to occur for the reasons that are summarised below.

- Increased runoff from Kings Hill East during low flow periods is expected to flow efficiently and in a relatively linear manner along the proposed diversion drain through the original spillway channel to the Pennington Drain channel and discharge through the existing flood gates to the Williams River. It is expected that these diverted low flows would not impact on the northern Seasonal Swamp Meadow and Melaleuca Woodlands in Irrawang Swamp.
- Increased runoff diverted from Kings Hill East to Irrawang Swamp during high flow periods would typically coincide with periods where inflows to the swamp are already elevated resulting in wide-spread inundation across Irrawang Swamp. The estimated increase in high flows from Kings Hill East represents approximately 10% of the average annual spillway volume from Grahamstown Dam. These high flow events typically dissipate rapidly and would not cause long term ecological damage.
- Increased runoff volumes from King Hill South during low flow periods are estimated to be substantially lower than those from Kings Hill East. Increased runoff from Kings Hill South will disperse more readily through the wetland vegetation and it is estimated that the increase in water depth during the critical drying period will largely be contained within 5 ha area aligned with currently regularly wetted areas in the northern part of the swamp (refer Zone 1 in Figure 1-1). These additional flows will support the existing areas of open water and stands of *Typha orientalis.*
- Increased annual high flow volumes from King Hill South are estimated to be minor and would have an insignificant impact on increasing water levels in Irrawang Swamp during high flow periods.
- There will continue to be seasonal dry periods in the Swamp Oak and Melaleuca Woodlands and Seasonal Swamp Meadow areas and estimated changes in inundation depths are within the ecological tolerance range of the vegetation communities.
- Modelling results for Wetland 803 in Kings Hill West indicate that the WSUD strategy and partial catchment diversion outlined by Northrop Consulting Engineers (NCE, 2019) would result in water levels in the wetland increasing by less than 50mm across the critical drying period. The modelling results also indicate that wetting extents across the wetland would be similar during this period but may increase over existing conditions by up to 15% during short periods (days) during the drying period in response to small rainfall events in the Kings Hill West catchment.

- The Swamp Oak Woodland in Coastal Wetland 803 in Kings Hill West has been impacted due to increased water retention resulting from historical construction of a bund across its outlet and cattle grazing. Nonetheless a Swamp Oak (Casuarina) Woodland persists on the site with a mixture of fresh and saline understorey plants present. Controlling additional runoff to this wetland alone is unlikely to improve conditions for the remnant wetland vegetation. To maintain the condition of this wetland seasonal flow patterns are crucial for providing the conditions for the existing vegetation. This will ensure winter freshes lower the salinity for the less saline seasonal vegetation with lower summer water levels enabling regeneration to occur. The removal of stock may enable regeneration and healthy growth of the *Casuarina glauca* in the wetland and a woodland more representative of natural conditions to develop.

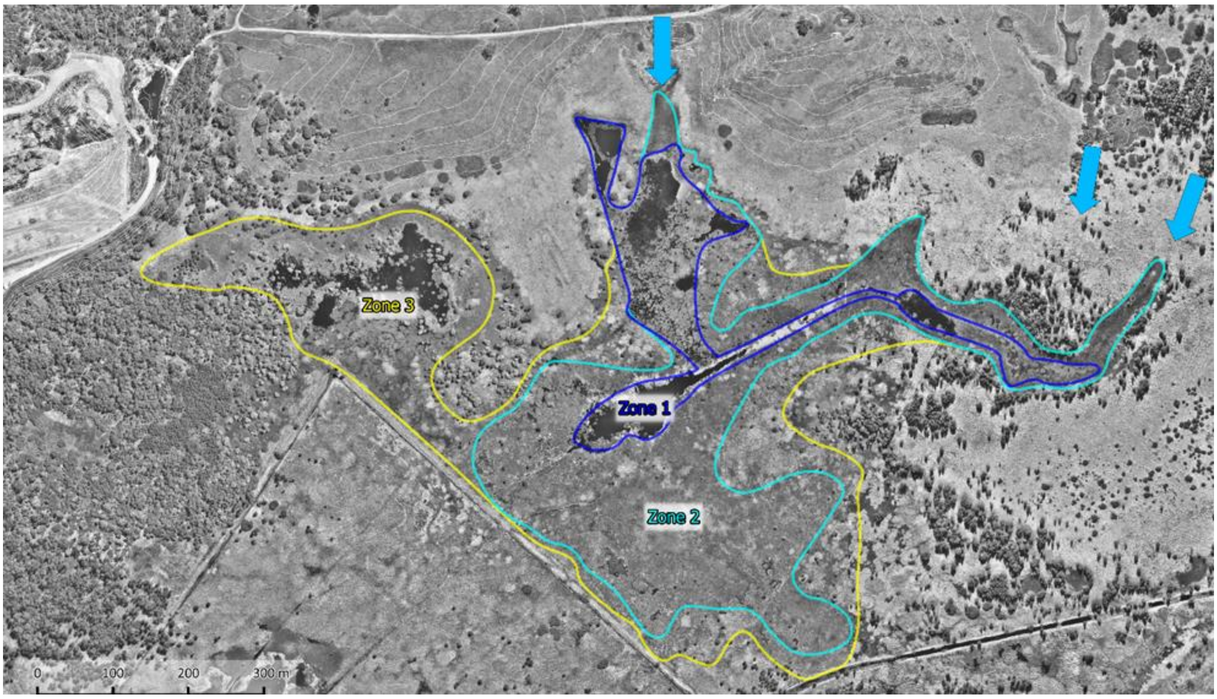


Figure 1-1 *Irrawang Swamp wetting zones showing key inflow locations from Kings Hill South*

2 Introduction

Irrawang Swamp (Coastal Wetland 804) is located just north of Raymond Terrace between New Line Road and the Pacific Highway (refer Figure 2-1), and is a protected Coastal Wetland under SEPP (Coastal Management) 2018 (SEPP 2018). The mapped extents of Irrawang Swamp comprise approximately 450 ha (SEPP 2018).

Kings Hill Developments Pty Ltd (KHD) is proposing to develop rezoned land within the northern catchments draining to the Irrawang Swamp for residential and mixed land uses. This land is referred to as Kings Hill South within this report. Additional land on the eastern side of Kings Hill that currently drains to Grahamstown Dam is also proposed to be developed for residential and mixed land uses. To avoid draining future urban runoff into Grahamstown Dam, a diversion channel is proposed on the eastern side of the Pacific Highway to divert all runoff up to the 0.2% AEP design storm event to the original spillway from Grahamstown Dam. This diverted runoff would be discharged into the eastern side of Irrawang Swamp. The land draining to the proposed diversion channel is referred to as Kings Hill East in this report. Additional development is proposed within the catchment of Coastal Wetland 803 located adjacent to New Line Road to the north of Irrawang Swamp. Development within the catchment of this wetland is referred to as Kings Hill West in this report.

Hunter Water Corporation (HWC) owns all the land within Irrawang Swamp and is currently actively managing the land in accordance with the Irrawang Swamp Plan of Management (Hunter Water, 2012a). Hunter Water previously lodged an application with OEH to register land they own within Irrawang Swamp as a biobanking/biodiversity stewardship site. We understand that HWC has now withdrawn this application and is not actively pursuing this outcome.

HWC's long term objective for Irrawang Swamp is to restore and maintain the environmental quality of the wetland, 'environmental quality' being defined as the range of environmental (predominantly ecological) services or functions provided by the wetland including:

- biodiversity conservation, including supporting habitat for threatened flora and fauna species;
- nursery and breeding grounds for various waterbirds, frogs and aquatic biota such as fish;
- improvement in water quality downstream by removing suspended matter, reducing numbers of faecal microorganisms and using dissolved nitrogen and phosphorus for plant growth;
- biological productivity and nutrient recycling;
- flood mitigation; and
- groundwater recharge.

To support these objectives Hunter Water has progressed a range of measures aimed at restoring the ecological function and integrity of Irrawang Swamp, including:

- Opening of the floodgates on Pennington Drain to reintroduce tidal inundation to the lower areas of the swamp;
- Tree planting;
- Cessation of grazing;
- Allowing drainage channels to naturally infill; and
- Weed control (primarily within the tree planting areas).

It will be important that effective management of stormwater quality and quantity is achieved in the future Kings Hill development areas to support achievement of the ecological protection criteria. HWC has advised that a detailed assessment of the impacts of stormwater discharge from the proposed Kings Hill development on the ecology of the swamp is to be completed before HWC can agree to any discharge into Irrawang Swamp.

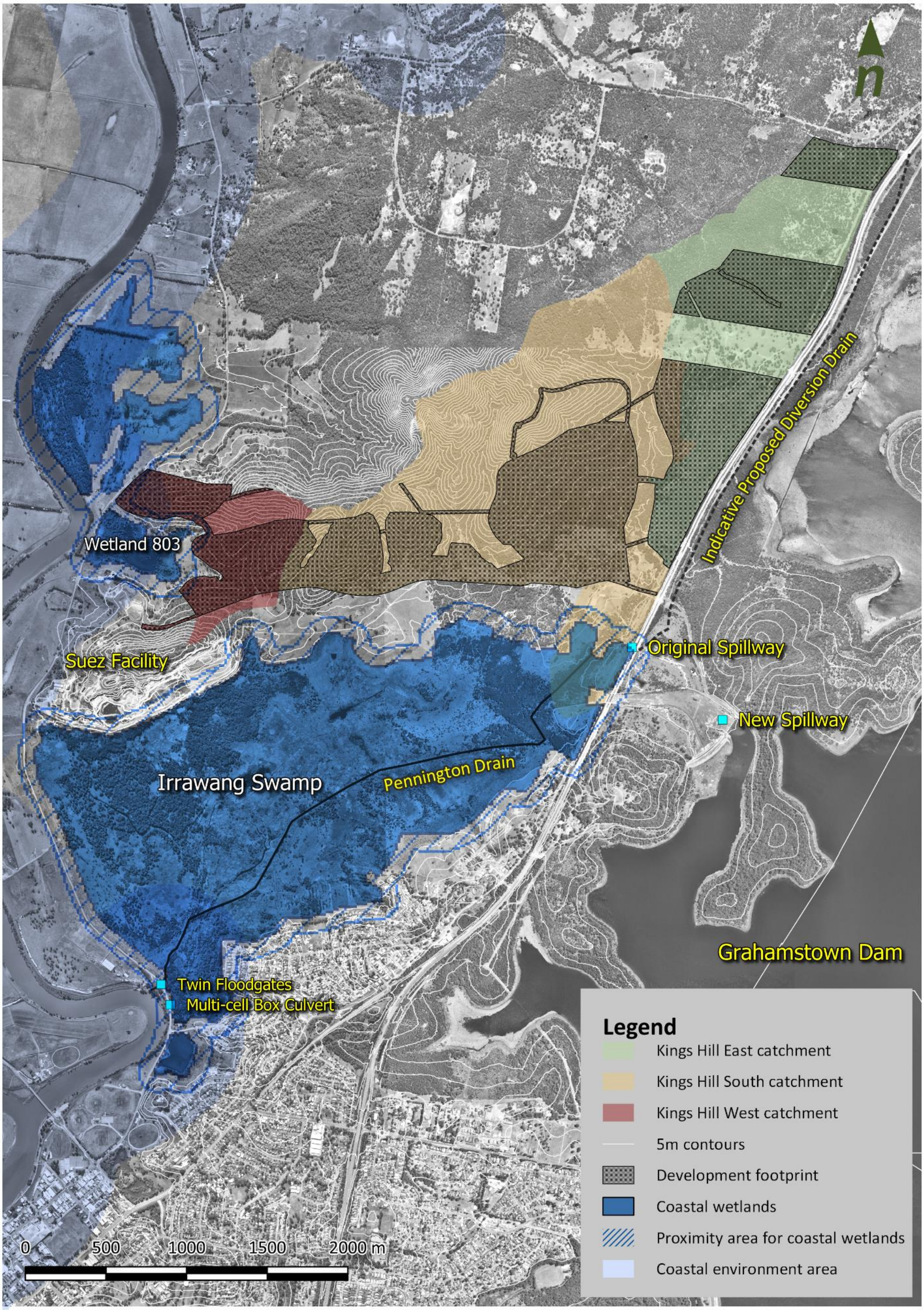


Figure 2-1 *Irrawang Swamp and Coastal Wetland 803 locality*

HWC outlined their concerns regarding the potential impacts of the Kings Hill development on Irrawang Swamp ecology in letter sent to Port Stephens Council dated 9 January 2018 (intended to be dated 9 January 2019) (Hunter Water, 2019). A summary of HWC's key concerns are outlined below:

- HWC has identified that increases in the volume, flow velocity and frequency of stormwater discharges associated with development have the potential to alter wetting/drying regimes in Irrawang Swamp and adversely impact on the composition and distribution of wetland communities.
- HWC has requested that the applicant closely consider the effects of stormwater discharge from the development including both the diverted Kings Hill East catchments and direct discharges from development in Kings Hill South. HWC has requested that consideration of changes to water quality and hydrology be assessed for both the diversion channel and direct discharge catchments.
- HWC has indicated that the applicant would need to demonstrate that the current wetting/drying regime of the receiving environment in Irrawang Swamp would not be adversely impacted by increased stormwater discharges. HWC refers to the "*Water Sensitive Urban Design Solutions for Catchments above Wetlands – Overview Report*" (McManus et al, 2007) prepared for HCCREMS. This guideline indicates that Water Sensitive Urban Design strategies associated with new development in catchments upstream of natural wetlands need to include methods to preserve the pre-development drying and/or flooding hydrology characteristics in order to protect wetland ecology.

This report focuses on potential changes to the Irrawang Swamp and Wetland 803 hydrology associated with the Kings Hill development. The report also includes an assessment of the potential impacts of hydrological changes on the ecology within each wetland. Our assessment is based on stormwater runoff estimates output from MUSIC models prepared by Northrop Consulting Engineers (NCE). We have assumed that the MUSIC modelling completed by NCE appropriately reflects the existing and developed hydrological conditions of the King Hill site and was completed in accordance with the relevant policies and guidelines. The details of NCE's modelling are not duplicated in this report, but are described in NCE, 2019.

The potential impacts on water quality in Irrawang Swamp and Wetland 803 associated with stormwater runoff from the Kings Hill development are also addressed in NCE, 2019.

This report is configured as follows:

- Section 3 summarises our understanding of the existing Irrawang Swamp and Wetland 803 hydrology.
- Section 4 summarises our understanding of the existing vegetation communities in Irrawang Swamp and Wetland 803 and historical changes that have occurred to the vegetation.
- Section 5 summarises the Kings Hill development impacts on catchment hydrology.
- Section 6 outlines the potential impacts of the changed catchment hydrology on the Irrawang Swamp and Wetland 803 hydrology and vegetation.
- Section 7 provides a summary of key points and our conclusions.

3 Existing hydrology

3.1 Irrawang Swamp (Wetland 804)

Overview

The hydrology of Irrawang Swamp has changed significantly from natural conditions due to historical land management practices associated with catchment development, land clearing, pasture irrigation, grazing and drainage channel construction. Under natural conditions, surface runoff from local catchments would have drained to a series of swamps including the Grahamstown Moors, Campvale Swamp and Irrawang Swamp. The hydrology of these swamps would have also been influenced by groundwater from the catchment. Although, clay soils are dominant in the local Irrawang Swamp catchment and it is expected that groundwater inflows to this swamp would be relatively low. The western extents of Irrawang Swamp were regularly inundated by tidal flows and it is envisaged that salt marsh and other salt tolerant species would have previously inhabited these areas.

Construction of the Grahamstown Dam wall across the natural outlet from the Grahamstown Moors resulted in Campvale Swamp and Irrawang Swamp being separated. The natural hydrology of Irrawang Swamp was significantly altered by the dam construction due to catchment flows now being stored in the dam and extracted for water supply. Diversion of river flows from the Williams River to the dam has also modified the Irrawang Swamp hydrology. Surface water flows from the east of the wetland are now limited to infrequent periods when the dam capacity is exceeded initiating spillway discharges to Irrawang Swamp. The dam construction has also modified groundwater flows.

Increasing residential development on the southern side of Irrawang Swamp has altered the hydrology for these catchments with the increased imperviousness in these catchments now contributing more regular pulses of stormwater runoff volume discharges into the southern area of Irrawang Swamp. In addition, the construction of rural dams and water holding dams associated with the waste recycling and recovery site on the northern side of the swamp has altered the hydrology in these areas.

Irrawang Swamp naturally would have received tidal inflows and been inundated during large overbank flooding events from the Williams River. Construction of the New Line Road embankment and flood gates on pipes under Newline Road has resulted in tidal inflows to the swamp and low flows from the swamp now being controlled through these gates. During large spillway events from Grahamstown Dam, water can rapidly fill Irrawang Swamp. To control flooding in these large events, a levee was constructed within the western extents of the swamp parallel to New Line Road to controls overflows from the swamp to the Williams River. A large multi-cell culvert was also constructed under New Line Road just south of the flood gates to convey spillway flows from Grahamstown Dam in a controlled manner to the Williams River.

A large open channel, Pennington Drain, was constructed centrally through Irrawang Swamp in the 1970's as a component of the initial Grahamstown Dam construction to efficiently convey spillway flows through the swamp to the Williams River. Pennington Drain was formed by excavating a trapezoidal-shaped channel from just downstream of the original spillway to the floodgates. A number of other minor interconnected lateral drains were also constructed in the wetland by landowners to enable efficient draining of the land for cattle grazing and to grow pasture grasses. Many of these drainage channels were connected to the Pennington Drain.

Further discussion on the key elements that influence hydrology in the Irrawang Swamp catchment is provided below.

Grahamstown Dam storage

Grahamstown Dam was originally formed by construction of an embankment across the outlet of a natural wetland area known as the Grahamstown Moors. Construction of the dam began in 1955 and was completed in 1965. Prior to completion, water was supplied from the dam in 1960 during a severe drought that extended from 1960 to 1963. Since 1965, the following main modifications to the dam have been completed (https://www.hunterwater.com.au):

- In 1973 a bentonite clay core was installed in the central section of the Grahamstown embankment to provide a watertight seal.
- In 1985 the Full Supply Level (FSL) was reduced from 11.1 metres to 10.6 metres as a temporary measure to reduce the risk of damage to the main embankment from major flooding.
- In 1994 Stage 1 augmentation works were completed to raise the level of the clay core to the road level along the full length of the embankment to enable the flood storage capacity to be increased. Rock armouring of the main embankment was also undertaken.
- In 2005 Stage 2 augmentation works were completed to increase the FSL from 10.6 to 12.8 metres. These works involve construction of a larger spillway and discharge channel under the Pacific Highway.

The Stage 2 augmentation works addressed two key objectives, improving the safety of the dam to bypass major flood events, and increasing the water storage capacity to improve regional drought security (Kinhill, 1993). The works resulted in the dam storage capacity increasing by 50%. Whilst the dam storage capacity increased, there was an associated reduction in temporary flood storage capacity. To reduce risks associated with this reduced temporary storage, the original dam spillway was replaced with a wider spillway.

The dam currently has a total storage volume of over 182 GL and covers an area of 28 km^2. The total catchment area for Grahamstown Dam is 115 km^2 (www.hunterwater.com.au). Additional catchment area is diverted to the dam from the Williams River through the Balickera Canal diversion that forms an off take from the Williams River at Seaham Weir.

Grahamstown Dam spillway
The original Grahamstown Dam spillway was constructed as a component of the Grahamstown Dam construction works between 1955 and 1965. Although the original spillway is no longer in operation, the spillway gates, outlet channel, weir and energy dissipator remain in place.

Figure 3-1 *Original Grahamstown Dam spillway gates*

A larger spillway was constructed as a component of the Stage 2 augmentation works in 2005 approximately 350m south of the original spillway. The current spillway is a labyrinth type spillway that provides more efficient flow discharges at lower depths. The current spillway was designed to have a capacity of 780 m^3/s which is significantly greater than the original spillway capacity of 60 m^3/s (Kinhill, 1993).

Figure 3-2 *New Grahamstown Dam labyrinth spillway (source: Port Stephens Examiner, 2008)*

The Stage 2 augmentation EIS identified that a major impact would be to increase the frequency of spillway discharges with associated increases in inundation frequency within parts of Irrawang Swamp (Kinhill, 1993). Whilst the water supply storage increased with the Stage 2 augmentation, the temporary flood storage reduced. It was identified that the reduction in temporary flood storage would result in the spillway being overtopped more frequently resulting in more frequent discharges to Irrawang Swamp.

It was estimated that Irrawang Swamp would be more frequently inundated for periods up to several days from flood flows from Grahamstown Dam and overbank flows from the Williams River. It was estimated that the new spillway would be overtopped on average once every two years (Kinhill, 1993). Review of spillway flow data provided by HWC indicates that flows have occurred in approximately 40% of the years since the current spillway was completed in 2005 and this aligns well with the EIS predicted spill frequency.

Irrawang Swamp drainage

Surface runoff currently drains into Irrawang Swamp from the surrounding catchment and additional flow is contributed from Grahamstown Dam during periods when the spillway level is exceeded. Surface runoff drains from the forested and pastured upper slopes of Kings Hill in a southerly direction along unnamed ephemeral watercourses into the northern section of Irrawang Swamp. Existing and future residential development in Raymond Terrace drains into the swamp from the south.

Pennington Drain was constructed centrally through Irrawang Swamp as a component of the initial Grahamstown Dam construction works to efficiently drain spillway flows through the swamp to the Williams River. This channel still functions to efficiently convey spillway flows through Irrawang Swamp, although the drain is increasingly becoming infilled and covered by vegetation due to cessation of drain maintenance. This infilling is being encouraged as a restoration action to reduce the drainage efficiency and enable more frequent spills from Pennington Drain into the adjacent wetland areas (Hunter Water, 2012a). This action supports the Irrawang Swamp plan of management objectives and Hunter Water expects this will assist to restore the natural hydrological regime and increase freshwater wetland vegetation (Hunter Water, 2012a).

Excavated soil from the Pennington Drain channel construction was deposited along the sides of the drain to form a levee. This levee functions to preferentially direct overbank flows from the drain into the northern areas of the wetland. In some locations, breaks in the channel banks and levee have been formed to facilitate past agricultural activities and potentially also to drain trapped areas.

A number of other minor interconnected lateral drains were previously constructed in the wetland to enable efficiently draining of the land for cattle grazing and other agricultural activities. Many of these drainage channels were connected to the Pennington Drain. These lateral drains are now not actively maintained and are being allowed to infill.

Newline Road drainage structures
Discharges from Irrawang Swamp to the Williams River can occur through the following mechanisms depending on the water level in Irrawang Swamp:

- Low flows from the swamp and tidal exchange can drain through open flood gates constructed at the end of Pennington Drain immediately downstream of New Line Road.
- High catchment runoff and spillway flows can result in water levels increasing rapidly across the swamp initiating flow through a multi-cell box culvert located just south of the flood gates when a levee in this area is breached.
- Very high flows exceeding the capacity of the multi-cell box culvert and minimum Newline Road crown level would weir flow across the road.

These drainage structures are discussed further below.

Flood gates
Floodgates were installed on the Pennington Drain outlet immediately downstream of Newline Road in the 1970's (Kleinfelder, 2018). We understand that the flood gates are installed on twin 900mm or 1050mm diameter pipe culverts (pers com. Holly Marlin, HWC). The flood gates are owned and operated by the NSW Department of Industry (Water). The gates originally functioned to prevent tidal inundation of the Irrawang Swamp and discharge of stormwater to the Williams River during periods when river water levels were elevated.

The flood gates currently remain open unless a Flood Watch is issued by the Bureau of Meteorology on either the Williams or Hunter Rivers. The flood gates are manually closed during a Flood Watch and re-opened when the flood risk has passed (Hunter Water, 2012b).

Figure 3-3 *Pennington Drain flood gates*

Over the 2010-11 period Hunter Water worked in partnership with the Department of Primary Industries (Fisheries) on the Irrawang SEPP 14 wetland rehabilitation project. The goal of this project was to reintroduce natural tidal flows to Irrawang Swamp through the flood gates. Two trial openings of the flood gates were undertaken and a draft Review of Environmental Factors (REF) prepared for the project (Hunter Water, 2011).

Over the 2011-12 period Hunter Water continued working with DPI (Fisheries) on the wetland rehabilitation project. Flood modelling identified the complexity of determining the impact of simultaneous spills from Grahamstown Dam and flooding from either the Hunter River or Williams River. Although not quantified, the completed modelling indicated that permanent opening of the flood gates could only increase the likelihood of residential impacts in the event of a simultaneous spill from Grahamstown Dam and flooding of either the Hunter River or Williams River. Further modelling was deemed unnecessary and it was decided that the flood gates would not be permanently opened (Hunter Water, 2012b).

New Line Road levee
In 2010, a new levee was constructed on the eastern side of Newline Road within Irrawang Swamp to protect private properties located between Irrawang Swamp and the Williams River during periods of high spillway discharges from Grahamstown Dam. This levee controls overflows from Irrawang Swamp across a section of New Line Road south of the existing flood gates. The construction of this levee was a condition of the Stage 2 augmentation consent (Kleinfelder, 2018).

Multi-cell culvert
HWC provided Alluvium with design details of a multi-cell culvert under Newline Road just north of the Newline Road and Beaton Avenue intersection. The design drawings (Hunter District Water Board, 1975) indicate that a six-cell reinforced concrete box culvert was proposed to be constructed at this location. Each cell was 3.3m (w) x 1.8 m (h). The culvert inverts were designed at 0.97 m AHD and the road crown level was designed at approximately 3.6m AHD.

The multi-cell culvert was constructed as part of the Irrawang Spillway works in 1975 in conjunction with roadworks in Newline Road. The culvert was funded by Hunter Water and constructed by Port Stephens Council, and is owned by Hunter Water (pers. com. Holly Marlin, HWC). The culvert is separated from the swamp by a high levee bank/weir (pers. com. Holly Marlin, HWC). The levee/weir was constructed with a crest at approximately 1.7m AHD (Hunter Water, 2012a). The constructed gabion weir at the entrance to the culvert is shown in Figure 3-4.

Figure 3-4 *Existing gabion supported bund upstream of multi-cell box culvert*

Based on the available data, when water levels in the Irrawang Swamp exceed 1.7m AHD, spills would be initiated over the levee bank/weir into the multi-cell culvert prior to discharge along a short section of channel to the Williams River. The level of the levee bank/weir effectively controls the maximum level for extended duration of water in Irrawang Swamp. Water levels in Irrawang Swamp would only exceed the levee bank/weir level for a relatively short period (days), as water above this level would discharge relatively efficiently through the multi-cell culvert. Water stored at levels below 1.7m AHD drains through the flood gates.

3.2 Wetland 803

The majority of the Kings Hill West development area drains to Wetland 803 located adjacent to New Line Road. The total catchment area draining to Wetland 803 is approximately 97 ha and the wetland covers approximately 14 ha of the catchment. The catchment is primarily forested in the upper reaches with cleared grazing areas observed around the lower reaches and the wetland perimeter. The existing wetland includes a number of distinct shallow cells that receive inflows from separate sub-catchments. The maximum water depth in the wetland prior to overflow through the outlet occurring is estimated to be approximately 0.25m. The shallow cells can be observed partially filled in Figure 3-5.

Figure 3-5 *Wetland 803 partially full*

Water level/electrical conductivity data available for the 210452 Raymond Terrace water level recorder over the 2013 to 2019 period indicates that exchange of saline inflows from the Williams River with the stored water in the wetland will occur (WaterNSW, 2019). Based on a recent survey of the wetland outlet (deWitt Consulting, 2019) it appears that tides can flow into the wetland when water levels in the Williams River exceed approximately 0.65m AHD (the minimum outlet/spill level in the north-western corner of the wetland). This level is estimated to be between the mean high water (MHW) and mean high water springs (MHWS) levels at this location (MHL, 2012).

The hydrology of Wetland 803 is influenced by catchment inflows and tidal inflows from the Williams River. Surface water can drain from the wetland when water levels exceed the outlet level. Surface water drains through a shallow trapezoidal channel located adjacent to the north-western extents of the wetland. The channel connects to a narrow drain located in the Newline Road reserve that conveys surface water through a twin 600mm diameter culvert under New Line Road to the Williams River. In addition to surface flows from the catchment, tidal inflows to the wetland can also occur when the tide level exceeds the outlet level.

During seasonally high rainfall periods, water levels in the wetland will typically be elevated and close to the outlet level for extended periods. During these periods, tidal exchange with the Williams River will occur with saline/brackish water flowing into the wetland when tidal flood flow levels exceed the outlet level. It is expected that tidal flood flows will partially mix with stored water in the wetland close to the outlet location, prior to draining from the wetland during the ebb tide.

During low rainfall and warmer periods, evapotranspiration across the wetland will reduce the water levels below the outlet level. During these periods, catchment inflows will typically be low and water levels primarily influenced by tidal flood flows into the wetland and evapotranspiration. It is envisaged that during these low catchment inflow periods, the water stored in the wetland will become increasingly saline under the dominant influence of tidal flows. During these drier periods, incoming flows during some high tides would be retained in the wetland on the ebb tide, with following high tides also functioning to gradually increase water levels until the outlet level is reached or high tide levels fall below the outlet level.

4 Existing wetland vegetation

4.1 Irrawang Swamp

Historical management practises impacting wetland vegetation
The vegetation in Irrawang Swamp is a mosaic of wetland marsh and woodland communities. These occupy areas of the swamp which experience different hydrological regimes (wetting/drying cycles and depth of inundation). These have developed depending upon the elevation and drainage patterns in the different areas of the Swamp.

The Irrawang Swamp vegetation was significantly modified after the 1950s to enable agricultural uses. This involved the cutting of drains through the central areas of the swamp and the clearing of some of the Swamp Oak (*Casuarina glauca*) woodland areas to enable pasture management. The Irrawang Swamp Plan of Management (Hunter Water, 2012a) outlines the following historical changes:

Irrawang Swamp has been subjected to a range of anthropogenic disturbances, all aimed at improving the area for agricultural activities, particularly grazing. This disturbance history has resulted in a degraded wetland system with a highly altered hydrological regime affecting inundation frequency, duration and extent, as well as salinity.

In addition to the hydrological changes outlined in Section 3, past land management practices that have altered the natural vegetation include:

- Clearing of native vegetation;
- Livestock grazing; and
- Introduction of exotic pasture species.

The 1954 aerial image of the Swamp (Figure 4-1) shows minimal constructed drainage. This contrasts with the 1977 and 2018 images (Figure 4-2 & Figure 4-3 respectively) which show development and constructed drainage through the central areas of the swamp.

The main historical changes in vegetation communities through the swamp were:

- Reduction in Swamp Oak and Paperbark Woodland areas.
- Reduction in Perennial Swamp meadow (Tall marsh) wetland vegetation
- Increase in Seasonal and Transient Swamp Meadow and pasture.

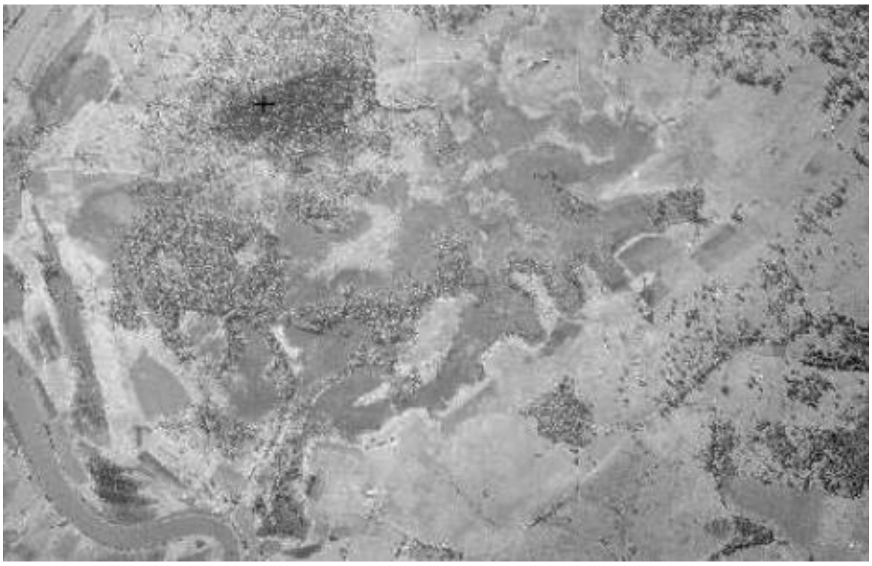


Figure 4-1 *1954 aerial image of Irrawang Swamp*

Figure 4-2 *1977 Aerial image of Irrawang Swamp*

Date: Sun, 09 Sep 2018

Figure 4-3 *2018 Aerial image of Irrawang Swamp*

The swamp vegetation is adjusting to the current flow regime which includes maintenance practices that are allowing the drainage channels to infill reducing their hydraulic efficiency. This will see water retained in the central areas of the swamp for longer periods and increased inundation for tolerant plant species.

Changes in the flows to Irrawang Swamp will alter the current hydrological regime with different areas more likely to be impacted than others.

Previous studies

The vegetation of Irrawang Swamp has most recently been mapped within the *Grahamstown Dam Stage 2 Augmentation Phase 3 – Flora Monitoring of Irrawang Swamp* monitoring report prepared by Kleinfelder (2018).

Alluvium has not undertaken a detailed flora survey, but has used the Kleinfelder (2018) report as a baseline for viewing the current vegetation community extents. An initial site visit was undertaken by Alluvium on 24 April 2019 to observe the vegetation communities outlined in the Kleinfelder report. A second site visit was undertaken on 16 October 2019 to observe the Melaleuca Swamp Sclerophyll Forest in the north-west area and Seasonal Swamp Meadow in the north-central area of the swamp.

The swamp vegetation mapped by Kleinfelder (2018) has been assigned to different communities (Figure 4-4) depending on the vegetation structure and hydrological regime. For the purposes of this assessment, Table 4-2 shows the alignment with the *Coastal Wetlands Classification* following McManus et al (2007). These communities occupy portions of the study area potentially impacted by changes in catchment runoff. Other more terrestrial areas have not been considered.

No individual flora species listed as threatened or endangered were observed during the site inspections.

Eight flora species listed as vulnerable or endangered species (under NSW and/or federal legislation) are recorded in the NSW BioNet Atlas database for the Irrawang Swamp and surrounding area. Suitable habitat to support four of these species is present within the Irrawang Swamp. One of these (*Maundia triglochinoides*) was recently observed in a dam adjacent to Wetland 803 (Mark Aitkens, pers com), although was not observed during the Alluvium site visits.

Table 4-1 *BioNet records for vulnerable or endangered flora species*

Data from the BioNet BioNet Atlas website.
Report generated on 12/11/2019 3:46 PM

Scientific Name	Common Name	NSW status	Comm. status	Records	Last record	Habitat present within Irrawang Swamp	Habitat likely to exist post development
Maundia triglochinoides	Maundia	V		3	2017	Yes	Yes
Commersonia prostrata	Dwarf Kerrawang	E1	E	1		No	
Eucalyptus camfieldii	Camfield's Stringybark	V	V	79		No	
Eucalyptus parramattensis subsp. decadens	Earp's Gum	V	V	35	2006	No	
Rhodamnia rubescens	Scrub Turpentine	E4A		1	1934	Possible	Possible
^Pterostylis chaetophora	Taree rustyhood	V,P,2		1	2017	No	
Persicaria elatior	Tall Knotweed	V	V	2	2010	Yes	Yes
Asperula asthenes	Trailing Woodruff	V	V	1	2009	Yes	Yes

Twenty-two fauna species (listed as vulnerable or endangered fauna species under NSW and/or federal legislation) which are likely to utilise Irrawang Swamp habitats for foraging or shelter are recorded in the NSW BioNet Atlas database for the Irrawang Swamp and surrounding area. Further consideration of impacts on fauna is provided in RPS (2019).

Table 4-2 *Vegetation community classification*

	Ecological community	Conservation status	Coastal Wetland classification
Woodland	Swamp Oak Woodland (Swamp Oak Floodplain Forest)	EPBC - listed as endangered vegetation community	Forest Swamp Ephemeral
Swamp Meadow Complex	Perennial Swamp-meadow (Freshwater Wetlands on Coastal Floodplains)		Deep Marsh (Tall Marsh)
	Seasonal Swamp-meadow (Freshwater Wetlands on Coastal Floodplains)		Shallow Marsh (wet)
	Transilient Swamp-meadow (Freshwater Wetlands on Coastal Floodplains)		Shallow Marsh (dry)
Woodland	Paperbark Woodland (Swamp Sclerophyll Forest on Coastal Floodplains)	EPBC - listed as endangered vegetation community	Forest Swamp Ephemeral

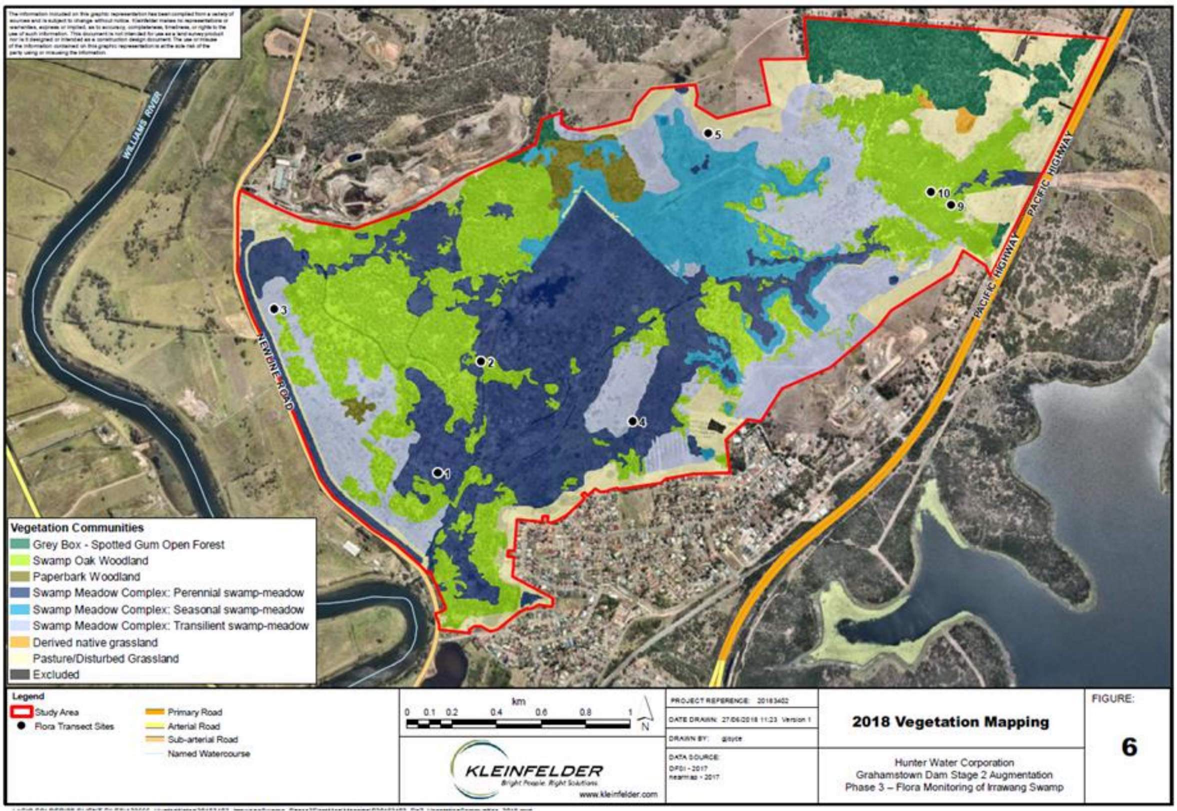


Figure 4-4 *Vegetation mapping by Kleinfelder 2018*

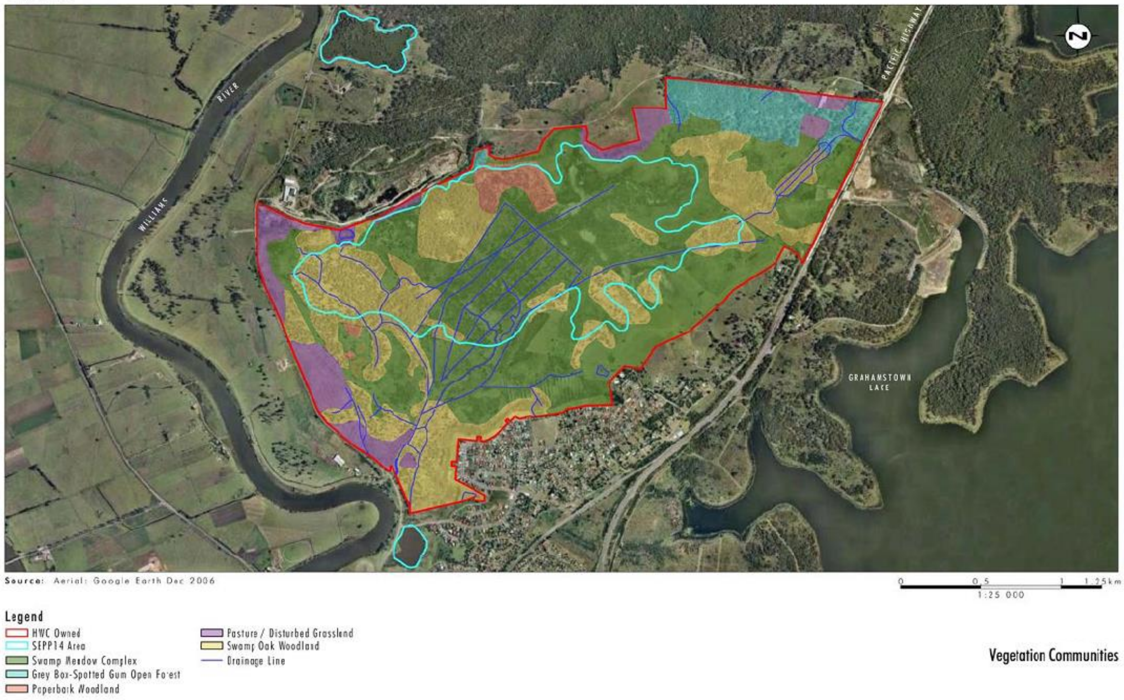


Figure 4-5 *Vegetation mapping by Umwelt 2011*

The Kleinfelder (2018) survey identified the vegetation communities in the wetland to be broadly similar to earlier vegetation assessments undertaken by Umwelt in 2011. Kleinfelder (2018) describes how the extent of the different vegetation communities had changed since the earlier studies in the following way:

> *the key differences are a general increase in the extent of Swamp Oak Woodland vegetation due to significant regeneration of Casuarina glauca (Swamp Oak); and an increase in the extent of swamp-meadow sub-units over the wet meadow sub-unit. In particular, the floristic monitoring shows that increases in the abundances of Bolboschoenus caldwellii, Typha orientalis (Broadleaf Cumbungi) and Casuarina glauca (Swamp Oak), and decreases in the abundance of Cynodon dactylon (Common Couch) over time have made the highest contributions to the overall changes in the vegetation between 2002 and 2018.*

The historic changes in the woodland vegetation can be seen by comparing the estimated Swamp Oak Woodland and Melaleuca Woodland extents from the 1954 image shown in Figure 4-6 with the 2018 extents in Figure 4-4. Due to the clarity of the images, distinctions between the two woodland types cannot be made and therefore they have been combined on the image.

The combined Swamp Woodlands extent in 1954 is estimated to be 174 Ha with the 2018 extent recorded by Kleinfelder (2018) to be 149 Ha. This shows a historic decline in the Swamp Woodlands of approximately 25 Ha (14% of the 1954 extent).

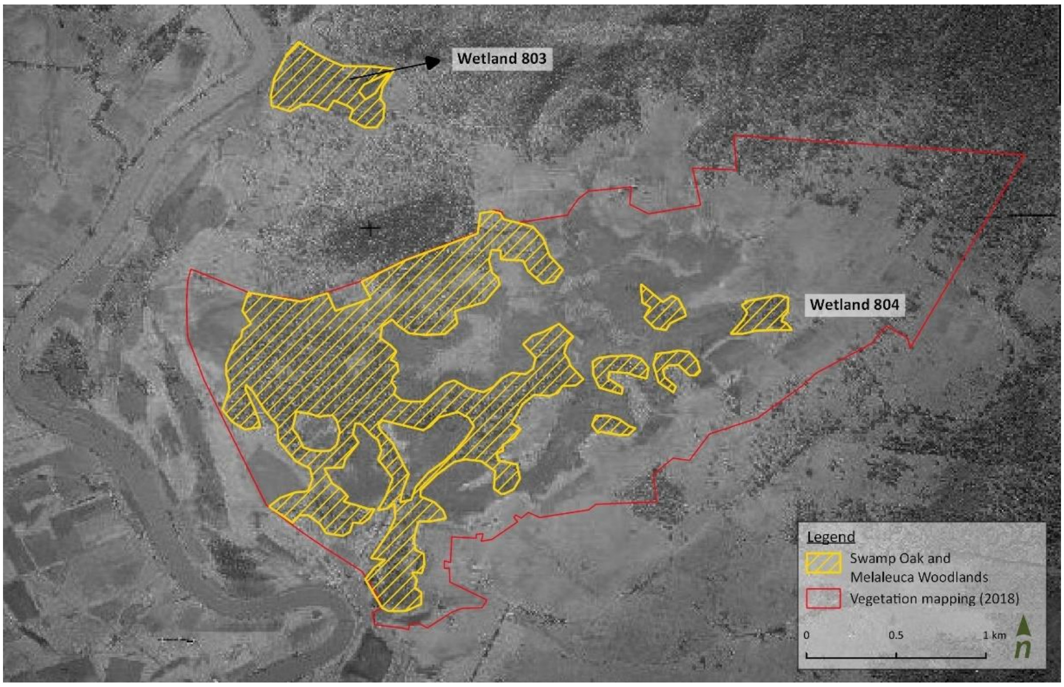


Figure 4-6 *1954 extent of Swamp Oak and Melaleuca Woodlands*

The historic change in Swamp Oak woodland is more pronounced for Wetland 803 which will receive Kings Hill West catchment flows. The Swamp Oak Woodland in this wetland has reduced in extent and density by up to 30%.

Figure 4-7 *1954 and 2019 extents of Swamp Oak Woodland in Wetland 803*

These recent trends of increasing areas of some vegetation communities and species in Irrawang Swamp noted by Kleinfelder (2018) may be a result of a few significant changes that have occurred in the swamp post 2000 including:

- Removal of the cattle and grazing pressure that has:
    - Enabled regeneration of woodland species *Casuarina glauca* and *Melaleuca* sp; and
    - Enabled regeneration of seasonal wetland vegetation such as *Bolboschoenus caldwellii, Carex appressa, Juncus* species.
- Reduction of drainage efficiency to retain water within the swamp that has:
    - Increased perennial marsh *Typha orientalis* and *Phragmites australis*

- Reducing *Cynodon dactylon* (Common Couch) and replacement with more inundation tolerant species such as *Bolboschoenus caldwellii*, *Phragmites australis* and *Typha orientalis*.

4.2 Wetland 803

Wetland 803 is a *Casuarina glauca* Swamp Oak Woodland with areas of submerged vegetation and open water. The wetland is a shallow water body, with a small volume relative to its catchment, which fills readily from the catchment and tidal inflows. Livestock have had historic access to the wetland.

The mature *Casuarina glauca* (Swamp Oak) are growing on pedestals of their own roots (see Figure 4-8) indicating that they have been growing under elevated water levels for a significant period of time. The healthiest *Casuarina glauca* are seen in the north-western corner - which is a shallower area on the wetland and less “pedestaling” is seen in this area. The extent and density of the Casuarina has changed over time with a historic reduction of up to 30% between 1954 and 2019 (see Figure 4-9).

Figure 4-8: *Casuarina glauca growing on a root pedestal within Wetland 803*

Figure 4-9 *1954 and 2019 extents of Swamp Oak Woodland in Wetland 803*

The shallow gradient banks of Wetland 803 have a mixture of herbs, grasses and sedges including: *Paspalum distichum* (Water Couch), *Cotula coronopifolia* (Water Buttons), *Samolus repens* (Creeping Brookweed), *Triglochin* sp (Water Ribbons, Juncus sp, *Bolboschoenus caldwellii* (Marsh Club Rush). In some areas the bank has a sharply stepped bank (at the high water level) reducing the shallow bank vegetation extent.

Extensive emergent macrophytes stands, as seen in Irrawang Swamp, are not present. However, emergent species such as: *Carex appressa* (Tall Sedge), *Eleocharis equisetina* (Spike Sedge), *Bolboschoenus caldwellii* (Sea Club-rush), *Juncus continuus* (Rush), *Ranunculus inundata* (River Buttercup) and Ludwigia peploides (Water Primrose) are present at low cover abundance. This may reflect the hydrology which draws down and then rapidly refills possibly drowning any new emergent macrophyte species. Historic grazing by cattle will have impacted on the emergent vegetation with grazing by water-fowl expected to have some ongoing impact. The lack of *Typha orientalis* indicates that the site periodically dries out.

Areas of submerged vegetation dominated by *Thyridia repens* (Syn *Mimulus repens* - Monkey face) were present during the site visit. This species often occupies areas of sub-saline seasonal mudflats indicating the wetland water level varies through a cycle of complete drying in most years. Other seasonal aquatic species are present including *Callitriche stagnalis* (Common Star-wort), *Potamogeton sulcatus* and *Triglochin* sp. (Water-ribbons).

Wetland 803 has a number of saline tolerant species including *Cotula coronopifolia, Mimulus repens* and *Samolus repens*. Their presence is an indicator of saline influence in the wetland. They are particularly abundant in the areas near the outlet where frequent inflow of saline water occurs. The banks which undergo frequent wetting and drying (which will accumulate salts) are also dominated by these species. However, other non-saline tolerant aquatic plants such as *Callitriche stagnalis* and *Potamogeton sulcatus* were present during the site visit. The presence of these varying tolerance species indicates that inflow from the estuary occurs and that seasonal winter inflow must lower the salinity level significantly. Maintaining these conditions will enable the diversity of flora in the wetland to persist.

4.3 Significant weeds

Two aquatic weeds of national significance (WONS) were identified in vegetation surveys. These are Alligator Weed (*Alternanthera philoxeroides*) and Water Hyacinth (*Eichhornia crassipes*). Both these weeds pose a significant threat to the biodiversity of the wetland and will need to be managed to prevent their spread through the system.

Other WONS recorded or observed on the site are:

- Blackberry (*Rubus fruticosus* species aggregate)
- Lantana (*Lantana camara)*
- *Willows (Salix sp)*

During the April 2019 site visit Alligator Weed was observed adjacent to the north-western boundary of Irrawang Swamp. During the October 2019 site visit a wider area was accessed and Alligator Weed was observed across large areas of Irrawang Swamp. The infestation occupied large areas of the inundated zones and extended into the drier more terrestrial boundary of the swamp. Figure 4-10 shows the spreading infestation smothering over Seasonal Meadow and into the Melaleuca Woodland. A systematic survey of the infestation was not undertaken with Figure 4-11 showing locations where Alligator Weed was observed.

Figure 4-10: *Alligator Weed infestation at North Western corner of Irrawang Swamp*

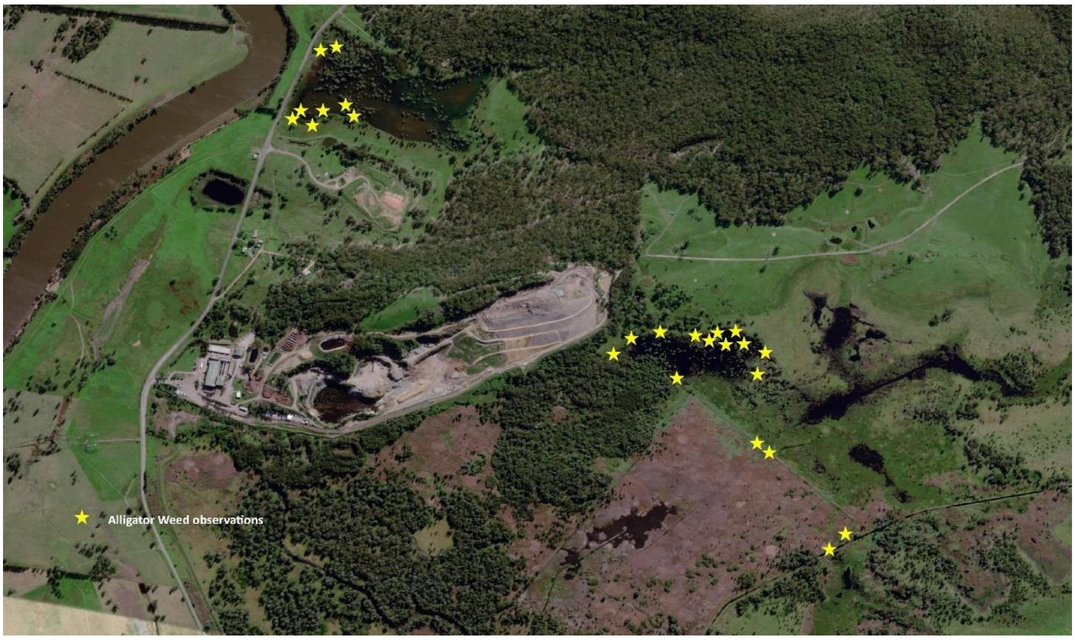


Figure 4-11: *Observed locations of Alligator Weed October 2019*

The infestation in October 2019 is estimated to cover 2 to 5 Ha and is actively expanding. There is an associated infestation of Water Hyacinth which is more restricted to frequently inundated areas and is estimated to cover 1 to 2 Ha within Irrawang Swamp.

Weed control programs need to be implemented and ongoing to ensure these weeds are kept to an acceptable low level throughout the wetland.

4.4 Site visits

A site visit was undertaken on 24 April 2019 to observe the vegetation communities outlined in the Kleinfelder (2018) report. A second site visit was undertaken on 16 October 2019 to review the north-west portion of Irrawang Swamp focussing on the Melaleuca Woodland and Seasonal Meadow north of the central bund/channel. Hydraulic structures were also accessed to further understand their impact on flows through the reserve. The site visits did not include a detailed flora survey, but the Kleinfelder (2018) report was used as a baseline for the current vegetation community extents. Vegetation communities within Wetland 803 were also noted during this site visit.

The site visit was able to confirm the floristic makeup of the different vegetation communities described in Kleinfelder (2018). The relative position of the vegetation communities within the swamp areas and inundation profile was also observed. This has enabled cross checking to historic mapping and LiDAR to determine estimates of the inundation frequency and depths of the vegetation communities.

4.5 Wetland typologies

The vegetation communities in Irrawang Swamp and Wetland 803 occupy different areas depending upon the hydrology of those areas. The hydrological regimes for the different communities described below are shown in Table 4-3. Hydrology risks to these vegetation communities are shown in Table 4-4.

Swamp Meadow Complex

This vegetation community is a mosaic of grasses, sedges and herbs with occasional trees (e.g. Casuarina and Melaleuca) occupying areas of varying inundation. Kleinfelder (2018) mapped this vegetation into three floristic communities shown below. These are stable assemblages of plants but will vary in their composition and extent in response to micro-topography across the site, seasonal water availability and land management practices.

Perennial Swamp Meadow – areas of frequently deep (0.5 to 0.8m deep) and prolonged inundation including during summer. This is found in the lower sections where the Pennington Drain spills frequently and dominates the former agricultural pasture area centrally within the swamp. The vegetation is dominated by monospecific stands of *Typha orientalis* (Broadleaf Cumbungi) and/or *Phragmites australis* (Common Reed). Diversity in these areas is low. Serious weeds such as *Eichhornia crassipes* (Water Hyacinth) and *Alternanthera philoxeroides* (Alligator Weed) have been observed in this zone. Areas of open water occur in within this zone where the water depth prevents tall marsh plants from growing.

This vegetation community is equivalent to the Deep Marsh wetland vegetation in McManus et al (2007). Present in Irrawang Swamp.

Figure 4-12 *Perennial Swamp Meadow on the former agricultural pasture area that is dominated by Typha orientalis.*

Seasonal Swamp Meadow – areas of seasonal inundation (0.2 to 0.5m deep) with an annual drying period of 3 to 6 months. The vegetation of this community can be dominated by *Paspalum distichum* (Water Couch) but shows more diversity in plant species than the Perennial Swamp Meadow areas. Plants observed in this community include *Eleocharis equisetina* (Spike Sedge), *Bolboschoenus caldwellii* (Sea Club-rush), *Juncus continuus* (Rush), *Ranunculus inundata* (River Buttercup), Ludwigia peploides (Water Primrose), *Carex appressa* (Tall Sedge), *Triglochin* sp (Water-ribbons) and *Persicaria decipiens* (Slender Knotweed). Serious weeds such as *Alternanthera philoxeroides* (Alligator Weed) and *Eichhornia crassipes* (Water Hyacinth) have been observed in this zone with *Xanthium occidentale* (Noogoora Burr) also common.

This vegetation community is equivalent to the Shallow Marsh wetland vegetation type in McManus et al (2007). Present in Irrawang Swamp and Wetland 803.

Figure 4-13: *Seasonal Swamp Meadow vegetation with Eleocharis, Triglochin and Paspalum sp.*

Figure 4-14: *Seasonal Swamp Meadow showing variations in vegetation.*

Transient Swamp Meadow – areas that are flooded for short periods after significant rain events. The vegetation is dominated by *Cynodon dactylon* (Common Couch) with *Juncus continuus* and *Carex appressa* commonly seen. Herbaceous weeds such as *Xanthium occidentale* (Noogoora Burr) are also common in this area. Alligator Weed can also invade this zone with this weed invading areas of Transient Swamp Meadow in the NW corner of Irrawang Swamp.

This vegetation community is equivalent to the Shallow Marsh wetland vegetation type in McManus et al (2007). Present in Irrawang Swamp and Wetland 803.

Figure 4-15: *Transient Swamp Meadow dominated by Couch and Tall Sedge (Seasonal Swamp Meadow in lower left corner).*

Swamp Oak Woodland

Swamp Oak Woodland is a floodplain vegetation dominated by *Casuarina glauca* (Swamp Oak) with a variable understorey depending upon the inundation frequency and density of the canopy. Melaleuca species can form part of the canopy structure. This is the most widespread woodland community within Irrawang Swamp. The mapping by Kleinfelder (2018) shows most of the Swamp Oak woodland to be consistent with the community definition under the EPBC Act.

The Swamp Oak Woodlands occupy saturated soils which have a seasonal drying cycle. They periodically flood for short periods (up to 1 month) following large runoff events which recedes rapidly from these areas.

The Swamp Oak Woodland has expanded since the 1970s recolonising areas previously drained and grazed. This is a response to the removal of the cattle and increased soil moisture through the previously drained areas.

This vegetation community is equivalent to the Forest Swamp Ephemeral wetland vegetation type in McManus et al (2007). Present in Irrawang Swamp and Wetland 803.

Figure 4-16 *Swamp Oak Woodland showing recruitment with juvenile plants present.*

Paperbark Woodland

This is an alluvial plain woodland community dominated by Melaleuca species including *Melaleuca linariifoli*a (Snow in Summer), *Melaleuca styphelioide*s (Prickly Paperbark) and *Melaleuca ericifolia* (Swamp Paperbark). This is a seasonally inundated vegetation community with water up to 0.5m deep. It occupies areas at a slightly lower (100-200mm) elevation than the Swamp Oak with longer inundation periods.

Kleinfelder (2018) have mapped it at two main locations. One in the northern boundary of Irrawang Swamp where a drainage line enters and the other near the western boundary.

The northern Paperbark Woodland (Melaleuca Swamp) is susceptible to impacts from increased summer flows as this area is a natural depression and increased summer flows may prevent this area from drying out.

This vegetation community is equivalent to the Forest Swamp Ephemeral wetland vegetation type in McManus et al (2007). Present in Irrawang Swamp.

Figure 4-17 *Melaleuca Woodland with Triglochin dominated understorey***.**

Table 4-3 *Vegetation community hydrological regimes*

	Ecological community	Wetland classification	Dominant species	Hydrological conditions							
				Soil water conditions	**Inundation frequency**	**Inundation depth**	**Inundation duration**	**Inundation regularity**	**Drying period**	**Drying frequency**	**Water quality**
Woodland	Swamp Oak Woodland (Swamp Oak Floodplain Forest)	Forest Swamp Ephemeral	*Casuarina glauca*	Water logged	Episodic	0 to 0.4m (RL 0.6 to 1)	<3 days	4-6 times per year	4-8 months	Annually	Fresh to brackish
Swamp Meadow Complex	Perennial Swamp-meadow Freshwater Wetlands on Coastal Floodplains	Deep Marsh (Tall Marsh)	*Typha orientlis/Phragmites australis*	Saturated	Seasonal to permanent	0.5 to 0.8m (RL 0.2 to .5)	6 months to perennial	Annual	1 - 4 months	1.5 - 3 years	Fresh to brackish
Swamp Meadow Complex	Seasonal Swamp-meadow Freshwater Wetlands on Coastal Floodplains	Shallow Marsh (wet)	*Paspalum distichum* (Water Couch), *Bolboschoenus caldwellii, Ludwigia pleboides, Carex appressa. Juncus* sp	Water logged	Seasonal to episodic	0.2 to 0.5m (RL 0.4 to 0.8)	1-2 months	2-3 times per year	3 - 6 months	Annually	Fresh
Swamp Meadow Complex	Transilient Swamp-meadow Freshwater Wetlands on Coastal Floodplains	Shallow Marsh (dry)	*Cynodon dactylon* (Common Couch), *Juncus sp, Carex appressa*	Water logged	Episodic	0 to 0.4m (RL 0.6 to 1)	1 month	2-3 times per year	8 - 12+ months	Annually	Fresh
Woodland	Paperbark Woodland Swamp Sclerophyll Forest on Coastal Floodplains	Forest Swamp Ephemeral	*Melaleuca styphelioides, Melaleuca linariifolia, Melaleuca ericifolia*	Water logged	Seasonal (Spring)	0 to 0.5m (RL 0.5 to 0.9)	2 to 3 months	Annual	3-6 months	Annually	Fresh to brackish
				Water logged	Episodic	0.2 to 0.4m (RL 0.6 to 0.8)	1 month	2-3 times per year			

Table 4-4 *Vegetation community hydrology risks*

	Ecological community	Wetland classification	Dominant species	Hydrology risk		
				Current trajectory	Increase in depth and duration	Reduced depth and duration
Woodland	Swamp Oak Woodland (Swamp Oak Floodplain Forest)	Forest Swamp Ephemeral	*Casuarina glauca*	Increase in extent. Unclear ff this is due to hydrology or reduced grazing pressure.	>200mm of drawdown depth for more than 1 month duration. Drowning of Swamp Oak, reduced extent.	Increase in Swamp Oak if reduction is low and waterlogged soils are retained.
Swamp Meadow Complex	Perennial Swamp-meadow Freshwater Wetlands on Coastal Floodplains	Deep Marsh (Tall Marsh)	*Typha orientlis/Phragmites australis*	Increase in extent	Further spread especially if summer inundation increses	Reduction in perrennial to Season Swamp-meadow
	Seasonal Swamp-meadow Freshwater Wetlands on Coastal Floodplains	Shallow Marsh (wet)	*Paspalum distichum* (Water Couch), *Bolboschoenus caldwellii, Ludwigia pleboides, Carex appressa. Juncus* sp	Reducing	Reduction with increase in Perennial Swamp-meadow	Potential increase
	Transilient Swamp-meadow Freshwater Wetlands on Coastal Floodplains	Shallow Marsh (dry)	*Cynodon dactylon* (Common Couch)*, Juncus sp, Carex appressa*	Reducing with Swamp Oak Woodland colonising into this area.	Reduction with increase in Perennial Swamp-meadow	Potential increase
Woodland	Paperbark Woodland Swamp Sclerophyll Forest on Coastal Floodplains	Forest Swamp Ephemeral	*Melaleuca styphelioides, Melaleuca linariifolia, Melaleuca ericifolia*	Stable with some increase	>200mm of drawdown depth for more than 1 month duration. Reduction with increase in Perennial Swamp-meadow	Potential increase

5 Development impacts on catchment hydrology

5.1 Hydrological model development

MUSIC models were prepared by Northrop Consulting Engineers (NCE) to evaluate runoff quality from the development site for existing, developed (untreated) and developed (with treatment) scenarios.

The five-year modelling period adopted by NCE for stormwater quality modelling was considered insufficient for the purpose of completing flow regime analysis. Alluvium assisted NCE with extending the modelling period to reflect an appropriately representative period for the hydrology analysis. A representative continuous 20-year rainfall period with good quality and complete 6-minute time step data was selected from the nearby Williamtown RAAF rainfall station. The period from 1989 to 2008 provided good quality data with a mean annual rainfall consistent with the long-term average.

Alluvium sourced appropriate daily potential evapotranspiration data from the SILO database covering the rainfall data period. Daily estimates of Mortons PET (wet) were adopted as being most appropriate for hydrologic modelling.

A MUSIC template was prepared utilising the above data and supplied to NCE. NCE modified their MUSIC models to incorporate the new template and provided updated daily flow estimates for 3 scenarios; existing, developed (untreated) and developed (with treatment).

NCE provided daily flow outputs from their models for Alluvium's hydrological analysis. In completing this analysis, Alluvium has assumed that the models developed by NCE appropriately reflect the site characteristics and conditions for each development scenario. We understand that the process followed to develop the MUSIC models is outlined in a separate report prepared by NCE (NCE, 2019).

Northrop provide flow outputs at three separate locations relevant to the assessment:

- Kings Hill South includes the future development and remaining forest areas that drain into the northern side of Irrawang Swamp through ephemeral gullies.
- Kings Hill East includes areas draining to a location where the original spillway channel joins the eastern side of Irrawang Swamp. For the existing scenario, the sub-catchments only include areas draining to an ephemeral creek located between the Pacific Highway and the Riding for the Disabled site. For the developed (treated) scenario the catchment draining to this location will increase significantly due to construction of a diversion channel required to prevent the discharge of runoff from development in Kings Hill East into Grahamstown Dam.
- Kings Hill West includes areas draining to a small coastal wetland previously listed as Coastal Wetland 803 under repealed SEPP 14 legislation.

5.2 Mean annual runoff volume

Changes in mean annual runoff volume provide a coarse indicator of the catchment hydrology changes associated with the Kings Hill development. Table 5-1 summarises the estimated changes to mean annual runoff volumes draining to Irrawang Swamp and Wetland 803 that are associated with the Kings Hill development.

The Kings Hill East sub-catchment includes all future development areas (and forested areas draining through these areas) that will drain to the original Grahamstown Dam spillway outlet into Irrawang Swamp. The estimated mean annual runoff volumes for the developed and developed (with treatment) scenarios are based on a 0.2% AEP capacity diversion drain being constructed on the eastern side of the Pacific Highway in Hunter Water owned land. This drain would divert runoff that currently drains directly to Grahamstown Dam to the original spillway.

The Kings Hill East sub-catchment also includes an existing ephemeral creek between the existing Riding for the Disabled site and the Pacific Highway. This creek transitions to a section of concrete channel parallel to the original Grahamstown Dam. The creek discharges into Irrawang Swamp at the same location as the original spillway.

The Kings Hill South sub-catchment includes all future development areas (and forested areas draining through these areas) that drain through three existing ephemeral gullies into the northern side of Irrawang Swamp.

The sub-catchment extents for Kings Hill East, Kings Hill South and Kings Hill West are shown on Figure 2-1.

Table 5-1 *Estimated mean annual runoff volumes (1989 to 2008 modelling period)*

Sub-catchment	**Scenario**	**Catchment runoff discharge location**				
		Northern Irrawang Swamp	**Original spillway outlet channel**	**Grahamstown Dam**	**Wetland 803**	**Williams River**
Kings Hill East	Existing	0	625	925	0	0
	Developed	0	2300	0	0	0
	Developed (treated)	0	2120	0	0	0
	Change		+1495 (+240%)	-925 (-100%)		
Kings Hill South	Existing	470	0	0	0	0
	Developed	700	0	0	0	0
	Developed (treated)	575	0	0	0	0
	Change	+105 (+22%)				
King Hill West	Existing	0	0	0	427	0
	Developed	0	0	0	529	0
	Developed (treated)	0	0	0	458	31
	Change				+31 (+7%)	+31

The estimated mean annual runoff volumes summarised in Table 5-1 indicate that:

- The average annual runoff discharged to Grahamstown Dam from the Kings Hill East sub-catchments is estimated to decrease by approximately 925 ML/yr following construction of the diversion drain. Excluding infiltration and evapotranspiration losses along the diversion drain, most of this runoff would discharge to the original spillway channel and then to Pennington Drain.
- The average annual runoff discharged from the local Kings Hill sub-catchments to the original spillway channel is expected to increase by up to approximately 1500 ML/year following development. This increased volume includes the parts of Kings Hill East currently draining to Grahamstown Dam that will be diverted to the original spillway, and the increased runoff from the other parts of Kings Hill East that continue to drain to the original spillway.
- An increase in mean annual runoff of 105 ML is estimated from the Kings Hill South sub-catchments draining into the ephemeral gullies located to the north of Irrawang Swamp.
- The increase in runoff from Kings Hill West to Wetland 803 will be limited 31 ML/yr (7% increase).

As a proportion of the existing runoff, the increase in runoff discharged into the eastern extents of Irrawang Swamp is significantly greater than the increase from the northern catchments. Whilst the total volume of runoff will increase across the full range of small to large storm events, changes in the flow regime during drier low flow periods are expected to be more critical for the vegetation communities within Irrawang Swamp. How runoff characteristics are estimated to change with development for small and large rainfall events is discussed in Section 5.3.

5.3 Cumulative runoff

A plot of daily rainfall totals and associated cumulative runoff volumes for Kings Hill South is provided in Figure 5-1. Figure 5-1 is based on MUSIC model flow outputs from the 20-year models prepared by NCE for the existing and developed scenarios. The trends shown in the hydrologic modelling results presented in Figure 5-1 would also be representative of other areas of the Kings Hill development.

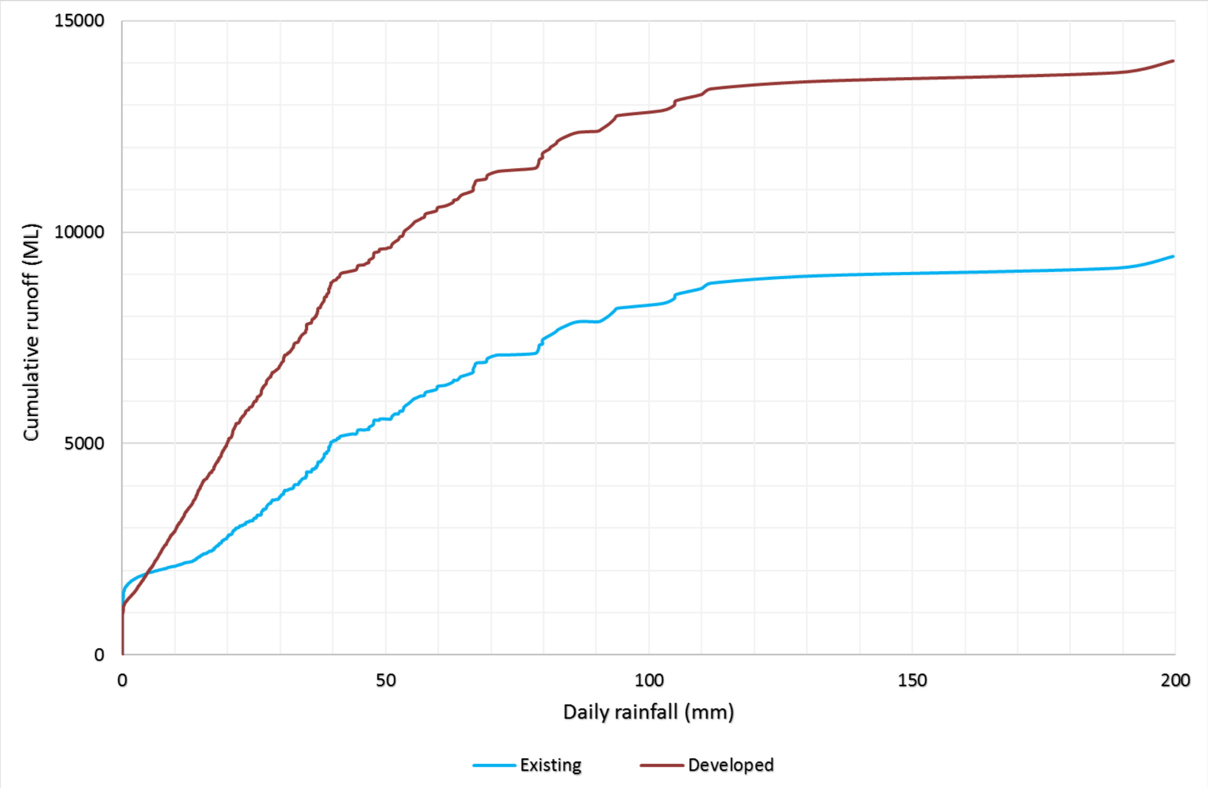


Figure 5-1 *Plot of daily rainfall and estimated cumulative runoff for Kings Hill South catchment (1989 to 2008)*

Figure 5-1 indicates that the most significant differences in runoff volumes between the existing and developed scenarios are likely to occur for days where the daily rainfall is less than 50mm. For daily rainfall totals between 50mm and 100mm there is a small difference, and above daily rainfall totals of 100mm the volume of runoff from the existing and developed site is expected to be similar. The reasons for these differences are discussed below.

For daily rainfall totals less than 50mm, a high proportion of rainfall within the existing forested and pasture areas will be retained in the upper soil layers with some intercepted rainfall draining slowly as either interflow or base flow to creeks in the days immediately following rainfall. Rainfall absorbed by the soil will typically evaporate or be transpired by plants in the days following a storm event. In a developed site, impervious roof and road surfaces only intercept a very small rainfall depth (typically less than 2mm) with any additional rainfall causing stormwater runoff to occur from these surfaces. This results in more frequent runoff from developed catchments during much smaller rainfall events and this cumulatively adds up to a significant volume.

For daily rainfall totals exceeding 50mm, it is likely that soils will become close to saturation in the early stages of a rainfall event, resulting in a high proportion of additional rainfall being converted to runoff. In this manner, pervious surfaces would tend to generate similar runoff volumes as developed impervious surfaces in larger rainfall events and this is why only a marginal increase in estimated runoff volume occurs above a daily rainfall total of 50mm in Figure 5-1.

Figure 5-1 indicates that cumulative changes in hydrology from developing catchments are likely to be more pronounced for days where the daily rainfall is less than 50mm. Mitigation strategies aiming to replicate pre-development hydrology conditions therefore need to focus on reducing changes in runoff volumes for days where the daily rainfall is less than 50mm. This requires a change in approach from conventional drainage and flooding studies where much larger storm events are the focus. It also requires a change from a focus on discrete peak stormwater flow rates to management of stormwater runoff volumes.

5.4 Legislation context

The *NSW Coastal Management Act 2016* replaced the *Coastal Protection Act 1979* and established a new strategic framework and objectives for managing coastal issues in NSW. This act includes *State Environmental Planning Policy (Coastal Management) 2018.* ('the SEPP'). The SEPP identifies areas of interest that are delineated on the *Coastal Wetlands and Littoral Rainforest areas map*. This map highlights the coastal wetlands and a proximity buffer area which the SEPP applies to.

The study area contains two Coastal Wetlands (803 & 804) listed in SEPP 2018 and these are shown on Figure 2-1. Whilst the proposed Kings Hill development extents lie outside the mapped Coastal Wetlands and the Proximity Area for Coastal Wetlands, the development has the potential to impact within the areas of interest to the SEPP.

SEPP Clauses 10 and 11 provide guidance on the threats that need to be considered to determine if an impact will occur (see relevant sections of the SEPP outlined below). The key threatening processes posed by the development are identified in other legislation that is also outlined below.

Clause 10: Development on certain land within coastal wetlands and littoral rainforests area

(1) The following may be carried out on land identified as "coastal wetlands" or "littoral rainforest" on the Coastal Wetlands and Littoral Rainforests Area Map only with development consent:

(a) the clearing of native vegetation within the meaning of Part 5A of the Local Land Services Act 2013,

(b) the harm of marine vegetation within the meaning of Division 4 of Part 7 of the Fisheries Management Act 1994,

(c) the carrying out of any of the following:

(i) earthworks (including the depositing of material on land),

(ii) constructing a levee,

(iii) draining the land,

(iv) environmental protection works,

(d) any other development.

Clause 11: Development on land in proximity to coastal wetlands or littoral rainforest

The Coastal Wetlands and Littoral Rainforests Area Map identifies certain land that is inside the coastal wetlands and littoral rainforests area as "proximity area for coastal wetlands" or "proximity area for littoral rainforest" or both.

(1) Development consent must not be granted to development on land identified as "proximity area for coastal wetlands" or "proximity area for littoral rainforest" on the Coastal Wetlands and Littoral Rainforests Area Map unless the consent authority is satisfied that the proposed development will not significantly impact on:

(a) the biophysical, hydrological or ecological integrity of the adjacent coastal wetland or littoral rainforest, or

(b) the quantity and quality of surface and ground water flows to and from the adjacent coastal wetland or littoral rainforest.

This report documents the potential changes to the surface water flows and the estimated impacts of those changes if the Kings Hill development proceeds. If direct impacts on the values in the wetland are not likely to occur then SEPP 2018 Clause 10 is not active.

***NSW Biodiversity Conservation Act 2016* (BC Act), Threatened Species Conservation Act 1995 and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)**

These Acts provide protection to individual species and vegetation communities throughout NSW. If listed species or vegetation communities are identified in project areas or areas to be impacted as a consequence of development, these Acts must be referred to for assessment and response requirements.

Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands is listed as a 'key threatening process' in Schedule 3 of the Threatened Species Conservation Act 1995 [31 May 2002]. Understanding the potential for this threatening process to impact on the values within Irrawang Swamp is a key objective of this assessment. This threatening process aligns to the requirements in SEPP 2018 to protect coastal wetlands.

Eight flora species listed as vulnerable or endangered species (under NSW and/or federal legislation) are recorded in the NSW BioNet Atlas database for the Irrawang Swamp and surrounding area. Conditions suitable to support four of these species occur within the Irrawang Swamp. See Table 4-1 for details on these species. No flora species listed as threatened or endangered were observed during the site visits.

Three vegetation communities listed as vulnerable or endangered in the BC Act or EPBC Act (shown in Table 5-2) have been recorded and observed in the site.

Table 5-2 *Vegetation communities of interest within Irrawang Swamp*

Vegetation community	NSW Biodiversity Conservation Act 2016 (BC Act)	Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)
Swamp Meadow Complex	Freshwater Wetlands on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions **Endangered**	
Swamp Oak Woodland	Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner bioregions **Endangered**	Coastal Swamp Oak (Casuarina glauca) Forest of New South Wales and South East Queensland **Endangered**
Paperbark Woodland (Melaleuca Swamp)	Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions **Endangered**	

The listing of a vegetation community under these Acts requires the protection of the area occupied by them from the key threatening processes listed in the Acts.

Activities which can lead to changes to natural drainage regimes, such as the diversion of water, affecting the ecological community can require a referral under the Acts if they will have an impact on the listed species or communities. With the presence of listed species and vegetation communities in the wetland evidence needs to be provided to ensure that they will not be impacted.

This assessment investigates the potential for the changes in flows from the catchment following development to have an impact on the Irrawang Swamp values.

5.5 Kings Hill East and Kings Hill South flow regimes (Irrawang Swamp)

HWC has requested that an assessment of the effects of changes to stormwater discharges to Irrawang Swamp be completed to address biodiversity values and ecological integrity. HWC has indicated it expects that the Kings Hill development proponent demonstrate that the current wetting / drying regime of the Irrawang Swamp would not be adversely impacted by stormwater discharges from the diversion channel and direct discharges from other catchments areas.

HWC has referred to the approach outlined in the guideline document *Water Sensitive Urban Design Solutions for Catchments above Wetlands – Overview Report* (McManus et al, 2007) which indicates that WSUD strategies associated with new developments in the catchments upstream of natural wetlands need to include measures to preserve the pre-development drying and flooding hydrology characteristics in order to protect the wetland ecology.

McManus et al (2007) outlines drying and flooding hydrology management targets for a range of wetland categories and these are summarised in Table 5-3. Wetland categories identified in Section 4.5 that would be relevant to Irrawang Swamp include Shallow Marsh, Deep Marsh and Forest Swamp - Ephemeral.

Table 5-3 *Hydrologic management targets for natural wetlands (McManus et al, 2007)*

Wetland Category	Flooding Hydrology	Drying Hydrology		Reference Duration
	High Flow Duration Frequency Curve	Low Flow Duration Frequency Curve	Low Flow Spell Frequency	
1. Coastal Flats	✓			7 days
2. Inland Flats	✓	Isolate wetland from upstream catchment		30 to 60 days
3. Bogs	✓	✓	✓	30 to 60 days
4. Deep Marsh		✓	✓	30 to 60 days
5. Fen	✓	✓	✓	30 to 60 days
6. Shallow Marsh		✓	✓	60 days
7. Salt Marsh	✓	✓	✓	7 days
8. Seagrass Beds	✓			7 days
9. Deep Salt Pans	✓	Isolate wetland from upstream catchment		30 to 60 days
10. Deep Open Water	No hydrologic management objectives required			
11. Shallow Open Water		✓	✓	60 days
12. Wet Heath		✓	✓	60 days
13. Mangrove	✓			7 days
14. Scrub Swamp	✓	✓*	✓*	60 days
15. Forest Swamp – Wet		✓	✓	60 days
16. Forest Swamp – Ephemeral		✓	✓	60 days
17. Forest Swamp – Dry	✓	✓*	✓*	60 days

Considering the targets outlined in Table 5-3 for the identified relevant wetland categories within Irrawang Swamp, flow regime analysis was completed focusing on the drying hydrology. Inflows to Irrawang Swamp were analysed to derive dry spells curves (low flow spells) and low flow duration frequency curves for 30 and 60-day reference durations. Additional analysis of 7-day duration high flows was also completed to evaluate the impact of diverting runoff from Kings Hill East to Irrawang Swamp. The completed analysis covers the range of wetland vegetation communities currently observed in the swamp. The approach followed to derive the flow regime curves is described in the following sections.

Critical drying period
The critical drying period for Irrawang Swamp is from September to March when average monthly potential evapotranspiration typically exceeds average monthly rainfall at this location (refer Figure 5-2). It is during this period that rainfall and associated runoff to the wetland would be lower enabling soils to partially dry in areas of a wetland to support new plant growth. Minimising changes to hydrology during this drying period are particularly important for the Shallow Marsh, Deep Marsh and Forest Swamp - Ephemeral communities within Irrawang Swamp.

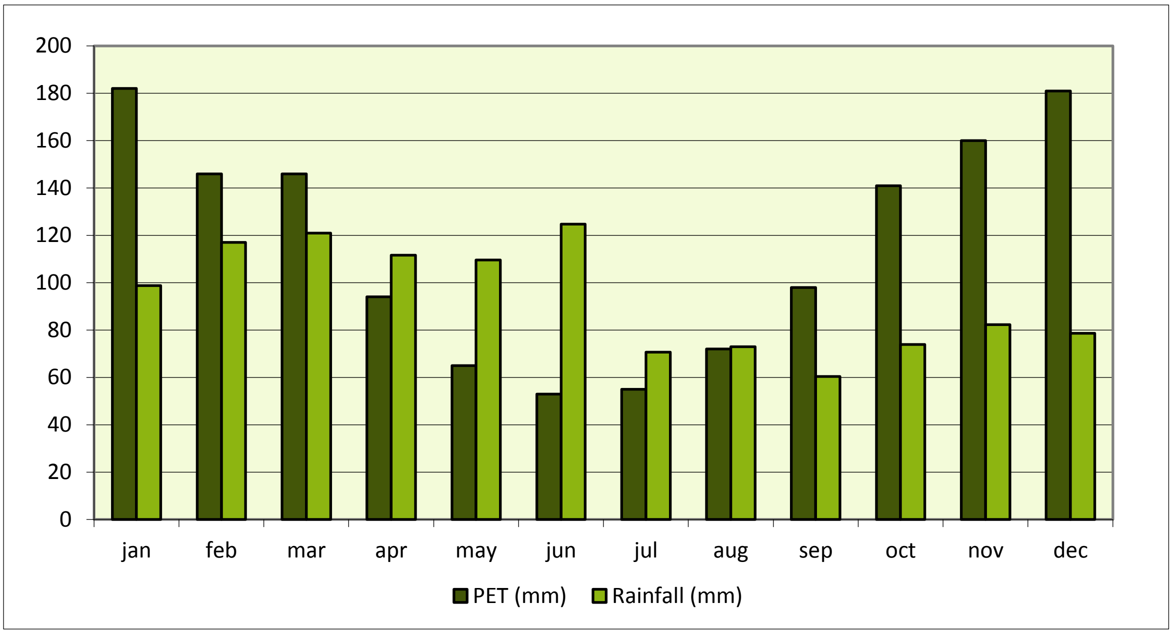


Figure 5-2 *Average monthly potential evapotranspiration and rainfall depths for Irrawang Swamp (BoM Climate Atlas of Australia)*

Dry spells curves
The MUSIC models prepared by NCE to evaluate runoff quality for Kings Hill were adopted for developing the dry spells curves. The approach outlined in McManus et al (2007) was applied to develop the dry spells curves. This approach involves completing annual flow frequency analysis considering the critical drying period for the swamp. As outlined above, for Irrawang Swamp this period was assessed to be from September to March. For each of modelled years, the longest continuous period where estimated daily runoff was lower than the long-term median flow was calculated within the critical drying period. Flow frequency analysis was then completed using the flows estimated by NCE for the existing, developed (untreated) and developed (treated) scenarios and the results plotted. The dry spell curves derived for the Kings Hill South and Kings Hill East sub-catchments are show on Figure 5-3 and Figure 5-4 respectively.

An example of how these curves may be interpreted is indicated by the dashed green line shown on Figure 5-3. This line indicates that there is a 10% chance in any year that the maximum dry spell will exceed 32 days for developed conditions and 190 days for the existing conditions. Typically, a 10% AEP dry spell would be representative of that occurring in a dry year, whilst a 90% AEP dry spell would occur within a wet year. A 50% AEP dry spell is considered to be that occurring in a typical year.

The dry spells curves indicate that the length of the maximum annual dry spell is expected to reduce following development for the full range of dry to wet years. The stormwater management strategy proposed by NCE would partially mitigate reductions in dry spells through the provision of 5 kL rainwater tanks, biofiltration systems and urban lakes throughout the development.

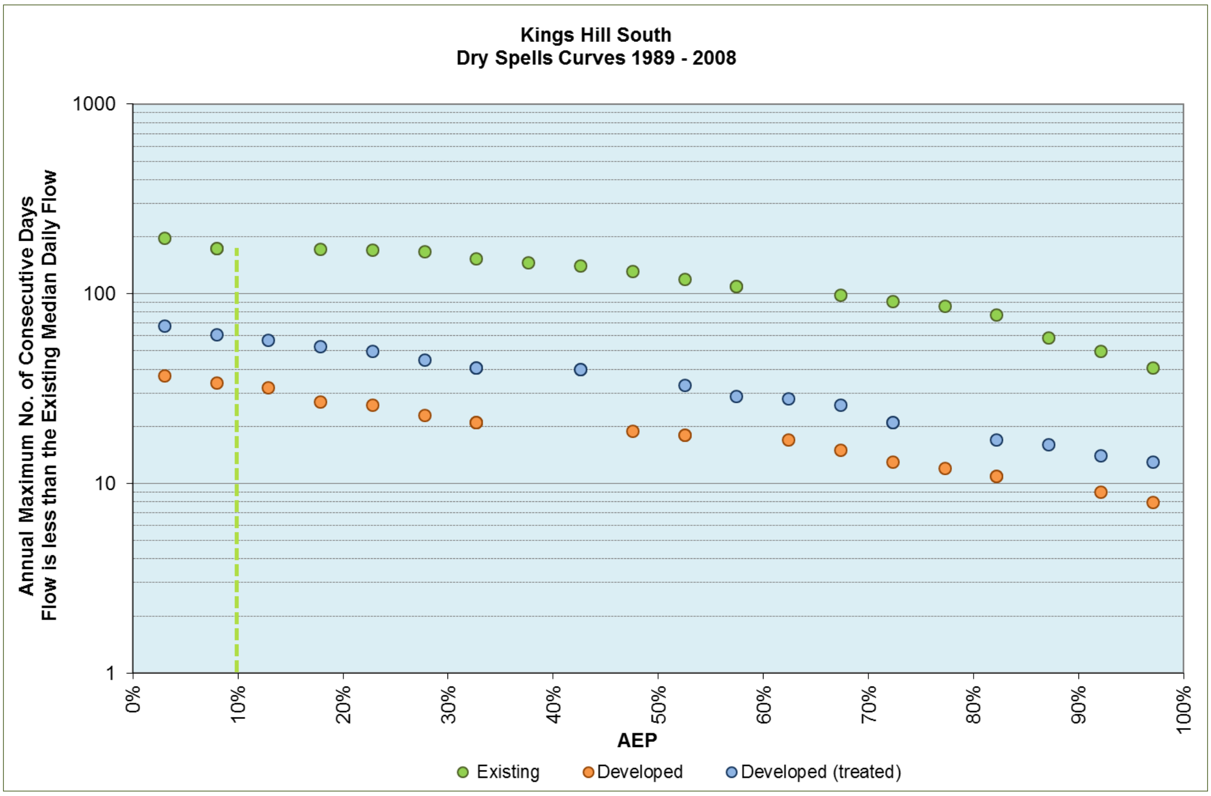


Figure 5-3 *Kings Hill South – Dry Spells Curves*

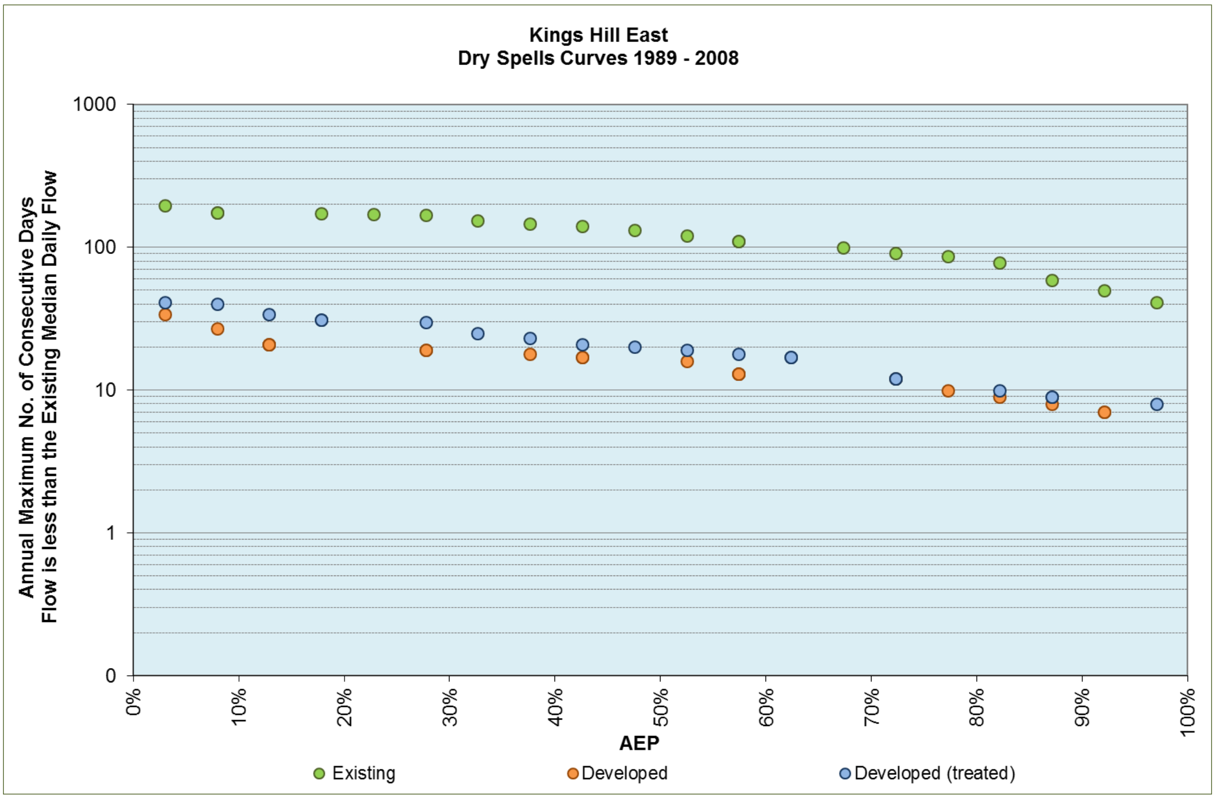


Figure 5-4 *Kings Hill East – Dry Spells Curves*

Low flow duration frequency curves
Similar to the dry spells analysis, the approach outlined in McManus et al (2007) was adopted to develop low flow duration frequency curves. This approach also involves completing annual flow frequency analysis considering the critical drying period for the swamp. A continuous moving average (30 days and 60 days) of the mean daily flow was calculated over the entire modelled period. For each of the modelled years, the maximum average daily 30 and 60-day flows within the critical drying period for each year were calculated. Flow frequency analysis was then completed on the averages for the existing, developed (untreated) and developed (treated) scenarios and the results plotted. The low flow curves derived for the Kings Hill South and Kings Hill East sub-catchments are show on Figure 5-5, Figure 5-6, Figure 5-7 and Figure 5-8.

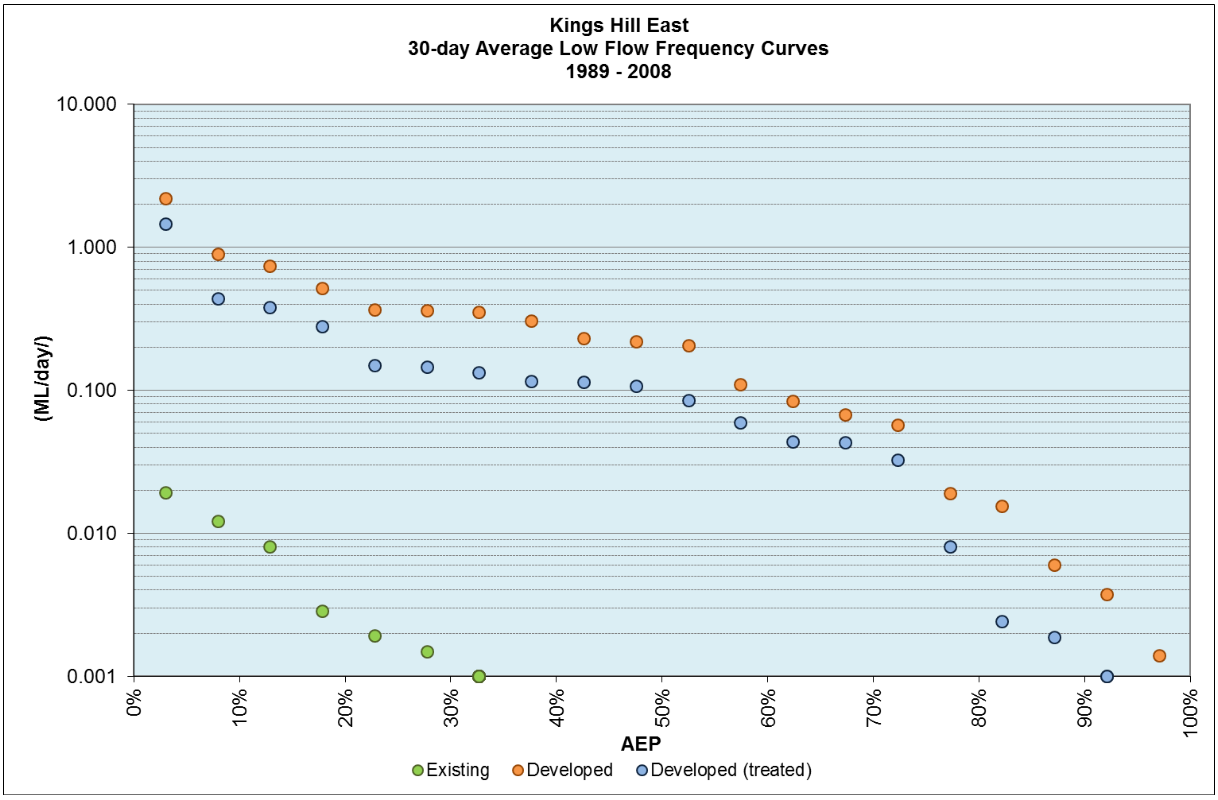


Figure 5-5 *Kings Hill East – 30-day average low flow frequency curves*

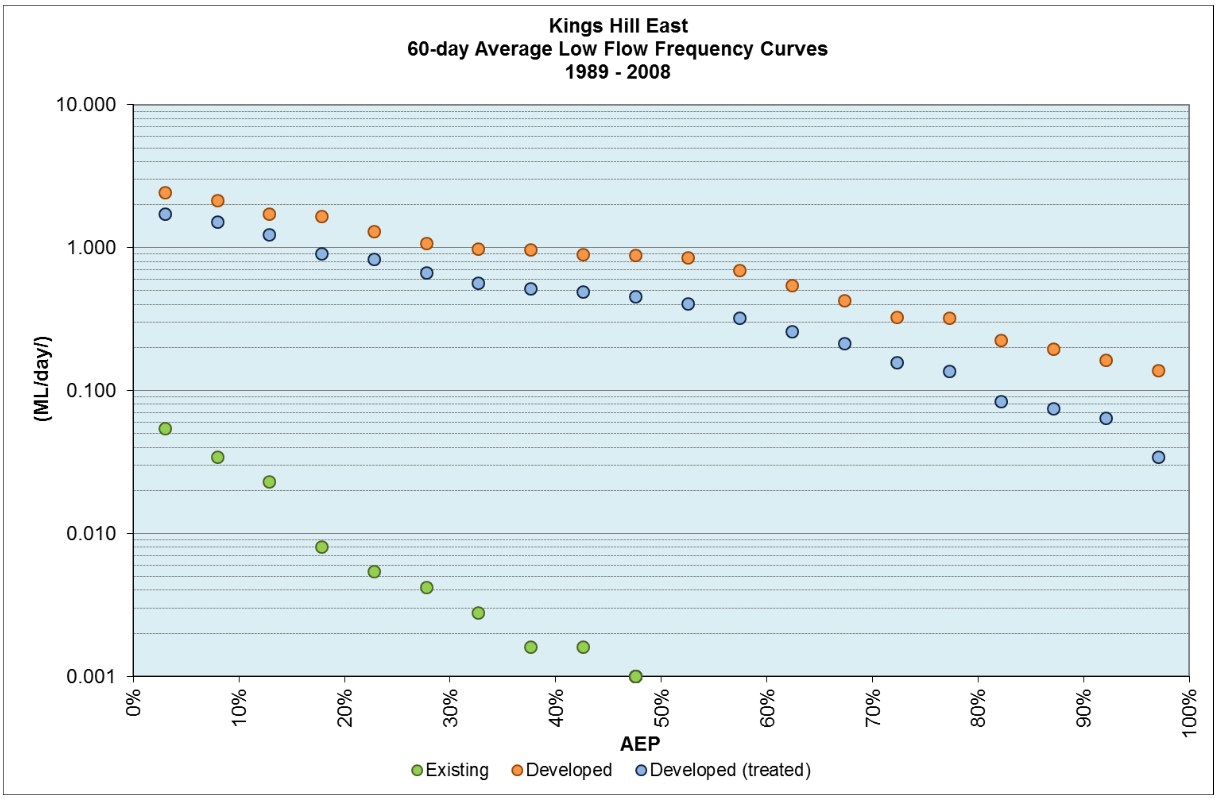


Figure 5-6 *Kings Hill East – 60 day average low flow frequency curves*

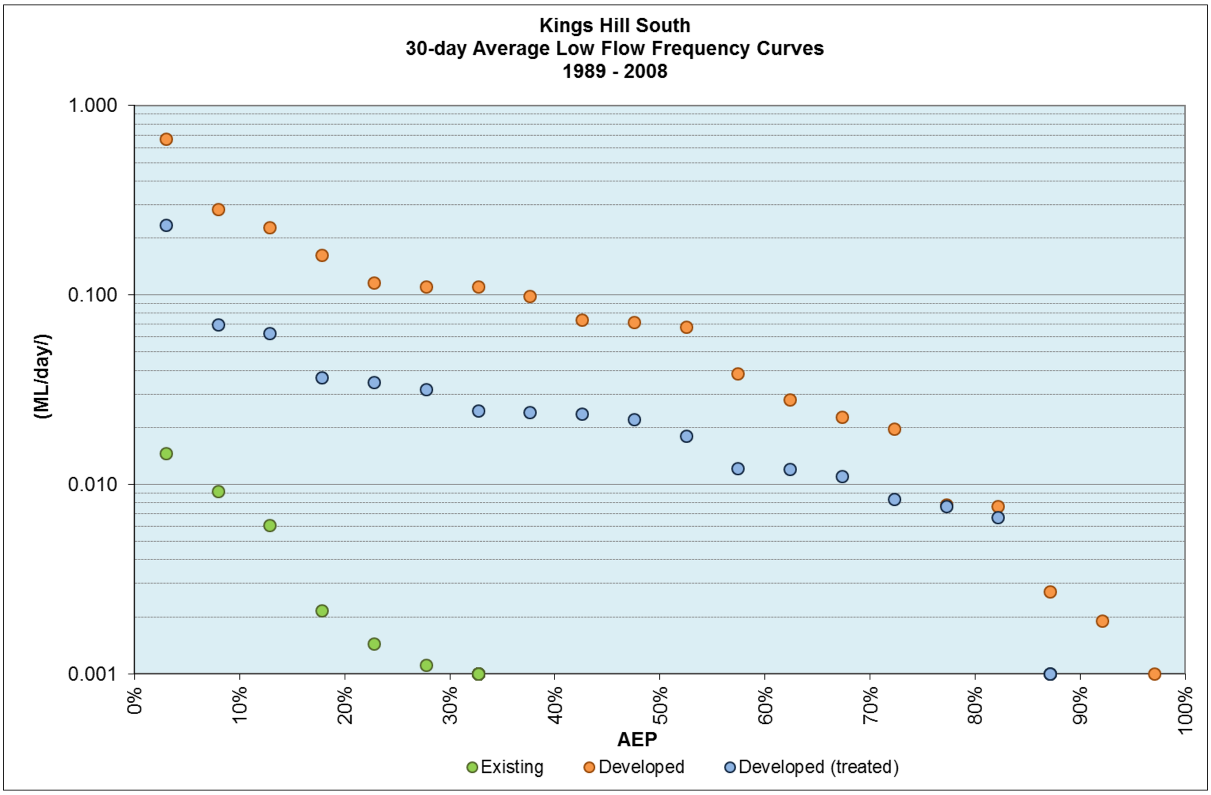


Figure 5-7 *Kings Hill South – 30-day average low flow frequency curves*

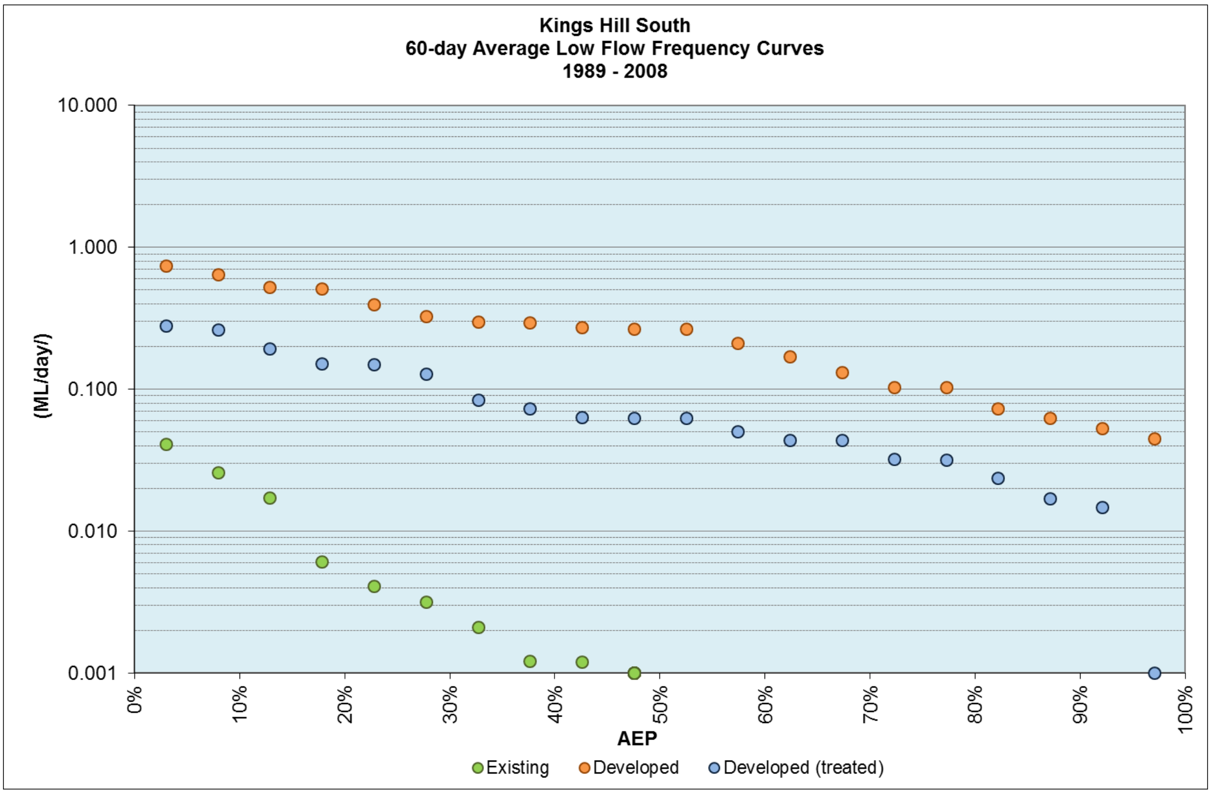


Figure 5-8 *Kings Hill South – 60-day average low flow frequency curves*

The low flow frequency curves indicate that the average daily flow during the 30 and 60-day low flow periods is expected to increase following development for the full range of dry to wet rainfall years. The stormwater management strategy proposed by NCE partially mitigates increased low flows through the provision of 5 kL rainwater tanks, biofiltration systems and urban lakes throughout the development.

The low flow frequency curves indicate that under existing conditions, there is a 50% chance in any year that the average daily flow volume during the critical drying period will be approximately zero. For developed conditions, it is estimated that for all but very dry years, runoff will discharge into Irrawang Swamp from the developed catchments during the critical drying period. Whilst low flow discharges are likely to occur, the magnitude of the increased low flows and associated impacts on wetland vegetation inundation are expected to be low. These impacts are discussed further below.

High flow duration frequency curves

Potential impacts on the wetland vegetation from Kings Hill runoff are expected to be largely related to changes in increased frequency of runoff from impervious surfaces within the development during natural low flow periods. Irrawang Swamp is currently already exposed to high discharges associated with spillway releases from Grahamstown Dam that differ significantly to natural conditions.

It is expected that the runoff volumes from Kings Hill South and Kings Hill West during high flow periods will not change significantly from existing conditions as these would generally align with periods where soils would be saturated or close to saturation for extended periods (refer to Section 5.1 for further discussion on this) and this is demonstrated in Figure 5-9 for Kings Hill South.

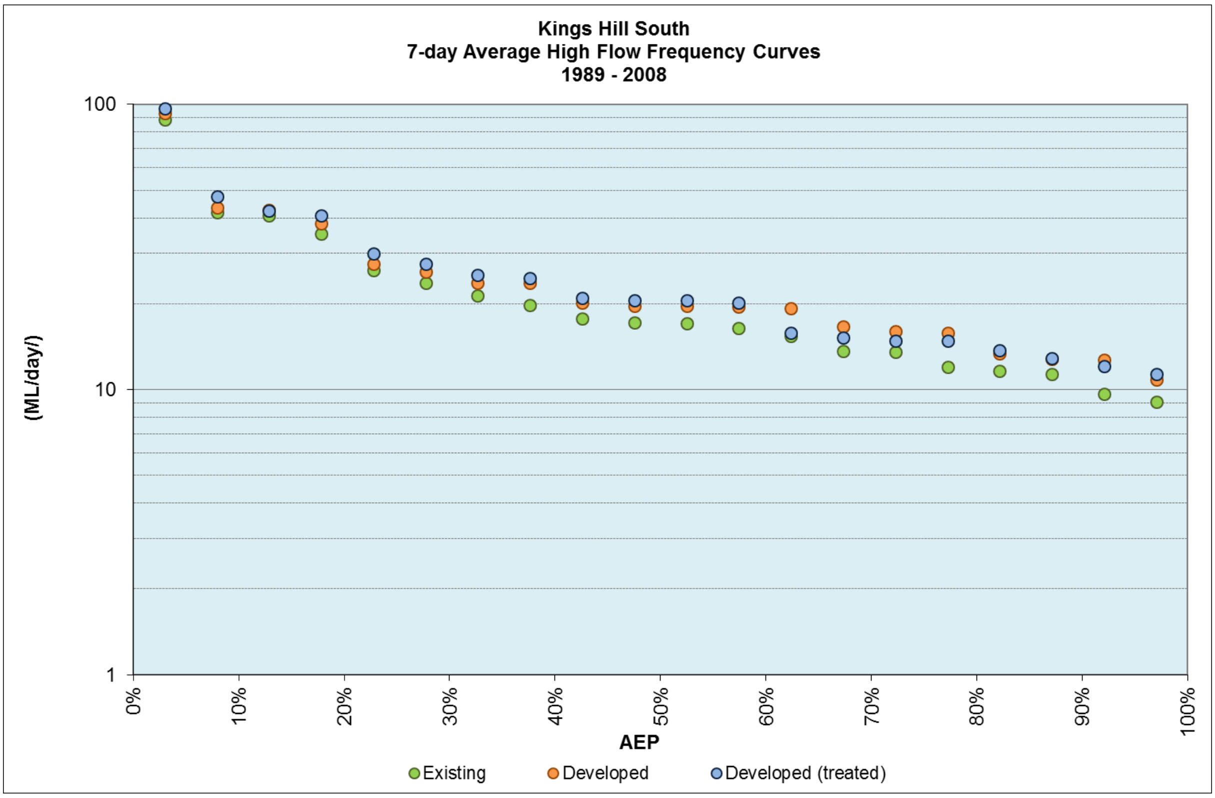


Figure 5-9 *Kings Hill South – 7-day average high flow frequency curves*

The main change from developed conditions would be that increased high flows from Kings Hill East will be directed to Irrawang Swamp along the diversion channel. Under existing conditions, high flows from Kings Hill East discharge directly into Grahamstown Dam. Although, during periods when dam storage levels in Grahamstown Dam are close to the spillway level, existing high flow discharges from Kings Hill East to Grahamstown Dam may indirectly discharge to Irrawang Swamp through the spillway.

Figure 5-10 summarises the estimated high flow discharges from Kings Hill East under existing and developed conditions. The existing high flows are for the portion of the Kings Hill East catchment that drains south of the proposed interchange along an existing ephemeral creek through the Riding for the Disabled site to a concrete channel that joins Irrawang Swamp at the same location as the original Grahamstown Dam spillway. The developed high flows for Kings Hill East include contributions from the catchment described above and the remaining part of the Kings Hill East catchment directed to the proposed diversion channel.

Figure 5-10 indicates that for a high rainfall year (10% AEP), the Kings Hill East development is estimated to increase average 7-day high flows by approximately 85 ML/day (600 ML over the 7 day period). For a typical rainfall year (50% AEP), the model results indicate that the Kings Hill East development and diversion drain would increase average 7-day high flows by approximately 40 ML/day (280 ML over the 7-day period) from Kings Hill East.

Figure 5-10 also indicates that the stormwater management measures proposed by NCE are unlikely to have any significant impact on reducing high flow discharges. This is expected as the magnitude of the high flows would require the provision of an excessively large volume of additional retention storage similar in size to the estimated increase to have any significant influence on reducing the high flow volumes.

The impact of this increase in high flow discharge is discussed and compared with current Grahamstown Dam discharges below.

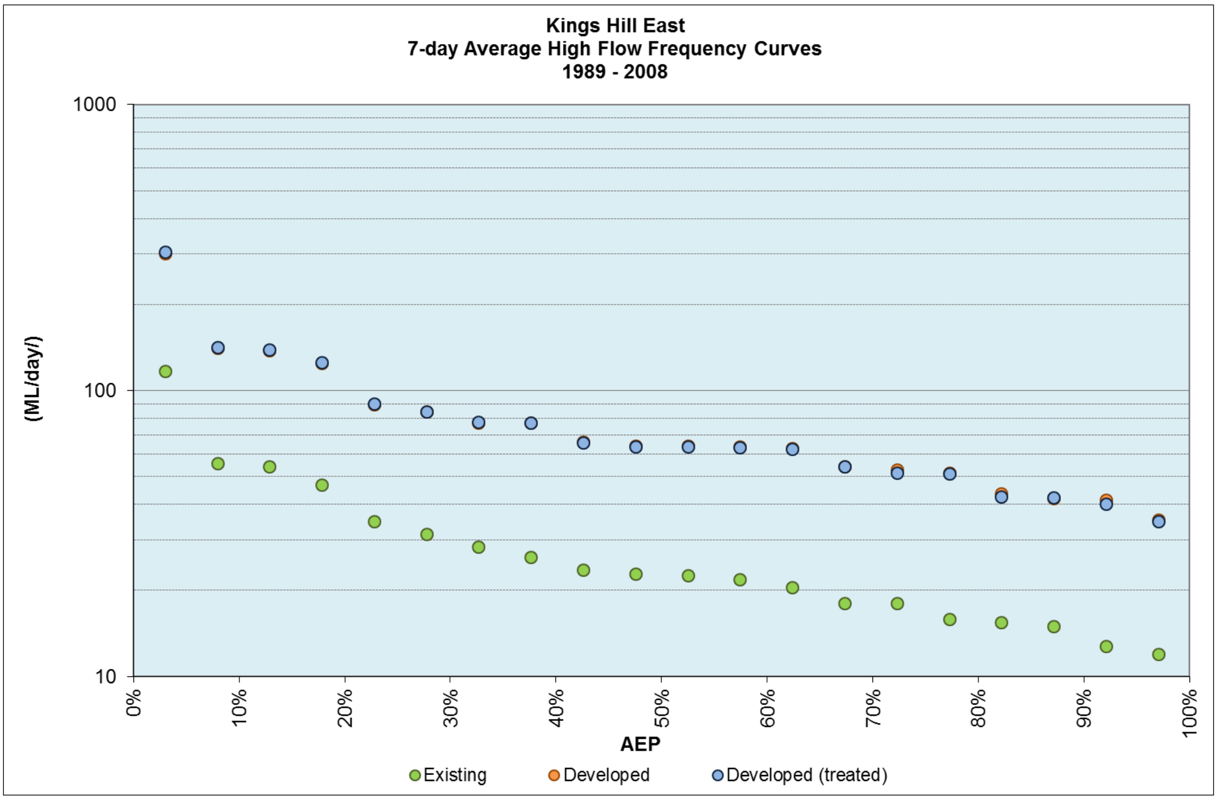


Figure 5-10 *Kings Hill East – 7-day average high flow frequency curves*

Grahamstown Dam spillway discharges

HWC provided Alluvium with estimates of Grahamstown Dam spillway discharges for the period 1974 to 2019. A summary of the recorded spillway discharges is provided in Table 5-4. The data indicates that between 1974 and 1989 no spillway discharges were observed from Grahamstown Dam to Irrawang Swamp. Between 1990 and 2005 (prior to the new spillway being constructed), spillway discharges were recorded in four separate years (1990, 1998, 1999 and 2001). Between 2006 and 2018 (after the new spillway construction), spillway discharges were recorded in five separate years (2008, 2011, 2013, 2015 and 2016).

Table 5-4 *Grahamstown Dam spillway flows (source: Hunter Water Corporation, 2019)*

Years with releases	Total annual discharge (ML/yr)	No. discharge days	Discharge months (No. Days)
1990	18850	13	Aug (13)
1998	9750	15	Aug (7), Nov (8)
1999	24050	37	Apr (6), Jun (12), Jul (17), Aug (2)
2001	10150	7	May (7)
Mean 1990 to 2005	**3925**	**5**	
Mean in overflow years	**15700**	**18**	
2008	9355	25	Apr (8), Jun (12), Sep (5)
2011	4159	8	Jul (6), Oct (2)
2013	484	3	Mar (3)
2015	5539	8	Apr (4), May (4)
2016	15096	17	Jan (17)
Mean 2006 to 2018	**2664**	**5**	
Mean in overflow years	**6927**	**12**	

The average annual spillway flow since the Stage 2 augmentation was completed in 2005 is approximately 2,700 ML/yr, and spills have occurred in 40% of the years and on average for 5 days a year. The increase in average annual 7 day high flow discharge from Kings Hill East to Irrawang Swamp during a typical year (50% AEP) following development is estimated to be 280 ML (refer Figure 5-10).

An increase in flow volume of 280 ML over 7 days represents an average depth of approximately 65mm across the total area of the swamp (estimated to be 450 ha from the SEPP 2018 mapping). This increased flow as a proportion of the average annual spillway flow from Grahamstown Dam to Irrawang Swamp is approximately 10%. This increase in flow is considered a conservative estimate, as it assumes that high flows from Kings Hill East that current drain to Grahamstown Dam do not contribute to existing spillway flows. During high rainfall years (10% AEP), runoff volumes diverted from Kings Hill East would be higher, although it is considered likely that spillway flows during these wetter years would similarly be elevated resulting in the overall proportional increase being similar.

Most spills from Grahamstown Dam to Irrawang Swamp have occurred during the wetter April to August period. Increased high flow discharges from Kings Hill East are likely to coincide with this period when inflows from direct rainfall on the swamp and other local catchment inflows are also elevated resulting in wide-spread inundation across Irrawang Swamp.

The critical drying period for Irrawang Swamp is from September to March (refer to Figure 5-2). Approximately 25% of days where spillway discharges have occurred fall within this critical drying period. The records indicate that spillway discharges to Irrawang Swamp have occurred only once during summer over the entire 1974 to 2019 period. Based on the available data, it appears that spillway discharges are unlikely to have a significant impact on drying hydrology in Irrawang Swamp.

5.6 Kings Hill West flow regimes (Wetland 803)

A different approach to Kings Hill South and Kings Hill East flow regime analysis was adopted for the Kings Hill West development. The entire Kings Hill West catchment drains to Wetland 803 located adjacent to New Line Road. As discussed in Section 3.2, the hydrology of Wetland 803 is currently influenced by catchment inflows from the Kings Hill West catchment and tidal inflows from the Williams River. Whilst catchment inflows are estimated to change following development, there is no proposal to modify the existing outlet/spill level from the wetland to the Williams River that would change the periods where tidal interactions between the river and wetland could occur. The following analysis is based upon changes to catchment inflows only. Discussion is provided in Section 6.4 on how mixing with tidal flows may change with modified catchment inflows.

MUSIC models of the entire Wetland 803 catchment including future developed areas and undeveloped areas were prepared by Northrop Consulting Engineers (NCE) and provided to Alluvium. The MUSIC models included existing, developed and developed (with treatment) scenarios. In addition to including the sub-catchment areas draining to Wetland 803, the models included allowance for direct rainfall within the extents of the wetland. The surface area of this wetland represents approximately 15% of the total catchment area.

NCE also provided estimates of stage / storage within Wetland 803 based on available LiDAR data. The LiDAR data were reviewed closely and assessed to be providing inaccurate wetland bathymetry levels below approximately 0.65m AHD. A level of 0.65m AHD corresponds with the spill level for the wetland adjacent to New Line Road. The LiDAR survey was completed during winter and it is suspected that elevated water levels in the wetland at that stage prevented the gathering of accurate bathymetry levels across inundated areas. Additional survey cross sections were gathered by a surveyor on site to supplement the LiDAR data. The additional survey data were compared with inundation extents shown in historical aerial imagery (refer Figure 5-11) to assist with estimating storage volumes at various stages below the wetland spill level.

Survey detail were also gathered by de Witt Consulting from the wetland overflow location and New Line Road reserve along an existing drainage channel. Culvert dimensions and inverts were confirmed in addition to cross sections of bed and bank levels along the drainage channel leading to the culvert. Surveyed cross sections were also taken of a narrow shallow trapezoidal channel within the wetland leading to the wetland outlet. The above survey data was utilised to develop a one-dimensional hydraulic model of the wetland outlet to assist with developing a stage / discharge relationship for the wetland.

The MUSIC flow estimates and derived stage / storage and stage / discharge relationships were applied to develop a temporal water balance model for Wetland 803. The model outputs were utilised as the basis for the flow regime analysis for this wetland.

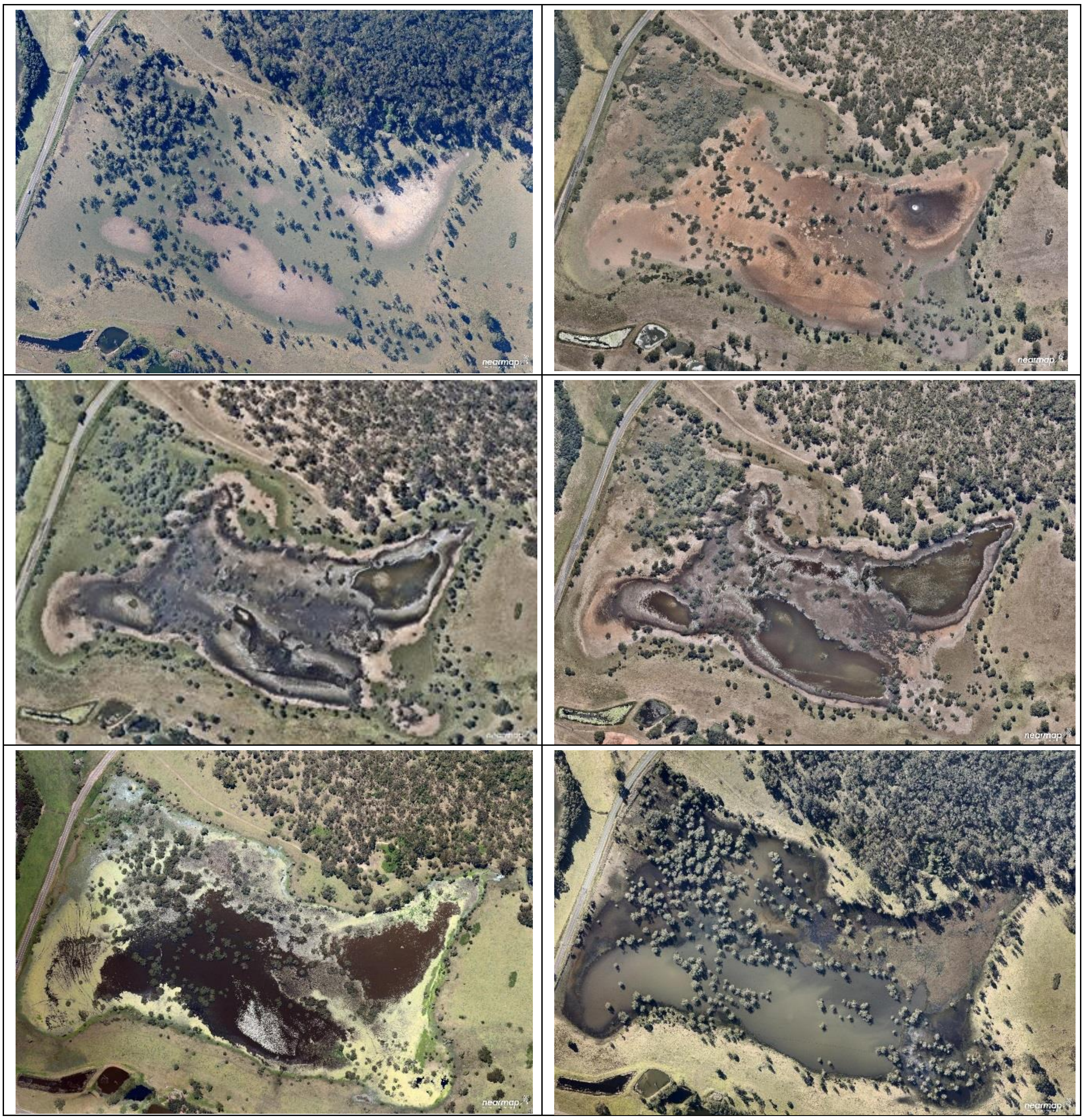


Figure 5-11 *Historical aerial images of Wetland 803 showing varying wetting extents*

The results of the temporal water balance modelling over the 1989 to 2008 modelling period are shown in Figure 5-12 and Figure 5-13. Figure 5-12 provides estimates of the proportion of time in the modelling period (during the September to March drying period) that particular water levels (m AHD) would be exceeded.

The results indicate that for around 50% of the time, water levels in the wetland would be elevated and similar for existing and developed conditions. This period would coincide with the early spring period where initial water levels would be high in the wetland from winter rainfall and evapotranspiration is lower.

In the 50% to 95% range shown in Figure 5-12, there is an apparent divergence in water levels between the modelled existing and developed conditions, with modelled water levels being up to 50mm higher following development. The reason for this divergence is associated with more regular pulses of stormwater during small rainfall events that would flow into the wetland from roof and road surfaces during warmer periods from future development. Under existing conditions during warmer months, a high proportion of the smaller rainfall events would be adsorbed by the soil and evaporate with minimal runoff occurring. The developed condition runoff has the effect of providing regular top ups to the water levels in the wetland.

Above the 95% range shown in Figure 5-12, existing and developed condition water levels would be similar as this range would represent a period closer to the end of summer where runoff from development areas would be low and evapotranspiration rates high.

The developed (with treatment) results shown in Figure 5-12 indicate that the proposed WSUD strategy would reduce impacts on water levels. This reduction is achieved through the application of rainwater tanks that will be effective at harvesting a high proportion of roof runoff during the critical drying period. In addition, the proposed bioretention measures would also absorb a high proportion of additional runoff during the drier periods. The treatment strategy also incorporates a proposal to divert over 5% of the Kings Hill West catchment (modelled developed sub-catchment C02 refer NCE, 2019) around the wetland.

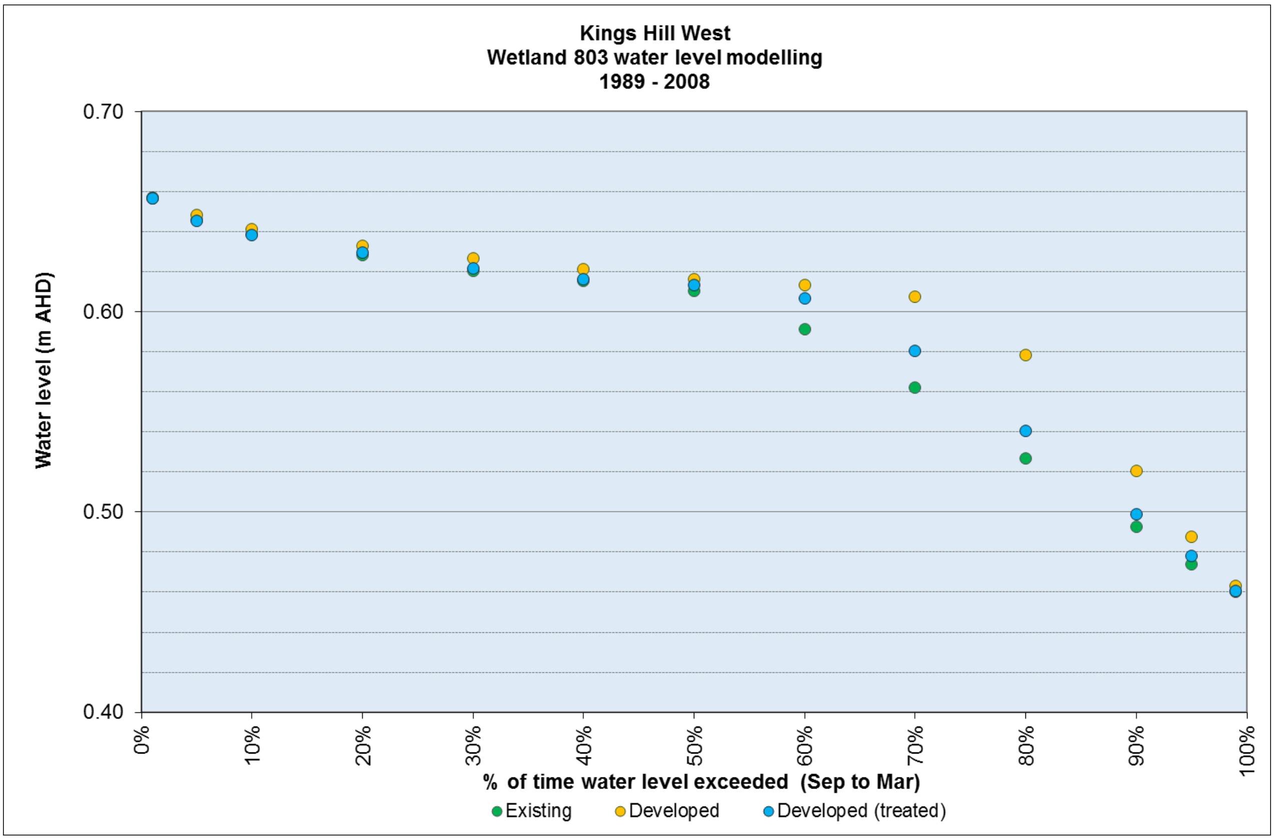


Figure 5-12 *Kings Hill West – Wetland 803 water level modelling results*

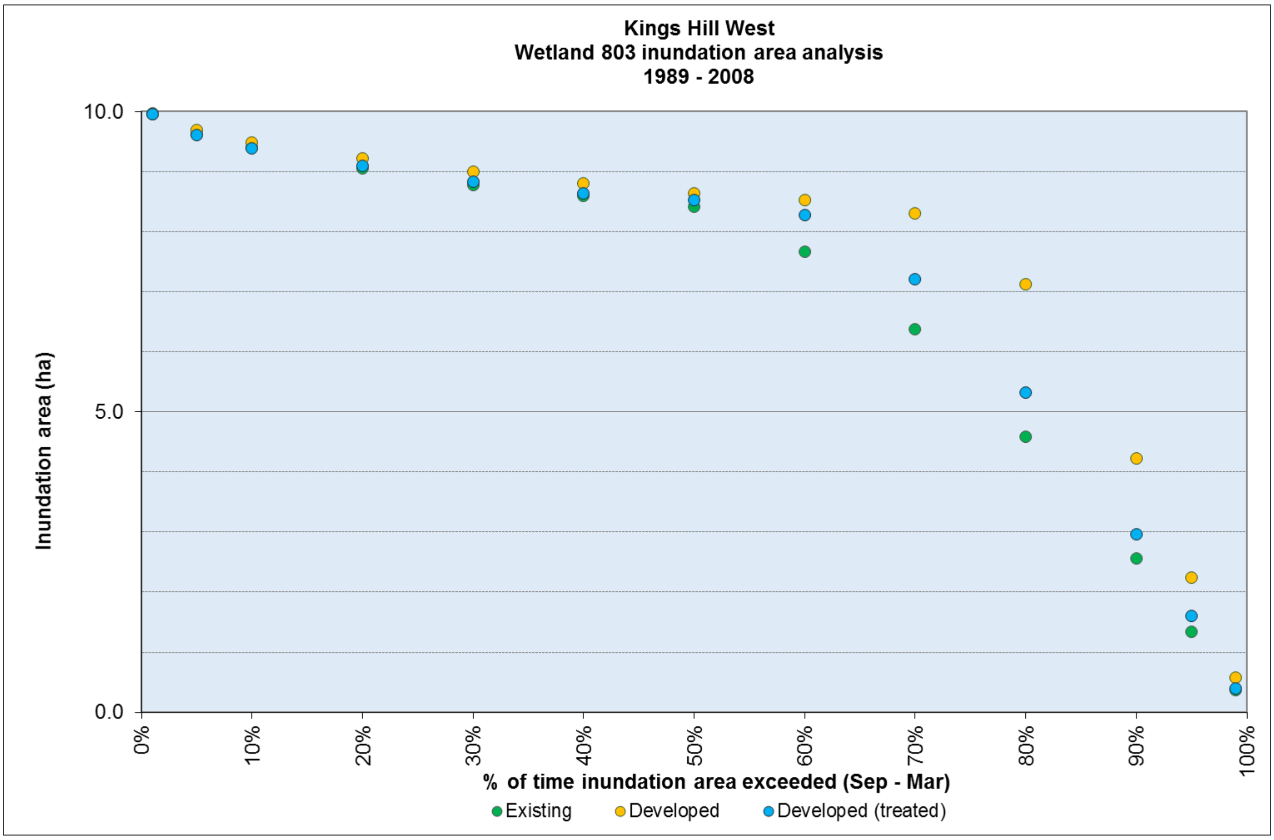


Figure 5-13 *Kings Hill West – Wetland 803 inundation modelling results*

6 Development impacts on wetland hydrology and ecology

6.1 Overview

Section 5 outlines the estimated impacts of future development in Kings Hill on catchment hydrology. This section of the report focuses on the impacts of the development modified catchment hydrology on the wetland hydrology and ecology.

The vegetation communities within Irrawang Swamp and Wetland 803 occupy the sites in a dynamic manner evolving in their extent in response to management practices. The hydrological regimes shown in Table 4-3 detail the inundation depths and drying periods required for the persistence of the different vegetation communities.

The critical hydrological items for the vegetation in the swamp is the presence of waterlogged soils, seasonal inundation and seasonal drying periods for all the communities except for the Perennial Swamp Meadow.

The key concern is the potential change in inundation extents across Irrawang Swamp associated with increased low flows following development.

Wet season flows

It is estimated that the runoff volumes from Kings Hill South and Kings Hill West during high flow periods will not change significantly from existing conditions as these generally occur during periods where soils would be saturated or close to saturation for extended periods. In these conditions pervious areas will generate similar runoff volumes as equivalent impervious areas.

Diversion of the Kings Hill East catchment to Irrawang Swamp is estimated to increase typical high flows (50% AEP) by 280 ML over 7 days. This represents an average water depth of approximately 65mm across the entire area of the swamp (estimated to be 450 ha from the SEPP 2018 mapping). This increased flow as a proportion of the average annual spillway flow from Grahamstown Dam to Irrawang Swamp is approximately 10%.

Increased high flow discharges from Kings Hill East are likely to coincide with periods where direct rainfall on the swamp, other local catchment inflows and dam spillway flows are also elevated resulting in wide-spread inundation across Irrawang Swamp. The increase in high flows will predominately coincide with the wet season flows when the wetland vegetation is seasonally inundated or growing on saturated soils.

The estimated increase in water depth of 65mm over the site for the 7-day high flow duration event is considered insignificant and is only temporary (<5 days). Infrequent wet season inundation events are not a serious concern ecologically as their impact is temporary and doesn't change the long-term seasonal wetting and drying patterns required by the vegetation communities.

Increased high flows are not considered a significant threat to the vegetation within the wetland.

6.2 Kings Hill South

Available LiDAR data and observed inundation extents interpreted from historical aerial imagery were reviewed to predict where additional inflows would drain to and be stored within the wetland during the critical drying period. Considering the available data, three zones were mapped indicating areas of the wetland that would progressively be wetted by inflows from Kings Hill South during dry periods. These three zones are mapped on Figure 6-1 with the three key locations where stormwater runoff from the future development in Kings Hill South would discharge into the wetland along existing gullies**Error! Reference source not found.**. Zone 1 covers a total area of approximately 5 ha, Zone 2 approximately 15 ha and Zone 3 approximately 35 ha.

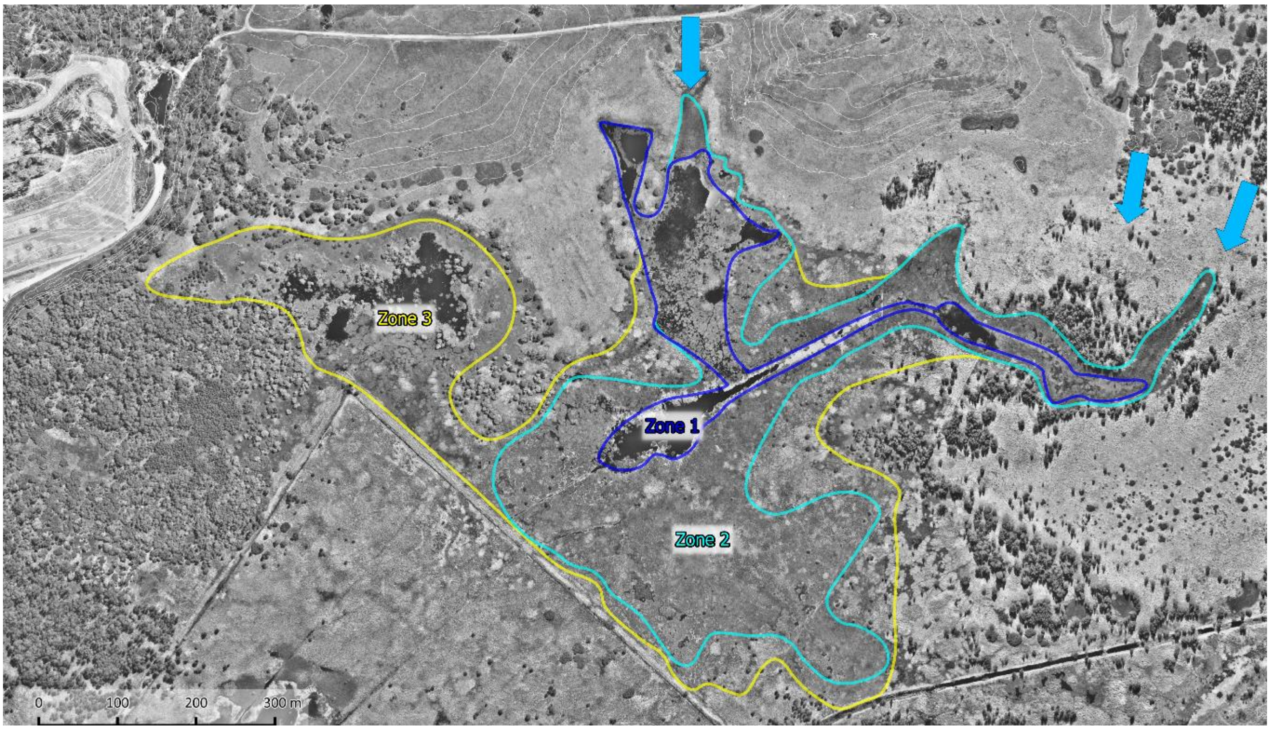


Figure 6-1 *Estimated critical drying period wetting zones in Irrawang Swamp receiving Kings Hill South inflows*

Dry season hydrology impacts

Low flows from Kings Hill South drain along the existing gullies that discharge into the northern extents of Irrawang Swamp. Concentrated flow along these natural gullies naturally spreads out into the wetland where the lower hill slopes meet the wetland floodplain areas. Natural drainage of this area was restricted after 1954 when a channel and elevated bund was constructed in a north-west to south-east alignment across the wetland to enable controlled irrigation of pasture areas south-west of the bund. The channel is connected to Pennington drain enabling irrigation from and drainage to Pennington Drain. It appears that an opening was cut through the bund to enable water to flow from the north-east for distribution along channels for irrigation of the pasture areas. Recent observation of this cut by Alluvium indicates that following cessation of irrigated pasture activities, the cut has partially infilled with sediment and dense growth of *Typha orientalis* (Cumbungi) has established. This has reduced the drainage connectivity between wetland areas on either side of the bund.

Review of historical aerial imagery covering the northern extents of Irrawang Swamp highlighted areas that would be more regularly inundated by stormwater runoff from future development in Kings Hill South. The observed inundation patterns indicate that surface runoff would initially fill areas aligned with the central part of the wetland mapped as Zone 1 on Figure 6-1. It is estimated that the majority of runoff during the critical drying period would be retained within Zone 1.

As inflows from the King Hill South sub-catchments increase, inundation is estimated to increase laterally from Zone 1 into Zone 2 (refer Figure 6-1). Review of historical aerial imagery and LiDAR data indicates that a spur of higher ground extending out into the wetland separates Zone 2 from the Melaleuca Swamp. The Melaleuca Swamp receives direct inflows from a local catchment adjacent to the existing Suez Waste Recycling and Recovery facility. This local catchment does not include any proposed future development in the Kings Hill South.

As inflows from the King Hill South sub-catchments increase further, inundation would increase laterally from Zone 2 into Zone 3 (refer Figure 6-1). At this stage, it is estimated that inflows to the wetland from Kings Hill South would increase water levels in the wetland sufficiently to interact with the Melaleuca Swamp and Pennington Drain.

Table 6-1 *Irrawang Swamp conditions (October 2019)*

 Spur separating the Melaleuca Swamp from other wetland areas	 Seasonal Swamp Meadow infested by Xanthium occidentale (Noogoora Burr).
 Swamp Oak Forest showing minimal inundation.	
 Central channel/bund with Perennial Swamp Meadow on the SW side.	 Central drain from the channel/bund leading to the frequently inundated zone in the northern section of the swamp.
 Perennial Swamp Meadow with Bolboschoenus fluvilatus and Typha orientalis	 Seasonal Swamp Meadow transitioning to Transient Swamp Meadow

Frequently inundated zone (Zone 1) that receives flow from Kings Hill South.

View into Irrawang Swamp from Kings Hill South boundary looking towards Zone 1.

The Kings Hill South 30 and 60 day average low flow frequency curves presented in Figure 5-7 and Figure 5-8 provide estimates of increased flow volumes draining to Irrawang Swamp following development. The estimated increases in flow volumes formed the basis for evaluating changes to inundation extents in areas of the wetland receiving these inflows.

Table 6-2 summarises the estimated increase in average water depths across the potential wetting zones. For example, in a typical 50% AEP year the 60 day inflow volume to Irrawang Swamp from the Kings Hill South development area is estimated to increase by 3.6 ML. If this additional volume is retained within Zone 1, this will result in the average water depth over this area increasing by 1.2 mm/day during the 60 day period.

Table 6-2 *Estimated average increase in wetland water depth during low flow periods from Kings Hill South*

Frequency	**Period (days)**	**Increase in flow volume (ML)**	**Estimated increase in average water depths (mm/day)**		
			Zone 1 (5 ha)	**Zone 2 (20 ha)**	**Zone 3 (35 ha)**
10% AEP	30	1.8	1.2	0.3	0.2
(wet year)	60	12.6	4.2	1.1	0.6
50% AEP	30	0.6	0.4	0.1	0.1
(typical year)	60	3.6	1.2	0.3	0.2
90% AEP	30	0.0	0.0	0.0	0.0
(dry year)	60	1.2	0.4	0.1	0.1

The estimated increases in water depth conservatively assumes that none of the additional flow volume infiltrates, evaporates, transpires or drains from each zone. The results indicate that for the flow frequency and periods evaluated, the average increase in water depth over the zones considered is below the typical average potential evapotranspiration rate of 5mm/day over the critical drying period. In most of the scenarios considered, the estimated increase in average water depth is less than 1mm/day and this water is likely to readily evaporate during these hot and dry periods.

The increase in average water depths outlined in Table 6-2 are approximate only as they are based on a number of simplifying assumptions. The estimated water depths assume that low flows spread out evenly across each of the mapped zones. This is unlikely to occur as subtle variations in terrain across the northern extents of the swamp will result in inundation depths varying. The water depths indicated are based on daily average inflows, and temporally are likely to vary across the relevant period with inflows during some days being higher, and others lower.

It is envisaged that any noticeable change in wetting of wetland areas from development in King Hill South during dry periods will be observed in the areas immediately downslope of the three stormwater outlets into the wetland. It is these locations that will be exposed to more regular stormwater discharges during the critical drying period. It is expected that the increased stormwater volumes during the critical drying period would primarily be intercepted in the existing constructed dams and shallow ponded areas within Zone 1. It is estimated that these dams and shallow ponded areas may experience a localised small increase in water depth, inundation extents and inundation period following development. Whilst additional Zone 2 and Zone 3 areas have been mapped on , it is considered unlikely any significant increased inundation of these zones would occur during the critical drying period following development.

Dry season vegetation impacts

It is expected that low flows from Kings Hill South would interact mostly with the existing swamp meadow vegetation communities located north of the Pennington Drain. It is estimated that increased low flows from Kings Hill South would tend to spread out across northern parts of the swamp and gravitate towards the existing large area of Perennial Swamp Meadow in this area.

A vegetation response to such inflows is already observed with an area of Perennial Swamp Meadow (*Typha* orientalis) below the existing dam on an existing gully from Kings Hill South. The lower areas and depressions in Zone 1 will continue to refill regularly supporting the growth of permanent water tolerant species such as *Typha orientalis in water 300-500mm depth*. Areas of open water in deep holes (>1.5m deep) will continue to be present.

The impact of the flows from Kings Hill South will be to increase the inundation depth in the northern sections of the swamp (Seasonal Swamp Meadow) by less than 10mm during winter and spring. This will not be an equal depth change with the micro-topography of the site that collecting flows into deeper areas resulting in a mosaic of vegetation response.

The increase in inundation depth is within the ecological depth tolerance of the vegetation. Seasonal drying in the Seasonal and Transient Swamp Meadow zones will still occur in most years, although the duration of drying may reduce. The impact of this may be localised changes in extent of the Seasonal Swamp Meadow with potential expansion into the Transient Swamp Meadow. Perennial Swamp Meadow is unlikely to expand into the Seasonal Swamp Meadow as seasonal drying will still occur reducing the spread of *Typha orientalis.*

The area of Paperbark Woodland in the north-west of the swamp may see increased inundation duration compared to the recent hydrology but not a significant increase in depth. If there was a change in permanent inundation of the *Melaleuca* species of >200mm there would be a negative impact. This impact would predominately be on the ability of the *Melaleuca* species to regenerate from seed. Inundation of >200mm over new seedlings for >3months will kill the new germinates reducing the capability of the woodland to regenerate. However, the analysis shows that the inundation depth increase is less than 50mm and drying periods are expected at least 1 in 3 years. This indicates that this vegetation will not be significantly impacted by increased flows from Kings Hill South.

Changes in water retention within Irrawang Swamp are expected to occur with reduced maintenance of the old agricultural drains by Hunter Water to align with actions in the management plan for the swamp. The reduction in the drainage efficiency of the old agricultural drains will see water retained in the areas south of the east-west channel/bund. The vegetation in these areas will adjust over time with consolidation of the perennial marsh in the central agricultural area and potential increase in Swamp Oak in the southern areas. The areas south of the east-west channel/bund are disconnected from the areas impacted by flows from Kings Hill South and the primary driver of their hydrology is the performance of the internal drainage south of the east-west channel/bund.

6.3 Kings Hill East

Dry season hydrology impacts

It is expected that additional low flow discharges would largely be conveyed within the Pennington Drain and if overflows from this drain occur during the critical drying period (September to March) these low flows would largely be contained in areas on both sides of drain where vegetation currently tolerant of extended inundation during low flow periods is located. As an example, considering the low flow curves in Figure 5-6, for a typical 50% AEP low flow, the increase in average daily low flow discharged to Irrawang Swamp is estimated to be less than 0.5 ML/day (i.e. average flow of 5 litres/s). It is envisaged that this additional flow would readily be conveyed along Pennington Drain without spilling into the adjacent wetland areas prior to discharge through the open flood gates.

Dry season vegetation impacts
The dry season flows from Kings Hill East will mostly be contained in the Pennington drain or spill to the Perennial Swamp Meadow areas. Both outcomes will not result in a negative ecological change to the vegetation.

6.4 Kings Hill West

Dry season hydrology impacts
The water balance modelling results for Wetland 803 outlined in Section 5.6 indicate that the WSUD strategy and partial catchment diversion proposed by NCE would result in water levels in the wetland increasing by less than 50mm across the critical drying period. The modelling results also indicate that wetting extents across the wetland would be similar during this period but may increase over existing conditions by up to 15% during short periods (days) during the drying period in response to small rainfall events in the Kings Hill West catchment.

The results in Figure 5-12 and Figure 5-13 show the estimated relative changes to water levels and inundation in Wetland 803 considering inflows, evapotranspiration and outlet flows associated with catchment runoff. The water levels in the wetland will also be influenced by tidal inflows that (excluding future sea level rise) are expected to be similar in magnitude to existing conditions. The main impact is estimated to be a small reduction in salinity in the wetland during drying periods due to the slight increase in catchment inflows. However, with predicted sea level rise the increased freshwater runoff from the catchment during drying periods may offset the increased saline inflows during the same period.

Dry season vegetation impacts
The vegetation within the wetland is currently adapted to the existing hydrological regime. The treated development flows are quite similar to the existing conditions with a slight (<50mm) increase in depth during the driest times and possible lowering of salinity in high runoff periods. The extent of the wetland surface area inundation will potentially increase for a period over the summer which may support the perimeter vegetation, enabling the more establishment of rushes and sedges.

Submerged plants within the wetland will be able to tolerate an increase in depth through summer and are tolerant of periodic drying if that occurs. Minor changes in the salinity profile can be tolerated due to the presence of species with a range of salinity tolerance.

Maintenance of periodic drawdown will advantage the site as this can stimulate germination of the *Casuarina* and emergent macrophytes in the damp mud. Increased salinity in the deeper sections of the wetland as the water recedes will control the incursion of *Typha* sp into these areas.

Overall the changes indicated for the treated development flows will support the existing vegetation with potential to increase the density and extent of marginal emergent rushes and sedges.

Figure 6-2 *Typical Casuarina glauca 'pedestal' observed in Wetland 803*

7 Summary and conclusions

Irrawang Swamp and Wetland 803 contain a number of vegetation species that are susceptible to impacts from altered hydrological regimes. McManus et al (2007) outlines drying and flooding hydrology management targets for a range of wetland categories represented in Irrawang Swamp include Shallow Marsh, Deep Marsh and Forest Swamp - Ephemeral. These key vegetation communities will be most susceptible to changes in the drying hydrology over the critical September to March period.

Flow regime analysis was completed focusing on drying hydrology in accordance with McManus et al (2007). Inflows to Irrawang Swamp were analysed to derive dry spells curves (low flow spells) and low flow duration frequency curves for 30 and 60-day reference durations. Additional analysis of 7-day duration high flows was also completed to evaluate the impact of diverting runoff from Kings Hill East to Irrawang Swamp. The completed analysis covers the key wetland vegetation communities currently observed in the swamp.

The dominant risks to the vegetation in Irrawang Swamp and Wetland 803 from hydrological changes include:

- increases in periods of increased inundation depth; and
- reductions in seasonal drying patterns

If these are realised, retention of diversity in the Seasonal Swamp Meadow vegetation in Irrawang Swamp would be compromised and the ability for the wood plants to regenerate would be reduced. The hydrological analysis indicates that these risks are unlikely to occur for a range of reasons that are summarised below.

Whilst the total runoff volume from Kings Hill East will increase, a high proportion of the increased runoff volume is expected to flow efficiently in a relatively linear manner along the proposed diversion drain through the original spillway channel to the Pennington Drain channel and discharge through the existing flood gates to the Williams River. During critical drying periods, low flows from Kings Hill East would be significantly lower than the Pennington Drain capacity. It is expected that even with consideration of infilling of the channel over time, increased low flows from Kings Hill East will continue to drain in a relatively linear manner through Irrawang Swamp to the flood gates. It is expected that these diverted low flows would not impact on the northern Seasonal Swamp Meadow and Melaleuca Woodlands.

During typical annual high flow periods, it is estimated that high flows from Kings Hill East would spill outside the Pennington Drain banks into the adjacent vegetated areas. Considering a representative 7-day high flow period, the increased flow from Kings Hill East represents an estimated increase in water depth of 65 mm over Irrawang Swamp. Although high flows would increase, the increase is estimated to be a maximum of 10% of the average annual spillway flow from Grahamstown Dam. It is expected that many of the high flow periods would coincide with periods where inflows from direct rainfall on the swamp, other local catchment inflows and spillway flows would also be elevated resulting in wide-spread inundation across Irrawang Swamp. These high flow events typically dissipate rapidly and would not cause long term ecological damage.

Increased runoff volumes from King Hill South are estimated to be much lower than those from Kings Hill East. Increased runoff from Kings Hill South will disperse more readily through the wetland vegetation. Based on a review of available LiDAR data and historical imagery, it is estimated that the increase in water depth during the critical drying period will largely be contained within a mapped 5 ha area (Zone 1) aligned with currently regularly wetted areas in the northern part of the swamp. These additional flows will support the existing areas of open water and stands of *Typha orientalis.* Localised increases in water depth are likely to occur due to subtle variations in the terrain leading to support of localised pockets of perennial swamp meadow. Some localised impacts on vegetation in Zone 1 are expected along the gullies leading into Irrawang Swamp from Kings Hill South as these areas will be most exposed to more frequent pulses of stormwater.

Increased annual high flow volumes from King Hill South are estimated to be minor and would have an insignificant impact on increasing water levels in Irrawang Swamp during high flow periods.

There will continue to be seasonal dry periods in the Swamp Oak and Melaleuca Woodlands and Seasonal Swamp Meadow areas and estimated changes in inundation depths are within the ecological tolerance range of the vegetation communities.

The Swamp Oak Woodland in Coastal Wetland 803 in Kings Hill West reduced in extent and density by approximately 30% between 1954 and 2019. It is clear that the condition of this wetland has been impacted due to increased water retention resulting from construction of a bund across its outlet and cattle grazing. Controlling additional runoff to this wetland alone is unlikely to improve conditions for the remnant wetland vegetation. To improve conditions for this wetland, ensuring seasonal flow patterns and lowering of the existing outlet weir would be crucial for controlling seasonal water levels to reflect more natural levels. This would enable regeneration and healthy growth of the Casuarina glauca in the wetland that is more representative of natural conditions. Without removal of the cattle and lowering of the current water levels restoring the wetland to a more natural ecological condition is unlikely to be feasible.

It is envisaged that increased runoff volumes could potentially create opportunities that support the management objectives for Irrawang Swamp including:

- Increased flows support the ongoing management actions in Irrawang Swamp which aim to reduce the drainage efficiency of the wetland and increase retention of water in the landscape to assist the wetland to transition back to a more natural state.
- Increased runoff volumes could potentially be diverted from urban lakes and other stormwater storages in the Kings Hill development to irrigate additional habitat and biobanking areas on the fringes of Irrawang Swamp. Harvested stormwater during summer would assist with irrigating young plants and further reduce low flows closer to existing conditions.
- Increase availability of water within the wetland would provide opportunities for increased resilience during extended period of drought and as predicted climate change impacts occur.
- The flows replicate the existing conditions to seasonally saturate the soils in the Swamp Oak and Paperbark Woodland areas of Irrawang Swamp, providing the soil conditions for these vegetation communities ensuring their survival.

Incorporation of effective water sensitive urban design (WSUD) into all stages of the Kings Hill development will be very important for managing water quantity and quality from development areas. Water quantity management strategies should focus on reducing stormwater runoff during frequent smaller rainfall events. Measures including disconnecting impervious areas, oversized BASIX rainwater tanks, infiltrating biofiltration systems, stormwater retention and harvesting systems would all have a role to play at appropriate locations within the development. Ensuring that the majority of future runoff passes through appropriately sized stormwater retention/detention measures will be important for protecting ephemeral watercourses from erosion.

Management of stormwater runoff quality will also be important for preventing coarse sediment, dissolved nutrients, fine sediment and other diffuse source stormwater pollutants from impacting on the wetland ecology. This includes effective measures (including regular inspections) in the subdivision construction, building construction and post development phases.

Proposed monitoring protocols for hydrology and vegetation with Irrawang Swamp and Wetland 803 prior to and following development are outlined in RPS (2019).

8 References

Hunter Water (2011). *Catchment Report – Annual Operating Licence Report 2010-11*

Hunter Water (2012a). *Irrawang Swamp Plan of Management*

Hunter Water (2012b). *Catchment Report – Annual Operating Licence Report 2011-12*

Hunter Water (2018). Letter from Hunter Water Corporation to Port Stephens Council dated 9 January 2018, Hunter Water reference HW2009-457/20/79

Kleinfelder (2018). *Grahamstown Dam Stage 2 Augmentation Phase 3 – Flora Monitoring of Irrawang Swamp*.

McManus, R., Wong, T., and Breen, P. (2007). *Water Sensitive Urban Design Solutions for Catchments above Wetlands – Overview Report.* Hunter & Central Coast Regional Environmental Management Strategy, Thornton, NSW.

Northrop Consulting Engineers (2019). *Engineering Report, Kings Hill – Masterplan*

RPS (2019). *Species Impact Statement for Stage 1 Site Preparation Works, Kings Hill*. Unpublished report prepared for Kings Hill Developments Pty Ltd, Carrington NSW.

BIOCM

Biodiversity Conservation Monitoring Pty Ltd

johnpaulking@biocm.com.au

Jason Wasiak

Director – Principal Urban Planner

JW Planning Pty L

Attn: Review Kings Hill SEPP 14 Wetland mapping assessment for East/West link Road alignment design

Dear Jason,

Introduction

This short report provides detailed mapping of the SEPP 14 Wetland located in the western extent of the Kings Hill development area, which is under the control of Kings Hill developments. Planning is underway to provide an east west link and concerns regarding any impacts with wetlands whether they be direct or otherwise drove the requirement to better understand the extent of the wetland and the buffers required to protect the integrity of the wetland.

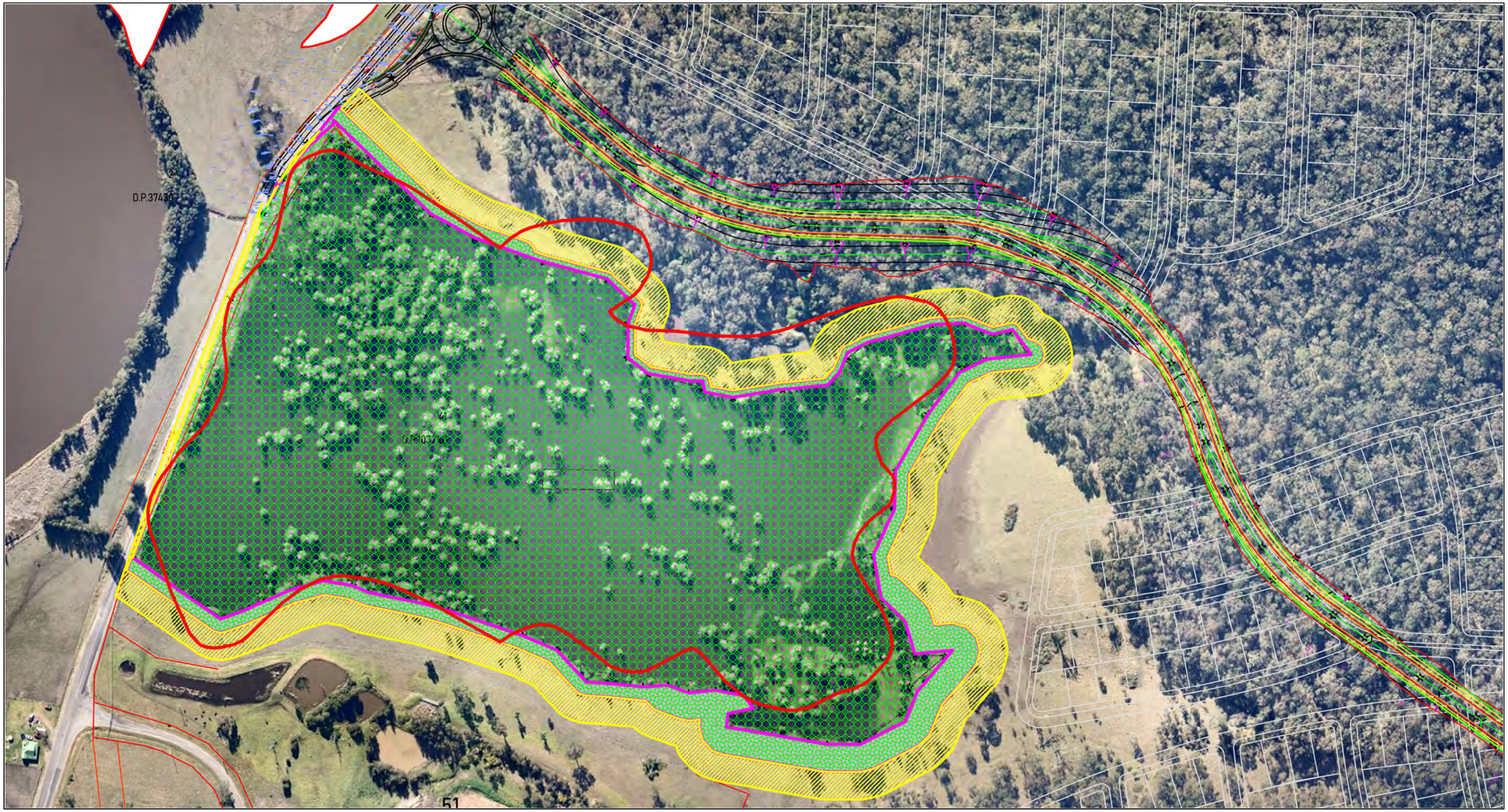
Methods

The entire boundary of the wetland as shown in Figure 1 below was initially walked, and at 10 metre intervals flagging tape was placed on vegetation that was visually assessed by the surveyor to be an approximate wetland boundary. This approximate boundary formed the basis for detailed quantitative sampling of the precise wetland boundary and an assessment of the likely width of this boundary. This was undertaken by a series of (25) transect running perpendicular with this approximate boundary, were by; the flagged line represented the middle of the planned transect, so that 10 1m x1m quadrats were placed within largely terrestrial vegetation and 10 within vegetation largely representing wetland vegetation. Within each quadrat the percentage cover of terrestrial and wetland plants were recorded. When wetland plants are recoded within a quadrat it is accepted that at some point in time, whether that be seasonally, or sporadically that this quadrat experiences inundation and under wetland recharge conditions that a greater cover of wetland plants would be expected.

Conversely quadrats that do not have any wetland plants present would not be inundated for extensive periods. However, this does not mean that these areas are not subjected to short period intensive flash flooding that last for very short periods (<2 days). These consecutive quadrats (1m x 1m) transects (No 25) were used to determine the width of this boundary. This is shown as the green buffer on Figure 1. A further 20 metre buffer (shown in Yellow) is added to this boundary to provide a natural buffer for the wetland edge.

I trust that this meets your requirements, if you have any queries please don’t hesitate to contact me on 0490887199.

Regards JP King



Legend

- SEPP 14 Wetland boundary mapping line
- Extent of wetland boundary as mapped using methods detailed within this report
- Variable buffer (1m-20m) added to wetland extent based on the likelihood of the wetland extending into these areas during extended wet periods
- Standard 20m buffer added to the extent of variable wetland boundaries to provide practical wetland buffer

Figure 1: Wetland boundary assessment results April 2016

Kings Hill western precinct east/west link road ecological and wetland background surveys and mapping