



FINAL REPORT

Preliminary assessment of the Kings Hill development impacts on
Irrawang Swamp ecology

May 2019

Document history

Revision:

Revision no.	02
Authors	Mark Wainwright, David Carew
Checked	Peter Morison, Stuart Clevon
Approved	Peter Morison

Distribution:

Revision no.	02
Issue date	22/05/19
Issued to	Ben Clark (Northrop Consulting Engineers)
Description:	This report outlines a preliminary assessment of the impacts on the Irrawang Swamp ecology 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: https://alluvium-my.sharepoint.com/personal/mwainwright_alluvium_com_au/Documents/Newcastle_Work/Projects/022_Irrawang_Swamp_Assessment/10_Project/1_Deliverables/P619022.01_Irrawang_Swamp_preliminary_ecohydrology_assessment_190522.docx

Contents

1	Introduction	1
2	Existing hydrology	4
2.1	Overview	4
2.2	Grahamstown Dam storage	4
2.3	Grahamstown Dam spillway	5
2.4	Irrawang Swamp	6
2.5	Newline Road drainage structures	7
	Flood gates	7
	New Line Road bund	8
	Multi-cell culvert	8
3	Existing wetland vegetation	9
3.1	History of management impacting wetland vegetation	9
3.2	Previous studies	11
	Significant weeds	14
3.3	Legislation context	14
3.4	Site visit	16
3.5	Wetland typologies	16
4	Hydrological and ecological impacts	19
4.1	Hydrological model development	19
4.2	Mean annual runoff volume	19
4.3	Cumulative runoff	20
4.4	Flow regimes	22
	Critical drying period	22
	Dry spells curves	23
	Low flow duration frequency curves	25
	Low flow inundation extents	27
	High flow regime	28
	Grahamstown Dam spillway discharges	30
4.5	Assessment of ecological impacts	31
5	Summary and conclusions	33
6	References	36

Figures

Figure 1-1	<i>Irrawang Swamp locality</i>	2
Figure 2-1	<i>Original Grahamstown Dam spillway gates</i>	5
Figure 2-2	<i>New Grahamstown Dam labyrinth spillway (source: Port Stephens Examiner, 2008)</i>	6
Figure 2-3	<i>Pennington Drain flood gates</i>	7
Figure 3-1	<i>1954 aerial image of Irrawang Swamp</i>	10
Figure 3-2	<i>1977 Aerial image of Irrawang Swamp</i>	10
Figure 3-3	<i>2018 Aerial image of Irrawang Swamp</i>	10
Figure 3-4	<i>Vegetation mapping by Kleinfelder 2018</i>	12
Figure 3-5	<i>Vegetation mapping by Umwelt 2011</i>	12

Figure 3-6 1954 extent of Swamp Oak and Melaleuca Woodlands	13
Figure 3-7 1954 and 2019 extents of Swamp Oak Woodland in Wetland 803	14
Figure 3-8 NSW Coastal Wetlands 803 & 804	15
Figure 4-1 Plot of daily rainfall and estimated cumulative runoff for Kings Hill South catchment (1989 to 2008)	21
Figure 4-2 Average monthly evapotranspiration and rainfall depths for Irrawang Swamp (BoM Climate Atlas of Australia)	23
Figure 4-3 Kings Hill South – Dry Spells Curves	24
Figure 4-4 Kings Hill East – Dry Spells Curves	24
Figure 4-5 Kings Hill East – 30-day average low flow frequency curves	25
Figure 4-6 Kings Hill East – 60 day average low flow frequency curves	26
Figure 4-7 Kings Hill South – 30-day average low flow frequency curves	26
Figure 4-8 Kings Hill South – 60-day average low flow frequency curves	27
Figure 4-9 Kings Hill South – 7-day average high flow frequency curves	29
Figure 4-10 Kings Hill East – 7-day average high flow frequency curves	30

Tables

Table 3-1 Vegetation community classification	11
Table 3-2 Vegetation communities of interest within Irrawang Swamp	16
Table 3-3 Vegetation community hydrological regimes	18
Table 3-4 Vegetation community hydrology risks	18
Table 4-1 Estimated mean annual runoff volumes (1989 to 2008 modelling period)	20
Table 4-2 Hydrologic management targets for natural wetlands (McManus et al, 2007)	22
Table 4-3 Estimated average increase in inundation depth during low flow periods from Kings Hill South	28
Table 4-4 Grahamstown Dam spillway flows (source: Hunter Water Corporation, 2019)	30

1 Introduction

Irrawang Swamp is located just north of Raymond Terrace between New Line Road and the Pacific Highway (refer Figure 1-1), 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 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.

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 has lodged an application with OEH to register land they own within Irrawang Swamp as a biobank/biodiversity stewardship site. Under this agreement, HWC is required to manage Irrawang Swamp so that the ecology of the site is maintained and improved in perpetuity.

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 re-introduce 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 of the agreement with OEH. 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.

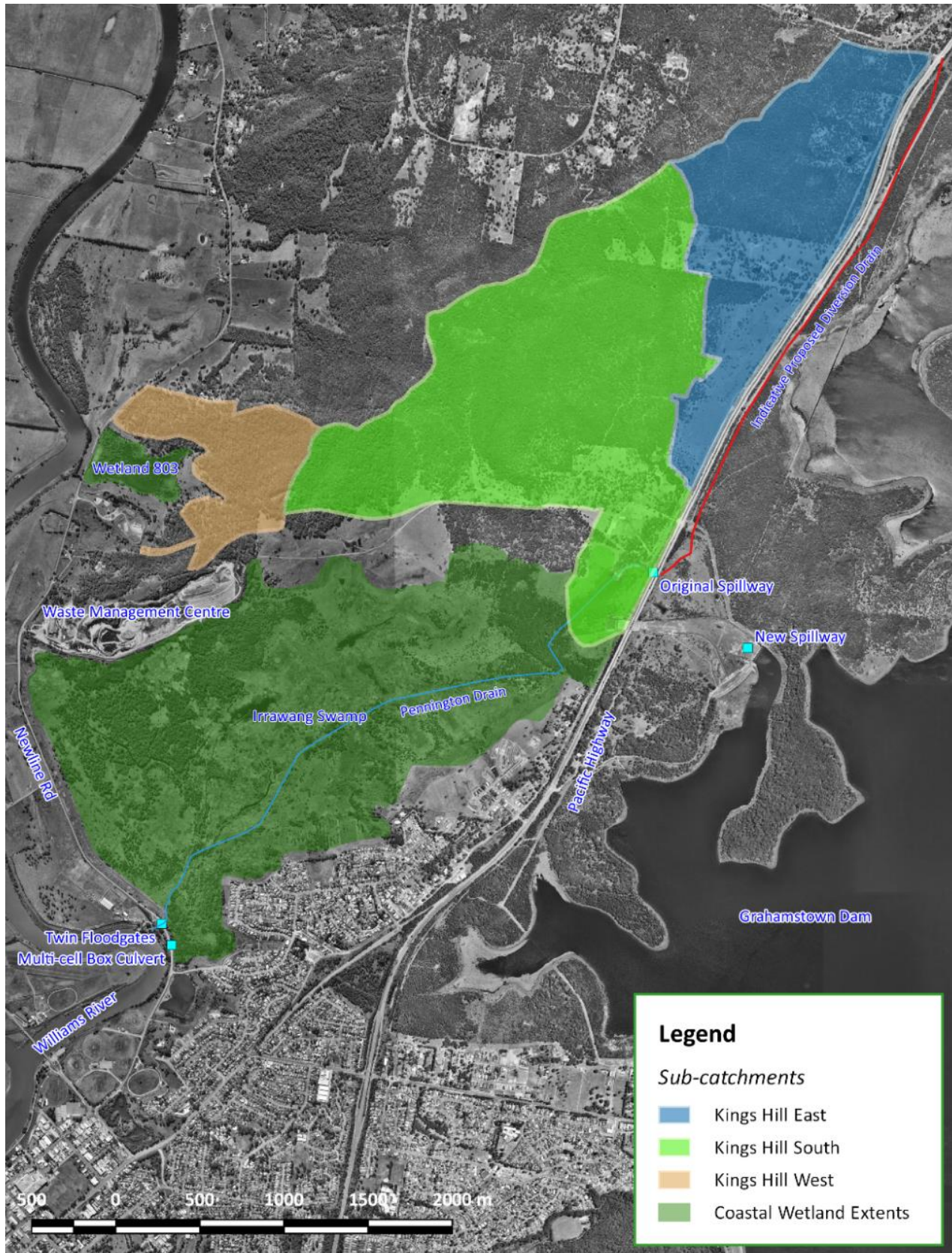


Figure 1-1 Irrawang Swamp locality

HWC outlined their concerns with the potential impacts of the Kings Hill development on the Irrawang Swamp ecology in letter sent to Port Stephens Council dated 9 January 2018 (Hunter Water, 2018). 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 outlines a preliminary assessment of the potential impacts of hydrological changes associated with the Kings Hill development on the Irrawang Swamp ecology. Our assessment is based on stormwater runoff estimates output from MUSIC models prepared by Northrop Consulting Engineers (NCE). Our assessment assumes that 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.

This report focuses on the Irrawang Swamp hydrology. The potential impacts on water quality in Irrawang Swamp (and other receiving waterways) associated with stormwater runoff from the Kings Hill development are addressed in a separate report prepared by NCE. This report is configured as follows:

- Section 2 summarises our conceptual understanding of the existing Irrawang Swamp hydrology including our appreciation of existing infrastructure that controls the movement of water through the wetland.
- Section 3 summarises our understanding of the existing vegetation communities in Irrawang Swamp and historical changes that have occurred to the vegetation.
- Section 4 discusses our assessment of the potential impacts of the Kings Hill development on hydrology and vegetation within Irrawang Swamp.
- Section 5 provides a summary of key points and our conclusions.

2 Existing hydrology

2.1 Overview

The hydrology of Irrawang Swamp has changed significantly from natural conditions due to historical land management practices associated with land clearing, grazing and drain construction. Under natural conditions, surface runoff from local catchments would have drained to a series of swamps in the local area including the Grahamstown Moors, Campvale Swamp and Irrawang Swamp. These swamps would have also been fed 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. Lower areas 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 effectively separated Campvale Swamp and Irrawang Swamp from this area. 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 would further limit 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 volumes being discharged into the southern section of Irrawang Swamp. In addition, the construction of rural dams and water holding dams associated with the former quarry 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 the 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 bund has been constructed on the western side of the swamp parallel to New Line Road to control overflows from the swamp to the Williams River. A large multi-cell culvert was 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 works 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. 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.

2.2 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. Although not completed, water was initially 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 road levels along the full length of the embankment enabling 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 were completed in December 2005 and 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 km². The total catchment area for Grahamstown Dam is 115 km² (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.

2.3 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 2-1 *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 m³/s which is significantly greater than the original spillway capacity of 60 m³/s (Kinhill, 1993).



Figure 2-2 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.

2.4 Irrawang Swamp

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 active drainage 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 it is expected 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 primarily deposited on the southern side 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 not actively maintained and are being allowed to infill.

2.5 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 occur through 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 2-3 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 bund

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 bund 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).

Based on the available data, when water levels in the Irrawang Swamp currently 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 exceeding the levee bank/weir level would only be sustained 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 Existing wetland vegetation

3.1 History of management 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 has been significantly modified since 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 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 2, 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 3-1) shows minimal constructed drainage. This contrasts with the 1977 and 2018 images (Figure 3-2 & Figure 3-3 respectively) which show development and constructed drainage through the central areas of the swamp.

The historic 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.

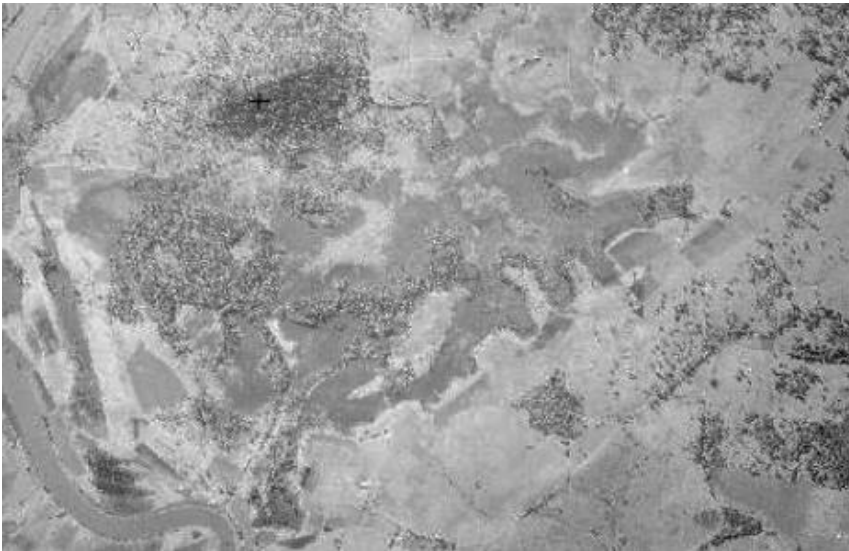


Figure 3-1 1954 aerial image of Irrawang Swamp



Figure 3-2 1977 Aerial image of Irrawang Swamp



Figure 3-3 2018 Aerial image of Irrawang Swamp

The swamp vegetation is adjusting to the current flow regime which includes allowing the drainage channels to naturally 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.

3.2 Previous studies

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

Alluvium did not undertake a detailed flora survey but has used the Kleinfelder 2018 report as a baseline for viewing the current vegetation community extents. A site visit was undertaken by Alluvium on 24 April 2019 to observe the vegetation communities outlined in the Kleinfelder report.

The swamp vegetation mapped by Kleinfelder (2018) has been assigned to different communities (Figure 3-4) depending on the vegetation structure and hydrological regime. For the purposes of the report, Table 3-1 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 species listed as threatened or endangered were identified in the surveys.

Table 3-1 *Vegetation community classification*

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

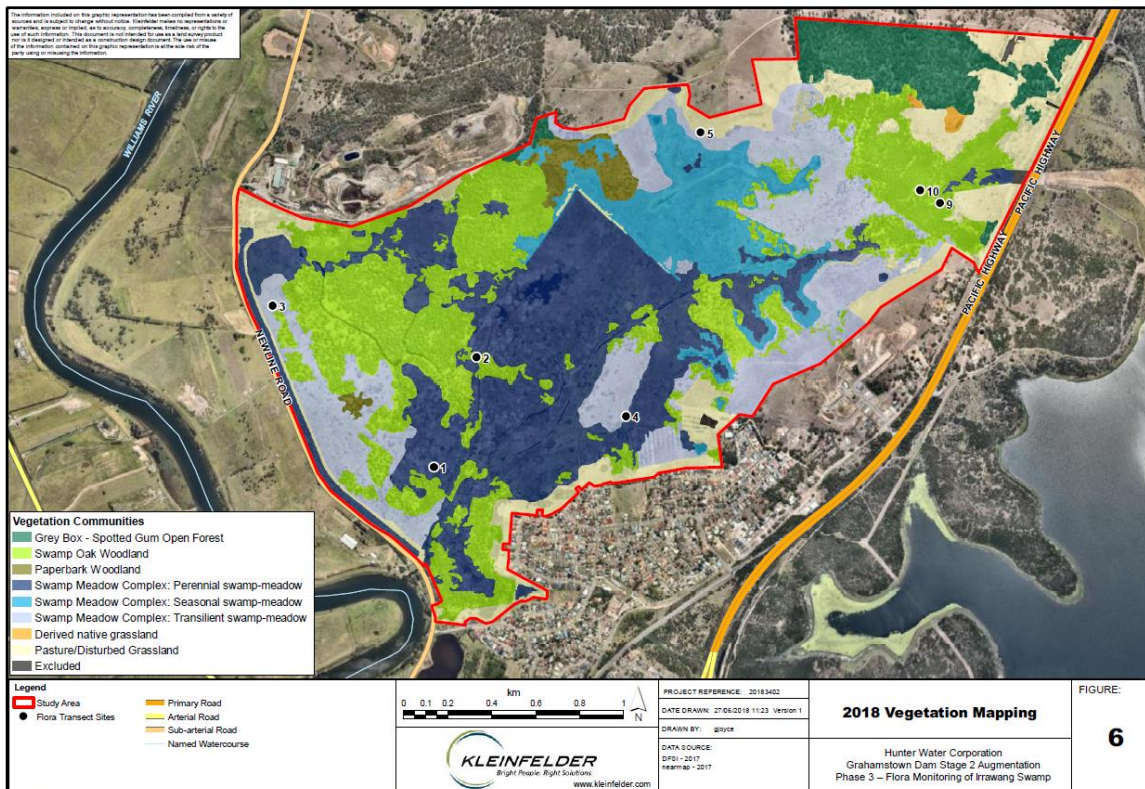


Figure 3-4 Vegetation mapping by Kleinfelder 2018

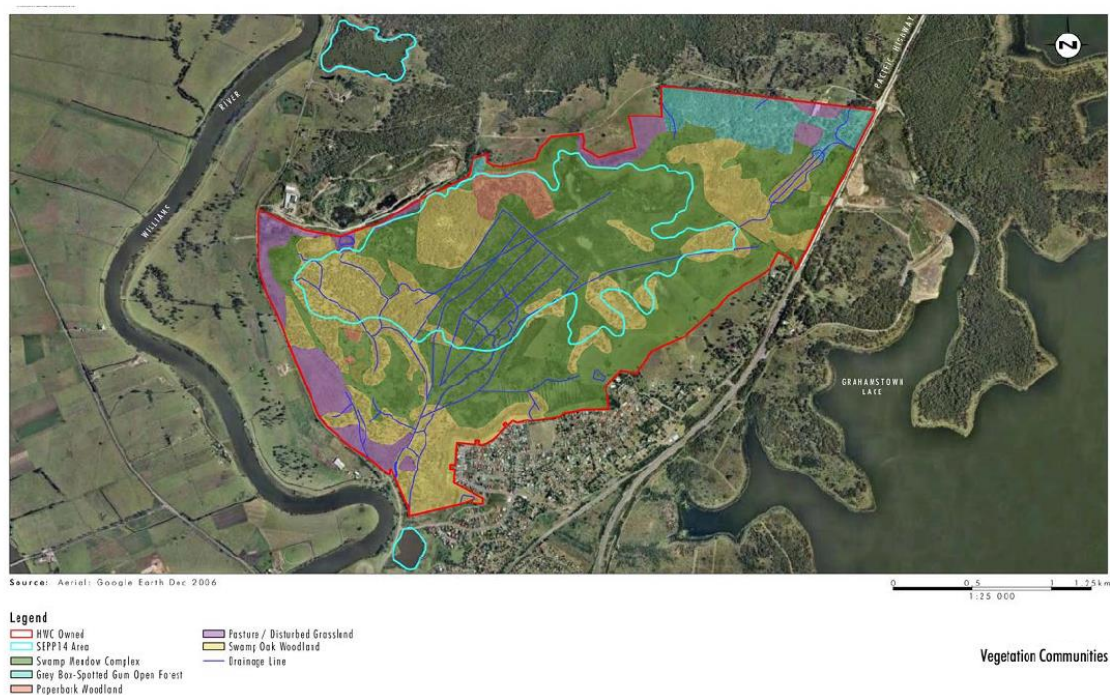


Figure 3-5 Vegetation mapping by Umwelt 2011

The 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 3-6 with the 2018 extents in Figure 3-4. Due to the clarity of the images, distinctions between the two woodland types cannot be made, therefore they have been combined on the image.

The combined Swamp Woodlands extent in 1954 is estimated to be 173.9 Ha with the 2018 extent recorded by Kleinfelder (2018) to be 149.18 Ha. This shows a historic decline in the Swamp Woodlands of approximately 24.5 Ha (14% of the 1954 extent).

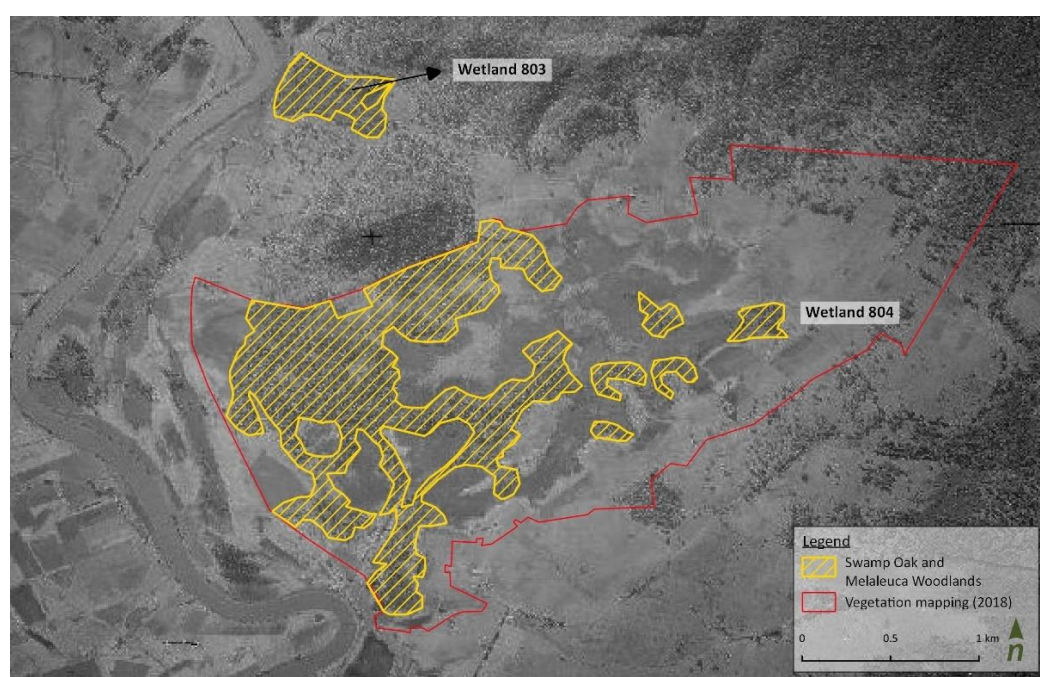


Figure 3-6 1954 extent of Swamp Oak and Melaleuca Woodlands

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

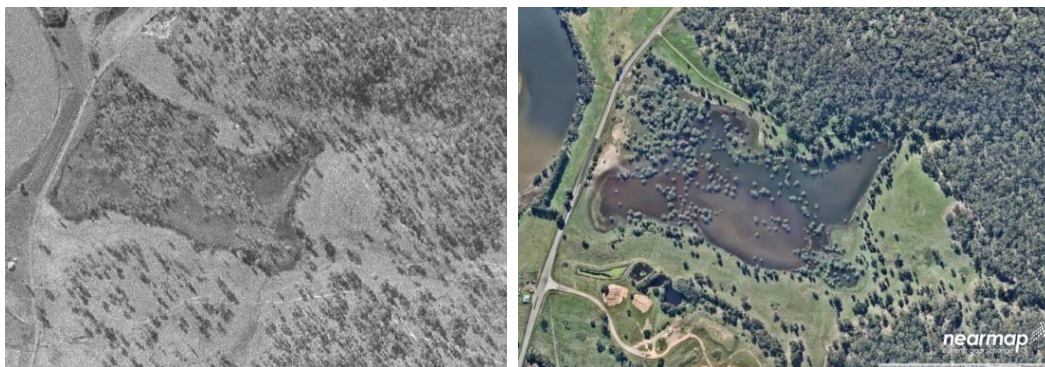


Figure 3-7 1954 and 2019 extents of Swamp Oak Woodland in Wetland 803

These recent trends of increase 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:
 - Enabling regeneration of woodland species *Casuarina glauca* and *Melaleuca* sp
 - Enabling regeneration of seasonal wetland vegetation such as *Bolboschoenus caldwellii*, *Carex appressa*, *Juncus* species.
- Reduction of drainage efficiency to retain water within the swamp:
 - Increasing 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*.

Significant weeds

Two aquatic weeds of national significance (WONS) have been 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 must 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)

Weed control programs need to be ongoing to ensure these weeds are kept to an acceptable low level through the reserve.

3.3 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 the *State Environmental Planning Policy (Coastal Management) 2018*. (SEPP, 2018).

The Irrawang Swamp study area contains two Coastal Wetlands (803 & 804) listed in SEPP 2018 and these are shown in Figure 3-8.

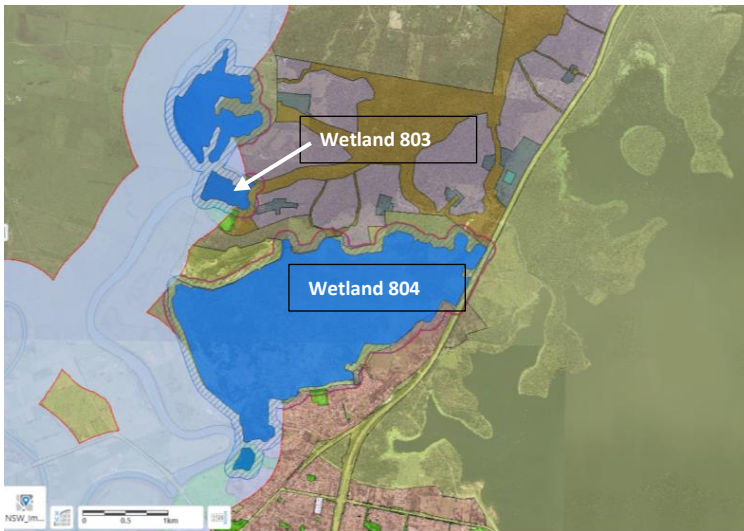


Figure 3-8 NSW Coastal Wetlands 803 & 804

The clause in the SEPP 2018 most relevant to the changes in catchment flows from the developments is:

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 clause requires an understanding of the surface water flows to the wetlands from land use changes in the catchment.

NSW Biodiversity Conservation Act 2016 (BC Act) 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.

No individual listed species have been recorded in Irrawang Swamp.

Three vegetation communities of interest have been recorded on the site.

Table 3-2 *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 (<i>Casuarina glauca</i>) Forest of New South Wales and South East Queensland Endangered
Paperbark Woodland	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 threatening processes listed in the acts.

The threatening process related to the vegetation communities listed in the EPBC Act is:

- changes to natural drainage regimes, such as the diversion of water, affecting the ecological community.

This threatening process aligns to the requirements in SEPP 2018 referring to water flows to coastal wetlands.

Wetlands in Irrawang Swamp are identified in SEPP 2018 (see Figure 3-8) and must be considered by any development which may impact on it through the identified threatening processes.

3.4 Site visit

The site visit did not include a detailed flora survey, but the Kleinfelder 2018 report was used as a baseline for the current vegetation community extents. A site visit was undertaken on 24 April 2019 to observe the vegetation communities outlined in that report.

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.

3.5 Wetland typologies

The vegetation communities occupy different areas depending upon the hydrology of those areas. The hydrological regimes for the different communities are shown in Table 3-3. Hydrology risks to these vegetation communities are shown in Table 3-4.

Swamp Meadow Complex

Kleinfelder (2018) mapped this vegetation into three floristic communities:

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 of the swamp and where the Pennington Drain spills frequently. 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.

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

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 is dominated by the exotic plant *Paspalum distichum* (Water Couch) but shows more diversity in plant species than the Perennial Swamp Meadow areas. A number of native wetland plants are also present, including *Bolboschoenus caldwellii* (Sea Club-rush), *Juncus continuus*, *Ludwigia peploides* (Water Primrose), *Carex appressa* (Tall Sedge) and *Persicaria decipiens* (Slender Knotweed). Serious weeds such as *Alternanthera philoxeroides* (Alligator Weed) have been observed in this zone.

This vegetation community is equivalent to the Shallow Marsh wetland vegetation type in McManus et al (2007).

Transient Swamp Meadow – areas of temporary inundation flooded only 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.

This vegetation community is equivalent to the Shallow Marsh wetland vegetation type in McManus et al (2007).

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 at 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 inundation events which recede 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).

Paperbark Woodland

This is an alluvial plain woodland community dominated by *Melaleuca* species including *Melaleuca linariifolia*, *Melaleuca styphelioides* and *Melaleuca ericifolia*. This is a seasonally inundated vegetation community with water up to 0.5m deep. It occupies areas slightly lower (100-200mm) than the Swamp Oak with longer inundation periods.

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

The northern *Melaleuca* stand is susceptible to increased summer flows as this area is a natural depression and 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).

Table 3-3 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	<i>Casuarina glauca</i>	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	Deep Marsh (Tall Marsh)	<i>Typha orientalis/Phragmites australis</i>	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
	Freshwater Wetlands on Coastal Floodplains										
	Seasonal Swamp-meadow	Shallow Marsh (wet)	<i>Paspalum distichum</i> (Water Couch), <i>Bolboschoenus caldwellii</i> , <i>Ludwigia pleboides</i> , <i>Carex appressa</i> , <i>Juncus sp</i>	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
	Freshwater Wetlands on Coastal Floodplains										
	Transilient Swamp-meadow	Shallow Marsh (dry)	<i>Cynodon dactylon</i> (Common Couch), <i>Juncus sp</i> , <i>Carex appressa</i>	Water logged	Episodic	0 to 0.4m (RL 0.6 to 1)	1 month	2-3 times per year	8 - 12+ months	Annually	Fresh
	Freshwater Wetlands on Coastal Floodplains										
Woodland	Paperbark Woodland	Forest Swamp Ephemeral	<i>Melaleuca styphelioides</i> , <i>Melaleuca linariifolia</i> , <i>Melaleuca ericifolia</i>	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
	Swamp Sclerophyll Forest on Coastal Floodplains			Water logged	Episodic	0.2 to 0.4m (RL 0.6 to 0.8)	1 month	2-3 times per year			

Table 3-4 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	<i>Casuarina glauca</i>	Increase in extent. Unclear if 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	Deep Marsh (Tall Marsh)	<i>Typha orientalis/Phragmites australis</i>	Increase in extent	Further spread especially if summer inundation increases	Reduction in perennial to Season Swamp-meadow
	Freshwater Wetlands on Coastal Floodplains					
	Seasonal Swamp-meadow	Shallow Marsh (wet)	<i>Paspalum distichum</i> (Water Couch), <i>Bolboschoenus caldwellii</i> , <i>Ludwigia pleboides</i> , <i>Carex appressa</i> , <i>Juncus sp</i>	Reducing	Reduction with increase in Perennial Swamp-meadow	Potential increase
	Freshwater Wetlands on Coastal Floodplains					
	Transilient Swamp-meadow	Shallow Marsh (dry)	<i>Cynodon dactylon</i> (Common Couch), <i>Juncus sp</i> , <i>Carex appressa</i>	Reducing with Swamp Oak Woodland colonising into this area.	Reduction with increase in Perennial Swamp-meadow	Potential increase
	Freshwater Wetlands on Coastal Floodplains					
Woodland	Paperbark Woodland Swamp Sclerophyll Forest on Coastal Floodplains	Forest Swamp Ephemeral	<i>Melaleuca styphelioides</i> , <i>Melaleuca linariifolia</i> , <i>Melaleuca ericifolia</i>	Stable with some increase	>200mm of drawdown depth for more than 1 month duration. Reduction with increase in Perennial Swamp-meadow	Potential increase

4 Hydrological and ecological impacts

4.1 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. 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 considered most appropriate for the purposes of the 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.

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.

4.2 Mean annual runoff volume

Changes in mean annual runoff volume provide a coarse indicator of the hydrological changes associated with the Kings Hill development. Table 4-1 summarises the estimated changes to mean annual runoff volumes draining to Irrawang Swamp 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 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 existing ephemeral gullies into the northern side of Irrawang Swamp.

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

Table 4-1 *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
Kings Hill East	Existing	0	625	925
	Developed	0	2300	0
	Developed (treated)	0	2120	0
	Change		+1495 (+240%)	-925 (-100%)
Kings Hill South	Existing	470	0	0
	Developed	700	0	0
	Developed (treated)	575	0	0
	Change	+105 (+22%)		

The estimated mean annual runoff volumes summarised in Table 4-1 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.
- 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. Although, it is expected that a proportion of this runoff volume currently indirectly contributes to Grahamstown spillway discharges into Irrawang Swamp during high rainfall periods.
- 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.

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 4.3.

4.3 Cumulative runoff

A plot of daily rainfall totals and associated cumulative runoff volumes for Kings Hill South is provided in Figure 4-1. Figure 4-1 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 4-1 would also be representative of other areas of the Kings Hill development.

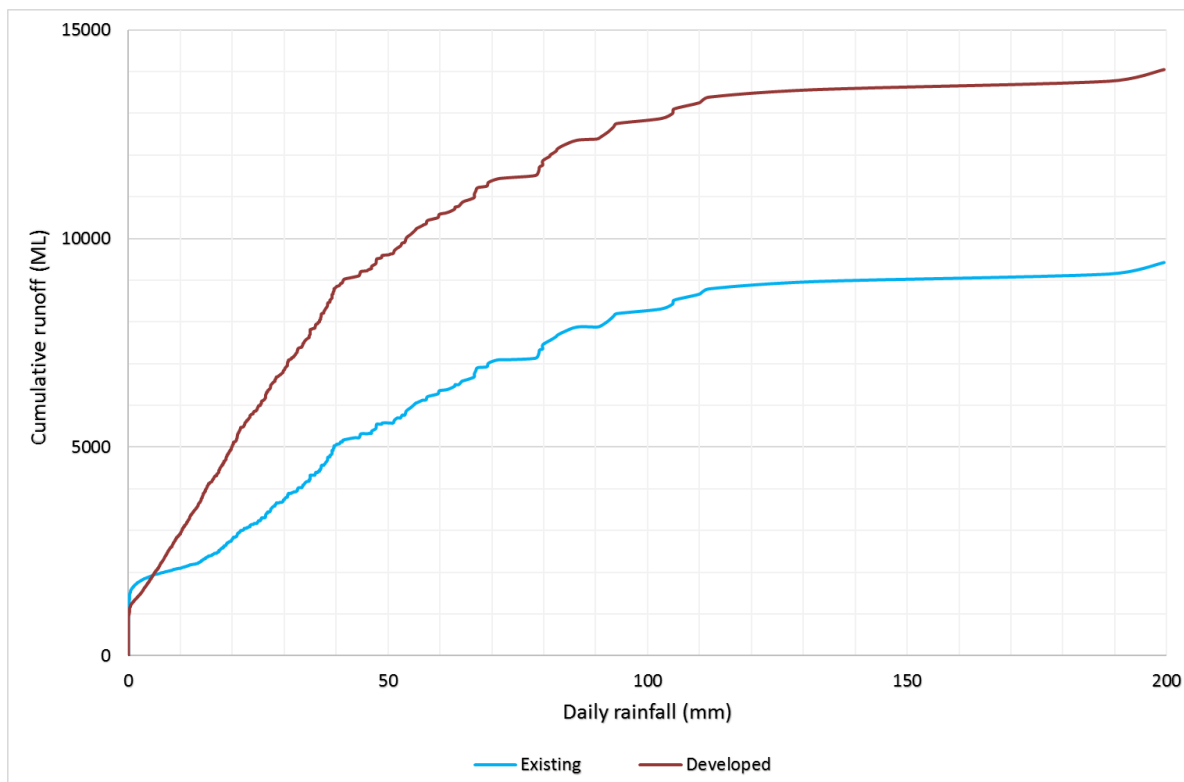


Figure 4-1 Plot of daily rainfall and estimated cumulative runoff for Kings Hill South catchment (1989 to 2008)

Figure 4-1 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 limited additional increases in estimated runoff volumes occurs above a daily rainfall total of 50mm in Figure 4-1.

Figure 4-1 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.

4.4 Flow regimes

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 4-2. Wetland categories that would be relevant to Irrawang Swamp include shallow marsh, deep marsh, wet heath, wet forest swamp and ephemeral forest swamp.

Table 4-2 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 4-2, 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 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. This analysis approach 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 evapotranspiration typically exceeds average monthly rainfall at this location (refer Figure 4-2). 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 supporting new plant growth. Minimising changes to hydrology during this drying period are particularly important for the shallow marsh, deep marsh and forest swamp – ephemeral vegetation communities within Irrawang Swamp.

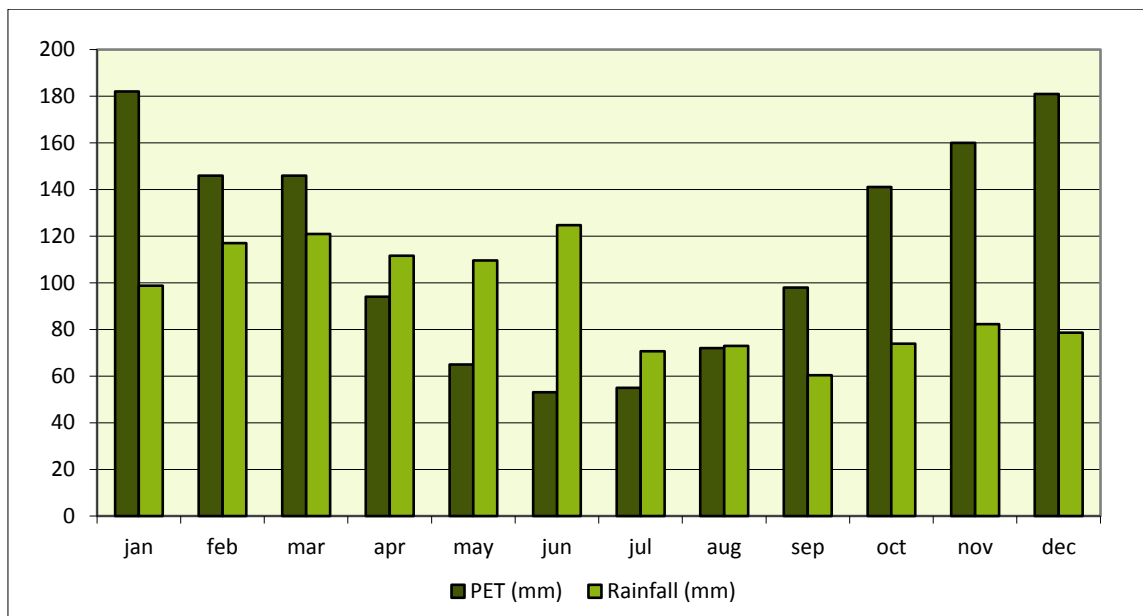


Figure 4-2 Average monthly evapotranspiration and rainfall depths for Irrawang Swamp (BoM Climate Atlas of Australia)

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. In summary, 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 is 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 shown on Figure 4-3 and Figure 4-4 respectively.

An example of how these curves may be interpreted is indicated by the dashed green line shown on Figure 4-3. This line indicates that there is a 10% chance in any year that the maximum dry spell will be longer than 32 days for developed conditions and longer than 190 days for 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 be representative of a wet year. A 50% AEP dry spell may be considered as 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 partially mitigates reductions in dry spells which is primarily associated with the provision of 5 kL rainwater tanks, biofiltration systems and urban lakes modelled throughout the development.

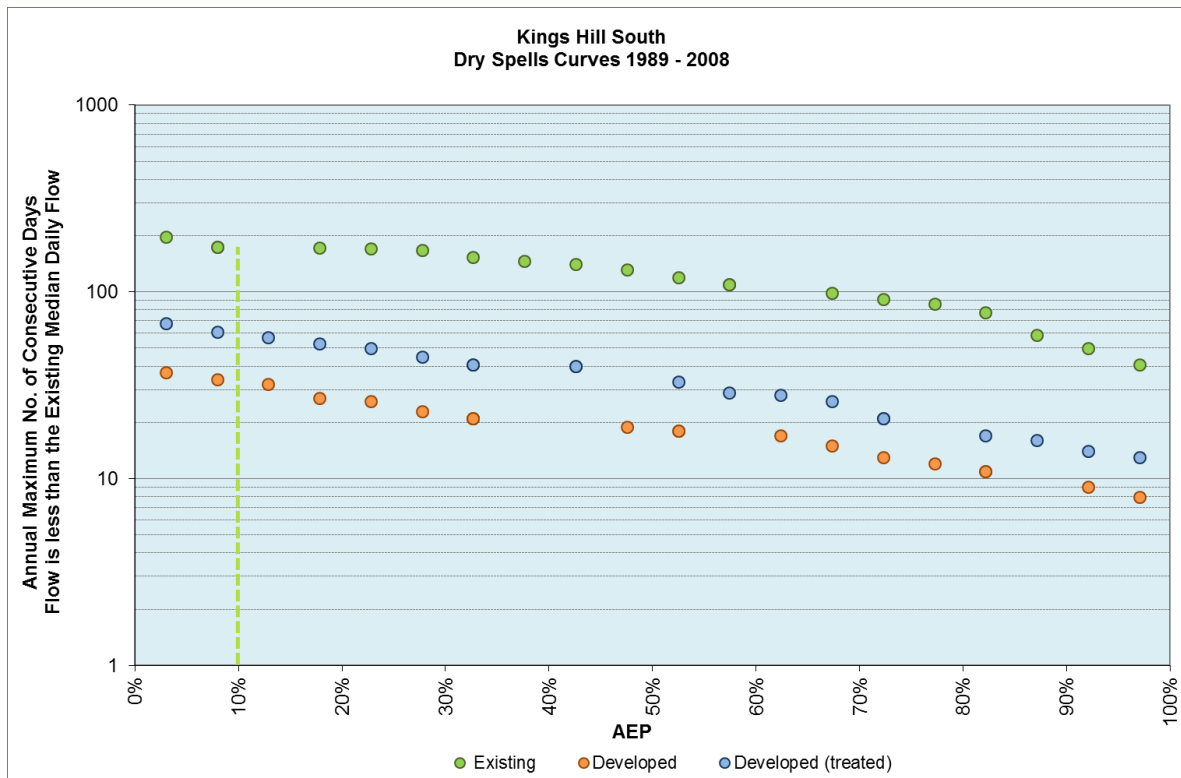


Figure 4-3 Kings Hill South – Dry Spells Curves

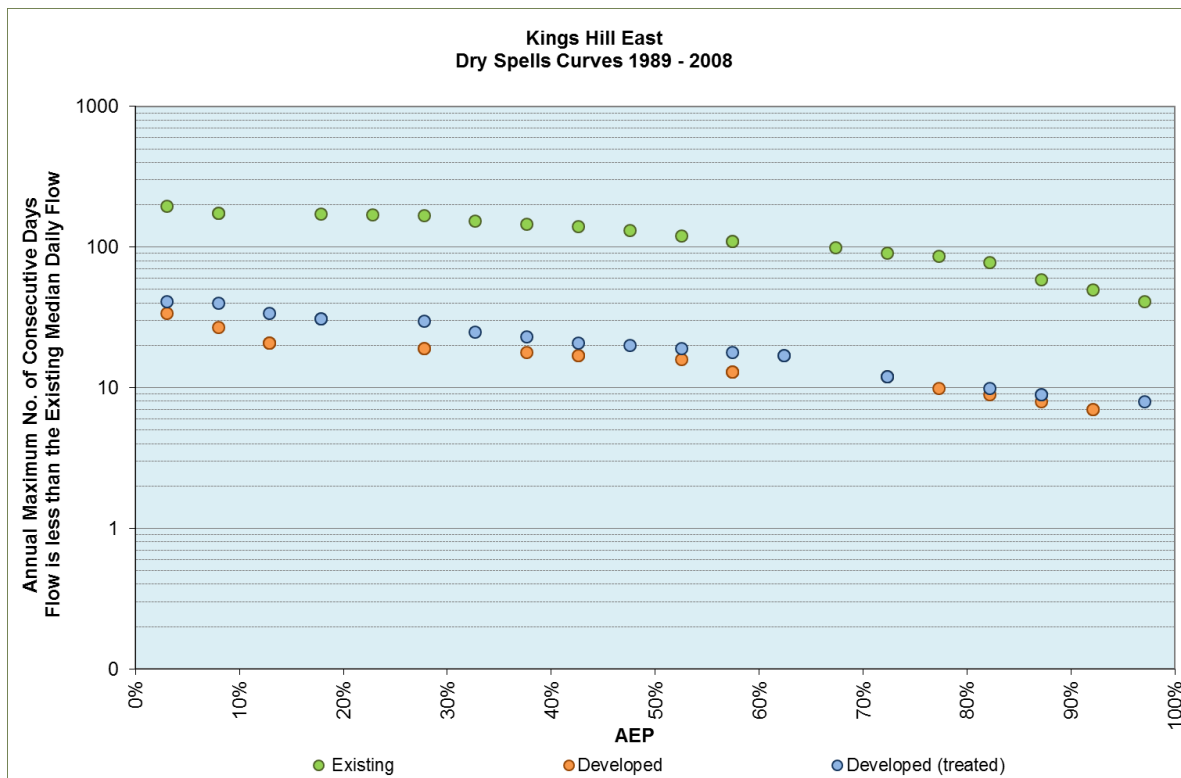


Figure 4-4 Kings Hill East – Dry Spells Curves

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 4-5, Figure 4-6, Figure 4-7 and Figure 4-8.

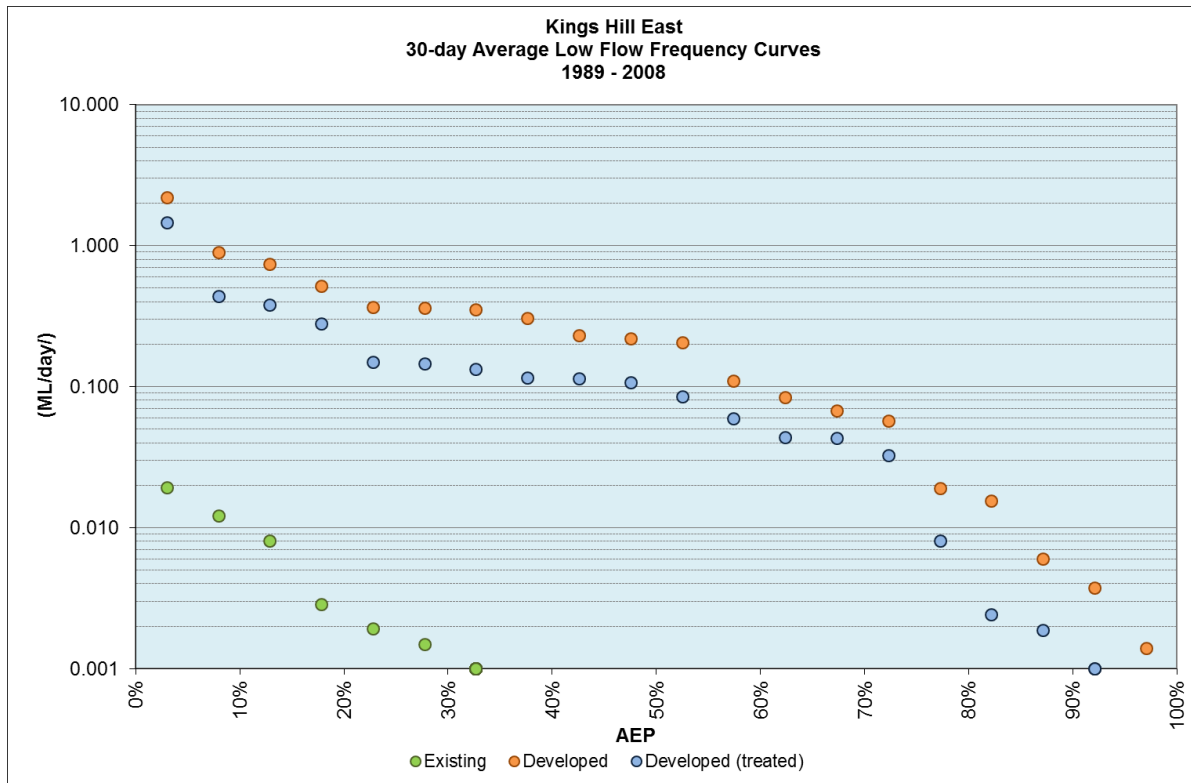


Figure 4-5 Kings Hill East – 30-day average low flow frequency curves

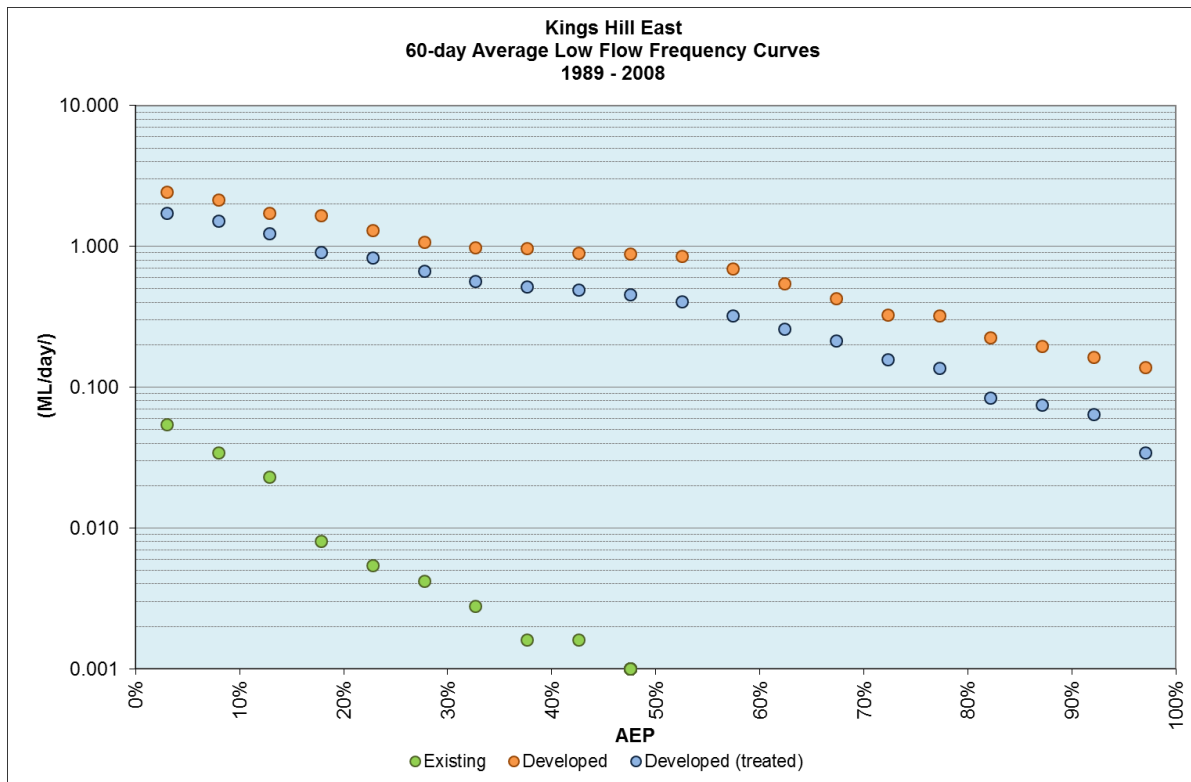


Figure 4-6 Kings Hill East – 60 day average low flow frequency curves

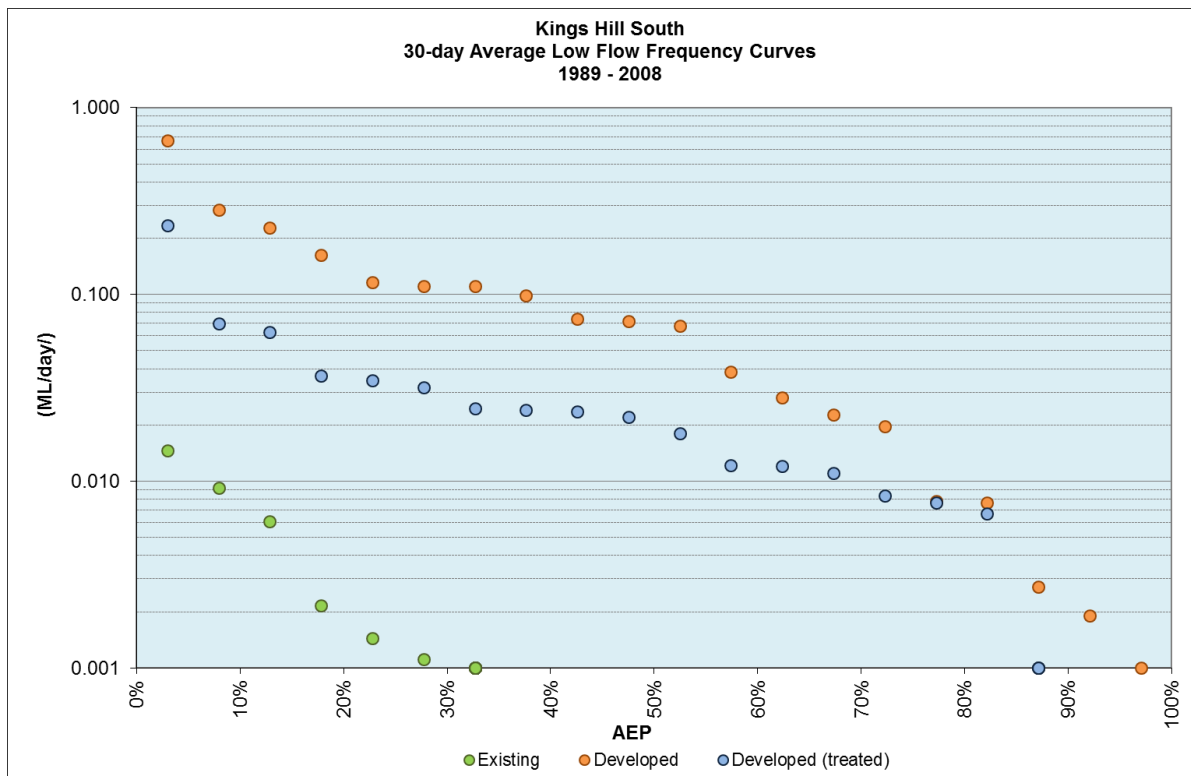


Figure 4-7 Kings Hill South – 30-day average low flow frequency curves

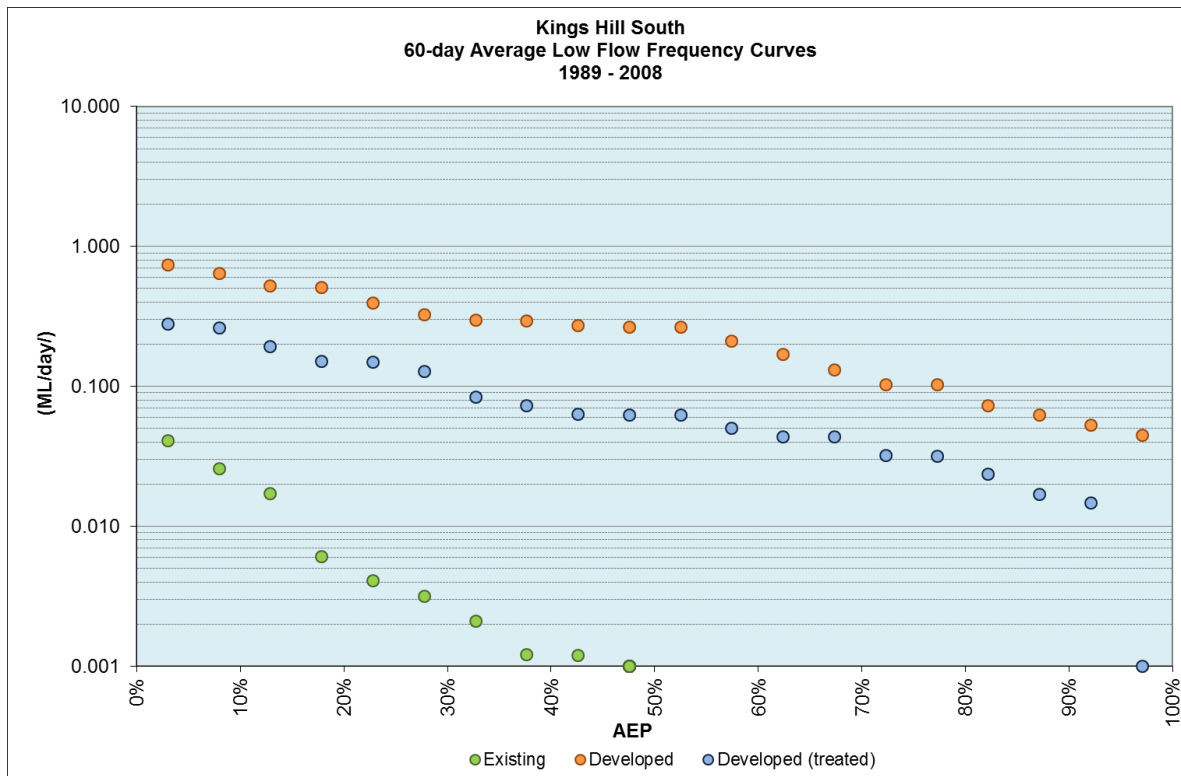


Figure 4-8 Kings Hill South – 60-day average low flow frequency curves

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 which is primarily associated with the modelled 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 during the critical drying period will be close to 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.

Low flow inundation extents

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

For Kings Hill East, 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 low flow 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 4-6, 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 5 litres/s). It is envisaged that this scale of flow would readily be conveyed along Pennington Drain without spilling into the adjacent wetland areas prior to discharge through the open flood gates.

Low flows from Kings Hill South drain along the existing gullies that discharge into the northern side 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. 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. Although a detailed analysis of the Irrawang Swamp levels has not been completed (due to

limitations in the accuracy of available ground survey and LiDAR data), 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 large area of perennial swamp meadow in this area.

The Kings Hill South 30 and 60 day average low flow frequency curves presented in Figure 4-7 and Figure 4-8 respectively were interpreted to estimate potential changes in inundation depths across the northern extents of Irrawang Swamp during low flow periods. Based on the Kleinfelder (2018) mapping of the swamp oak woodland, seasonal swamp meadow, paperbark woodland and perennial swamp meadow extents in this area, it is estimated that up to approximately 210 ha of vegetation potentially could interact with low flows discharged from King Hill South to Irrawang Swamp. Based on the estimated changes in 30 and 60 day low flow volumes and the potential 210 ha inundation area, average increased inundation depths over this area associated with increased low flows are summarised in Table 4-3.

Table 4-3 Estimated average increase in inundation depth during low flow periods from Kings Hill South

Low flow period	Existing low flow volume (ML)	Developed (treated) low flow volume (ML)	Increase in low flow volume (ML)	Inundation area (ha)	Average increase in inundation depth (mm)
30 days	0.3	2.1	1.8	210	1 mm
60 days	1.2	13.8	12.6	210	6 mm

The increase in inundation depths outlined in Table 4-3 are approximate only as they are based on a number of broad assumptions. The estimated inundation depths assume that low flows spread out evenly across the entire areas mapped for the indicated vegetation communities. This is unlikely to occur as subtle variations in terrain across the northern extents of the swamp will result in inundation depths varying. It is also likely that vegetation closer to the gully inflow locations would be wet more regularly during individual runoff events over these low flow periods than vegetation further away from the inflow locations. A vegetation response to such inflows is already observed with an area of Perennial Swamp Meadow (*Typha* sp) below the dam on the central outfall from Kings Hill South. Vegetation responses such as this may be quite localised.

The estimated increased inundation depths also assume that the increase in low flows would be retained within the mapped vegetation areas for the entire 30 or 60-day duration. This is unlikely as the low flows would tend to gravitate towards Pennington Drain and be conveyed along the channel prior to discharge through the flood gates. In addition, soils in the inundation area would tend to be drier during the summer period and adsorb a high proportion of this increase in low flow discharge, resulting in limited inundation and increased evapotranspiration.

The impacts of the small increase in inundation depths presented in Table 4-3 would be similar to an additional small rainfall event (<10mm) occurring during the critical drying period.

High flow regime

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 4.1 for further discussion on this) and this is demonstrated in Figure 4-9.

The main change from developed conditions would be that increased high flows from Kings Hill East would be directed to Irrawang Swamp along the diversion drain. 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 would indirectly discharge to Irrawang Swamp through the spillway.

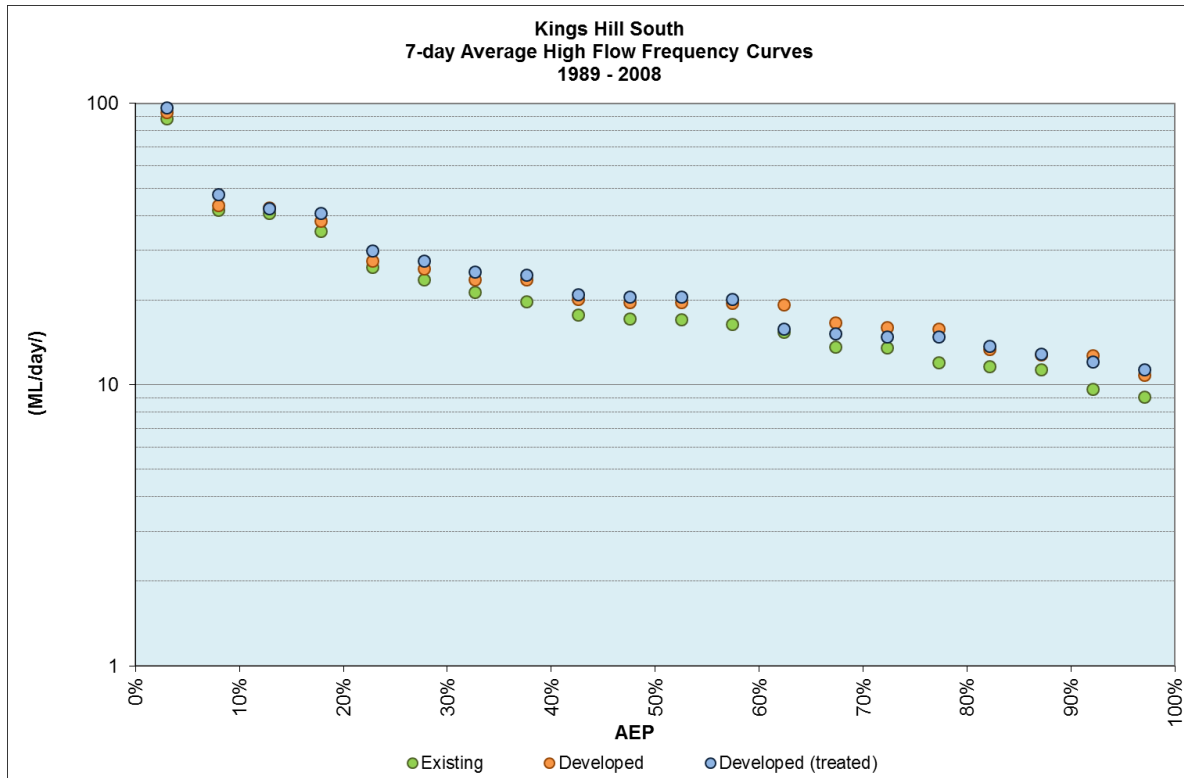


Figure 4-9 Kings Hill South – 7-day average high flow frequency curves

Figure 4-10 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 discharging into 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 Kings Hill East catchment directed to the proposed diversion channel.

Figure 4-10 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 4-10 also indicates that the stormwater management measures proposed by NCE are unlikely to have any significant impact on mitigating increased 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 lowering the high flows.

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

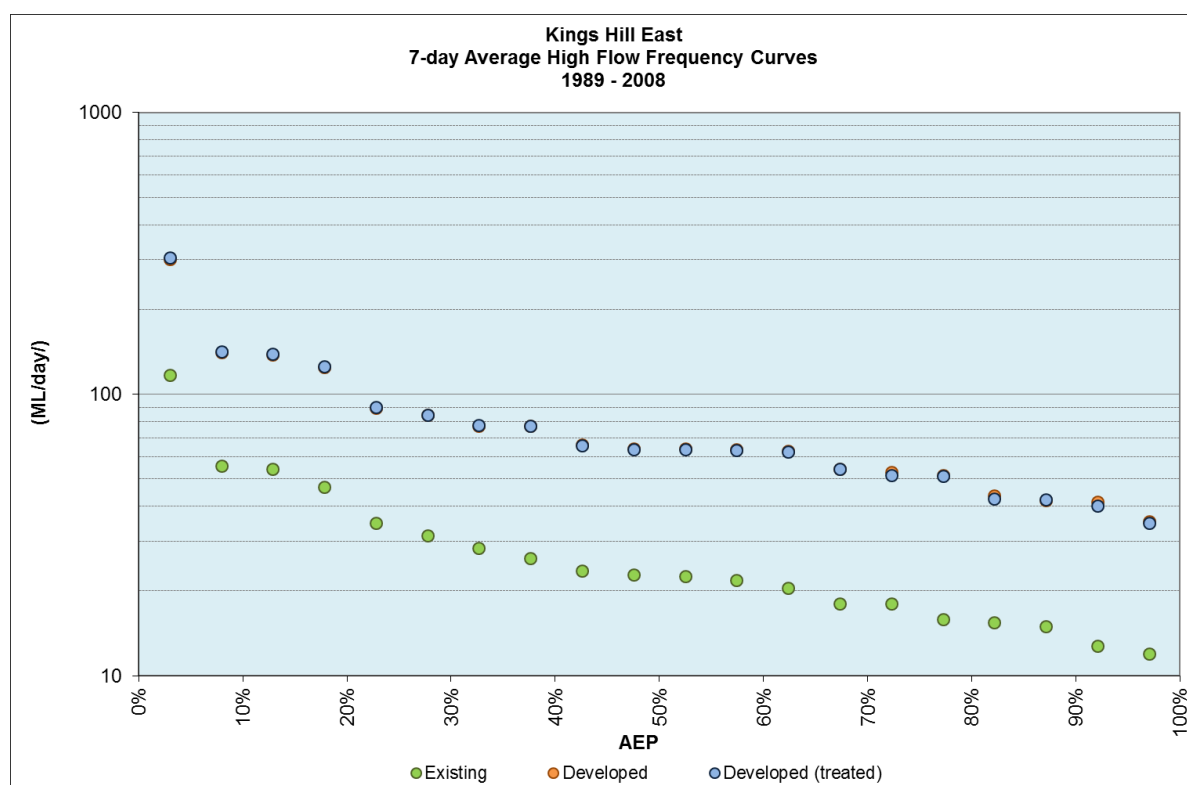


Figure 4-10 Kings Hill East – 7-day average high flow frequency curves

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 4-4. The data indicates that between 1974 and 1989 no spillway discharges from Grahamstown Dam to Irrawang Swamp occurred. 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, spillway discharges were recorded in five separate years (2008, 2011, 2013, 2015 and 2016).

Table 4-4 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 4-10). Most spills from Grahamstown Dam have occurred during the wetter April to August period and it is expected that future high flow periods from Kings Hill East would coincide with this period.

An increase in flow 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 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 currently draining 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.

Increased high flow discharges from Kings Hill East are more likely to coincide with periods where inflows from direct rainfall on the swamp, other local catchment inflows and spillway flows are also elevated resulting in wide-spread inundation across Irrawang Swamp.

The critical drying period for Irrawang Swamp is from September to March (refer Figure 4-2). Approximately 25% of days where spillway discharges have occurred fall within this critical drying period. Most spillway discharges have occurred during the wetter late autumn to late winter period and this period is likely to coincide with high flow discharges from Kings Hill East. 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.

4.5 Assessment of ecological impacts

The vegetation communities within Irrawang Swamp occupy the site in a dynamic manner evolving in their extent in response to management practices. The hydrological regimes shown in Table 3-3 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 estimated main changes in flow to the swamp area from the Kings Hill development areas are:

- Increased dry season flows in volume and frequency.
- Increased peak event flows.

Kings Hill South dry season flows

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. This will not be an equal depth change within the micro-topography of the site that collects flows into deeper areas resulting in a mosaic of vegetation response. This increase in depth is within the ecological depth tolerance of the vegetation. Seasonal drying 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 expanding into the Transient Swamp Meadow or being replaced by Perennial Swamp Meadow. These changes are also expected to occur with reduced drain maintenance by Hunter Water with the intent to retain water for longer periods in the swamp.

One 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 this resulted in a permanent inundation of the Melaleuca species of >200mm there would be a negative impact. However, as the inundation depth increase is less than 200mm and drying periods are expected at least 1 in 3 years there will

be negligible ecological impact on the vegetation. A positive impact may be the reduction in some weeds such as *Xanthium occidentale* (Noogoora Burr) which are less tolerant of increased inundation.

Kings Hill East dry season flows

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.

Kings Hill West dry season flows

Dry season flows from Kings Hill West to Wetland 803 need to be managed to reduce the depth of inundation and allow the regeneration of the Swamp Oak in this wetland.

Increased peak flows

The increase in peak 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 depth of 65mm over the site for the 7-day high flow duration event is not significant and is only temporary (<5 days).

Infrequent dry 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 peak flow is not a significant threat to the wetland.

5 Summary and conclusions

The average annual runoff volume from Kings Hill East that drains to Irrawang Swamp is estimated to increase by approximately 1500 ML/yr from existing conditions when planned development of this catchment is completed in the next few decades. The majority of this estimated increased volume (approximately 60%) is due to diversion of runoff from Grahamstown Dam. The remaining increase in volume is associated with increased catchment imperviousness.

Whilst runoff volumes 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 twin 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.

During typical annual high flow periods, it is estimated that high flows from Kings Hill East would typically increase by approximately 40 ML/day compared to existing conditions. During these periods it is expected that flow would spill over the Pennington Drain banks into the adjacent vegetated areas. Considering a representative 7-day high flow period, this increased flow represents an increased depth of 65 mm over the total swamp area. Although the 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.

Reducing runoff volumes during annual high flow periods would be challenging, as retaining the large volumes of runoff within the Kings Hill development area will be impractical. Flood detention storages provides a slight delay in the additional flow volumes reaching Irrawang Swamp, but this delay will be insignificant for reducing inundation extents due to the significant flow attenuation that occurs within the swamp and the limitations of the flow discharges through the flood gates at the end of Pennington Drain. Monitoring the response of Irrawang Swamp during high flow periods following commencement of development should be a fundamental consideration. Options to adapt the Pennington Drain floodgates and multi-cell culvert inlet levee level would be available to regulate flow levels during high flow periods in response to vegetation changes associated with hydrological changes associated with development, climate change or other variables.

Increases in runoff volumes from King Hill South are estimated to be much lower than from Kings Hill East. Although, runoff from Kings Hill South will be less constrained by drainage channels and will disperse more through the wetland vegetation. The average increase in flow depth over the northern part of Irrawang Swamp is expected to be less than 10 mm and within the range of variations in summer rainfall across the wetland. Although, localised increases in water depth are likely to occur due to subtle variations in the terrain leading to additional localised pockets of perennial swamp meadow. Increased annual high flow volumes from King Hill South are estimated to be minor and have an insignificant impact on increasing water levels in Irrawang Swamp during these periods.

The dominant risks to the vegetation from changes in the hydrology include:

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

The preliminary hydrological analysis indicates there will be seasonal dry periods in the Woodland and Seasonal Swamp Meadow areas and that potential changes in depth are within the ecological depth range of the vegetation communities. Some local areas may see an increase in inundation depth and duration but the surrounding vegetation will colonise into those areas retaining a mosaic of vegetation types as can be currently observed. The soil moisture status will not change as this is driven by the low lying topography and drainage system of the swamp.

These observations show the dominant risks are not likely to occur in Irrawang Swamp.

On-going monitoring of vegetation in Irrawang Swamp should be undertaken as the Kings Hill development proceeds. The assessment in this report is based on the ultimate development condition. Monitoring of initial development impacts should assist with improving WSUD responses in future subdivisions to further mitigate any additional potential impacts. Actions to monitor and mitigate threats to the wetland vegetation include:

- Monitoring of vegetation as development proceeds over the following decades. This provides time to respond to hydraulic changes to the drainage system. This will also enable Hunter Water to determine what the acceptable distribution of vegetation communities is and particularly the extent of Perennial Swamp Meadow which will be driven by the level of drainage to Pennington Drain.
- Monitor summer low flows from Kings Hill East to determine if they are retained in Pennington Drain and not impacting on the northern Seasonal Swamp Meadow.
- Reduce the inundation depth and period of normal water level in Wetland 803 by installing a new outlet with level control. This will enable regeneration and healthy growth of the *Casuarina glauca* (Swamp Oak Woodland) in the wetland.
- Monitor the Paperbark Woodland for extended inundation to ensure seasonal drying occurs. Consider diversions around this community if summer inflows perpetually flood this area.

The Swamp Oak Woodland in Wetland 803 reduced in extent and density by approximately 30% between 1954 and 2019. Although detailed analysis of Coastal Wetland 803 in Kings Hill West was not completed as only limited ecological data was available, it is clear that the condition of this wetland has been impacted due to increased water retention resulting from construction of a weir 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 objectives for the 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 climate change impacts progress. In circumstances where increased water is not desirable, opportunities are available to regulate increased flows through existing outlets.
- The flows will support ongoing waterlogging of the soils in the Swamp Oak and Paperbark Woodland areas of the swamp providing the soil condition for these vegetation communities ensuring their survival.
- Potentially an annual average of over 1200 ML of runoff could be transferred from the diversion drain into Grahamstown Dam if future risk assessment, monitoring and technology advances identify that the water would be appropriate as a drinking water source. This would assist to improve the resilience of the Lower Hunter region drinking water supply under climate change conditions.

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 Irrawang Swamp ecology. This includes effective measures in the subdivision construction, building construction and post development phases.

6 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.