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Woodberry Swamp Hydrologic Study

WRL Technical Report 2016/03

November 2016

By D S Rayner, W C Glamore and J E Ruprecht

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University of New South Wales
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Executive Summary

Woodberry Swamp is a low-lying floodplain and wetland area located between Maitland and Hexham on the western side of the Hunter River estuary. With a catchment of approximately 4,350 hectares, the Woodberry Swamp landscape is comprised of permanent open water, intermittently inundated wetland areas, and pastures. The area receives runoff from the catchment, flows from a licensed discharge, and direct rainfall. The Woodberry Swamp floodplain also functions as a retention basin during large floods (part of the larger Hunter River floodplain retention network) to reduce peak river flood levels. The floodplain is drained via Greenways Creek, with six large tidal floodgates located at the Hunter River estuary, which restrict water from the Hunter River flowing into Woodberry Swamp.

Over the past two centuries the construction of flood mitigation infrastructure has separated the floodplain from the estuary and encouraged dry-land agricultural development of Woodberry Swamp. Significant floodplain drainage works were carried out following major flooding in 1955, including the construction of drains and levees, and the installation of tidal floodgates. The levees were designed to protect farming and urban areas from small to medium sized floods, whereas the drains and floodgates were designed to maintain the same rate of drainage that existed prior to the levee construction. Presently, the drainage system downstream of Woodberry Road is managed and maintained by the NSW Office of Environment and Heritage. No co-ordinated drainage management, or drainage union, exists for the network upstream of Woodberry Road.

The primary aim of this study was to provide a comprehensive scientific analysis of hydrologic issues relating to Woodberry Swamp and provide recommendations for managing water movement and water quality across the floodplain and wetland, with environmental outcomes a priority, but understanding that social and economic needs must also be accommodated. Key outcomes from the study include:

- A literature and data review;
- Detailed on-ground investigations of the existing state of the site, including the monitoring of water levels during a large rainfall event in January 2016;
- Development of a conceptual understanding of the Woodberry Swamp system during wet and dry periods;
- An upgrade of the existing catchment rainfall-runoff numerical model to estimate catchment runoff rates and volumes;
- Development of a detailed hydrodynamic model to investigate the movement of flows through the floodplain and wetland in terms of flow inundation area and depths, flow distribution, water surface levels, flow velocities and inundation time (hydro period); and
- Development of staged management approach options for four specific floodplain management areas.

A review of previous studies indicated that floodplain drainage and water quality have been ongoing issues at Woodberry Swamp. In particular, a recent landholder survey indicated key water management issues relating to catchment runoff, day-to-day nuisance flooding, post-flood drainage, and ongoing daily discharges from an EPA licensed discharge. Despite these hydrologic issues at Woodberry Swamp, limited information was available regarding the drainage network and water level fluctuations within the drainage system. A field campaign was undertaken to address these knowledge gaps, with all major floodplain drains and hydraulic structures surveyed to a high accuracy.

The connectivity, capacity, and condition of drainage infrastructure are critical to providing efficient drainage under day-to-day conditions and during flood events. The field survey found that the drainage network upstream of the Hunter Water Corporation pipeline contains significant in-drain vegetation which inhibits the flow of water. Low-lying areas that experience prolonged inundation were found to be poorly drained, with drainage channel elevations measured as being higher than the areas they drain. A number of structures in poor condition were observed, with two completely collapsed structures recorded. Structures in poor, or dysfunctional condition, act to limit drainage during day-to-day flows. The large open water area, located at the south-western extent of the floodplain adjacent to the railway, was measured to have permanently elevated water levels. Further investigations found that a large blockage comprised of vegetation, organic matter and sediment was observed downstream of the open water area.

A large rainfall event (~6% Annual Exceedance Probability) that occurred in early January 2016 provided an excellent opportunity to gain a detailed understanding of the hydrologic behaviour of the site. Four (4) water level monitoring stations were installed and instrumented during the field survey prior to the storm. The stations measured the rise of water levels due to catchment runoff and the drainage of floodwaters from the floodplain in the days following the event. The observed data indicated that floodplain drainage following the event was mainly controlled by the downstream Hunter River levels. Water level data and aerial imagery also indicated that the Greenways Creek catchment and the adjacent catchment to the north, Scotch Creek, can be connected during local catchment flood events, although the size, duration and direction of inter-catchment flows is unknown. The drainage of floodwaters in the upstream areas of Woodberry Swamp were observed to lag downstream water levels due to possible restrictions caused by Woodberry Road and the Hunter Water Corporation pipeline.

The influence of catchment development on the water balance of Woodberry Swamp was assessed using a numerical rainfall-runoff model. The model simulated the volume and quality of runoff from the catchment under various land use scenarios. The scenarios incorporated the development of the site from past to present, including natural bushland and mixed rural, urban and industrial developments. Results of the analysis indicated that increased catchment development has altered the water balance by reducing groundwater infiltration, reducing evapotranspiration, and increasing runoff. For example, assessment of proposed developments by 2020 indicated that the area of hard surfaces (i.e. impervious surfaces) will increase to approximately 20% of the total catchment (from 18% in 2015). Results from modelling this scenario indicated that the total annual average runoff from the catchment will increase by approximately 5% compared to present day runoff volumes.

The predicted increase in runoff due to the proposed developments by 2020 was also compared to the recorded annual variability in rainfall-runoff from the site. Analysis of rainfall data near the Woodberry Swamp catchment indicated that total rainfall volume regularly varies by ±30% from year-to-year, in comparison to the long-term average. As the relationship between rainfall and runoff is not directly proportional, the amount of catchment runoff entering Woodberry Swamp varies greatly from year to year. That is, if annual rainfall for the site is below average by 30% then runoff would be significantly reduced (i.e. greater than 30% reduction in runoff). Conversely, the same is true for a 30% above average rainfall year. Subsequently, variation in catchment runoff due to changes in catchment land use is difficult to differentiate from the natural variability in meteorological (rainfall, evaporation etc.) processes.

The impact of an industrial licensed discharge on swamp hydrology is significant. A constant daily flow of up to 2,300 m^3 (2.3 mega litres) of nutrient-rich water is discharged into the south-western area of Woodberry Swamp, just south of the railway each day. This constant daily flow alters the natural wetting and drying cycle of the wetland. The licensed discharge was found to account for over 85% of the nitrogen (TN) load and over 90% of the phosphorus (TP) load in the Woodberry Swamp catchment. By way of reference, the total load of nutrients from this industrial discharge is up to twice that discharged by nearby waste water treatment plants in Morpeth and Raymond Terrace. The vegetation/sediment blockage at the downstream end of the large open water area in the south-western area of Woodberry Swamp has likely been exacerbated by the constant discharge of high nutrient water from the industrial site significantly increasing vegetation growth rates in this part of the swamp. Historical aerial imagery indicates that vegetation and the area of open water increased between 1977 and 1995. Currently, the large open water area and associated vegetation act as a large treatment pond that assists in capturing nutrients from the water before the flow is discharged downstream and into the Hunter River estuary.

Predicted sea level rise will be of particular importance to the future drainage of Woodberry Swamp. Although the levee banks will prohibit inundation of the floodplain due to increased high tide levels, elevated low tide levels in the Hunter River due to climate change are likely to have a greater impact on backswamp drainage (and thus agricultural productivity). This is also likely to result in an increased duration of inundation of low-lying areas during catchment runoff events.

Due to varying stakeholder interests and the variety of pressures and different requirements of each area of Woodberry Swamp, it is unlikely that there will be one solution, or, that will solve all issues raised. The lack of a single solution and the number of stakeholders are the key reasons why there has been limited on-going action over previous decades.

As such, the management recommendations provided by this study are based on the division of the floodplain into different management areas to enable the separate issues to be addressed individually. This provides the opportunity for targeted actions to be undertaken. The following four management areas are proposed (Figure E.1):

1. Hunter River floodgates to Hunter Water Corporation pipeline;
2. Central Woodberry Swamp floodplain, to upstream of the Hunter Water Corporation pipeline;
3. North-western area towards Thornton North; and
4. South-western area towards Beresfield.

There are a range of management options for Woodberry Swamp that address the immediate drainage and water quality issues but may also provide some environmental benefits. These management options primarily focus on landholder concerns, such as maintaining existing land use practices and improved drainage and vegetation control, and consider them against the environmental changes that may result.

In the immediate (5 years) timeframe, management options include (but are not limited to):

- Regular connection of Greenways Creek with the Hunter River to promote flushing. This will provide benefits to water quality and ecological connectivity (i.e. fish passage);
- Clearing of in-drain vegetation and inefficient hydraulic structures to improve day-to-day drainage of the floodplain and permit aquatic connectivity deeper into the wetland;
- Further investigation of options surrounding the industrial licensed discharge, and the impact of removing the blockage that maintains the present day open water area in Management Area 4 (see Figure E.1);
- Further investigation of the Hunter Water Corporation pipeline and Woodberry Road constrictions on floodwater drainage and the modification/design required to adequately convey floodwaters; and

- Promotion of wet pasture management and invasive vegetation species control which may lower the risk of deoxygenated ‘black water’ events.

Long-term (> 5 years) options available for Woodberry Swamp rely on adaptive or altered land use management. Potential long-term management options include (but are not limited to):

- Acquisition of the wetland areas from private landholders to expand the environmental values of Woodberry Swamp;
- Introduction of intermittent tidal flushing to low-lying areas to promote tidal wetland habitat and increase connectivity;
- Increase the extent of water sensitive urban design infrastructure in catchment development areas to improve water quality and reduce drainage; and
- Increase pre-treatment of licenced discharge and/or re-locate licensed discharge outside of Woodberry Swamp catchment.

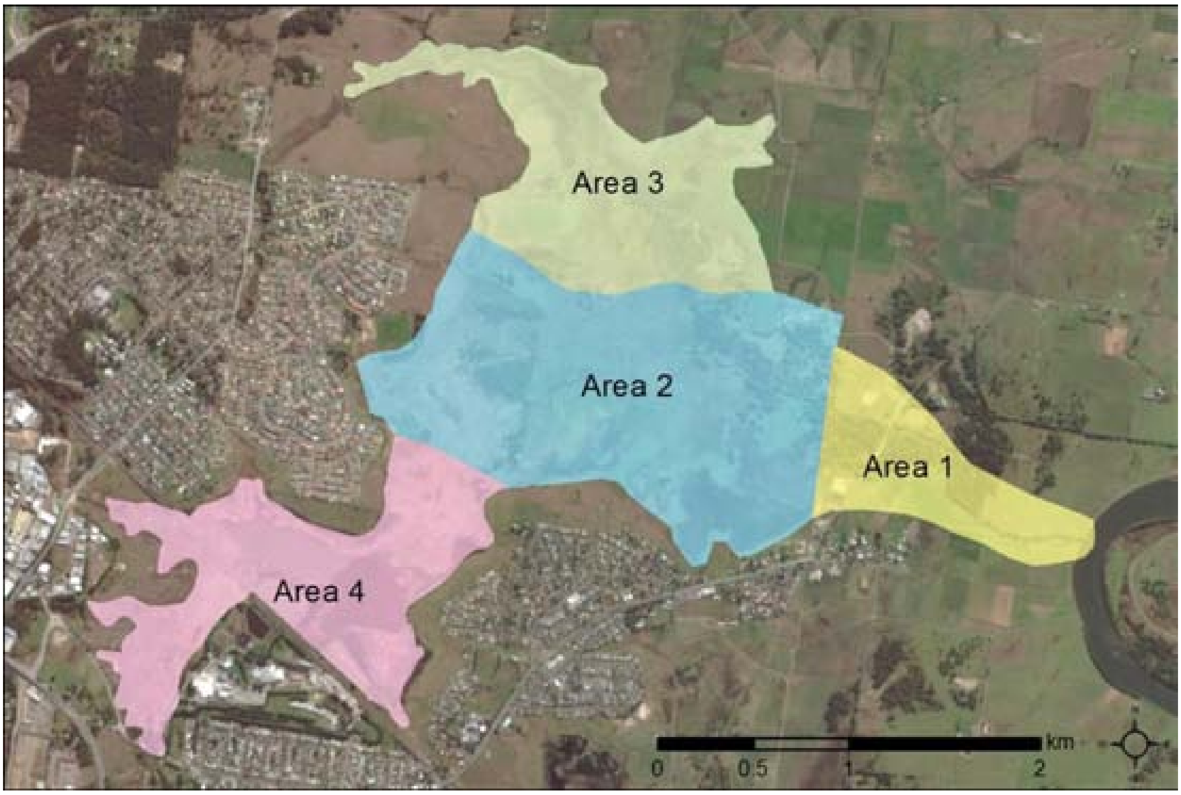

Figure E.1: Proposed management areas

Four management scenarios were investigated in detail, examining both landholder and environmental concerns:

1. **Tidal flushing of Greenways Creek:** Tidal flushing could be achieved at lower elevations (below -0.1 m AHD) with limited infrastructure, resulting in improved fish passage, improved water quality, and reduced in-channel vegetation. Further infrastructure is required to manage impacts of flushing at higher tidal elevations if existing land use is maintained.
2. **Drain cleaning:** Clearing of the in-channel vegetation in the floodplain drainage network would cost in the order of $60,000 and improve day-to-day drainage. Approvals for works

in SEPP 14 wetlands would be required and limited environmental benefits are expected. Additional costs are required to deepen and widen existing drains.

3. **Improved flood drainage:** Removal of large drainage restrictions (HWC pipeline) and increasing channel area beneath Woodberry Road would result in a slight improvement in post-flood inundation duration (~24 hours) but limited environmental benefits. Detailed flood modelling would be required and a cost-benefit analysis is recommended for this management option.
4. **Drainage of Management Area 4:** Drainage of Management Area 4 by construction of a channel through the existing vegetation/sediment blockage would reduce the residence time of licensed discharged waters from approximately 24 days to 4.5 hours, significantly altering the quality of water flowing to the Hunter River. A fringing area of approximately 66 hectares of previously inundated land would be drained. The historical wetland extent is likely to remain following drainage.

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1. Introduction

Woodberry Swamp is located on the west bank of the Hunter River, approximately 26 km upstream from the ocean entrance at Newcastle (Figure 1.1). Comprising a catchment of approximately 4,350 hectares (previously estimated to be 5,340 by Yeend (2003)), Woodberry Swamp is characterised by high surrounding hills draining to a low-lying floodplain which is comprised of protected wetlands and rural pastures (Figure 1.2). Woodberry Swamp receives inflows from Weakley's Flat, Scotch Dairy Creek and Viney Creek, as well as runoff from the fringing suburbs of Thornton, Beresfield, Woodberry and Millers Forest. A chicken processing facility at Beresfield also has a licence to discharge approximately 2.3 ML of treated effluent per day into the south-western area of the wetland. Overland flow drains through a complex network of minor and main drainage channels and hydraulic structures. Francis Greenways Creek forms the main trunk drain connecting Woodberry Swamp to the Hunter River estuary.

Woodberry Swamp was historically a large fresh to brackish backswamp, common to the Hunter region. Salinity and water depth throughout the swamp would have varied over time depending on rainfall, flood events, and tidal ingress, with some elevated areas of the swamp regularly drying out. Woodberry Swamp was connected to the Hunter estuary through a number of interconnected channels and provided a significant area of aquatic habitat and food source for juvenile aquatic species and those that prey on them.

The swamp itself covers an area of approximately 1,600 hectares (16 km^2) below an elevation of 1.5 m AHD, of which approximately 330 hectares (3.3 km^2) is zoned as SEPP 14 wetland (State Environmental Planning Policy). The majority of the swamp is privately owned, except for a 103 hectare area owned by Maitland City Council. Since European settlement the catchment has been traditionally utilised for agriculture, however large areas of catchment have undergone significant development over recent decades with a mixture of urban, rural, and industrial land zoning. The floodplain west of Woodberry Road is zoned E1-Environmental Conservation, while the floodplain east of Woodberry Road, extending to the Hunter River, is zoned R1 Primary Production with land uses including grazing (mainly cattle and horses) and lucerne cropping.

1.1 Catchment issues as identified by stakeholders

A survey in October 2015 by Hunter Local Land Services (LLS) of 16 landholders on the floodplain was undertaken to determine issues impacting landholder land-use (Appendix A). A range of issues have been highlighted, including water quality issues as well as water management/drainage concerns.

General issues raised by landholders can be summarised as:

- 88% are concerned about surface water management; and
- 100% indicated an increase in surface water and floodwater duration on their property.

Landholders raised a number of specific issues/concerns, including:

- Ongoing residential development in Thornton and the impact on runoff volumes;
- General increase in catchment wide development, both proposed and approved;
- Licensed discharge from upstream processing plant;
- Increases in flood mound construction and other filling on the floodplain and the potential impact on overland flow;
- Poor water quality in the lower reaches of Greenways Creek;
- Impacts of recent (2015) raising of Woodberry Road on floodwater drainage; and

- Overland flow from Woodberry catchment into the Scotch Creek catchment over Turners Rd.

A range of recommendations were provided by landholders, including:

- Additional higher elevation floodgates in the river levee bank to enable high floodwaters to drain faster;
- Pumping of floodwaters over the levee to increase post-flood drainage;
- Increased maintenance of drainage channels;
- Stormwater capture infrastructure in surrounding suburbs;
- Increased conveyance of Woodberry Road bridge; and
- Assessment of impact of Hunter Water pipeline and access track.

Previous studies undertaken by Lyall and Macoun (1998) and BMT WBM (2008) identified similar issues to those raised above, indicating that water management at Woodberry Swamp has been an ongoing issue.

1.2 Summary of findings from previous studies

Lyall and Macoun (1998) provided commentary on the above issues at Woodberry Swamp that are still of relevance to this study in 2015 and worth highlighting:

- Increased urbanisation of the catchment is likely to have led to changes in the volume of runoff entering the immediate receiving waterways. When considered across the entire catchment, the change in total volume is insignificant. However, land immediately adjacent to development areas is likely to be subjected to changes in the frequency and volume of nuisance flooding.

- The ability of floodplain landholders to manage and maintain their property is hindered by inputs from the catchment (nutrient and sediment load) and the limitations of wetland areas classified as SEPP-14 in relation to undertaking drainage maintenance. WRL also notes that there is a lack of co-ordinated drainage management (i.e. no formalised drainage union) across the catchment which hinders property maintenance.

- There is a community view that the on-going management and preservations of SEPP-14 wetland areas will be achieved by a do nothing approach. This area of the Hunter River floodplain has undergone ongoing degradation by external influences over many decades. WRL notes that it is unlikely that the environmental values of the SEPP-14 wetlands are the same in 2016 as they have been previously, and active management would benefit the wetlands.

- Construction of roads and pipelines intersecting the floodplain have not been constructed with sufficient attention paid to the discharge characteristics of the floodplain. Due to the flat drainage gradient across the floodplain, small changes in road elevation and culvert size and location, can alter the duration of inundation and drainage time from agricultural land, impacting its agricultural productivity.

- There appears to be a view among landholders that the drainage infrastructure was constructed to provide improved agricultural drainage. In fact, the drainage infrastructure was designed and constructed to ensure that main river floodwater (for small to medium floods only) would be prevented from entering the floodplain, and floodwaters could drain from the floodplain at the same rate as it would have done prior to the construction of the river levee banks. Any benefit gained in improved drainage of local runoff from agricultural floodplain land is incidental to the main purpose of the flood mitigation system. If an improved level of drainage service is required to meet current agricultural demands, then improvements need to be justified and funded in terms of agricultural benefit gained, rather than any perceived deficiency in performance of systems not designed to fulfil that purpose.

- Total annual runoff volume from the catchment can vary by a factor of approximately three between wet and dry years. The perception that drainage conditions have worsened may be, in part, due to this variation in rainfall and runoff from the catchment.

- Water levels in the main Hunter River are the primary control and restraint of drainage across the system. Modification and increases in the size of existing drainage control structures will have limited effect on the drainage of floodwaters. No matter how many floodgates are installed, a fundamental constraint is the lack of hydraulic gradient (i.e. the floodplain is flat) since the floodplain land elevation is only slightly above the river level.

BMT WBM (2008) assessed catchment runoff impacts on the wetland, finding that 80% of the nutrients discharged to Woodberry Swamp are sourced from one industrial licensed discharge (approved by the NSW Environment Protection Agency (EPA)). This licensed discharge provides a constant baseflow generally in excess of 2 ML/day to the wetland and limits the wetting and drying cycle that occurs in a natural wetland system. The licensed discharge provides significant nutrient loads to the wetland, promoting vegetation growth.

1.3 Aims of the study

Based on the ongoing issues surrounding drainage and water quality at Woodberry Swamp, the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia, was commissioned by the NSW Department of Primary Industries (DPI) in conjunction with Hunter Local Land Services (LLS) to investigate the hydrology of the Woodberry Swamp floodplain and catchment. Whilst the study was initially commissioned with environmental outcomes as the priority, the assessment of water quality and movement across the entire Woodberry Swamp ultimately became the primary focus of the hydrologic investigation. This was in recognition that achieving environmental improvements would be unlikely without also understanding and addressing the inter-related social issues affecting the catchment, and to document the environmental consequences of some common landholder recommendations. A timeline of the project is outlined in Appendix B.

The specific aims of this study are:

- To assess the change to catchment stormwater runoff over time due to historical, current and future levels of development in the catchment;
- To assess how surface water is conveyed over the floodplain, including identification of the constraints in the natural and constructed drainage system; and
- To assess options for changes to drainage infrastructure, considering the community and environment.

1.4 Report Outline

This report details the study findings including:

- Section 1.4 presents a brief history of Woodberry Swamp hydrology;
- Section 2 outlines available data;
- Section 3 presents results of a field investigation including detailed survey of the drainage network and monitoring results from a large flood event in early January 2016;
- Section 4 outlines the review and update of BMT WBM (2008) MUSIC rainfall runoff model;
- Section 5 presents the development and verification of a detailed 2-dimensional floodplain drainage numerical model verification of a floodplain drainage numerical model; and
- Section 6 presents recommendations for management options and scenario testing.

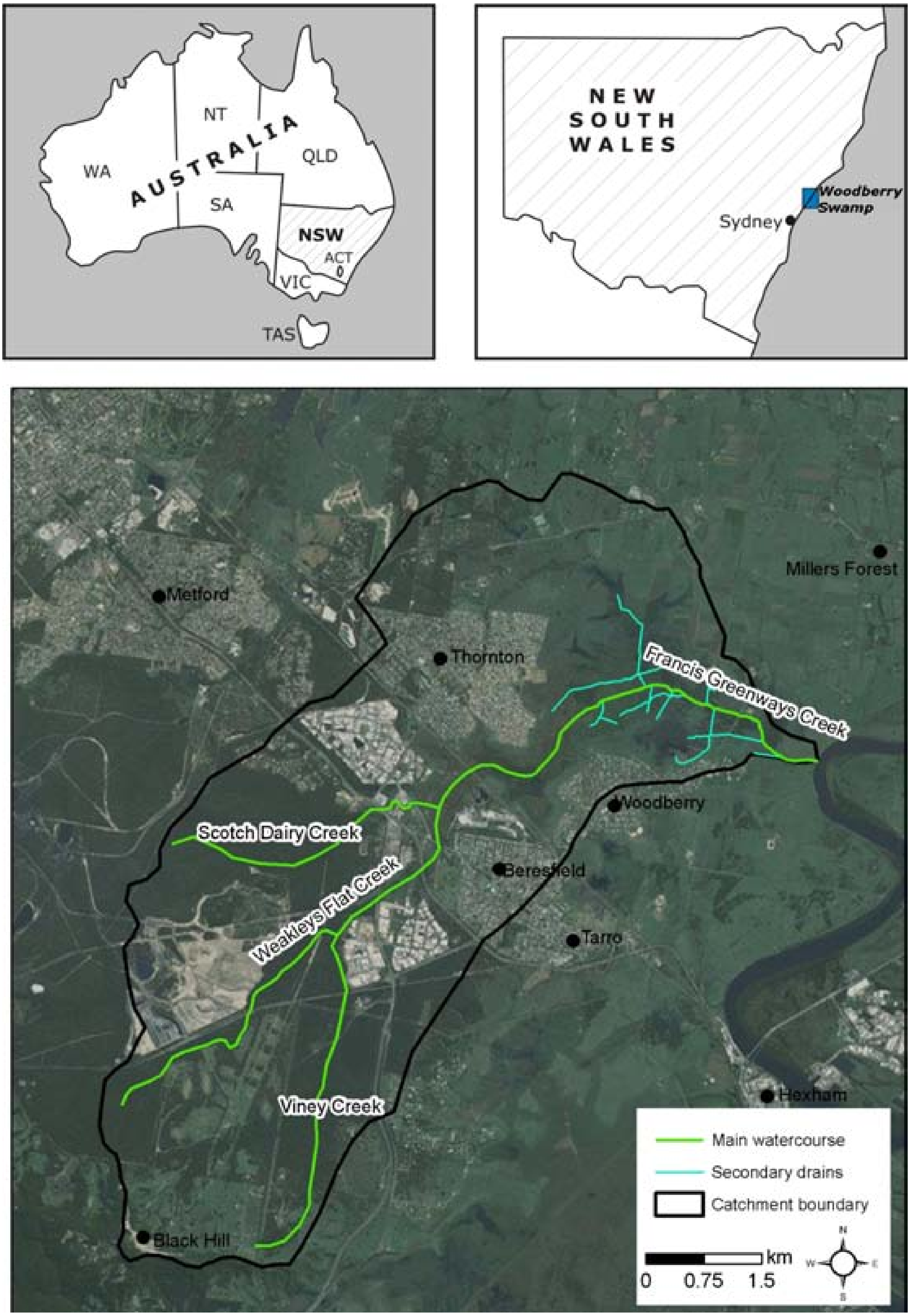


Figure 1.1: Study location and catchment drainage

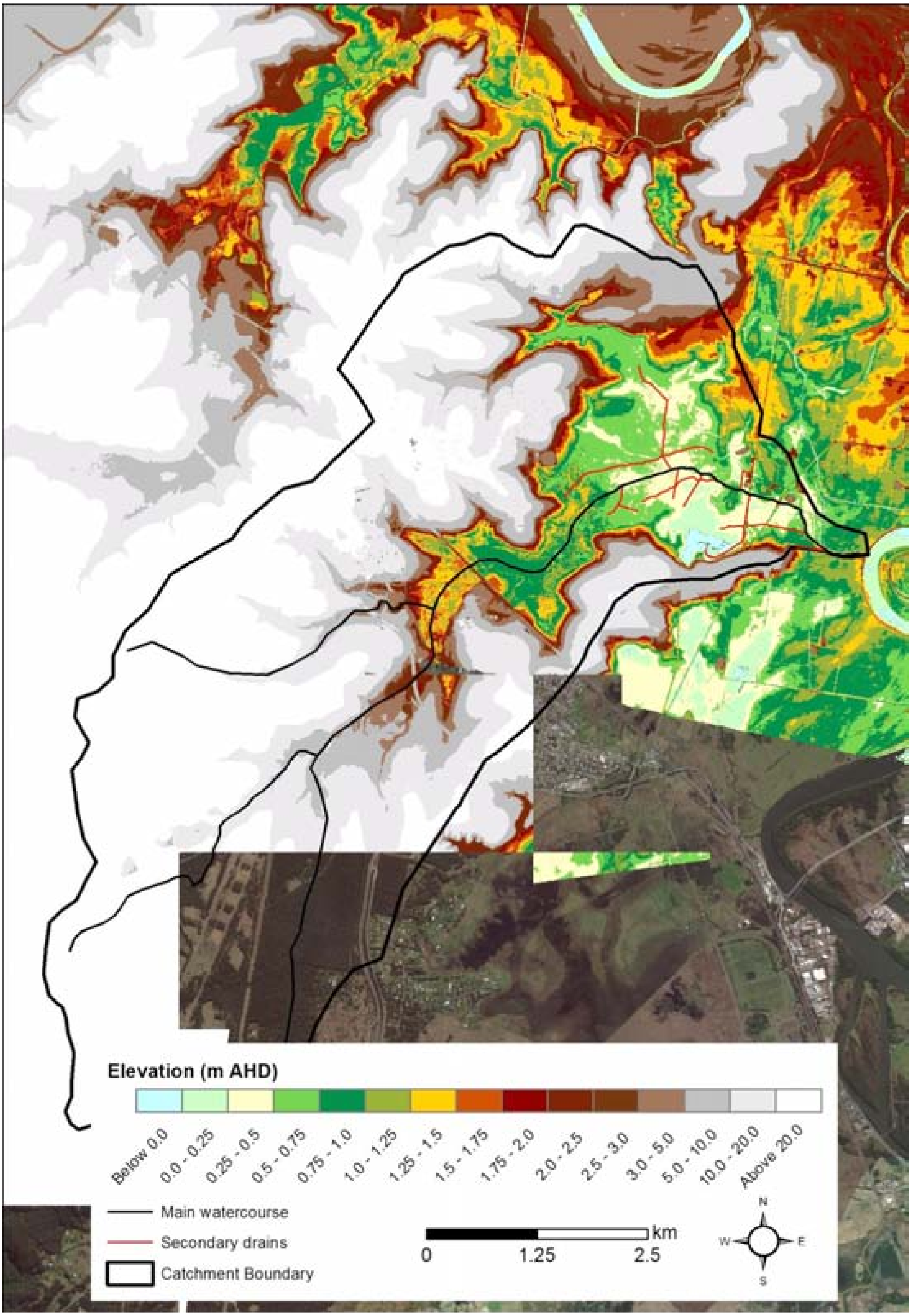


Figure 1.2: Woodberry Swamp topography (LiDAR survey date August 2008)

1.5 Drainage history

Woodberry Swamp has a long history of hydrological modification. A concise history of the floodplain in the Woodberry Swamp region was provided in the previous literature of Patterson Britton (1989) and Lyall and Macoun (1998).

In the 1800s, prior to agricultural development, the lower Hunter River floodplain was covered in brush and bushland. The river banks were stable and covered in dense riparian vegetation, mainly comprised of eucalypt and swamp oak. By 1830 much of the floodplain was utilised for agriculture, with the majority of the floodplain vegetation removed. Significant floods that occurred in the mid-19th century reportedly deposited significant volumes of sediment on the floodplain at rates exceeding the previous natural rate of siltation (Patterson Britton, 1989). Ongoing clearing of the floodplain and riverbanks resulted in channel scouring upstream of Maitland during flood events of 1879, 1890 and 1893. Subsequently, in the years preceding 1900 significant siltation of the backswamps, in the order of metres, occurred and agriculture was expanded to areas previously considered not suitable for farming.

Prior to significant flooding in the early 1950s, the period between 1910 to 1948 experienced limited major flooding. However, a major flood in 1955 destroyed much of the levee system. In 1956, the Hunter Valley Flood Mitigation Act was passed to allow implementation of an integrated system of levees and floodplain storages.

The flood control works were designed to minimise flood losses and maximise development (Connor and Hulcome, 1972, as cited in Lyall and Macoun, 1998). The scheme was not designed to provide complete protection for farming and urban areas, but aimed to limit the impacts of events in the 5 to 20 year range (i.e. small to medium level floods). Levees were constructed using on site alluvium and rarely exceeded a height of 1.5 m. Floodgates were constructed to provide drainage of areas behind the levees and limit the inflow of tidal and flood waters.

Responsibility for the flood mitigation network is currently held by the NSW Office of Environment and Heritage (OEH). This includes levees, floodgates and drains. The extent of OEH maintenance of drains extends upstream from the floodgates at varying distances across the lower Hunter River floodplain. For Greenways Creek, OEH manages the section between Woodberry Road and the Hunter River including floodgates and river levee banks. Ownership and maintenance of drainage infrastructure upstream of Woodberry Road falls under the responsibility of individual landholders. There is no drainage union representing private landholder interests at Woodberry Swamp.

The drains constructed as part of the flood mitigation program were designed to drain floodwaters from the floodplain, however they also provide a mechanism for the drainage of catchment runoff. The agricultural productivity of low-lying floodplain land is, therefore, likely to have improved after the construction of the flood mitigation infrastructure.

Comparison of catchment development and wetland extent over the past 50 years (Figures 1.3 to 1.8), shows that urbanisation has increased significantly, particularly within the northern half of the catchment. The low-lying backswamp areas of the wetland, where prolonged inundation occurs, were of similar extent to that of today, however vegetation had increased across the floodplain. Early imagery enables topography beneath existing vegetation to be visualised, with backswamp areas connected to drainage channels to improve drainage.

Wetland extent in the south-western portion of Woodberry Swamp increased between 1977 (Figure 1.4) and 1995 (Figure 1.5). No aerial imagery exists for Woodberry Swamp prior to the implementation of the Hunter Valley Flood Mitigation Act.

The clearing, draining and development of the catchment has resulted in environmental degradation of wetland habitats, alteration to natural wetting / drying cycles, loss of fisheries habitats, increases in catchment runoff volumes, a reduction in water quality due to blackwater events (i.e. low dissolved oxygen following flood events) and increased catchment loads (i.e. nutrients, sediment and other contaminants). Further, Industry & Investment NSW (I & I NSW, 2010) found that Woodberry Swamp presents a low-medium ASS risk to the lower Hunter River estuary. While the risk posed by subsoil ASS is low, the presence of surface sulfides in the permanently submerged areas in the southwest of the swamp is likely impacting on surface water quality. However, no evidence of acidic discharges from Greenways Creek has been observed.

Recent studies have recommended the Greenways Creek floodgates be opened at times of low flow to re-establish tidal flushing, improve water quality and fish passage (I & I NSW, 2010 and NSW DPI, 2012). In 2012, NSW DPI (2012) identified the floodgates at Woodberry Swamp/Greenways Creek as the seventh highest priority floodgates (out of 320 identified) within the Hunter Catchment Region, and are presently one of the highest ranked remaining priority set of floodgates in the Hunter River without an adaptive management regime.

Background Summary

- Woodberry Swamp was originally a large fresh to brackish backswamp connected to the Hunter estuary providing significant aquatic habitat.
- Flood mitigation works, including drains, floodgates and levees, were constructed following flooding in 1955.
- The flood mitigation levees were designed to protect farming and urban areas.
- Flood mitigation drains and floodgates were designed to maintain the same rate of drainage of floodplain areas that existed prior to levee construction.
- The lower reaches of Greenways Creek (downstream from Woodberry Road) are maintained by NSW Office of Environment and Heritage.
- There is no drainage union controlling maintenance of floodplain drainage upstream of Woodberry Road.
- Wetland vegetation and the extent of open water areas increased significantly between 1977 and 1995, with present day extents similar to 1995.
- Water quality and water movement have been previously highlighted as an issue for floodplain landholders.
- Adaptive management of the Hunter River floodgates has been identified as a high priority for improving water quality and fish passage.

Figure 1.3: 1965 (Maitland City Council)

Figure 1.4: 1977 (Maitland City Council)

Figure 1.5: 1995 (Maitland City Council)

Figure 1.6: 1st October 2007 (Google Earth)

Figure 1.7: 5th July 2014 (Near Map)

Figure 1.8: 5th April 2016 (Near Map)

2. Existing Data

A range of existing data and literature is available for the Woodberry Swamp area. Data which is relevant to the hydrology and water quality of the wetland area was reviewed and formed the foundation of later field investigation and numerical modelling stages of the project.

2.1 Previous studies

A number of previous studies have been undertaken at Woodberry Swamp which involved the hydrology and/or water quality of the catchment and floodplain. Previous studies which were found to be directly relevant to this investigation were:

- Catchment Management Plan: Woodberry, Morpeth-Tenambit and Millers Forrest Catchments (Gippel and Priestly, 1998);
- Catchment Management Plan: Woodberry, Morpeth-Tenambit and Millers Forrest Catchments (Lyall and Macoun, 1998);
- Woodberry Swamp Sustainable Stormwater Runoff Study (BMT WBM, 2008);
- Acid sulfate soils: Further investigations into the Lower Hunter River estuary (Woodberry, Irrawang and West Hexham Swamps) (I & I NSW, 2010); and
- Hunter River floodgate scoping document (NSW DPI, 2012).

2.2 Topography

Detailed topographic data is available from aerial LiDAR surveys in August 2008 (Figure 2.1) and July 2013 (Figure 2.2). LiDAR surveys are undertaken by flying a laser scanner over the study area, providing vertical accuracy of ±0.15 m and a horizontal accuracy of ±0.3 m. LiDAR surveys are an efficient means to obtain broad-scale topographic data, providing significant spatial coverage in comparison to conventional, labour intensive ground surveys. Due to the remote sensing method of obtaining LiDAR surveys, detection of the ground surface by the laser scanner can be hindered by dense vegetation and water. Features such as vegetation filled drainage channels are poorly represented in the LiDAR datasets. The ground surface in areas featuring dense stands of phragmites are misrepresented, with the top of the vegetation measured rather than the ground surface elevation. Subsequently, care must be taken when utilising LiDAR survey datasets in swamp and wetland environments.

The two LiDAR datasets between 2008 and 2013 are useful in determining areas of change, such as additional flood mound construction and the resurfacing of Woodberry Road. Comparison of the two datasets also indicates that the 2013 survey measured generally higher elevations across Woodberry Swamp. This is likely due to increased floodplain vegetation heights. Therefore, the 2008 survey lacks details of new floodplain features such as flood mounds and new developments, however the broad floodplain elevation measurements are a better representation of the actual ground elevations.

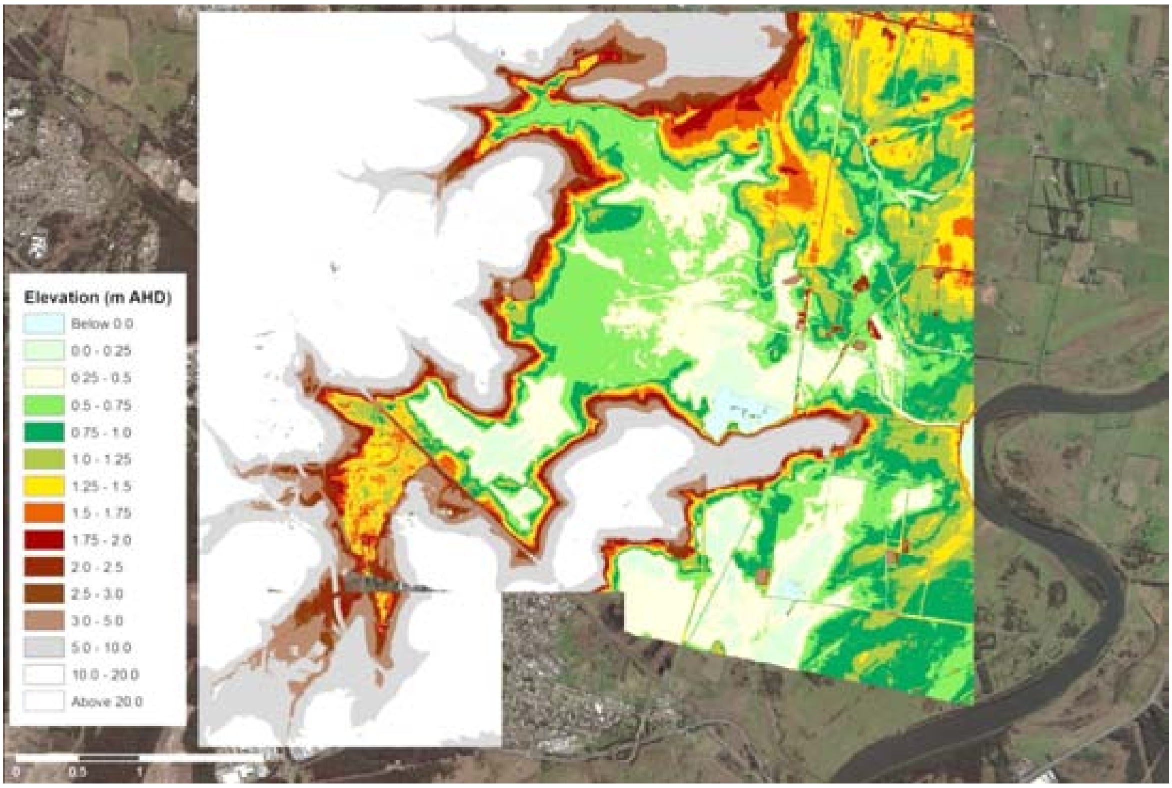


Figure 2.1: August 2008 Aerial LiDAR survey (Background image: ESRI)

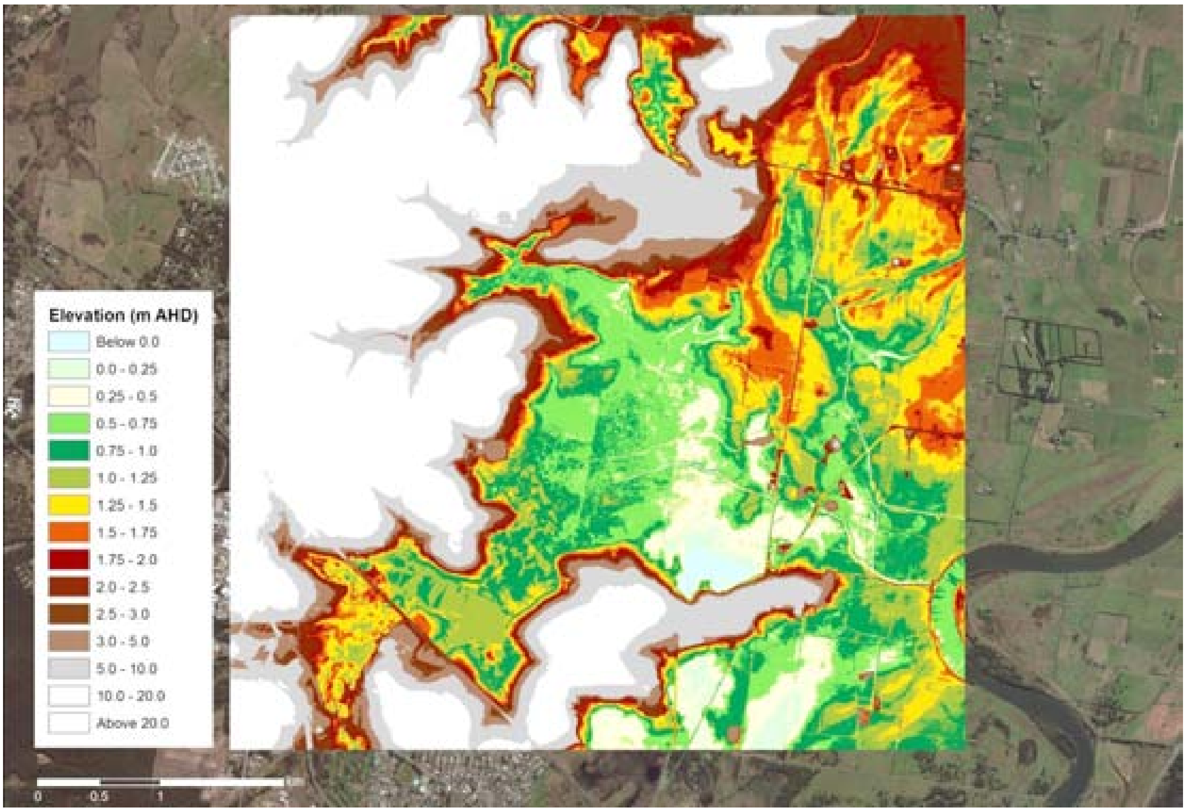


Figure 2.2: July 2013 Aerial LiDAR survey (Background image: ESRI)

2.3 Soils

Soil mapping of the area was undertaken by Matthei (1995) of the Department of Land and Water Conservation. The Woodberry Catchment features high hills draining to a low-lying floodplain, with a mixture of bushland, rural, industrial and urban land uses. As such, the soils of the catchment vary. The upper slopes feature erosional (water sculpted) and colluvial (mass movement) landscapes, while the floodplain area of the catchment features alluvial (river deposits) and swamp (waterlogged) landscapes. The predominant soil landscape of the lower catchment is classified as residual landscapes, where deep soils have formed from in-situ weathering of parent materials and typically have a level to undulating topography.

Acid sulfate soils in coastal NSW are predominantly located in low-lying backswamp areas, adjacent to estuaries and coastal environments. Acid sulfate soils are soils which have a high sulfur content which, when exposed to the atmosphere, can result in acidified surface and ground water. The resulting acidified waters often contain high concentrations of aluminium and iron. When located near the surface, acid sulfate soils can cause acidification of drain and creek waters and can result in bare, un-vegetated areas which are scalded from acidification. Exposing, or excavating, acid sulfate soils requires approval and appropriate treatment measures.

State wide acid sulfate soil risk mapping, based primarily on elevation, indicates potential acid sulfate soils at Woodberry Swamp (Figure 2.3). Recent (I & I NSW, 2010) investigation of acid sulfate soils across the lower Hunter floodplain measured limited acid risk at Woodberry Swamp (Figure 2.3). Surface acidity was found to be the main risk, with oxidised surface sulphides observed at sites W1 and W6. Actual acid sulfate soil (AASS) was found at soil profile W6 within the top 1 metre of profile, and a moderate potential acid sulfate soil (PASS) was found 1.9 m below the surface at site W5 (approximate elevation of – 1.3 m AHD).

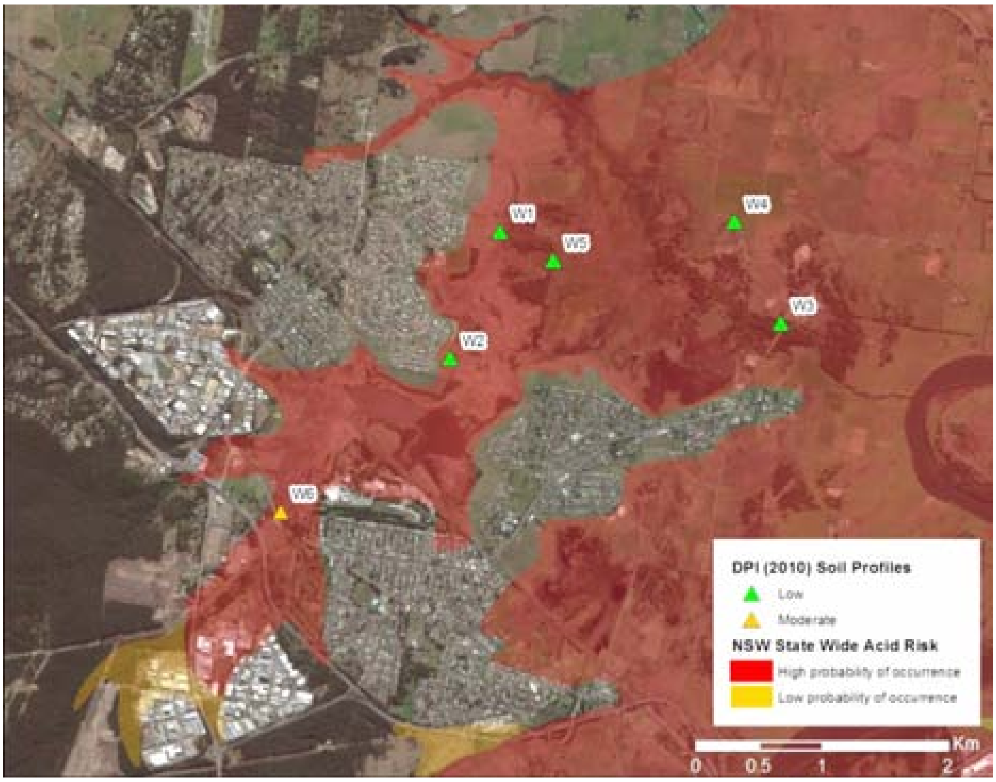


Figure 2.3: Acid risk at Woodberry Swamp (Background image: ESRI)

Surface sulphides are likely to impact local surface water quality at selected locations during dry periods, but are likely to be diluted during wet weather events under current surface water regime. I & I NSW (2010) noted that drainage of surface waters at site W6 could result in accumulation of surface sulphides and may result in scalding of the surface, whereby vegetation does not grow. This may also result in acidic runoff from the area near site W6. Acid sulfate soils pose limited risk to overall water quality across the wider Woodberry Swamp floodplain. However, these soil profiles indicate that acid sulfate soils should be considered when excavating soils and/or altering surface water drainage at Woodberry Swamp.

2.4 Water quality

Water quality has been highlighted as an issue at Woodberry Swamp (I & I NSW, 2010; NSW DPI, 2012). However, limited historical water quality data for the Woodberry Swamp catchment has been identified. Water quality at Woodberry Swamp is a product of:

- Diffuse catchment inputs (nutrient loads and runoff volume);
- Licensed discharge (nutrient load and discharge volume);
- Vegetation decay processes; and
- Groundwater – surface water interactions.

An EPA (NSW Environmental Protection Agency) licensed industrial discharge (EPA license number 1329) located at the south-western extent of the floodplain discharges daily volumes up to 2.3 ML/day, with annual total phosphorous (TP) loads of 30,000 kg/year, annual total nitrogen (TN) loads of 130,000 kg/year, and annual total suspended solids (TSS) loads of 33,000 kg/year (from averaged 2014 and 2015 discharge data) (Baiada Poultry Pty Ltd, 2016).

Water quality monitoring at the downstream extent of Greenways Creek during 2015 indicated relatively good water quality (Table 2.1). Note that no monitoring of nutrient concentrations and nutrient flux (discharge volume x concentration) is undertaken downstream of the licensed discharge location. Monitoring was undertaken approximately every 2 months by Les Armstrong of the Kooragang Wetland Rehabilitation Project from April 2015 (on-going) between the Greenways Creek floodgates, and the Hunter Water Pipeline, located approximately 1,600 m upstream. Dissolved oxygen concentrations were above hypoxic levels (i.e. > 2 ppm) and pH was observed to be near neutral. Low electrical conductivity (an indicator of salt water) in Greenways Creek indicates that the floodgates are functioning effectively, limiting tidal intrusion.

Table 2.1: Water quality in lower Greenways Creek during period 27/4 to 15/12/2015 (Source: Les Armstrong)

Location	Statistic	Temp (°C)	pH	EC (mS/cm)	Turbidity (NTU)	DO (ppm)	DO (%)	TDS (mg/L)
D/S Floodgates	Median	18.4	7.8	1.4	20.6	8.8	95.6	0.9
	Min	10.9	7.2	1	1.2	5.8	75	0.6
	Max	24.6	8.3	15.9	47	10.2	103.9	9.3
U/S Floodgates	Median	17.7	7.9	0.9	18.2	8.8	88.8	0.6
	Min	11.1	7.4	0.5	3.6	5.7	67.3	0.3
	Max	24.7	8.5	11.6	34.9	10.2	101.3	7.2
Halfway	Median	18.1	7.8	0.9	15.3	7.5	75.2	0.6
	Min	10.8	7	0	0.6	5.6	62.9	0
	Max	25.5	8.1	6.7	151	8.8	109.6	4.2
Bridge	Median	18	7.6	0.5	19.3	5.9	64	0.4
	Min	11.4	7.2	0.1	1.3	3.4	36.7	0.1
	Max	23.7	8.1	3.8	64	8.9	96.5	2.4
Pipeline	One off	23	6.6	3.2	46.4	6.8	81.5	2

This monitoring provides a useful indication of day to day water quality parameters, however nutrient monitoring is not undertaken. Furthermore, water quality following flood events is not targeted. Poor water quality events, such as low dissolved oxygen discharge (termed 'blackwater') and acid sulfate soils discharges, typically occur in the days to weeks following a flood event or periods of prolonged floodplain inundation. Such events are unlikely to be measured during a routine monitoring program such as the one undertaken at Greenways Creek.

2.5 Protected wetlands (SEPP-14)

Large areas of the low-lying backswamp at Woodberry Swamp are recognised as wetlands of regional significance. Approximately 330 hectares is classified as SEPP 14 wetlands under the NSW State Environmental Planning Policy No. 14 (Figure 2.4).

This policy applies to wetlands on the coastal fringe of NSW with the aim of protecting wetlands from infilling, clearing, draining and levee construction. Where such activities are proposed an Environmental Impact Statement (EIS) is required to be prepared whereby the full impact of the proposed works to hydrology, flora and fauna are assessed.

Similarly, works that propose the restoration of coastal wetlands through the clearing, infilling, modification or removal of drains, structures and levees also require an EIS to be completed. An EIS enables the impacts of additional works or remediation to be considered and impacts on not only the immediate area, but adjacent stakeholders, to be assessed.

Figure 2.4: SEPP 14 Wetlands (Background image: ESRI)

Existing Data Summary

- Detailed topographic survey data is available, but vegetation reduces accuracy on the floodplain. There is limited information of drainage channels and hydraulic structures.
- There is no survey data of areas which are currently underwater or beneath dense vegetation.
- Acid sulfate soils appear to be a low risk, however any excavations should be tested for the presence of acidic soils.
- Recent water quality in Greenways Creek indicates reasonable dry period water quality.
- No water quality data is available following rainfall events.
- There are significant baseflow volumes and nutrient loads from an upstream licensed discharge.
- There is no monitoring of nutrients concentrations downstream of the licensed discharge.
- Large areas of Woodberry Swamp are listed as SEPP-14 wetlands. Any on-ground works which impact the SEPP-14 areas require prior assessment and approval.
- No water level data has been collected in the Woodberry Swamp catchment.
- There is no record of catchment runoff volume or runoff quality.

3. Field Investigation

Based on the review of available data provided in Section 2, a detailed field investigation was undertaken to survey floodplain topography and drainage infrastructure. Extended water level data (~3 months) and spot water quality were also targeted. Field investigations were undertaken over four (4) non-consecutive days.

- 3rd and 4th December 2015: Surveys of channel bathymetry, floodplain topography and structures were undertaken, water level loggers were deployed and water quality monitored.
- 22nd February 2016: Retrieved loggers and additional investigations of a large stand of phragmites separating the open water at the south-western extent of the floodplain from the remaining drainage network.
- 6th April 2016: Additional survey of the north-western extent of floodplain topography and drainage channels.

3.1 Survey

The drains, structures and topography of Woodberry Swamp were surveyed for this project. Drain cross-section locations and floodplain topography survey locations are shown in Figure 3.1. Identified structures are presented in Figure 3.2 and details outlined in Table 3.1. Selected images of the floodplain during the survey are presented in Appendix A.

Greenways Creek forms the central drainage channel, conveying flows from the central inner floodplain/wetland area, to the Hunter River. The conveyance of Greenways Creek varies, with a wide, deep, clear channel between the floodgates and Woodberry Road, with channel width decreasing and in-channel vegetation increasing upstream of Woodberry Road. At the time of survey, all drains upstream of the Hunter Water pipeline were choked with vegetation, particularly water hyacinth. Large areas of the south-western extent of the floodplain were observed to be covered in dense, tall stands of phragmites.

Although the drainage channels provide some hydraulic gradient from the floodplain to the Hunter River, in comparison to tidal water levels in Hunter River, main drain elevations are typically below the elevation of all but the lowest of the low tides. Many of the lowest lying backswamp areas were measured to be below mean sea level (below 0 m AHD), and are poorly connected to drainage channels which feature channel invert elevations higher than that of the backswamp. Several drainage restrictions and blockages were identified (Figure 3.3). During flood events, river levels control overall drainage of Woodberry Swamp.

The north-western backswamp (near Thornton) has historically been a wetland area, indicated by stable wetland vegetation extents in historical aerial imagery (Figure 1.3 and Figure 1.4). Although the extent of long-term wetland area and inundation has varied little since 1965, anecdotal evidence suggests that the areas remains wetter for longer than during the mid-20th century. Backswamp elevations in this area are typically below +0.1 m AHD, with areas of open water surveyed to be below – 0.1 m AHD. The drainage channels conveying flow to the south from this area were surveyed to have invert elevations of approximately -0.1 to + 0.2 m AHD, and dense vegetation approximately 1 m high.

The south-western area of the floodplain is characterised by a large open water area, fringed by water hyacinth and phragmites. A dense plug of sediment and phragmites limits drainage of the open water area and maintains water levels above +0.8 m AHD. A schematic is presented in Figure 3.4. This area historically featured a backswamp area with wetland vegetation and was connected to Greenways Creek for improved drainage. Since 1977, however, (Figure 1.4), drainage of this area has been restricted due to vegetation and the area of inundation increased to a large area of permanent open water. This is likely due to increased vegetation growth stimulated by the nutrient load and daily flow provided by the licensed discharge located just upstream of the railway at Beresfield, in addition to catchment runoff.

The central section of Woodberry Swamp features generally higher elevation land than the backswamp areas, approximately +0.4 m AHD, with 1.5 m deep by 5 m wide drainage channels dissecting the floodplain, the largest being Greenways Creek. A range of small culvert structures provide access across the drains. Some culvert structures were observed to be collapsed (Figure 3.5 and Figure 3.6). A long-section of the drainage channel network (Figure 3.7 and Figure 3.8) show that the main drainage channel provides suitable depth in comparison to receiving water levels in the Hunter River.

The eastern section of the catchment, directly adjacent to the Hunter River, is generally of higher elevation topography and is disconnected from the central floodplain area by the Hunter Water pipeline and Woodberry Road. As this section of Greenways Creek is maintained by NSW OEH, drainage is efficient, with water levels controlled by Hunter River water levels. During flood events, the flat topography of the wider Hunter River floodplain results in some connectivity between Greenways Creek and the adjacent catchments of Scotch Creek and Tarro Swamp catchments.

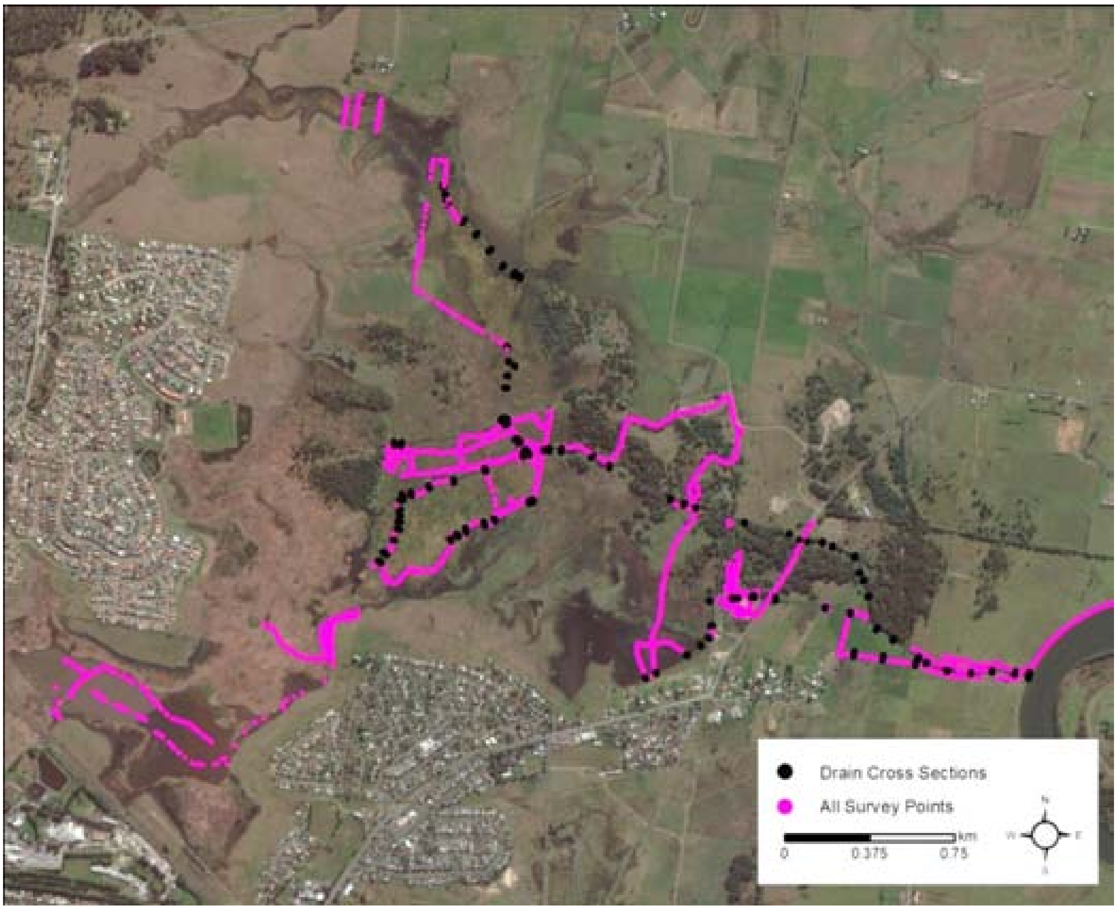


Figure 3.1: Survey locations (Background image: ESRI)

Figure 3.2: Key structure location and type (Background image: ESRI)

Table 3.1: Key hydraulic structures

ID	Easting	Northing	Shape	Invert	Length	Culverts	Width/ Diameter	Height (from invert)	Weir crest (m AHD)	Condition
1	377738	6371360	Rectangular	-0.85	14.5	6	2.1	2.1	2.4	Good
2	377055	6371611	Collapsed						-0.45	Collapsed
3	376983	6371627	Circular	0.1	5	1	1.5		1.30	Good
4	376893	6371645	Circular	-0.25	5	2	1.2		1.00	Good
5	376629	6371698	Circular	0	20	3	1.1		1.50	Fair
6	376771	6371947	Bridge	-1.39	10	1	3.9		2.70	Good
7	376454	6372030	Circular	-0.5	5	5	0.95		0.70	Fair
8	376483	6371693	Circular	-0.22	4	1	0.5		0.70	Good
9	376432	6371689	Circular	0	5	2	0.38		0.46	Fair
10	376398	6371689	Circular	0.2	5	4	0.9		1.20	Poor
11	375515	6372388	Circular	-0.3	5	1	0.75		0.50	Good
12	375520	6372308	Circular	-0.55	5	1	0.75		0.35	Good
13	376091	6371345	Circular	-0.35	3	1	0.5		0.30	Fair
14	375439	6372463	Circular	-0.2	5	1	0.75		0.50	Fair
15	375047	6372155	Collapsed	0.5		1			0.50	Collapsed
16	376384	6371546	Circular	0.4	5	4	0.5		0.93	Values estimated
17	376424	6371867	Circular	0.52	5	4	0.5		0.93	Poor
18	376470	6372273	Bridge	0	5				2.10	Values estimated
19	375920	6372277	Bridge	-0.9				1	0.50	Good
20	376306	6372094	Bridge	-0.9	3			1.5	0.75	Fair
21	377071	6372308	Circular							Values estimated
22	373319	6371198	Rectangular	-1	20	1	14	3.1		Values estimated
23	373173	6371344	Rectangular	-1	17	1	14	3.1		Values estimated

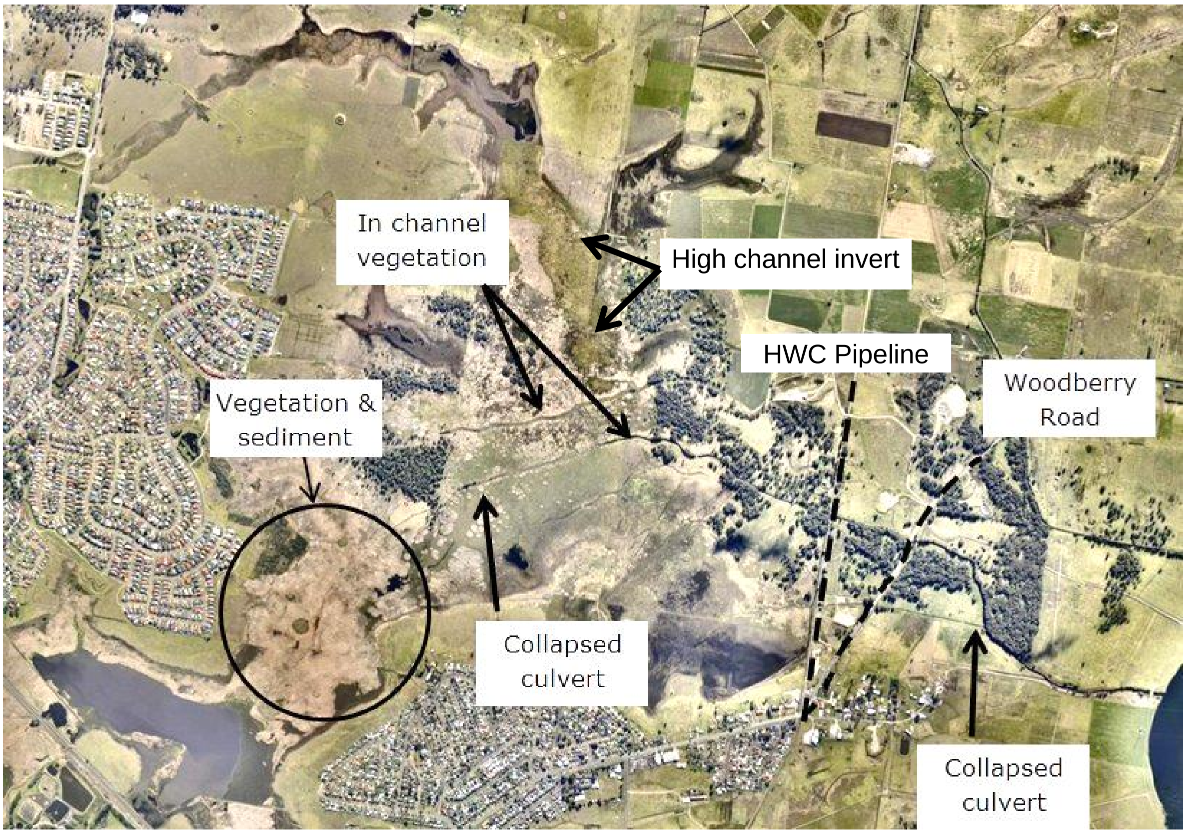


Figure 3.3: Identified drainage restrictions (Background image: Near Map)

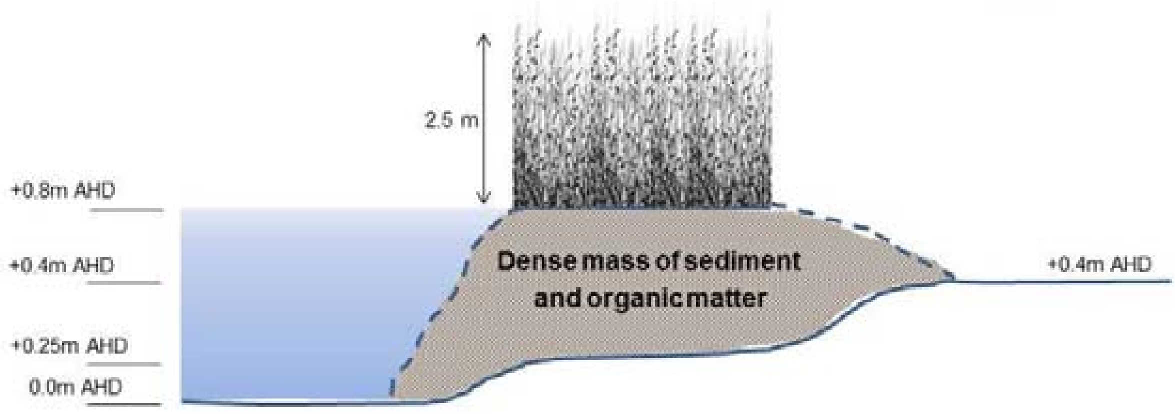


Figure 3.4: Schematic of dense phragmites/sediment limiting drainage of open water area

Figure 3.5: Collapsed culvert in the middle of the floodplain (Background image: Near Map)

Figure 3.6: Collapsed culvert on side drainage channel, downstream of Woodberry Road

Figure 3.7: Alignment of channel long-section presented in Figure 3.8 (Background image: Near Map)

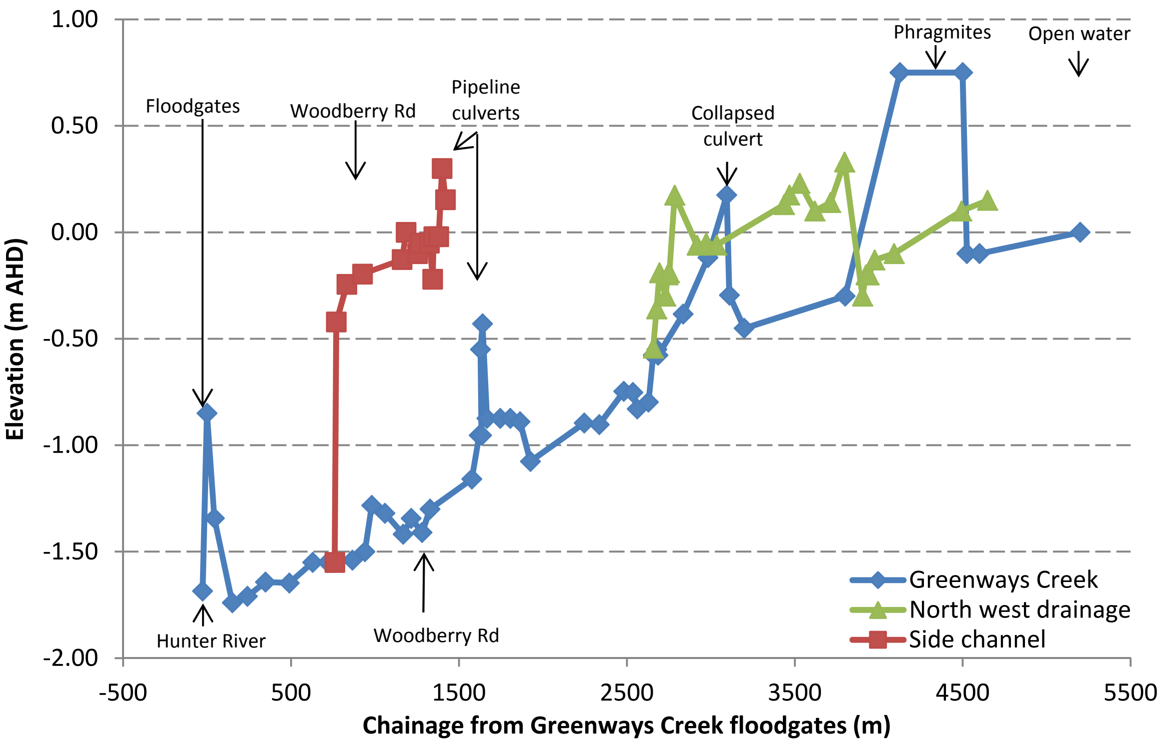


Figure 3.8: Long-section of drainage channel thalweg (minimum elevation) with distance from floodgates at Hunter River

3.2 Cross section comparison 2006 – 2015

Flood mitigation assets managed by NSW Office of Environment and Heritage (OEH) were surveyed in 2006. All drains, levees and structures were surveyed including the lower reaches of Greenways Creek (Figure 3.9). Comparisons of the drain survey undertaken as a part of this study in December 2015 and the previous OEH 2006 survey indicate that the conveyance of the creek has not changed over the previous decade (Figure 3.10, Figure 3.11 and Figure 3.12).

The cross-section profiles vary slightly due to changes in vegetation and sedimentation, however the general shape and overall invert indicate that infilling from sedimentation is not an issue within lower reaches of Greenways Creek. It is likely that during flood events some sediment from catchment runoff is stored on the floodplain and in the floodplain drainage network. The remainder is likely discharged into the Hunter River.

Figure 3.9: Greenways Creek survey locations WRL 2015 and OEH 2006 (Background image: ESRI)

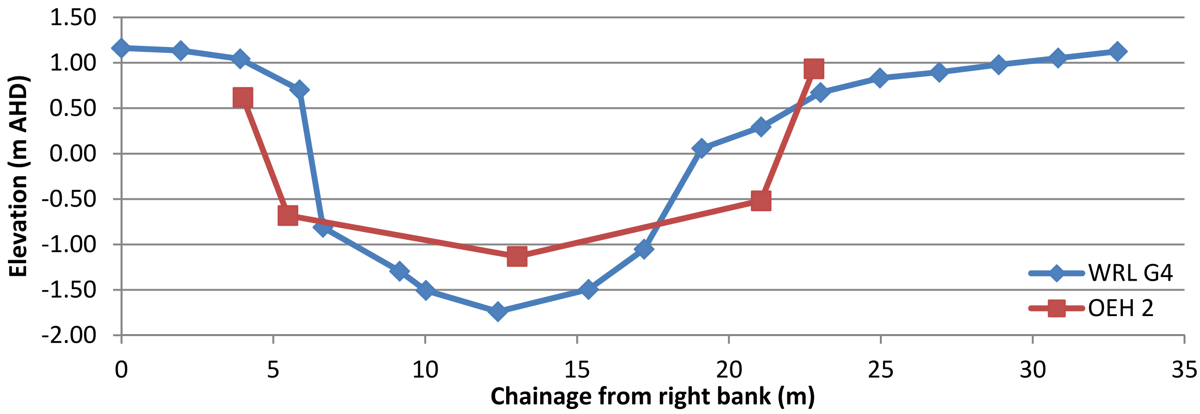


Figure 3.10: Example comparison of Greenways Creek - cross-section G4

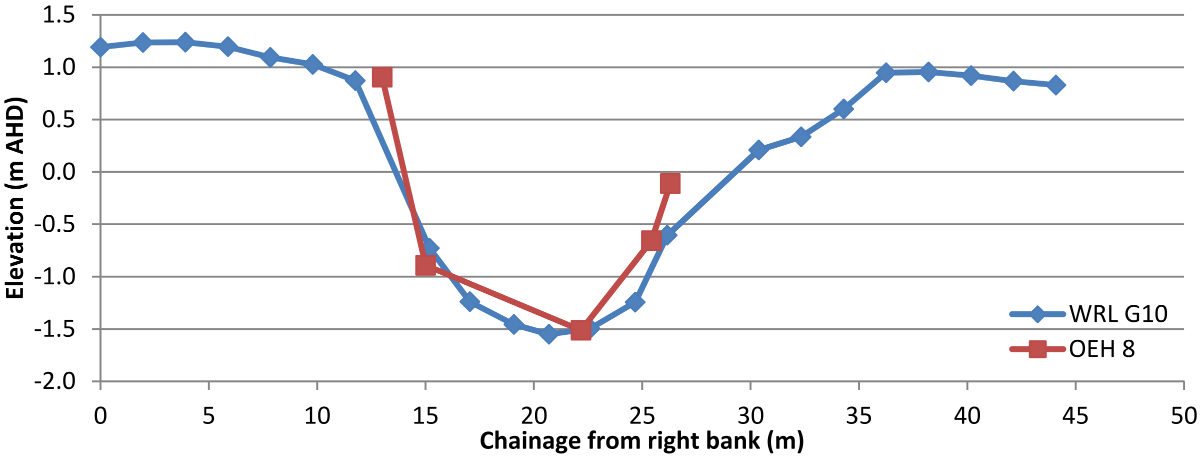


Figure 3.11: Example comparison of Greenways Creek – cross-section G10

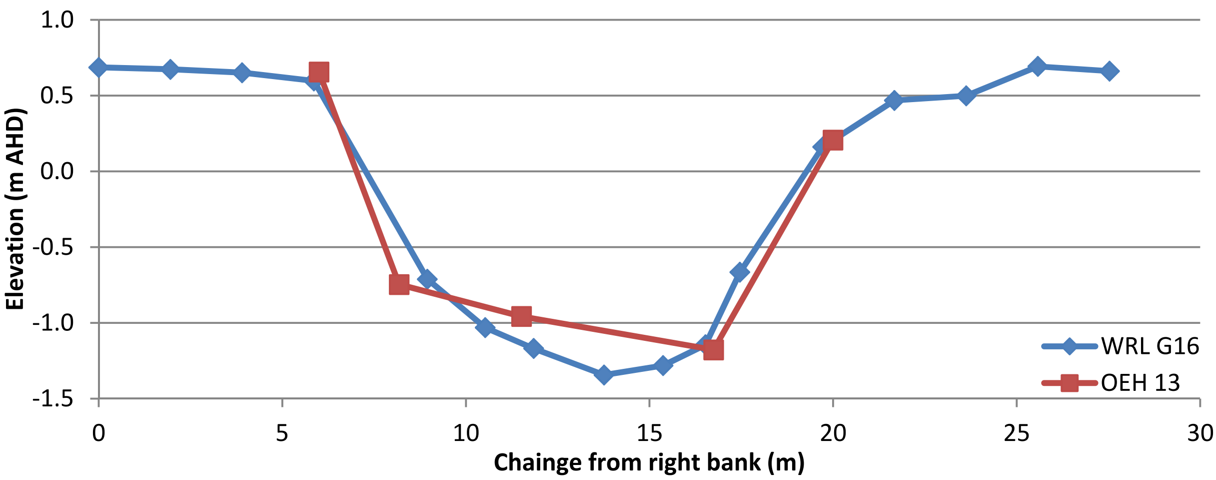


Figure 3.12: Example comparison of Greenways Creek - cross-section G16

3.3 Water level monitoring (3rd Dec 2015 – 23rd Feb 2016)

Water level loggers were installed at four (4) locations across Woodberry Swamp on 3rd December 2015 (Figure 3.13).

In early January 2016, a significant catchment rainfall event occurred with approximately 266 mm of rainfall over a four day period, with approximately 195 mm occurring over a 21 hour period between 5th – 6th January (Figure 3.14). Based on design Intensity-Frequency-Duration (IFD) rainfall curves this has an annual exceedance probability (AEP) of approximately 6% for the Woodberry region. This is equivalent to a 1 in 16 year rainfall event for the Woodberry area (BoM, 2016). An additional rainfall of 80 mm occurring 10 days following the large rainfall event resulted in an increase in water levels on the floodplain. Water levels in Woodberry Swamp were a product of in-catchment rainfall only. River levels were not observed to exceed levee bank elevations in the Woodberry area.

Capturing such an event within the timeframe of the study, with water level loggers deployed and data successfully captured, provides a rare and fortuitous opportunity to assess water level response to large catchment inflows and subsequent drainage. Inference to overland flow, drainage restrictions and connectivity can be deduced from the water level data.

Analysis of water levels before and after the rainfall event (Figure 3.15) shows that the open water area at logger Location 4 is permanently elevated at approximately + 0.9 m AHD. Water levels at other monitoring locations during dry periods were observed to be low, between – 0.5 m and 0 m AHD. This indicates a significant drainage blockage between Locations 3 and 4. Surveying of floodplain topography and drainage connection showed that a large stand of phragmites, organic matter and sediment, form a blockage downstream of logger Location 4. This blockage, in conjunction with a permanent inflow from the licensed discharge, maintains an elevated water level in the permanent open water area in the south-western extent of the wetland.

Water levels in the main Hunter River (logger Location 1) were observed to peak after water levels in the upstream areas of Woodberry Swamp peaked (logger Location 4). Peak river levels did not exceed the elevation of the levee bank adjacent to the Greenways Creek floodgates. Hunter River water levels were observed to return to regular tidal levels by 14th January. Salinity in the river was also observed to be flushed from the receiving water due to the rainfall event (Figure 3.16). Salinity was not observed to return until February.

During the flood event, water levels in the upstream extents of the wetland were observed to reach a peak elevation of 2.07 m AHD. Peak water levels were observed to be of a short duration. A comparison of all four water level time series, shows that generally uniform water levels at all locations occurred on the 8th January, after river water levels peaked on the 7th January. This indicates that the floodplain was completely inundated to an elevation of 1.65 m AHD, an approximate volume of 8,400 ML. The overall drainage of the floodplain was generally controlled by levels in the Hunter River, however water levels at logger Locations 3 and 4 drained at a slower rate than Logger location 2.

A gradient between logger Locations 3 and 4 was observed. This indicates that there is headloss between these locations during drainage, likely due to high overland friction caused by dense floodplain vegetation. During drainage, the gradient of receding water levels is similar between locations 3 and 4 indicating that, when fully submerged, drainage of the wider floodplain is controlled by features downstream of Location 3.

Water levels at logger Location 3 showed a limited tidal signal when draining following the flood event, in comparison with downstream water levels at logger Location 2 (which was controlled by river water levels). The difference in receding water level gradients between logger Locations 2 and 3 indicates that the drainage between these locations is limited during flood events, either by the Hunter Water pipeline, or Woodberry Road, or both.

Anecdotal evidence from a nearby resident in Millers Forest indicates that the neighbouring Scotch Creek catchment recedes faster than that of Woodberry Swamp, with water flowing over Turners Road (to the immediate west of Woodberry Road) in the days following the peak of the rainfall event. Recent imagery from Google Earth, taken 5 days after the rainfall event, show Turners Road underwater and connection between Scotch Creek and Greenways Creek downstream of Woodberry Road (Figure 3.17). It is difficult to determine the magnitude of exchange of floodwaters between Scotch Creek and Greenways Creek without concurrent water level measurement in both waterways.

Figure 3.13: Water level logger locations (Background image: ESRI)

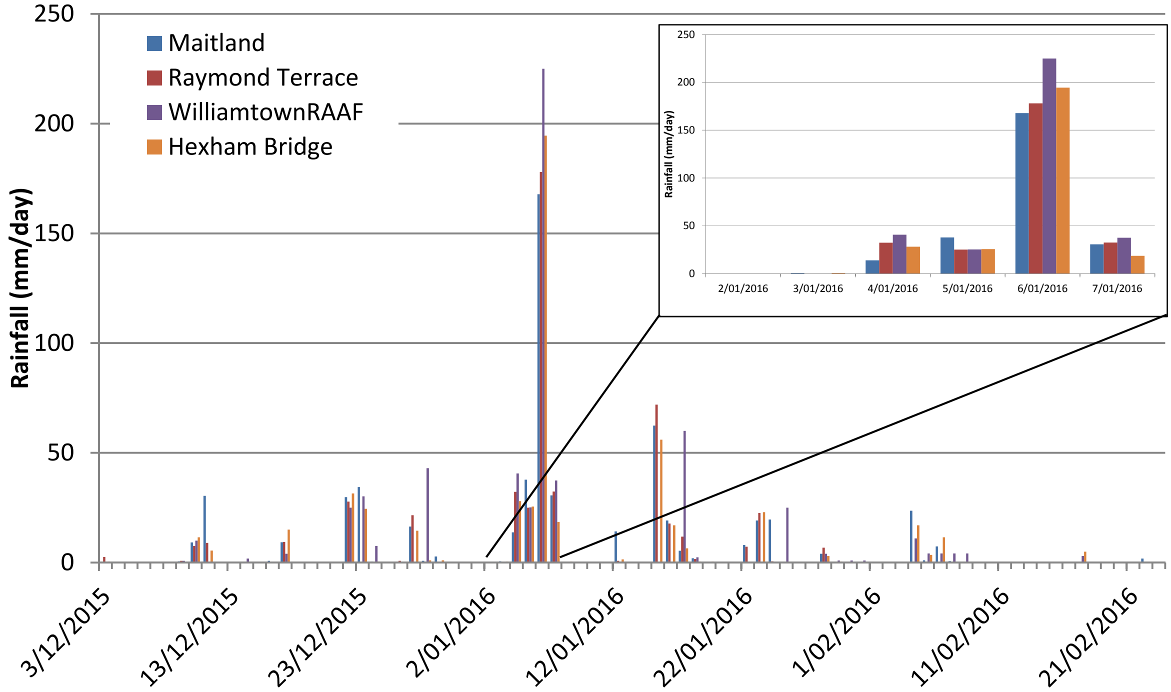


Figure 3.14: Daily rainfall at nearby locations during 3/12/2015 to 22/2/2016

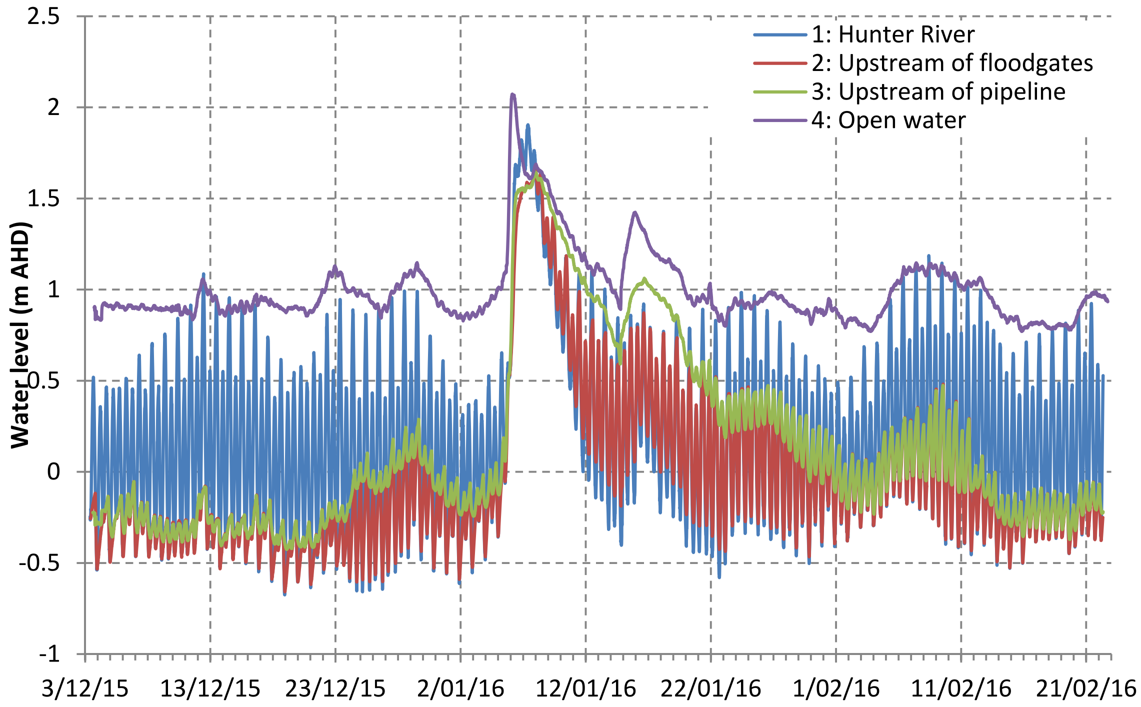


Figure 3.15: Water level during 3/12/2015 to 22/2/2016

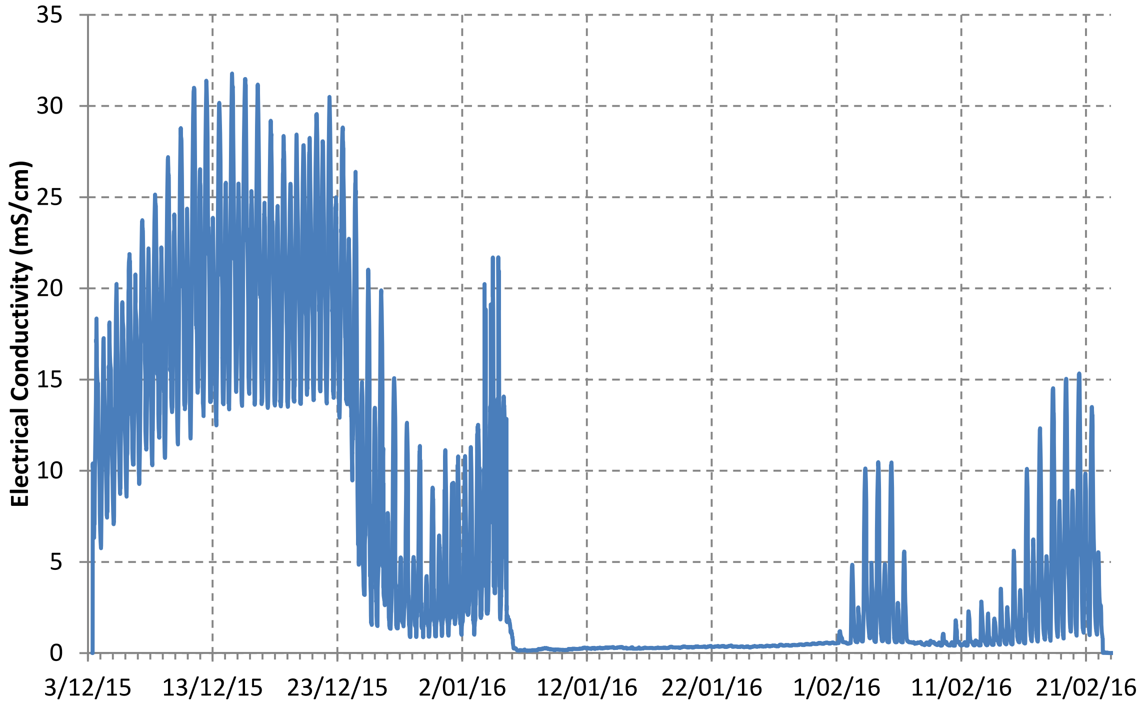


Figure 3.16: Hunter River (Location 1) electrical conductivity (ocean EC ~ 55 mS/cm)

Figure 3.17: Aerial image of January 2016 flood (10th January 2016, Google Earth)

3.4 Water quality (3rd December 2015)

Water quality during the field investigation for this study on 3rd December 2015 was measured using a YSI EXO2 multi-parameter water quality sonde (Figure 3.18). Acidity was observed to be near neutral pH. Electrical conductivity (i.e. salinity) was generally fresh, with higher conductivity measured near the floodgates. Dissolved oxygen (DO) was measured to be low at the downstream extent of Greenways Creek with DO concentrations below 2 mg/L, the concentration at which water becomes hypoxic to fish. DO concentrations in the open water backswamp areas were measured to be higher. Regular flushing of Greenways Creek would result in improved water quality including higher dissolved oxygen concentration, and connectively to the wider Hunter River estuary would benefit fisheries.

Figure 3.18: Water quality during field investigation (3rd Dec 2015) (Background image: ESRI)

Field Investigation Summary

- The drainage network upstream of the Hunter Water pipeline contains significant in-channel vegetation.
- Drains connected to low-lying backswamp areas were found to be higher than the area being drained (in some locations).
- Floodplain topography is very flat, with drainage generally controlled by river water levels.
- Two collapsed structures (culverts) were observed, which may limit drainage when water levels are in-drain.
- Drainage of the wider floodplain following flood events is limited by the Hunter Water pipeline, or Woodberry Road, or both.
- Drainage of the open water area in the south-western extent of Woodberry Swamp is blocked by an area of phragmites, organic matter and sediment resulting in permanently elevated water levels of approximately + 0.9 m AHD.
- Floodgates do not limit drainage.
- Some overland connection between Scotch Creek and Greenways Creek is likely during flood events, however the magnitude of flow between the two waterways is unknown.

4. Catchment Development and Runoff

4.1 Introduction

Woodberry Swamp receives flow inputs from the surrounding catchment. The main inputs to the swamp are:

- Runoff from the catchment;
- Licensed discharge;
- Groundwater; and
- Direct rainfall.

These contributions occur over different time scales, with some processes easier to quantify than others. The contribution from groundwater, and the interaction between surface and ground waters is difficult to quantify, however the remaining inputs are more easily estimated. Licensed discharge contributions from a poultry processing plant at Beresfield provides daily measurement of flow, and fortnightly monitoring of quality. Rainfall is measured at nearby locations, the closest being Hexham Bridge and Maitland. Contribution of volume and quality due to rainfall-runoff on the catchment can be estimated based on established hydrological models of the Woodberry Swamp catchment.

BMT WBM (2008) completed a detailed assessment of catchment runoff and urban stormwater contribution to water volumes and quality in Woodberry Swamp. The recommendations provided by BMT WBM (2008) guided Maitland City Council in the design of urban storm water management infrastructure for existing and future developments. Prior to BMT WBM (2008), Lyall and Macoun (1998) undertook less detailed rainfall-runoff modelling using a lumped catchment model to estimate the impact of development on runoff volume.

In 2011, Maitland City Council updated their Development Control Plan (MCC, 2011) and recently published a Manual of Engineering Standards (2014) whereby the impact of development on catchment runoff is discussed. The documents state that for new developments “the minor drainage system shall be designed to ensure that existing downstream drainage and ecological systems are not adversely affected” and that stormwater flow and water quality originating from new development be designed to “minimise potential adverse effects generated from development on the downstream environment, and to maintain as close as practically possible the pre-developed flow regime”.

For this study the MUSIC catchment model developed by BMT WBM (2008) was used to enable present day (2015) catchment developments to be represented, and provide boundary discharge conditions for the floodplain hydrodynamic model.

4.2 Water balance

Woodberry Swamp is supplied with surface water and groundwater from the surrounding catchment. During flood events, standing water levels increase significantly on the floodplain and inundate all low-lying backswamp areas before flowing into the Hunter River once river levels recede. During wet periods, which occur at regular intervals, runoff flows through the surface flow paths (creeks and drains) into the low-lying central floodplain where it inundates the lowest lying backswamp areas and ponds, before slowly draining into the network of drainage channels and infiltrating to the groundwater table. During dry periods, surface runoff from the catchment is limited and backswamp areas experience prolonged saturation due to inputs from groundwater. During these dry periods, the surface water level in the backswamp areas is essentially the same as the groundwater level. The permanent wetland areas of Woodberry Swamp are groundwater dependent ecosystems.

When urbanisation occurs in a catchment, the way in which water (both surface runoff and groundwater) is delivered to the catchment changes. Although the amount of rainfall a catchment receives is unchanged between pre and post-development, the interaction of rainfall with the surface, groundwater and vegetation is different. Urbanisation typically increases impervious surfaces, such as roads, roofs and pavement, and reduced vegetation. This reduces losses through evapotranspiration. Previous studies have found conversion of forested areas to urban or agricultural areas causes increased runoff (Bosch and Hewlett, 1982). Infiltration of rainfall into the ground also changes with an increase in impervious surface coverage. The result is a change in what is termed the runoff hydrograph (Figure 4.1), whereby more surface water is discharged in a shorter period of time in an urbanised catchment than for a forested natural catchment.

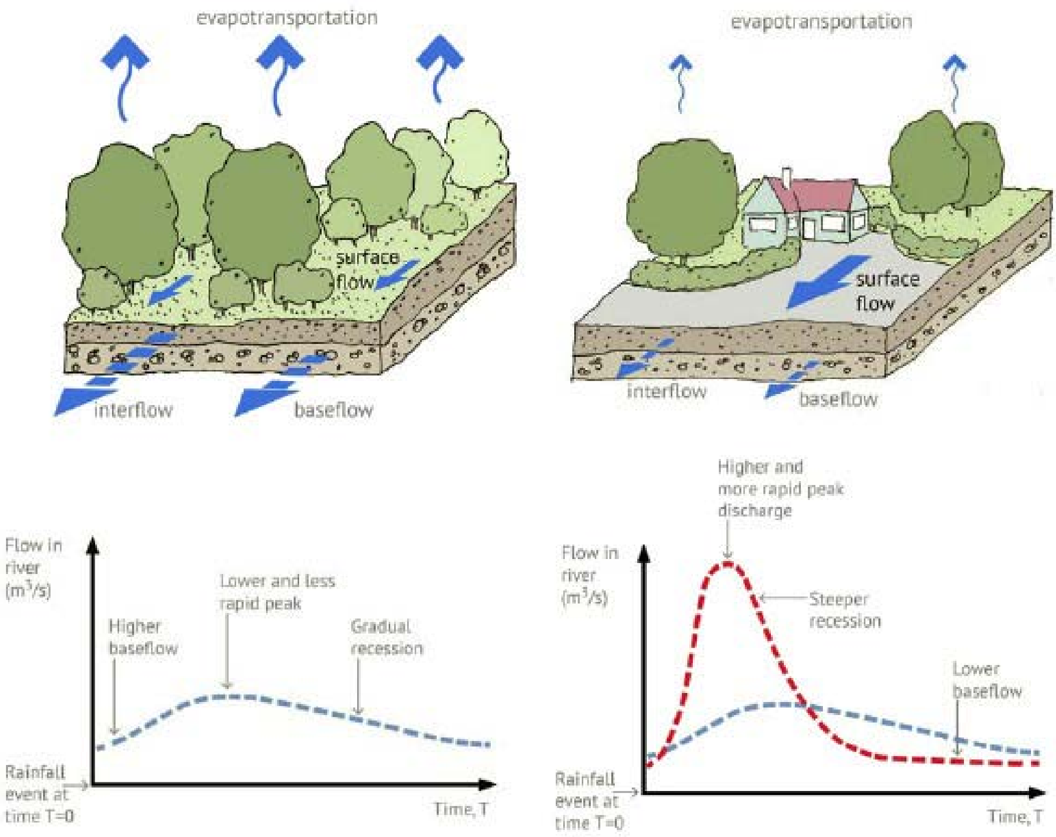


Figure 4.1: Impacts of urbanisation of the catchment water balance (Susdrain, 2016)

In a closed system such as the Woodberry Swamp catchment, where both surface and groundwater are discharged to the same receiving area, the main impact of urbanisation is the change in losses to evapotranspiration, which can be significant. A change in baseflow can also be a concern to groundwater dependent wetland ecosystems. The water balance of Woodberry Swamp is further modified by an industrial discharge licensed by the NSW EPA for discharges up to 2.3 ML/day.

4.3 Climate

The climate of the south-eastern Australia and the Hunter River Valley is dominated by regional climatic phenomenon such as the El Nino Southern Oscillation (ENSO), which vary in strength and influence from year to year. Subsequently, the climate and rainfall vary significantly from year to year in comparison to the long-term average.

Comparison of annual total rainfalls to the long-term average at Newcastle (Figure 4.2) and Paterson (Figure 4.3) show significant inter-annual variability. Such variation in rainfall can lead to larger variations in runoff as the ratio between rainfall and runoff is not linear.

Lyall and Macoun (1998) surmised that for the Woodberry region:

- An average rainfall year (930 mm) produces approximately 160 mm of runoff;
- A wet year (rainfall +30%) produces approximately 250 mm of runoff (55% increase); and
- A dry year (rainfall -30%) produces approximately 75 mm of runoff (55% decrease).

A large annual variation of annual rainfall, and subsequent runoff, has a significant impact on the wetting and drying of poorly drained backswamp areas. It is likely that such rainfall variation will influence perceived nuisance flooding more-so than the level of development within the catchment.

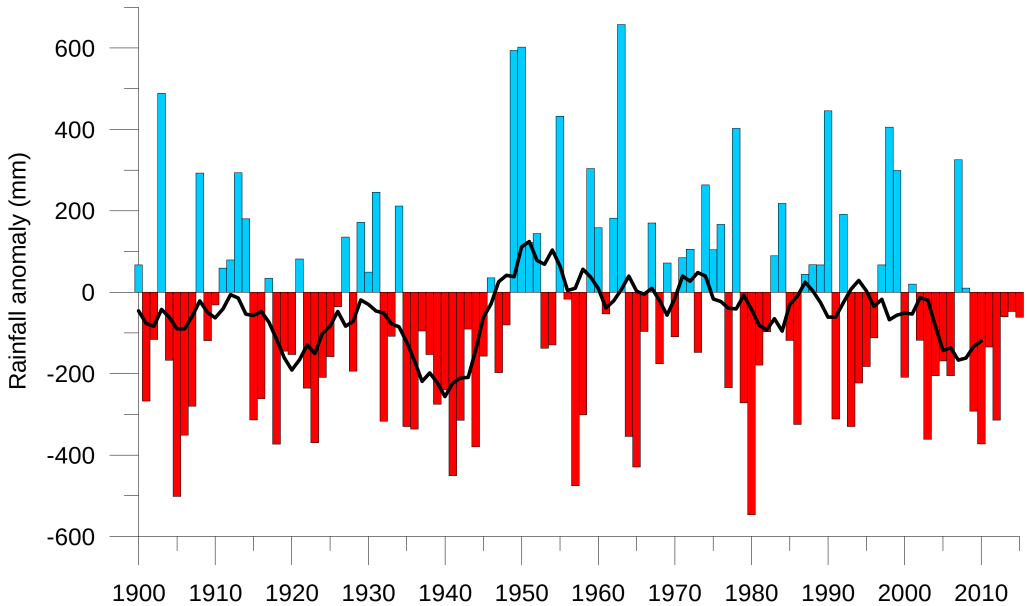


Figure 4.2: Rainfall anomaly at Newcastle (black line = 10 year moving average)

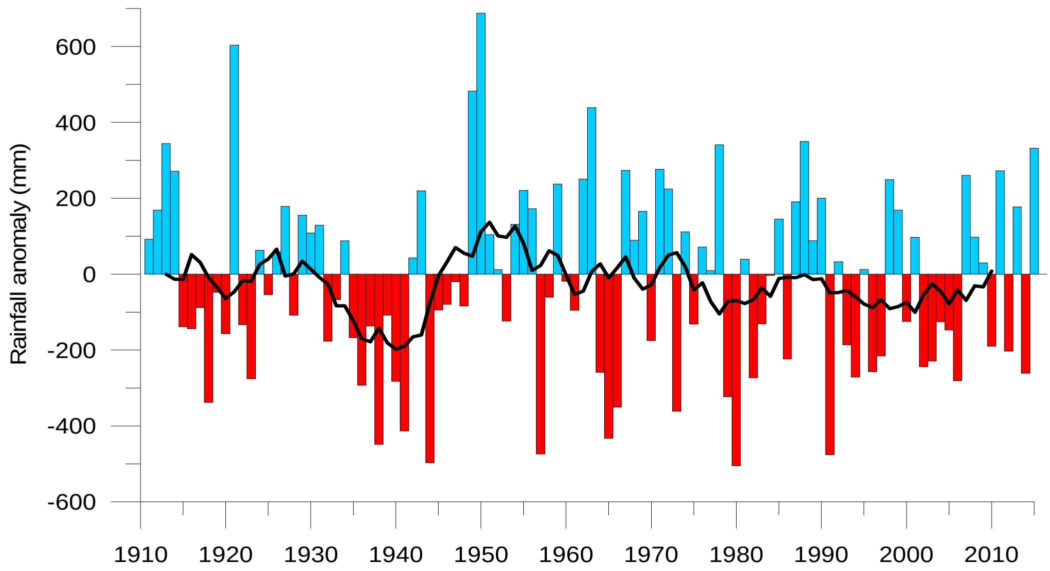


Figure 4.3: Rainfall anomaly at Paterson (black line = 10 year moving average)

4.4 Catchment development

The Woodberry Swamp catchment has changed significantly over the previous century with increased urbanisation and rural development (Figure 4.4). The extent of impervious surface coverage has increased from an estimated 8% in 1965, to 18% in 2015 (Table 4.1). The catchment has changed from predominantly bushland and rural, to a mixture of urban/industrial, bushland and rural. Based on the land zone mapping of the catchment, large areas of the catchment currently rural or bushland are zoned for future residential and industrial development (Figure 3.4).

4.4.1 Scenarios

The modelling scenarios undertaken using MUSIC are described below, with the land use distributions delineated by BMT WBM (2008) updated to represent present day 2015 land use. Historical (2004) and future (2020) catchment land use mapping were modified to provide a better representation of catchment areas based on recent LiDAR survey data. The total area of the catchment has been revised as less than estimated in previous studies (from 25 to 24, sub-catchment S7 removed).

Catchment land use is presented in Figure 4.4. Modelled sub-catchment delineation is presented in Figure 4.5. Impervious sub-catchment percentage is detailed in Table 4.1.

The following scenarios were tested:

Scenario 1 represents land use for **2004** as modelled by BMT WBM (2008).

Scenario 2 represents present day **2015** catchment conditions as indicated by aerial imagery. In comparison to the 2004 catchment composition, limited development occurred with the exception of some small areas at Thornton North and increased development density at Beresfield and Thornton industrial areas. All mining activity within the catchment has ceased since 2004.

Scenario 3 represents the **2020** catchment composition scenario, with an increase in residential development at Thornton North. The stormwater control measures as recommended by BMT WBM (2008) for these developments are incorporated into the numerical model.

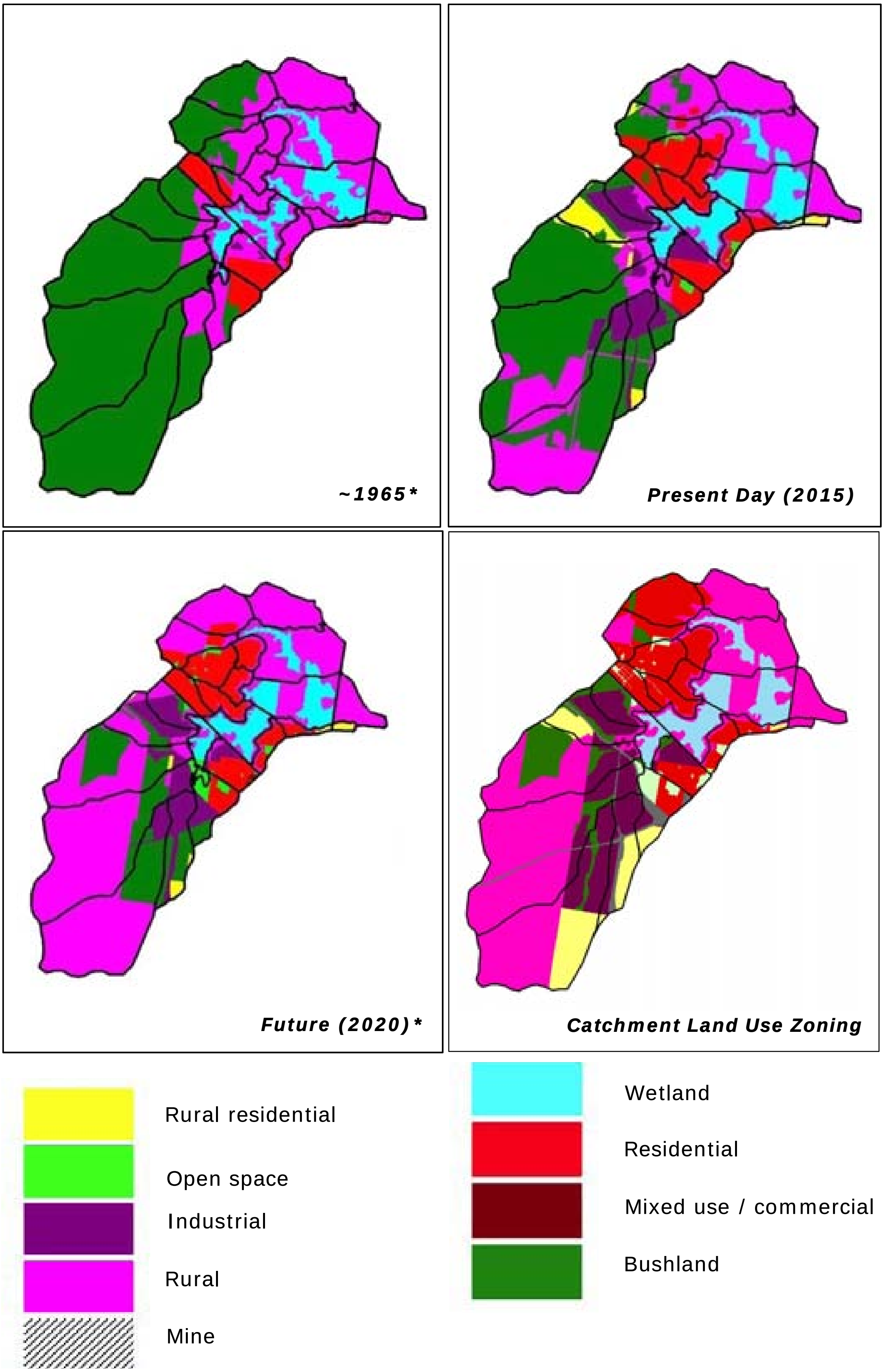


Figure 4.4: Catchment land use zoning (*as per WBM BMT (2008))

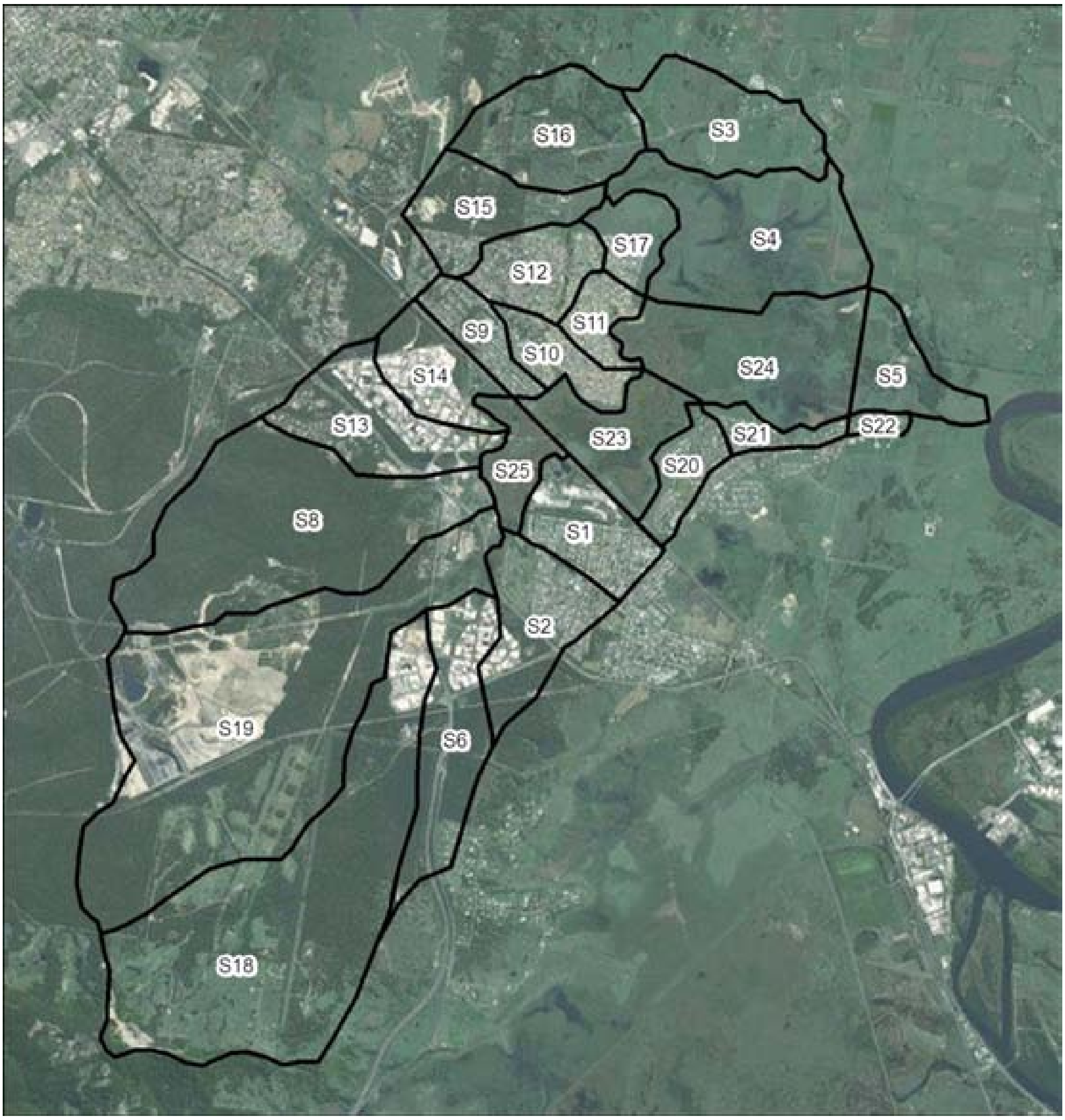


Figure 4.5: Music model sub-catchments (BMT WBM, 2008)

Table 4.1: Changes to catchment imperviousness

ID	Sub-catchment	Area (ha)	% Impervious				
			1965*	2004	2015	2020*	Fully Developed#
S1	Beresfield1	110.4	28	49	49	49	49
S2	Beresfield Golf Course	134.1	13	30	30	40	53
S3	Eales Road	164.6	0	1	1	1	1
S4	Floodplain	282.7	20	19	19	19	19
S5	Greenways Creek	94.2	1	1	1	1	1
S6	Lenaghans Drive	179.1	0	25	25	40	46
S8	Scotch Dairy Creek	468.4	0	2	2	8	10
S9	Thornton 1	66.3	34	47	47	47	47
S10	Thornton 2	71.9	6	41	41	41	41
S11	Thornton 3	50.2	0	42	42	42	42
S12	Thornton 4	114	0	41	41	41	62
S13	Thornton Industrial 1	171.3	0	31	31	31	31
S14	Thornton Industrial 2	96.9	0	47	47	47	47
S15	Thornton North 1	133.4	0	10	12	12	26
S16	Thornton North 2	173	0	1	3	8	45
S17	Thornton North 3	48	0	14	19	32	39
S18	Viney Creek	670	0	5	5	5	19
S19	Weakleys Flat Creek	768.6	0	1	3	5	13
S20	Woodberry 1	57.7	1	33	33	33	34
S21	Woodberry 2	33.7	1	30	30	30	32
S22	Woodberry 3	10.6	2	12	12	12	16
S23	Woodberry Swamp Middle	130.3	47	70	70	70	72
S24	Woodberry Swamp North	250.8	50	56	56	56	56
S25	Woodberry Swamp South	72.6	50	47	47	47	68
Total		4356	8	18	18	20	26

Note: Catchment S7 – Millers Forest previously incorrectly included as part of Woodberry catchment
* From BMT WBM (2008)
# Based on NSW Dept. of Planning land use zoning (LZN)

4.4.2 Rainfall-runoff parameters

In the absence of any site specific calibration data, the physical MUSIC rainfall runoff parameters used by BMT WBM (2008) to construct the MUSIC model remain adopted (Table 4.2). The model estimates stormwater runoff volume and load of common stormwater pollutants including Total Suspended Solids (TSS), Total Phosphorus (TP), Total Nitrogen (TN) and Gross Pollutants (GP). Wet weather (Table 4.3) and dry weather (Table 4.4) pollutant concentrations remain unchanged from BMT WBM (2008) and are based on Fletcher *et al.* (2004).

The MUSIC modelling software simplifies the rainfall-runoff process and requires the following inputs:

- Rainfall data;
- Potential evapotranspiration rates;
- Catchment parameters (area, % impervious area);
- Wet and dry weather pollutant concentrations; and
- Pervious and impervious area parameters (rainfall threshold, soil and groundwater properties).

Table 4.2: MUSIC rainfall-runoff parameters (BMT WBM, 2008)

Parameter		Urban	Non-Urban
Impervious Area	Rainfall threshold	1	1
Pervious Area	Soil Storage capacity (mm)	170	210
	Initial Storage (% of capacity)	30	30
	Field Capacity (mm)	70	80
	Infiltration Capacity Coefficient – a	210	175
	Infiltration Capacity Exponent - b	4.7	3.1
Groundwater	Initial depth (mm)	10	10
	Daily Recharge Rate (%)	50	35
	Daily Baseflow Rate (%)	4	20
	Daily Deep Seepage Rate (%)	0	0

Table 4.3: Wet weather concentrations (LOG_{10} transformed) (BMT WBM, 2008)

Land Use	TSS		TP		TN	
	mean	std. dev	mean	std. dev	mean	std. dev
Bushland	1.6	0.2	-1.1	0.22	-0.05	0.24
Rural	1.95	0.32	-0.66	0.25	0.3	0.19
Developed	2.15	0.32	-0.6	0.25	0.3	0.19

Table 4.4: Base flow (dry weather) concentrations (LOG_{10} transformed) (BMT WBM, 2008)

Land Use	TSS		TP		TN	
	mean	std. dev	mean	std. dev	mean	std. dev
Bushland	0.78	0.13	-1.52	0.13	-0.52	0.13
Rural	1.15	0.17	-1.22	0.19	-0.05	0.12
Developed	1.2	0.17	-0.85	0.19	0.11	0.12

4.5 Model Results

The MUSIC model was run for a 10-year period and the annual results summed and averaged to provide an estimate of catchment total annual loads and discharge volume (Table 4.5).

Total catchment runoff volume is estimated to have increased by 0.5% when comparing the 2015 to 2004 catchment composition scenario. This is due to limited change in catchment urbanisation in the preceding decade. The main change has been a slight increase in urban and industrial extent, and a change in land use from mining to rural/bushland. Daily discharges from the poultry processing facility at Thornton contributes daily flows to Woodberry Swamp. Discharges from the facility of 2.3 ML/day equate to approximately a 50^{th} percentile daily flow for the catchment upstream of the discharge point (Black Hill area), effectively doubling the dry weather base flow to Woodberry Swamp from that part of the catchment.

Projected changes in catchment composition at 2020 include increased development of Thornton North, which began in late 2015, and increased industrialisation in other parts of the catchment. These changes result in a 5% predicted increase in total average annual runoff volume when compared to 2015, assuming full implementation of stormwater control measures as recommended by BMT WBM (2008). Due to a reduction in rural land use and assumed implementation of stormwater treatment infrastructure, predicted loads of TSS, TP and GP decreased. Total Nitrogen is predicted to increase by 8% by 2020. If stormwater control measures are not implemented to the extent of the BMT WBM (2008) recommendations, total stormwater volume and water quality loads would be greater (in comparison to development scenario where stormwater control measures are not implemented).

Table 4.5: Estimate catchment loads

Scenario	Total flow volume (ML/yr)		Estimated catchment input loads						
			TSS (t/yr)		TP (kg/yr)		TN (kg/yr)		GP (t/yr)
	Runoff	Licensed*	Runoff	Licensed*	Runoff	Licensed*	Runoff	Licensed*	Runoff
1: 2004	16,115	600	1,086	16	2,257	18,050	20,663	70,000	177
2: 2015	16,237	810	1,094	33	2,266	30,000	20,799	130,000	185
3: 2020	17,095	-	988	-	2,205	-	22,380	-	141

Note: Rainfall from period 1999-2009 used to determine average annual runoff
* 2004 licensed discharge data from BMT WBM (2008). 2015 licensed discharge data from Baiada environmental monitoring data.

Land use practices that use additional fertilisers, such as horticulture and agriculture, are applied at a limited spatial scale within the catchment. The nutrient loads from the catchment (TN and TP) predicted by the numerical model account for 10% - 20% of the total nutrient load. Conversely over 85% of TN and over 90% of TP originate from the licensed discharge at Beresfield. In comparison to similar discharges in the Hunter River region (Table 4.6), the poultry processing facility discharges significantly higher TN loads, and equally large TP loads when compared to nearby large waste water treatment facilities. The loads from the poultry processing facility provide significantly elevated nutrients to the wetland, with high vegetation density in the immediate area receiving the licensed discharge. It is very likely that the vegetation growth and subsequent increased open water area at the south-western extent of the floodplain is due to the high nutrient load and vegetation response, and consistent volume supplied by the poultry facility. Further, the vegetation formed and the open water body effectively act as a large treatment wetland, which increases residence time and reduces nutrient concentrations in water subsequently released to the Hunter River estuary.

Table 4.6: TN and TP discharged to water from selected EPA-licensed industries in the lower Hunter River July 2000 – June 2001 (MHL, 2003)

Industry	Industry Classification	TN (kg)	TP (kg)
Steggles Beresfield	Poultry manufacturing	98,915	20,145
Morpeth WWTW	Sewage and drainage services	47,529	20,913
Raymond Terrace WWTW	Sewage and drainage services	17,865	6,503

Catchment Development and Runoff Summary

- Woodberry Swamp catchment is comprised of mixed land use of bushland, rural, industrial, urban, and wetland areas.
- Increased development alters the water balance of the catchment, reducing groundwater infiltration, reducing evapotranspiration and potentially increasing runoff.
- There has been limited catchment development since 2004.
- Development by 2020 is projected to increase total catchment imperviousness from 18% (present day 2015) to 20%. This is predicted to result in an increase of total annual average runoff of approximately 5% compared to present day if all recommended WSUD infrastructure is installed.
- Rainfall varies by ±30% from year to year in comparison to the long-term average.
- Runoff volumes vary by greater than ±30% from year to year.
- The natural wetting and drying cycle of the wetland has been altered due to the continuous licensed discharge, catchment development, and a modified drainage regime.
- The licensed discharge contributes over 85% of the Total Nitrogen and over 90% of the Total Phosphorus.
- The catchment model is uncertain due to a lack of catchment runoff volume and runoff quality data.

5. Numerical Hydrodynamic Model

The issue of water movement and drainage of floodwaters from the Woodberry Swamp complex is well established (Lyall and Macoun (1998); Gippel and Priestly (1998); BMT WBM (2008); I & I NSW (2010); NSW DPI (2012)). To test the impact of any proposed on-ground works on drainage and the extent of inundation, a detailed numerical floodplain inundation model was developed to assess the impact of any changes to the drainage system. The model was constructed using field observations, catchment modelling results and current understanding of the site.

It should be noted that irrespective of its size and complexity, a model is a predictive tool that incorporates site characteristics and field data into a mathematical approximate of reality. This is achieved by dividing the study area into discrete pieces (or grid cells) and applying mathematical equations within each grid cell to simulate the real world system. Once a model has been developed and validated to real world observations, it can be used as a predictive tool to test “what if” scenarios.

5.1 Model development

The numerical hydrodynamic model for this study was constructed using MIKE FLOOD (version 2016). MIKE FLOOD is a commercially available software package that has been specifically developed to simulate the problems of wetting and drying on a floodplain or a wetland. WRL has successfully used this model to simulate overbank inundation in the Anna Bay wetlands in Port Stephens, Yarrahapinni Wetland in Northern NSW, Big Swamp near Taree, and Tomago Wetlands in the Hunter River Estuary.

For this study, LiDAR data of Woodberry Swamp floodplain was adopted as the topography for the model. The resolution of the model was governed by balancing an appropriate grid resolution to represent the physical wetland process and maintain overland connectivity, against a reasonable simulation time within the time constraints of the project. If the grid size is overly coarse, the accuracy is likely to be compromised as the finer details and connectivity of the channel network across the floodplain may not be adequately represented.

For this study, a 6 metre grid resolution was selected to maintain the connectivity of grid cells defining the many small depressions in the floodplain. However, as this resolution is similar to the small floodplain drain widths, all main drains were represented using a 1-dimensional drain channel network.

A numerical model is only as accurate as the data used to construct the model domain. Accurate representation of the topography and drainage infrastructure is critical. Aerial LiDAR survey is not able to penetrate open water, and has difficulty determining the ground elevation in areas of dense vegetation. During the field survey, areas of dense vegetation were observed across large sections of the floodplain, as well as open water areas. Comparison of the two LiDAR datasets from 2008 and 2013 as well as field observations, indicated that the 2013 survey data had generally higher ground vegetation during the survey, whereas the 2008 survey data was generally lower across the floodplain. Other areas of change were observed adjacent to Woodberry Road where flood mound construction and road raising (Woodberry Road) has been expanded between the surveys. Subsequently, the 2008 LiDAR dataset was selected as the model topography. Areas of the LiDAR, and therefore model domain, were modified based on the field survey data collected to reduce the elevation across open water and vegetated areas. Areas that had increased in elevation due to flood mounds or road way construction were corrected to replicate observed topography. The extent of the model domain, the 1-D network, and the areas of the domain that were modified are presented in Figure 5.1.

Channel geometry and hydraulic control structures (Figure 3.1, Figure 3.2 and Table 3.1) were used to represent the 1-D channel network. Where channel survey data was unavailable, geometry was interpolated or extrapolated from the nearest survey data.

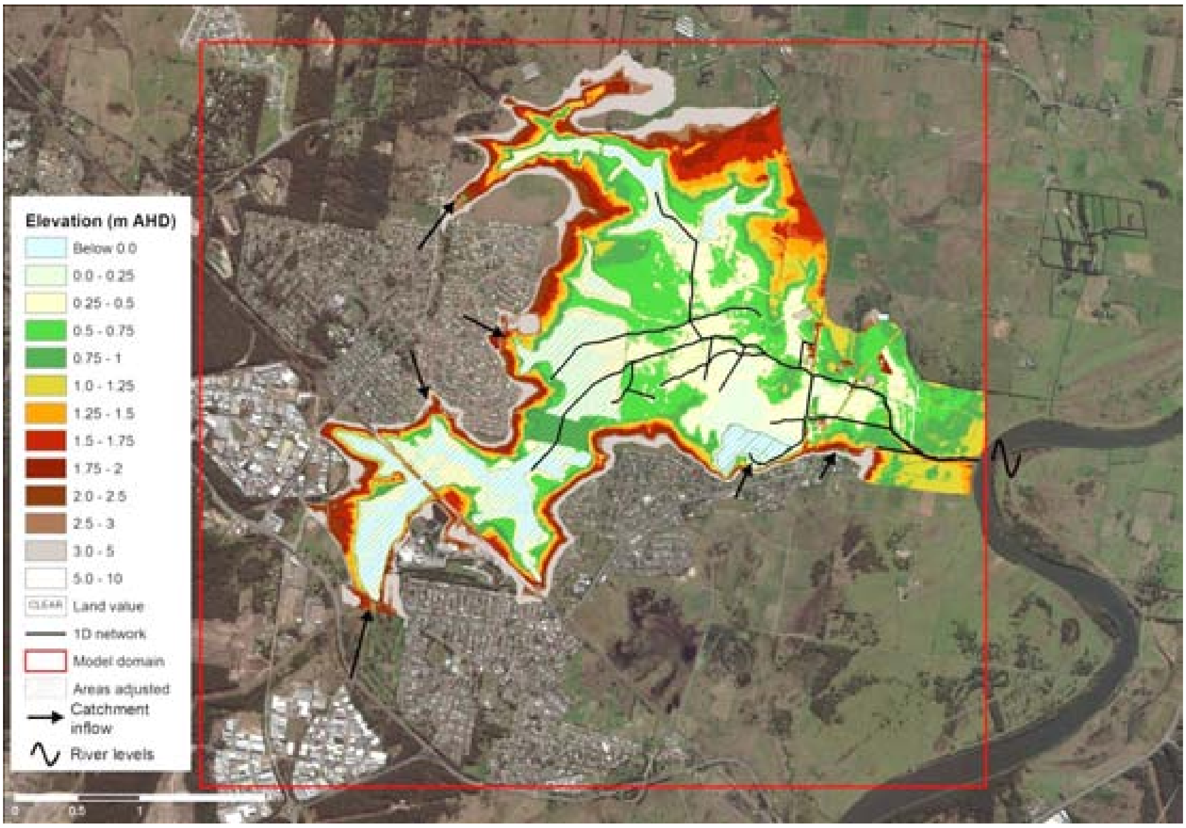


Figure 5.1: MIKE model extent and bathymetry

Due the extent of the floodplain and vegetation coverage, "roughness" influences the drainage and movement of water across Woodberry Swamp. Variable high roughness coefficients were selected to represent the in-drain and overland floodplain vegetation density (Figure 5.2). In-channel roughness was set to a Manning's n coefficient of 0.06.

The Hunter Water pipeline is difficult to represent numerically. The pipeline is elevated above an embankment with concrete blocks at varying heights resulting in a gap of approximately 0.3 m beneath the pipeline. An access roadway runs parallel to the pipeline and is also elevated above the floodplain. The pipeline spans concrete causeways at a number of locations, with corresponding culverts beneath the access road to enable floodwaters to flow across the pipeline alignment. Hydraulically, the pipeline acts to hold high elevation water back, with some flows discharging under sluice conditions beneath the pipeline. This was represented in the model by increasing model roughness along the pipeline alignment to replicate an increase of headloss. Conversely, roughness was reduced along Woodberry Road to represent reduced friction provided by the bitumen road surface.

Figure 5.2: MIKE model roughness and 1D network

Due to the flat topography of the lower floodplain, there is hydrological connection during high water events between the Woodberry Swamp/Greenways Creek catchment and the adjacent Scotch Creek catchment. Anecdotal evidence from landholders in Millers Forest indicates that water flows across Turners Rd into the Scotch Creek catchment during flood events. To incorporate this into the numerical model, a loss boundary was added on the western side of Woodberry Rd, once water has flowed over Turners Rd.

5.2 Model verification

To determine that the model is "fit for purpose" and capable of testing proposed modifications to the existing drainage system, the model was run to simulate the January 2016 rainfall event that was measured by water level loggers (Section 2.3). The rainfall event was a large in-catchment event of an annual exceedance probability (AEP) of approximately 6% (equivalent to a 1 in 16 year annual recurrence interval (ARI)). To simulate this event, 30 minute rainfall from Hexham Bridge gauging station (NSW Office of Water) was input into the present day (2015) MUSIC hydrological model to provide a time series of catchment inflows at a 30 minute time step. The 24 sub-catchments (Figure 4.5) were grouped according to discharge location and applied to the hydrodynamic model at six inflow boundary locations (Figure 5.3). Measured water levels in the Hunter River were applied to the model boundary at the downstream extent of the model domain.

Comparison of measured and modelled water level time series shows a good representation of flood levels and drainage gradients at different locations across the floodplain (Figure 5.4). A Google Earth image captured on the 10th January 2016 provides a fortunate opportunity to visually compare actual and modelled inundation extent.

Satisfactory replication of swamp water levels during the rainfall event relies on both a representative rainfall-runoff model (MUSIC model), and reliable representation of the floodplain geometry and drainage structures (MIKE model). Furthermore, the Hexham Bridge rainfall data used to generate the flows is assumed to be representative of all rainfall, distributed uniformly across the catchment. In reality, rainfall volume and intensity will vary across the catchment, and differ from that measured at Hexham Bridge.

The runoff time series from the MUSIC model was observed to be poorly routed, providing flows that arrive in the swamp too quickly from the catchment compared to the water level response in the water level logger data. A higher 2-D roughness was applied to upstream areas of the MIKE model to provide a slower, more gradual discharge to downstream areas of the hydrodynamic model. Peak levels at Location 4 (Figure 5.3) were modelled to be higher than observed, however the level across the floodplain on the 9th January indicates that the level (i.e. total volume of water stored on the floodplain) is similar to the measured water level. Differences between the timing and magnitude of peak water levels at Location 4 are due to the routing utilised by the MUSIC rainfall runoff model, however the total volume over a rainfall event is well represented. Discrepancies between peak water levels at Locations 3 and 4 during the secondary water level peak on 16th January is also a result of the rainfall-runoff model. However in this case it is a product of the rainfall input data, with the source rain gauge at Hexham not receiving the same rainfall as the Woodberry catchment, resulting in an under prediction of total runoff volume. The drainage gradient of Locations 3 and 4, and the difference in level between the two locations, is well represented. This outcome is crucial as it demonstrates that drainage restrictions within the hydrodynamic model have been adequately represented.

Water level at the floodgates is a function of boundary water levels in the Hunter River, and the volume of inflows from upstream. The presented model results show that tidal influences are well represented. An additional 80 mm rainfall fell (as measured at Hexham Bridge) between 15th - 17th January resulting in an increase in water levels across Woodberry Swamp. This response was not well replicated by the MUSIC model, and therefore the MIKE hydrodynamic model. Another contributing factor is the method which MUSIC uses to apply soils saturation, statistical monthly evaporation averaged to daily values, and losses to groundwater. Nonetheless, the hydrodynamic model provides an acceptable representation of the physical drainage of water from the floodplain through the complex network of hydraulic structures and drainage channels. This provides confidence that the MIKE hydrodynamic model is fit for the purpose of assessing on-ground options relating to modifying drainage infrastructure at Woodberry Swamp.

Figure 5.3: Modelled / measured water level locations and boundary conditions used to verify model

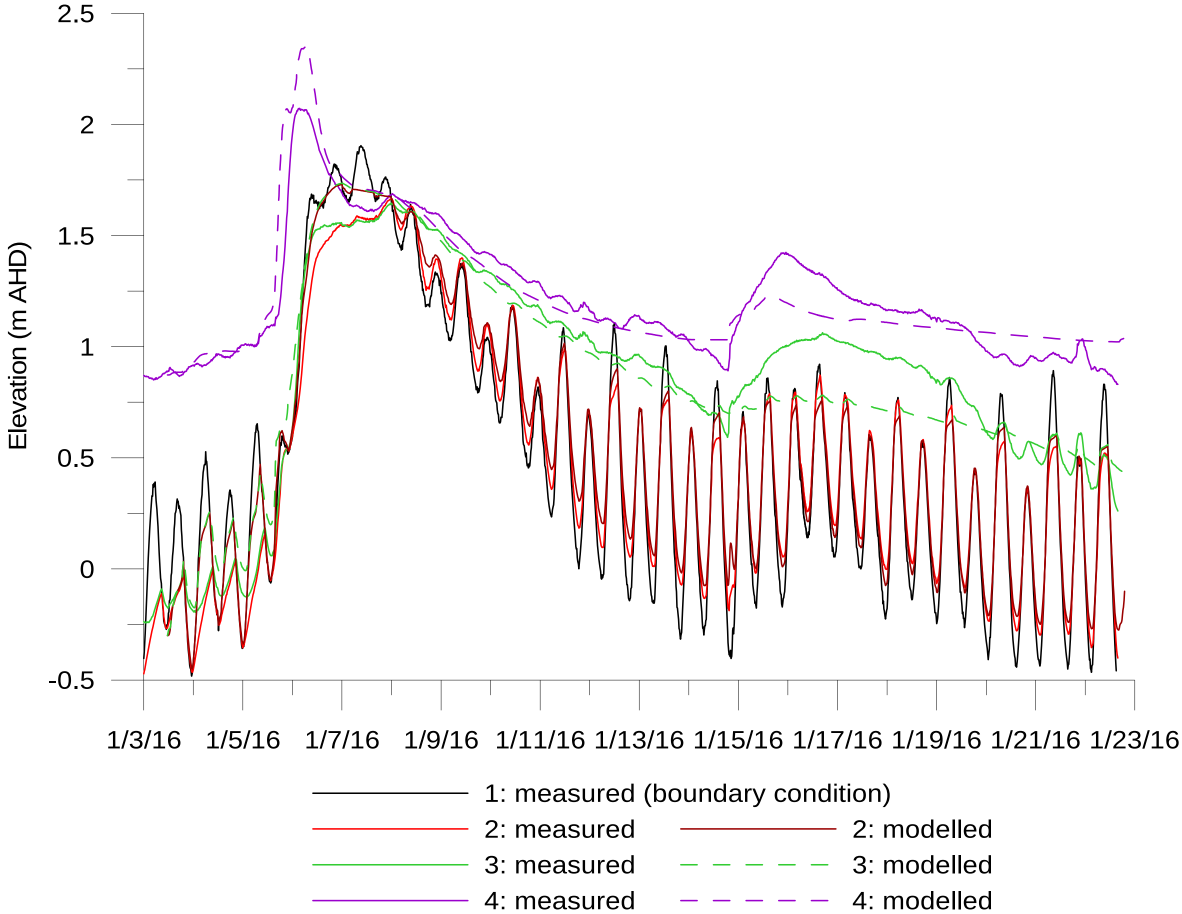
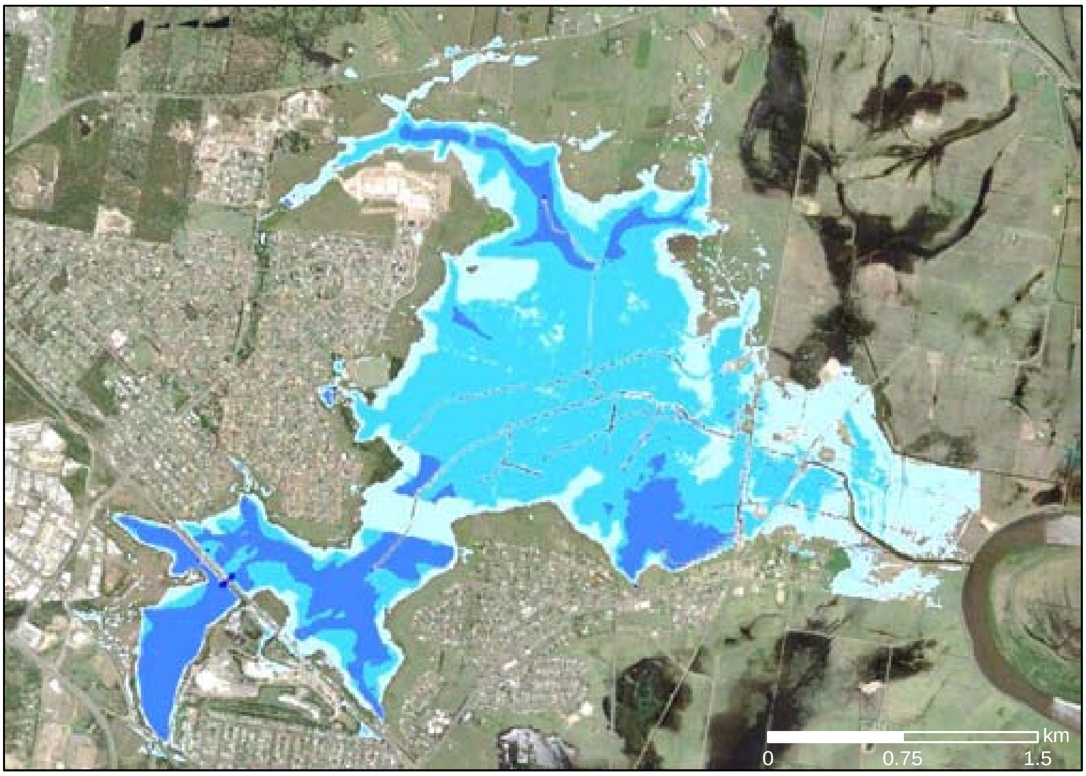


Figure 5.4: Model predictions for January 2016 flood event



Innundation Depth (m)

0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 3

Figure 5.5: Comparison of flood inundation levels as observed and modelled (10th Jan 2016) (Source: Google Earth)

6. Management Approach

Management of water quantity and quality has been an ongoing issue at Woodberry Swamp for decades (Lyall and Macoun (1998); BMT WBM (2008); I & I NSW (2010); NSW DPI (2012)). Lyall and Macoun (1998) identified that there are a large number of stakeholders and subsequently there is a need for co-ordination between agencies and landholders who have competing interests and objectives in management of floodplain drainage (none of which were satisfied at the time of the Lyall and Macoun (1998) study).

Based on a recent landholder survey and discussion with relevant stakeholders, there are differences of opinion in how Woodberry Swamp should be used and the purpose it serves. The hydrologic requirements of Woodberry Swamp operate at different scales:

Local scale: At a local floodplain scale, landholders aim to improve drainage and maximise agricultural productivity. Different areas of the low-lying central Woodberry Swamp are subjected to different hydrological conditions. For instance, utility managers require low ongoing costs, and infrastructure which is not inundated in large flood events. While Baiada Poultry Pty Ltd requires that licensed discharges are received and high nutrient concentrations are removed by the wetland.

Catchment scale: Woodberry Swamp is a sink for catchment runoff and licensed discharge. The catchment is evolving with time as development increases and land use changes.

Regional scale: Woodberry Swamp provides habitat for wildlife (SEPP 14 wetlands) and improves catchment runoff. Licensed discharge water is “polished” by Woodberry Swamp prior to being discharged into the Hunter River. The area also functions as a retention basin (part of the larger Hunter River floodplain retention network) during large floods to reduce peak river flood levels. The swamp also has significant potential as a reconnected estuarine wetland that could provide future habitat migration areas and restore brackish water habitat that has been historically lost.

Due to varying stakeholder interests and the variety of pressures and different requirements of each area of Woodberry Swamp, it is unlikely that there will be one solution, or “silver bullet”, that will solve all issues that have been raised. The lack of a single solution and the number of stakeholders are key reasons why there has been limited on-going action over previous decades.

Dividing the floodplain into different management areas would enable the separate issues of different areas of Woodberry Swamp to be addressed individually. This provides the option for targeted action to be undertaken.

For the purposes of identifying issues and recommending management options, the floodplain has been divided in to four management areas (Figure 6.1):

1. Hunter River floodgates to Hunter Water Corporation pipeline;
2. Central Woodberry Swamp floodplain, to upstream of the Hunter Water Corporation pipeline;
3. North-western area towards Thornton north; and
4. South-western area towards Beresfield.

The boundary and extent of the proposed areas is not definitive, but represents a hydrologic definition of different areas of Woodberry Swamp, with issues that are both unique and common to all areas.

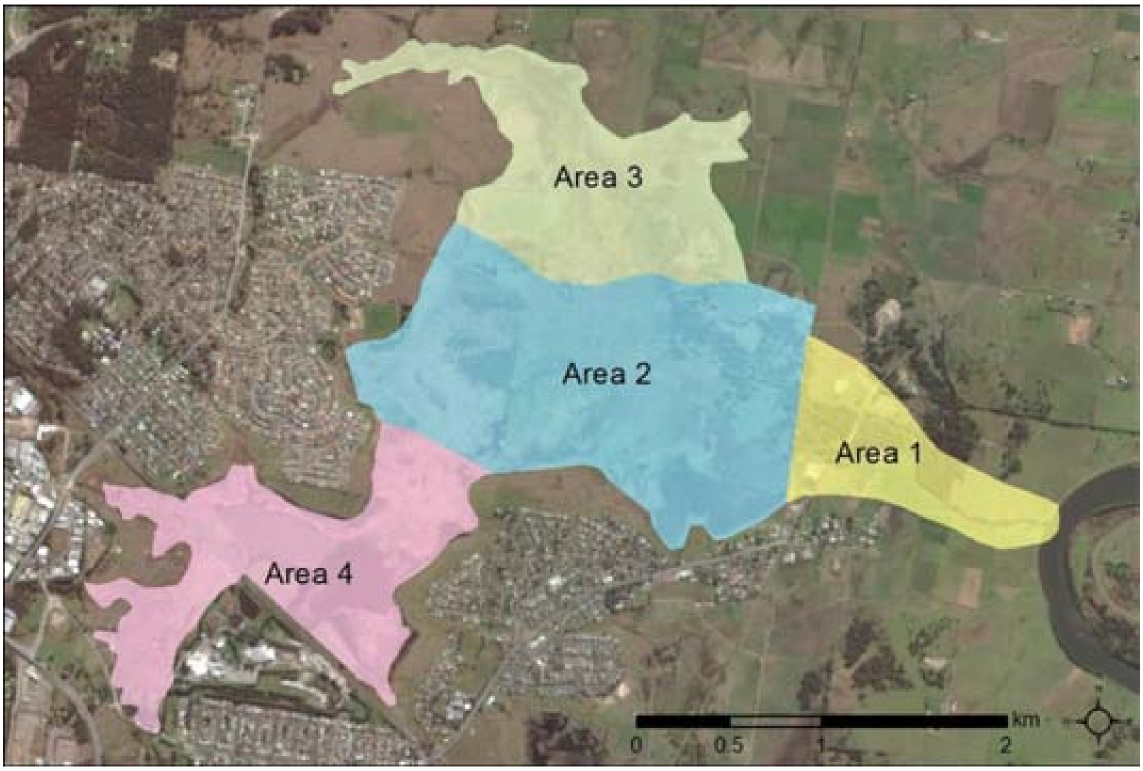


Figure 6.1: Indicative proposed management areas

7. Management Options and Issues

The following management options are provided for discussion with stakeholders.

7.1 Area 1: Floodgates to Hunter Water pipeline - Options

Area 1, the most downstream extent of the Woodberry Swamp is generally higher and better drained than the rest of the floodplain. The majority of this section of Greenways Creek is maintained by NSW Office of Environment and Heritage (OEH) and has a high conveyance. Maintenance of Greenways Creek and constructed drains upstream of Woodberry Road is the responsibility of private landholders.

During flood events, water can be exchanged overland between Greenways Creek and Scotch Creek, impacting some landholders. Water levels measured during the January 2016 rainfall event indicate that the Hunter Water pipeline and Woodberry Road, and associated drainage structures, potentially inhibit overland flow and increase drainage times for upstream floodplain.

Immediate options

1. Modify floodgates to enable controlled tidal exchange.
2. Modify drainage maintenance arrangements and or frequency, especially private drains.
3. Management of floodwater flow paths between Greenways Creek and Scotch Creek.

Long-term options

1. Increase the conveyance through the Hunter Water infrastructure. This could be achieved by burying the pipeline and reducing the height of associated access roads, or increasing the conveyance and connection of drainage structures under the pipeline and access roads.
2. Increasing conveyance of Woodberry Road bridge and, connection and conveyance of culverts beneath the road.

Detailed flood assessment and confirmation of the contribution of each structure to increased level and flood duration would be required before structure re-design could occur.

7.2 Area 2: Central floodplain

The central floodplain area is heavily vegetated with pasture, wetland and invasive species. Drainage efficiency is an issue in this area due to a failed structure, raised drain invert elevations, significant in-drain vegetation, limited hydraulic gradient due to the flat floodplain topography, limited elevation difference between the floodplain and Hunter River water levels. Following flood events, non-water tolerant vegetation species contribute to the creation of black water (low dissolved oxygen) events. Areas of central floodplain are very low lying and experience prolonged inundation resulting from poorly connected drainage, and an elevated high groundwater table. Practices which impact the SEPP-14 wetland areas of the central floodplain would be required to meet the appropriate legislation prior to any on-ground works.

Immediate options

1. Clearing of in-drain vegetation.
2. Removal of in-drain blockages.
3. Promotion of fresh water tolerance and wet pasture management.
4. Audit and maintenance of catchment Water Sensitive Urban Design infrastructure.

Long-term options

1. Improve drainage of floodwaters past the Hunter Water pipeline and Woodberry Road.
2. Promote changed land management (i.e. wet pasture management or conservation management).
3. Acquisition of wetland areas to be managed for environmental values.

7.3 Area 3: North-western area

The north-western area of Woodberry Swamp receives catchment runoff from Thornton north and surrounding rural properties. Whilst this area has historically been a wetland, residents have raised concern over increased nuisance flooding and increased duration of inundation. Prolonged inundation, or water logging, is a result of the groundwater table being at, or above, the ground surface. This is determined by the overall water balance of the catchment, with overall rainfall magnitude/frequency, groundwater flow rates, and Hunter River levels influencing groundwater levels.

While increased catchment urbanisation is likely to have increased catchment runoff, reduced baseflow and reduced groundwater discharge to the wetland area, the current state of the drainage network and the amount of rainfall received year to year also have a very significant impact on inundation extent and duration. Long-term rainfall records indicate that annual rainfall can vary by ±30%, with even greater variations in runoff volumes entering the swamp. A survey of low-lying areas, and the drains that connect the northern floodplain with the central floodplain, was undertaken and found that the drains are heavily vegetated and have high channel bottom elevations. The lowest channel elevation was found to be higher than elevation of the permanent wetland area being draining, which inhibits effective drainage.

Immediate options

1. Promote changed land management (i.e. wet pasture management or conservation management).
2. Improve drainage efficiency and conveyance by clearing drains and lowering drain invert. Note that clearing the existing drains will only improve drainage efficiency to a point and clearing of all drains downstream of Area 3 would be required to maximise drainage and reduce inundation duration. Appropriate measures to address changes to SEPP 14 areas would be required.
3. Audit and maintenance of catchment Water Sensitive Urban Design infrastructure.

Long-term options

1. Improve drainage of floodwaters past the Hunter Water pipeline and Woodberry Road.
2. Maintain and increase rainwater harvesting and pervious surface coverage in upper catchment (water sensitive urban design).
3. Promote changed land management (i.e. wet pasture management or conservation management).
4. Acquisition of wetland areas to be managed for environmental values

7.4 Area 4: South-western area

This area receives annual catchment runoff and daily licensed discharge. Prior to 1977, the large stand of dense vegetation currently at the north of the open water area was not present. It is highly likely that the growth of vegetation in this area is directly due to the discharge volume and high nutrient load supplied by the licensed discharge. The dense growth of vegetation has resulted due to vegetation decaying over time and capturing sediment, naturally building elevation to create a blockage that has permanently elevated upstream water levels. On-going daily licensed discharges, catchment inflows and direct rainfall eliminate the potential for the area to dry out through evapotranspiration. For the daily volume of licensed discharge only to be removed by evaporation, an evaporation rate of 11.5 mm/day would be required across the open water area. Furthermore, if a larger area is considered, whereby all vegetation and open water upstream of the present sediment/vegetation blockage, then a daily evapotranspiration rate of 2.3 mm/day would be required to remove all flow contributions originating only from the licensed discharge. All other forms of catchment inputs would be in addition to these figures. Average daily evaporation at Newcastle varies from 2.5 mm/day in June, to 7.2 mm/day in December. The inputs from the licensed discharge, catchment inflows and direct rainfall are collectively greater than the evapotranspiration potential of the south-western area and so the area is permanently inundated.

The vegetation that has grown to form a blockage has effectively turned the whole area into a large treatment wetland, which removes high nutrient concentrations from the water before it is slowly discharged downstream. Removal of the vegetation would result in increased drainage resulting in reduced water levels and a reduction in the area of open water, however the residence time of licensed discharge water would be significantly reduced. This would have implications for the water quality of the lower reaches of Greenways Creek and Woodberry Swamp, as well as the Hunter River estuary. Furthermore, removal of the vegetation blockage would require considerable ongoing maintenance to ensure drainage was maintained and vegetation did not increase again, which will occur if licenced discharges continue at the present day volume and nutrient load.

The perimeter of the open water/vegetation area is currently utilised for grazing and receives catchment runoff from surrounding urban areas.

Immediate options

1. Investigate long-term land use in this area.
2. Determine the impact of removing vegetation blockage and the associated costs/benefits (to both landholders and the environment).
3. Engage with all stakeholders to determine feasible options.
4. Maintain water sensitive urban design and urban catchment pollutant management (street sweeping etc.) to reduce additional pollutant loads to the receiving swamp.

Long-term options

1. Retain vegetation blockage and compensate affected landholders.
2. Increase pre-treatment of licensed discharge.
3. Remove vegetation/sediment blockage and maintain drainage.
4. Relocate licensed discharge outside Woodberry Swamp catchment.

8. Detailed Assessment of Selected Management Scenarios

Based on the options outlined for the four proposed management areas (Figure 6.1), the following four management options were assessed in further detail, including modelling using the Woodberry Swamp hydrodynamic MIKE numerical model:

1. Modification of Hunter River floodgates to improve flushing.
2. Clearing of in-channel vegetation and identified drainage blockages.
3. Reduced impact of Hunter Water pipeline and Woodberry Road on floodwater drainage.
4. Drainage of open water area impacting Management Area 4 via construction of channel through existing vegetation/sediment blockage.

Note that the above scenarios are considered independently of one another.

8.1 Tidal flushing in Greenways Creek

Prior to construction of one-way floodgates as a part of the Hunter Flood Valley Mitigation Program in the 1960s, Greenways Creek was directly connected to the Hunter River. Re-introduction of tidal flushing to Greenways Creek has many benefits for the local area of the Creek and Woodberry Swamp, and the wider Hunter River estuary. Flushing of Greenways Creek reduces maintenance as saline water inhibits the growth of in-drain vegetation, allowing efficient drainage. Off channel waterways, such as Greenways Creek, provide critical habitat for fisheries, acting as a nursery for fish and crustacean species. Restoration of tidal flows to similar drains in the lower Hunter River valley has seen significant improvement in fishery stocks.

A key concern with re-introducing tidal flushing is the potential impact on existing land use practices. The floodgates at Greenways Creek were initially constructed to limit tidal intrusion into the low-lying areas of Woodberry Swamp. Subsequently, any tidal flushing regime must consider existing land use practices. Flushing is achieved by modification of the steel floodgate with a hole cut in the middle. A hinged flap is installed to close the orifice and limit flushing at a specified elevation to protect upstream assets. A number of common modified floodgate designs are shown in Figure 8.1.

Figure 8.1: Different modified auto-tidal floodgate designs

8.1.1 Floodgate modification design requirements

The total volume in Woodberry Swamp and the associated drainage network is significant. For efficient flushing of the drains, with limited headloss and water surface elevation change through the modified floodgates, the total size of the opening in each floodgate needs to be maximised.

The options presented here were based on modified floodgates with an approximate 1 m wide x 0.9 m tall orifice with an invert elevation of approximately -0.6 m AHD. The total number of floodgates which require this modification (out of a total of six (6) existing floodgates) depends on the tidal flushing option.

The existing six (6) floodgates have dimensions 2.1 m x 2.1 m with an invert at -0.85 m AHD.

8.1.2 Tidal elevation options

Woodberry Swamp is currently being utilised for a range of agricultural and environmental benefits. Due to the low-lying topography of Woodberry Swamp, uncontrolled tidal flushing would result in regular inundation of floodplain areas. Such an outcome is desirable if tidal wetlands are required and would produce the greatest environmental benefits. However, if existing freshwater land use practices are to be maintained (i.e. agriculture, freshwater wetlands etc.) tidal inundation of these areas is not a desirable outcome. Intermediate levels of controlled tidal flushing can provide a compromise between improved environmental outcomes and existing land use.

A range of tidal flushing options (and corresponding tidal elevations) are presented in Table 8.1 and discussed below.

Table 8.1: Tidal flushing options

Tidal limit	Area flushed	Infrastructure required
-0.1 m AHD	In channel only (all drainage channels)	None.
+0.5 m AHD	Lower Greenways Creek (downstream of pipeline)	Floodgates installed at HWC pipeline culverts and side channel. Re-enforcement of channel levee banks and management of floodplain drainage into Greenways Creek.
None (above 0.5 m AHD)	All drainage channels and large areas of floodplain.	Change of land use for large areas of the floodplain. Uncontrolled tidal inundation will impact all of the floodplain.

Tidal elevation limit: -0.1 m AHD

Modification of floodgates to enable flushing at tidal elevations below -0.1 m AHD could be achieved with limited on-ground works required to mitigate impacts to existing land use. A tidal elevation limit of -0.1 m AHD would result in tidal waters remaining in-channel due to current channel bank and drainage channel elevations. This could be achieved via installation of a minimum of five (5) auto tidal gates with an approximate 1 m wide x 0.9 m tall orifice and an invert elevation of approximately -0.6 m AHD. . Note that nuisance flooding may be altered due to a reduction of in-channel storage. Groundwater salinity in some areas may also increase.

A total channel length of approximately 5 km would be flushed at this elevation. This would reduce in-channel vegetation and associated maintenance costs, improving day-to-day drainage and water quality while providing fish passage.

Tidal elevations above -0.1 m AHD would result in overbank inundation of low lying backswamp areas in Area 2 (which are at elevations of approximately 0.0 m AHD) with increasing inundation occurring as tidal elevation increases.

Tidal elevation limit: +0.5 m AHD in lower Greenways Creek only

Tidal flushing up to an elevation of +0.5 m AHD could be implemented to the lower reach of Greenways Creek only, in the area downstream of the Hunter Water Corporation pipeline. Currently, there are five (5) culverts conveying flow beneath the pipeline access road (road elevation approx. + 0.7 m AHD). Installation of one-way floodgates on these culverts would facilitate higher tidal elevations within the lower 1,600 m of Greenways Creek. There is also one (1) large side channel downstream of Woodberry Road that would also require a floodgate installed on an existing culvert. Levee banks on either side of Greenways Creek would also require re-enforcement to ensure no overbank tidal inundation occurs. This would provide some water quality improvements and limited fish passage benefits.

Adequate tidal flushing of the lower Greenways Creek with this configuration could be achieved via modification of a minimum of three (3) (out of the existing six) floodgates at the Hunter River with an approximate 1 m wide x 0.9 m tall orifice with an invert elevation of approximately -0.6 m AHD. This configuration would result in approximately 100 mm of headloss through the modified floodgates. Modification of more floodgates would result in reduced velocities and reduced headloss. Floodgate performance during draining would remain unchanged.

Tidal elevation limit: None

Uncontrolled tidal flushing, or controlled tidal flushing up to a high elevation, without any control measures would result in significant floodplain inundation. This could only be achieved if land use practices and land zoning were changed. A range of wetland habitats would establish, from freshwater wetlands in the upstream areas, to saline wetlands near the Hunter River, and brackish/transitional wetlands in-between.

Due to the significant overbank floodplain area, tidal conveyance through the existing culverts at the Hunter River would not be able to fill and drain Woodberry Swamp at the same rate at which the tide changes in the Hunter River. Water levels in Woodberry Swamp are likely to have a dampened tidal signal, neither fully draining nor filling.

8.2 Clearing of in-drain vegetation and identified blockages

Significant in-drain vegetation was identified during the field investigation between December 2015 and April 2016 (see Appendix A). Drains identified to have drainage limited by vegetation are shown in Figure 8.2. The total length of drains impacted by vegetation is approximately 8,600 m. Note that drainage of Management Area 4 is considered separately in Section 8.4.

Whilst clearing of drain vegetation is unlikely to influence drainage following major flood events, improvements to day-to-day drainage and nuisance inundation would be noticeable. Clearing of vegetation increases the effective cross-sectional area of the drainage channel and reduces the friction which acts upon flowing water. This results in improved drainage with low tidal levels in the Hunter River (which control overall floodplain drainage) reaching upstream areas faster, thereby improving drainage. If drain water levels are lowered, then groundwater levels are also likely to be lowered. This will result in reduced water logging of low-lying areas. Note that the regional groundwater table in Woodberry Swamp is a function of a range of processes, not just drain water levels.

Reduction of channel inverts for some channels, particularly the channel that drains Management Area 3, will also improve drainage of nuisance surface water. The elevation of the bottom of this channel was surveyed to be relatively high in comparison to the elevation of the backswamp areas that it is trying to drain.

Clearing of in-drain vegetation and identified blockages will address many landholders' concerns, however it will produce few environmental benefits for the swamp. It may exacerbate some environmental risks such as exposing acid sulfate soils to oxidisation or promoting the growth of pasture species that become susceptible to creating black water events. As large areas of Woodberry Swamp are zoned as SEPP14 wetlands (see Figure 2.4), approval may be required prior to clearing of drain vegetation. Assessment (and treatment) of drain spoil for acid sulfate soil may also be required as a part of an on-ground works.

Based on an excavator cost of approximately \$3,500 per 500 m, mechanical cleaning of the drains presented in Figure 8.2 would cost approximately \$60,000. Note that excavation of sediment for channel deepening or widening would increase costs and require further assessment and approval. Weed treatment of the excavated sediments may also be required. A cost–benefit analysis of the resources required, considered against the benefits to affected landholders from increased drainage, is recommended prior to implementing this option.

Figure 8.2: Identified drainage channels with significant in-drain vegetation

8.3 Increase floodwater drainage

A large flood event occurred in early January 2016 resulting from significant catchment rainfall (~200mm/24hrs). The response of water levels across Woodberry Swamp was captured by water level loggers deployed in early December 2015 (see Section 3.3). Water level data indicates that drainage of the wider Woodberry Swamp (upstream of the pipeline) is hindered by the Hunter Water Pipeline, or Woodberry Road, or both. Water levels upstream of Woodberry Road and the Hunter Water Pipeline were observed to fall slower than downstream water levels. Upstream water levels were delayed by approximately 24 to 48 hours compared to downstream water levels, with the overall time of drainage being approximately seven (7) days (Figure 8.3).

Prolonged floodwater inundation has been observed by landholders, with flow between Greenways Creek and Scotch Creek occurring after flood events. Floodwaters upstream of the Hunter Water Corporation pipeline are also observed to inundate Turners Road, impacting road access to adjoining properties. Improved drainage following flood events would enable improved access to properties, reducing the impact of overland flow between catchments and reducing the duration of inundation.

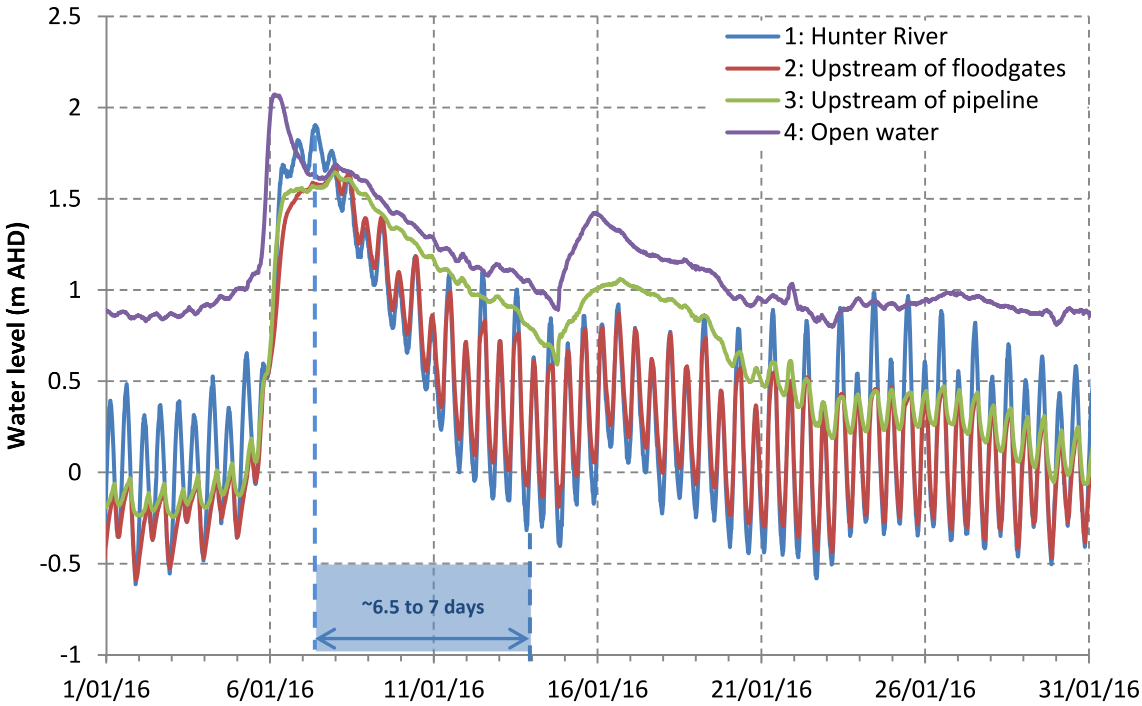


Figure 8.3: Water level drainage in Woodberry Swamp following the January 2016 flood event

8.3.1 Numerical model: January 2016 flood with removed pipeline and increased cross-section at Woodberry Road

The topography and 1-dimensional network of the verified numerical model was modified to provide an indication of the impact of removing (or burying) the Hunter Water Corporation pipeline and increasing the conveyance beneath Woodberry Road on flood water drainage. The January 2016 flood event was used as the basis for the assessment and is ideal as flooding from catchment based rainfall will drain faster than large flood events which impact the wider Hunter River valley.

The pipeline was removed in the section as shown in Figure 8.4, and the cross-section of Greenways Creek beneath Woodberry Road increased from 14 m width, to 30 m (Figure 8.5). This results in an increase in cross-sectional area by 2.5 times, from 35 m^2 to 89 m^2 (at an elevation of 2.1 m AHD). A reduction in in-channel vegetation was also incorporated by lowering the channel friction coefficient from 0.06 to 0.04.

The model results at monitoring locations 3 and 4 (refer to Figure 3.13) are presented in Figure 8.6. Modelled results at locations 1 and 2 are not presented as water levels at these locations do not vary significantly. Comparison of model results indicate that water levels at location 3 (located approximately 150 m upstream of the Hunter Water Corporation pipeline, on the upstream side of a wooden bridge) fall faster with modified topography. The tidal signal, however, is not pronounced at location 3 during the post-flood drainage (from 8th January onwards).

The verified numerical model of the existing floodplain topography and modified topography scenario results were compared at three (3) locations upstream of Woodberry Road and upstream of the Hunter Water Corporation pipeline (Figure 8.7, Figure 8.8). These results indicate that modifying the topography does improve drainage of the wider floodplain by approximately 12 to 24 hours. Further, the difference between water levels at Locations 2 and 3 indicate that smaller structures such as bridges and culverts in Greenways Creek, and the cross-sectional area of the channel at between these locations also impact post-flood drainage.

The numerical model predictions for this scenario indicated that floodwater drainage can be improved by removing in-channel and floodplain structures and expanding channel conveyance. Model results indicate that inundation duration at the peak of the flood is not impacted, however inundation at the tail end of the flood is improved by approximately 24 hours. It is unlikely that the modifications to floodplain topography and channel hydraulics would impact day-to-day drainage. These model results also re-iterate that the drainage of the floodplain is ultimately controlled by the Hunter River.

The impact of removing and modifying floodplain features was only assessed for one flood event (January 2016). The flood event in January 2016 was a particularly coastal based event, with Woodberry receiving 260 mm over a four (4) day period (with 195 mm in 24 hours), whilst upper Hunter River catchment locations such as Muswellbrook received approximately 30 mm over the same four (4) day period. Rainfall which is confined to the coastal fringe, results in water levels in the Hunter River rising and falling quickly, as observed in the January 2016 flood (Figure 3.15). Conversely, flood events which are caused by rainfall across the entire Hunter River catchment result in a flood which typically rises and falls slower, with a longer period of elevated water levels following the flood peak. These large flood events which cover the entire river catchment result in persistent inundation of floodplain retention basins, such as Woodberry Swamp, as Hunter River water levels control drainage following a flood. This means that any improvement in drainage due to modification of Woodberry Road and the Hunter Water pipeline, as were modelled for the January 2016 flood, may not occur during other flood events.

These modelling results provide an indication only of the impact of removing and modifying floodplain features which have been identified to potentially restrict drainage restrictions. Note that the modelling and analysis presented only considers one flood event (January 2016). Detailed flood modelling and design would be required prior to any on-ground works. A cost-benefit analysis is recommended to justify the cost of any on-ground works with respect to the economic return provided by a reduction in floodwater inundation duration. Again, while these works may address some landholder concerns about flood duration and connectivity, few environmental benefits would be likely from these works.

Figure 8.4: Removed section of pipeline, and modified Woodberry Road cross-section for numerical model scenario (Background image: Google Earth)

Figure 8.5: Modified channel cross-section beneath Woodberry Road

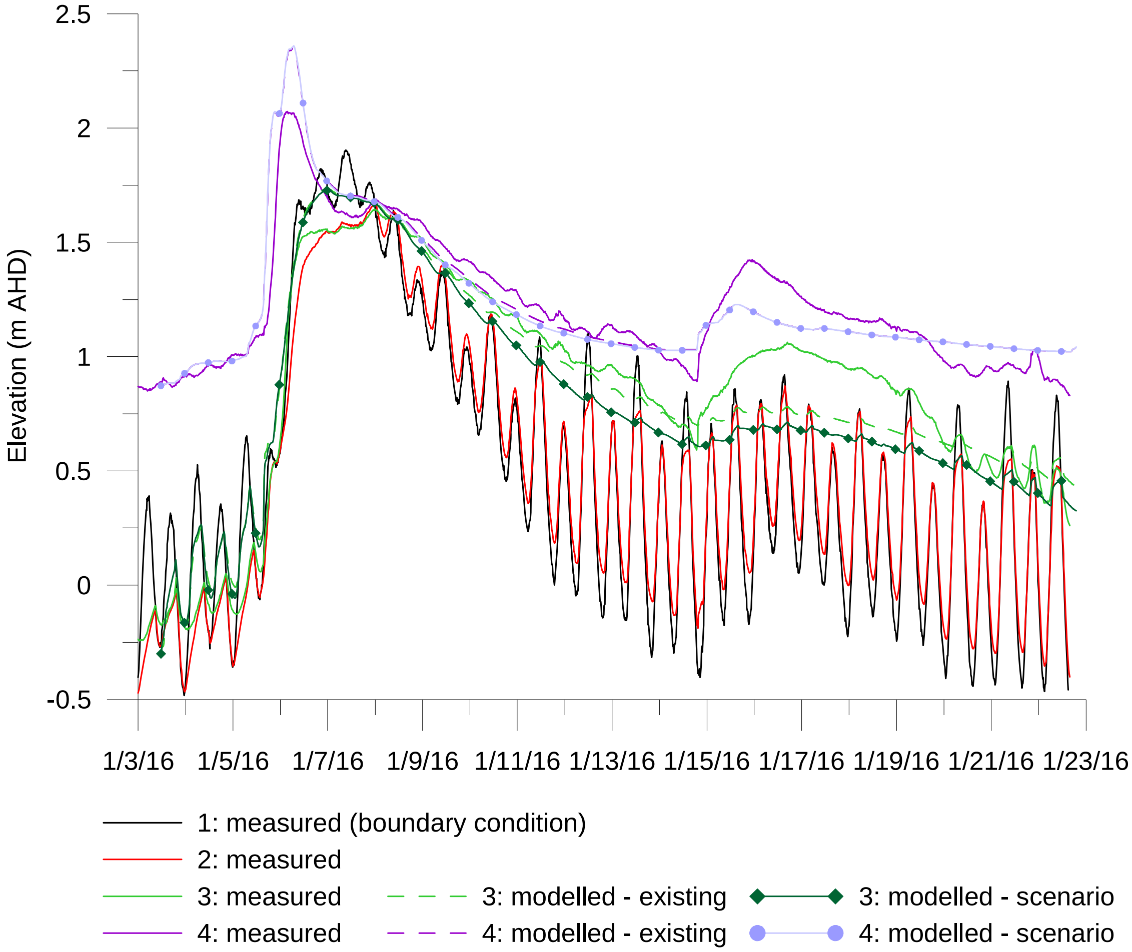
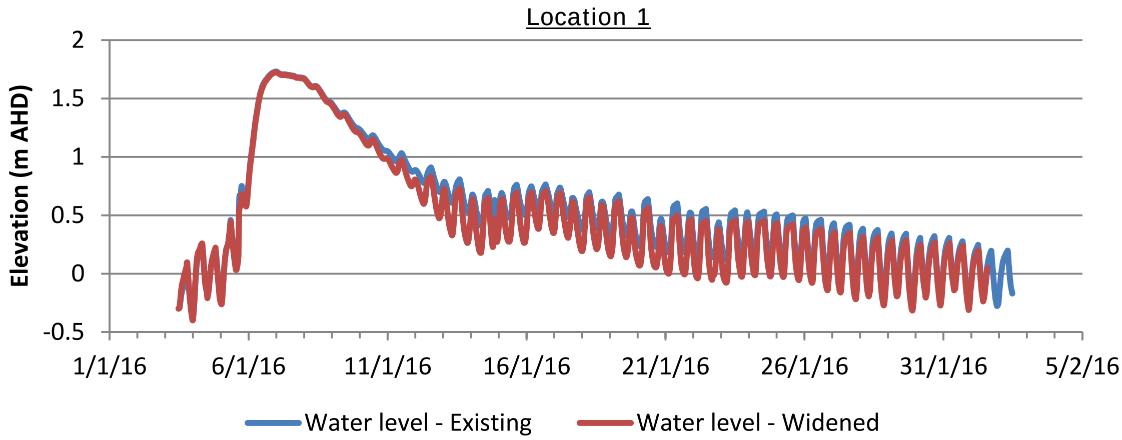
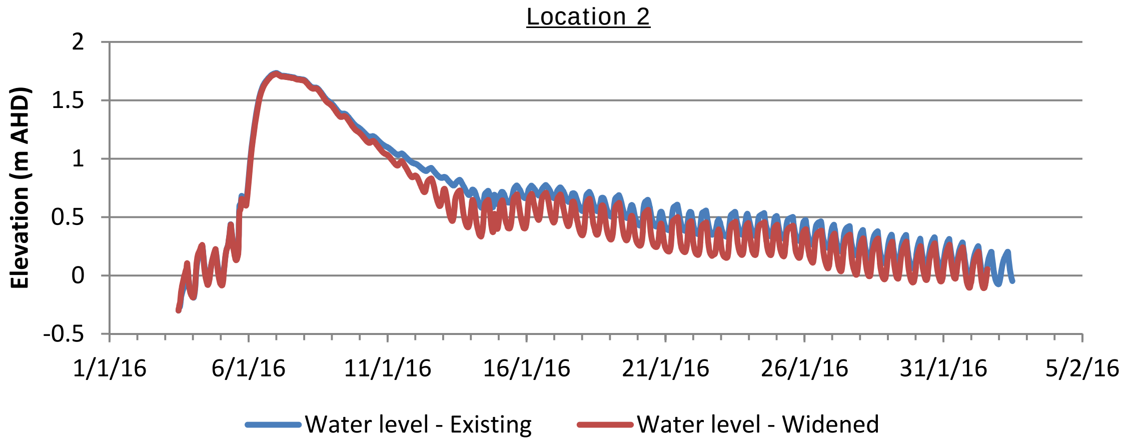


Figure 8.6: Water level as measured compared to model results for existing topography and a scenario where the Hunter Water Pipeline is buried and channel width beneath Woodberry Road is increased from 14 m to 30 m

Figure 8.7: Location of model water level results (Background image: Near Map)





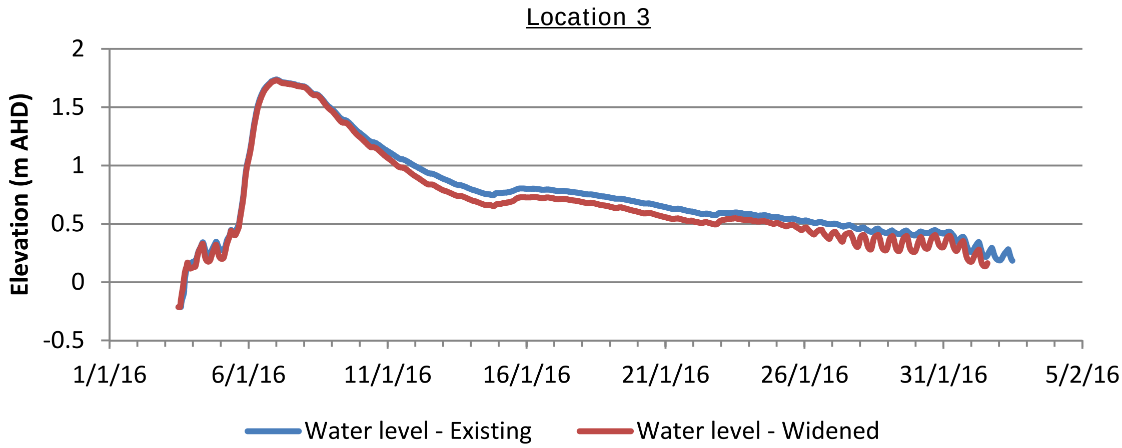


Figure 8.8: Comparison of modelled water level at three locations as shown in Figure 8.7

8.4 Drainage of Management Area 4

This management scenario considers the drainage of Management Area 4 by construction of a channel through the sediment/vegetation blockage. Management Area 4 currently receives inflows from the surrounding catchment and from a licenced industrial discharge. Nutrient concentrations and total nutrient loads originating from the licensed discharge are significant. Whilst the majority of the annual flow entering Management Area 4 originates from the catchment, particularly following rainfall events, consistent daily inflows are provided by the licenced discharged. The daily licensed discharge is approximately equal to the median catchment daily runoff volume from upstream catchment areas, effectively doubling flow volumes to the wetland during dry periods. This consistent daily inflow limits the natural wetting and drying processes and has resulted in the formation of a blockage which prolongs inundation at elevated levels. As a result there is limited floristic diversity compared with what would normally be associated with a healthy wetland.

Currently, the open water area and associated vegetation acts as a large treatment wetland that removes pollutants from the catchment runoff and industrial discharge. Draining of this area would reduce the effectiveness of the wetland to remove nutrients and may result in higher nutrient loads being discharged to the Hunter River. The effectiveness of the retention of pollutants, such as nitrogen, phosphorus and suspended sediment can be estimated by considering the residence time of water (hydraulic residence time (HRT)) once it enters Management Area 4. The residence time is dependent on the inflow rate compared to the total volume of wetland.

Note that wetland volume is a key parameter when assessing residence time. Wetland volumes for Management Area 4 were estimated for this study, with volume estimates based on limited survey data (see Figure 3.1). As such, results from the following pollutant retention calculations should be used as an indicator of the impact of draining Management Area 4 on water quality.

8.4.1 Hydraulic Residence Time: Existing

The design of urban stormwater wetlands is informed by the Constructed Wetlands Manual (DLWC, 1998). The manual provides pollutant removal curves which have been published for a number of stormwater wetlands in Sydney, Canberra and Adelaide. These curves relate retention time (in days) to pollutant removal (%) for total phosphorus, total nitrogen and suspended solids. The configuration of these wetlands is similar, being large deep open water bodies with fringing vegetation. Note that the generic pollutant retention curves provide an approximate range of pollutant retention only, and detailed assessment should be undertaken when designing a treatment wetland.

Water level observations from a water level logger installed in Management Area 4 for the period between December 2015 and February 2016 indicate that the average water level during this time was approximately 0.85 m AHD. Using the stage-volume relationship for Management Area 4, a water level of 0.85 m AHD corresponds to an approximate volume of 680,000 m^3. For an estimated mean annual runoff volume from the surrounding catchment of 9,400 ML/year (approximately) plus an additional 800 ML/year from the licenced discharge (approximately), the average hydraulic residence time (HRT) can be determined by:

$$HRT = \frac{Wetland\ System\ Volume}{Runoff}$$

$$\therefore HRT = \frac{680{,}000(m^3)}{10{,}200\left(\frac{ML}{year}\right) * 1000\left(\frac{m^3}{ML}\right)} = 0.067\ years \approx 24\ days$$

Using Figure 8.10 8.9 and 8.10, and plotting a HRT of 24 days, indicates that the wetland in Management Area 4 is likely removing nitrogen, phosphorus and suspended sediment from the licensed discharge and catchment runoff. Generic pollutant removal curves estimate that approximately 47% of nitrogen (38% lower bound and 60% upper bound), 60% of phosphorus (40% lower bound and 80% upper bound), and 75% of sediment concentrations (65% lower bound and 100% upper bound) are currently being removed by Management Area 4.

8.4.2 Hydraulic Residence Time: Drained

If Management Area 4 was drained by construction of a channel through the existing sediment/vegetation blockage, the level/volume of the open water wetland would be reduced, thereby impacting the hydraulic residence time (HRT) and the effectiveness of the area to remove pollutants from catchment runoff and industrial discharges. To estimate the impact of drainage on HRT and pollutant removal, a reduction of average open water level from +0.85 m AHD to 0.0 m AHD was considered. Based on this elevation, a drained wetland area would be similar to the extent observed in the historical 1965 and 1977 aerial photography (Figure 1.3 and Figure 1.4).

Using the stage-volume relationship for Management Area 4, a water level of 0.0 m AHD corresponds to an approximate volume of 5,000 m^3. This is significantly less (~1 %) than the volume calculated for a water level of +0.85 m AHD. For an estimated mean annual runoff volume from the surrounding catchment of 9,400 ML/year (approximately) plus an additional 800 ML/year from the licenced discharge (approximately), the average hydraulic residence time (HRT) can be determined by:

$$HRT = \frac{Wetland\ System\ Volume}{Runoff}$$

$$\therefore HRT = \frac{\sim 5{,}000(m^3)}{10{,}200\left(\frac{ML}{year}\right) * 1000\left(\frac{m^3}{ML}\right)} = 0.0005\ years \approx 0.2\ days \approx 4.5\ hours$$

When compared to the generic pollutant retention curves (Figure 8.9 and Figure 8.10), retention of nitrogen, phosphorus and suspended sediment based on a residence time of approximate 4.5 hours would generally be below 5% removal. This has significant consequences for the downstream areas of Woodberry Swamp and the Hunter River estuary given the inputs from the licenced discharge to this area.

Presently, the average concentration of key nutrients being discharged from the industrial site far exceed the ANZECC (2000) water quality guidelines for discharges into estuarine environments (Table 8.2). Drainage of Management Area 4 would have mostly detrimental environmental consequences. It would reduce the level of ‘treatment’ currently being applied to the licensed industrial discharge and potentially enable efficient delivery of large volumes of poor quality (high nutrient) water into the lower areas of Woodberry Swamp and the Hunter River estuary. It may however assist with reinstating some level of a wetting and drying cycle to fringing areas that are currently permanently open water.

Table 8.2: Comparison of licensed discharge nutrient concentrations and ANZECC (2000) water quality guidelines

	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Ammonia (mg/L)
ANZECC guideline trigger value for discharges to estuaries*	0.03	0.3	0.015
Average industrial discharge concentrations during 2014	36	147	126
Average industrial discharge concentrations during 2015	38	165	145

* For slightly disturbed ecosystems

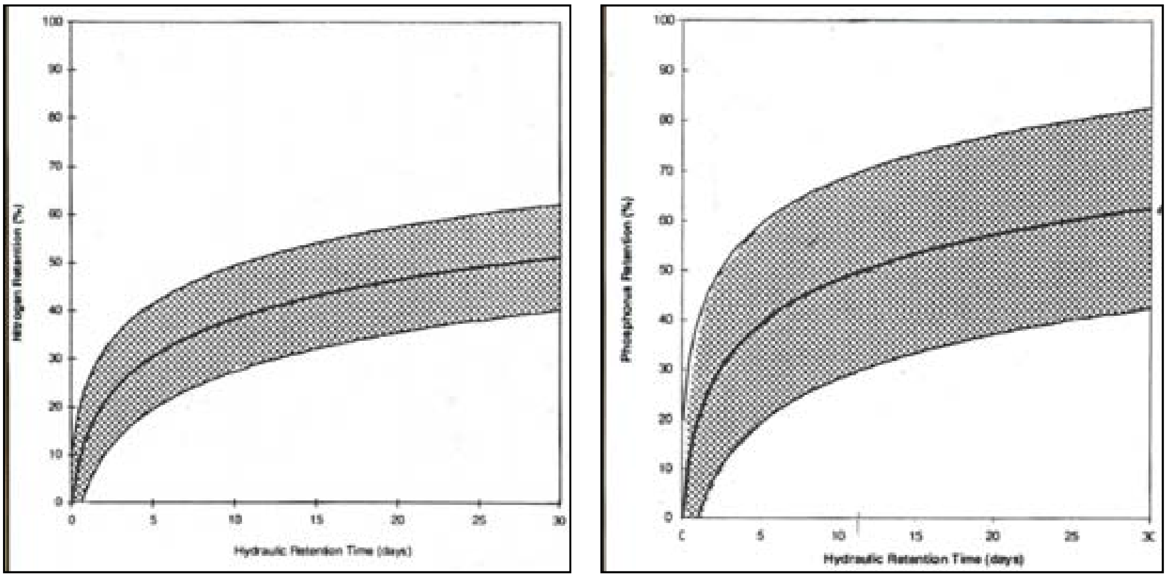


Figure 8.9: Generic curves for nitrogen and phosphorus removal in urban stormwater wetlands (DLWC, 1998)

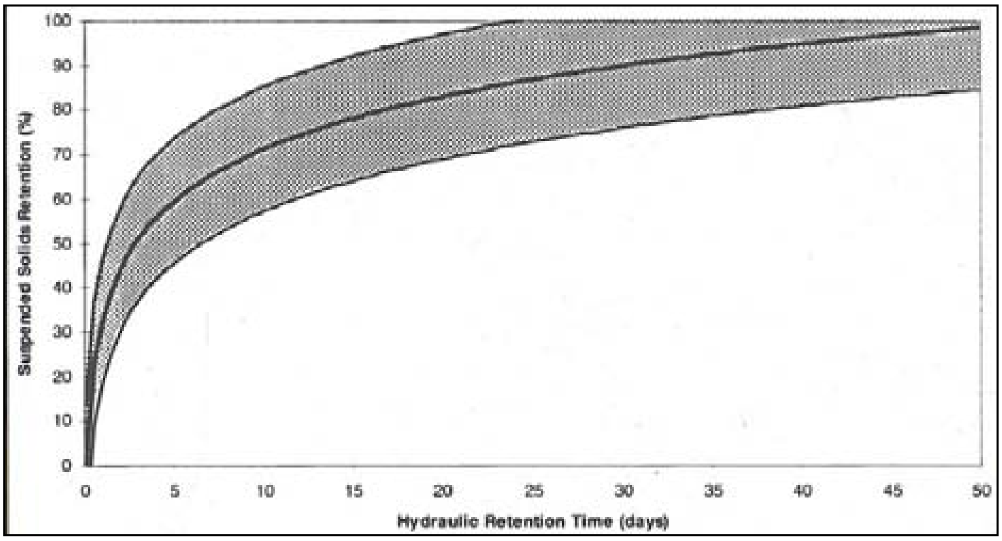


Figure 8.10: Generic curves for suspended sediment removal in urban stormwater wetlands (DLWC, 1998)

8.4.3 Additional area gained by drainage

Improved drainage of Management Area 4 via construction (and maintenance) of a channel through the sediment and vegetation blockage would achieve some benefits for landholders by ensuring areas currently inundated are accessible for other land use practices (Figure 8.11). The difference between the pre and post drainage areas, as detailed in Figure 8.11, is approximately 66 hectares. The actual area of land that is regularly dry following drainage would depend on a number of factors, such as the underlying topography (which has been estimated based on limited survey information), the extent/depth of drainage channel constructed, the condition of the downstream drainage network, and the extent of wetland vegetation cleared. If drained to a water level of approximately 0.0 m AHD, historical wetland areas as observed in 1977 (see Figure 1.4) would remain inundated with shallow water. Land elevations in the centre of the open water area were surveyed in December 2015 to be approximately –0.2 m AHD at the lowest.

A cost–benefit analysis of the required channel creation and maintenance costs and downstream water quality impacts, considered against the benefits to affected landholders from increased drainage, is recommended prior to implementing this option.

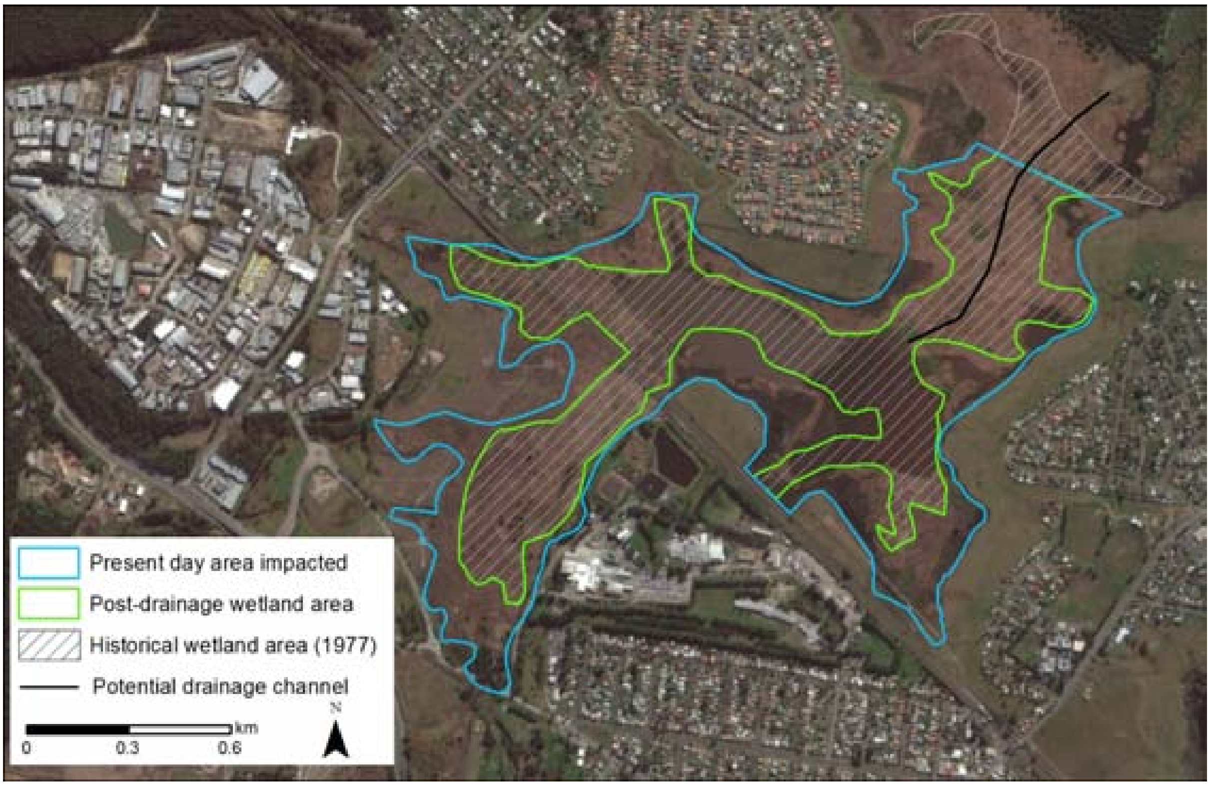


Figure 8.11: Approximate pre and post-drainage wetland extents

Management Scenario Summary

- Tidal flushing of Greenways Creek at low elevations (-0.1 m AHD limit) can be achieved with limited infrastructure. Further infrastructure is required for flushing at higher tidal elevations.
- Clearing of the in-channel vegetation in the floodplain drainage network would cost in the order of $60,000 and improve day-to-day drainage. Approvals for works in SEPP 14 wetlands would be required. Additional costs are required to deepen and widen existing drains.
- Removal of large drainage restrictions (HWC pipeline) and increasing channel area beneath Woodberry Road would result in a slight improvement in post-flood inundation duration (~24 hours), however Hunter River water levels ultimately determine flood drainage.
- Drainage of Management Area 4 would reduce the residence time of licensed discharged waters from approximately 24 days to 4.5 hours, significantly altering the quality of water flowing to the Hunter River. A fringing area of approximately 66 hectares of previously inundated land would be drained. Historical wetland extent is likely to remain following drainage.

9. Recommendations

This study investigated a series of hydrology, hydrodynamic and water quality issues across Woodberry Swamp. The wide range of complex issues highlighted during earlier studies and recent stakeholder consultation made it appropriate to divide the floodplain into four management areas which enabled issues which impact particular sub-sections of Woodberry Swamp to be addressed separately.

The following recommendations are made based on the outcomes of this investigation:

Stakeholder collaboration: Ongoing stakeholder consultation and collaboration is required to determine which (if any) management scenarios presented in this study are to be implemented, with prioritised actions that improve the environmental values of Woodberry Swamp and the wider Hunter River estuary.

Landholder consultation: A range of issues were highlighted by landholders following presentation of the findings of this study (22nd-23rd August 2016, Appendix C). Ongoing consultation between landholders and regulatory stakeholders is required to identify parties responsible for different issues, particularly drainage maintenance. Further, guidance should be provided to landholders regarding the regulatory requirements and approval process for undertaking drainage maintenance. Increased catchment runoff and concern regarding existing and future development were also a key issues highlighted by landholders. Consultation of Woodberry Swamp landholders by Maitland Council regarding future development should be increased.

Review of licenced discharge: The existing licensed discharge located at the south-western extent of Woodberry Swamp has significant impacts on landholders and wetland areas in the immediate receiving area. Impacts to the wider Woodberry Swamp and Hunter River have not been quantified. The concentration of nutrients in the licensed discharge are significantly higher than national water quality guidelines for discharges to lakes, wetlands and estuaries. Alternative management options for the effluent should be investigated.

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Appendix A – Landholder survey (October 2015)

Summary of Issues and Concerns of Woodberry Floodplain Landholders

Hunter LLS has received complaints about floodplain drainage in the Greenways Creek catchment in Woodberry/ Beresfield/ Millers Forest. In response, landholders of floodplain land in the lower Greenways Creek catchment were contacted (called and the majority were followed up with a site visit) to discuss drainage and property management issues one-on-one.

Total number of landholders visited/ talked to: 16

Number of landholders not yet spoken to, but letter sent to advise of study taking place: 2

Summary of issues raised by landholders:

Concerned about surface water management: 14/16

Has observed an increase in surface water and flooding duration on their property: 16/16

Directly objected to floodgate management: 1 or 2/ 16 (lowest lying properties are concerned about additional inundation)

Landholder's suggestions to improving drainage:

- Constructing additional higher invert floodgates in the Hunter River levee bank to allow flood water to start draining earlier as the Hunter River level drops,
- Install high volume pumps to pump standing floodwater over levees and in to river,
- More regular cleaning of drains, and wider drains however noting insufficient private funds and/ or collaboration of landholders (i.e. no Drainage Union in existence). Perception that it should be the Council's responsibility,
- Maitland Council/ developers invest in much larger stormwater capture infrastructure, and clear out drains in MCC property,
- Increase capacity of under-road culverts when raising roadways (Woodberry Road, Turners Rd), Note Woodberry Road works are now complete around Greenways Creek bridge, and there doesn't seem to have been an increase in culvert capacity resulting from these works.
- Perhaps the Hunter Water Pipeline and associated access track is holding back water.

Other concerns/ issues noted:

- Very negative feedback provided by the majority of landholders regarding ongoing residential development in Thornton and resultant changes in stormwater discharge rates,
- Three landholders expressed objection to discharges from Baiada/ Steggles,
- Increasingly developed large catchment, cumulative impacts of proposed and approved developments eg Black Hill Industrial Estate, north of Raymond Terrace Rd (around Macfarlane's Road).
- Increasing investment in flood refuge mounds and other filling on the floodplain (especially properties along Woodberry Rd), and the potential further impact on restricted surface water movement.

- Very poor water quality (black stagnant water) observed in the lower reaches of Greenways Creek, immediately above the floodgate. Landholders regularly observe poor water quality. Monthly water quality monitoring is carried out by Hunter LLS in the lower reach of Greenways Creek (commenced in June 2015).
- Recent raising Woodberry Road around Greenways Creek bridge with no additional culvert capacity, creating a higher 'weir'.
- Downstream of Woodberry Road drains and flood mitigation infrastructure (levees, floodgates) are regularly maintained by Soil Con through HVFMS.
- Connectivity of Woodberry floodplain and Scotch Ck catchment (over Turners Rd) – Millers Forest landholders have noticed Woodberry catchment runoff crossing Turners Rd and flowing in to Scotch Ck/ No 2 Drain.

Appendix B – Project timeline

12 January 2015 – First meeting of Woodberry Swamp Interagency Committee held with representation from OEH, MCC, NCC, DPI, LLS. The Committee agreed to seek resources for landholder survey, field investigation and hydrodynamic model.

February - March 2015 – Hunter LLS conducted verbal survey of landholders on floodplain properties.

April 2015 - Hunter River flood.

July 2015 – Funding confirmed for a hydrodynamic study, funds provided by enforceable undertakings and Hunter LLS, for NSW DPI Fisheries to manage project.

8 July 2015 – Letter sent to Woodberry floodplain landholders providing an update on the proposed hydrodynamic modelling project aims and timeline.

5 August 2015 – Woodberry Swamp Interagency Committee consulted on draft modelling specifications. Committee expanded to include representation from HWC, EPA and Baiada as well as those listed above.

18 August 2015 – Quotes sought for hydrodynamic modelling contract.

19 September 2015 – Two consultant's proposals received and assessed. Woodberry Swamp Interagency Committee consulted on results of Assessment of Proposals.

16 October 2015 – Water Research Laboratory engaged to conduct hydrodynamic investigation.

November – February 2016 – WRL field work and stage 1 of investigation.

January 2016 – Flood in Woodberry Catchment, valuable data collected by WRL during flood event.

6 April 2016 – Woodberry Swamp Interagency Committee meeting held to discuss the preliminary results of the Woodberry Swamp hydrodynamic investigation. Feedback provided for inclusion in draft report.

23 May 2016 – Presentation of WRL's draft report to Committee. Comments provided to WRL for inclusion in revised draft, and modelling scenarios agreed upon.

25 July 2016 – Presentation of WRL's draft report (version 2) to Woodberry Swamp Interagency Committee, including results of agreed modelling scenarios.

22 - 23 August 2016 – Presentation of hydrodynamic investigation to floodplain landholders in four small groups.

July – October 2016 – interagency committee considering a range of options based on the findings of this report.

Appendix C – Landholder meeting minutes (22-23 August 2016)

Summary of issues raised at August 2016 meetings with Woodberry Floodplain Landholders

Hunter LLS and Fisheries have engaged the Water Research Laboratory to complete a hydrodynamic investigation of surface water management issues on the Woodberry Swamp floodplain. The findings of this investigation were provided at a technical briefing to landholders at small group meetings held on 22 – 23 August 2016 at Raymond Terrace Library meeting room.

Jenny Weingott from Hunter LLS gave a brief project background, and Duncan Rayner from Water Research Laboratory at UNSW Australia gave a detailed presentation on the outcomes of field investigation and modelling.

Summary of issues and anecdotal observations raised by landholders during and following the presentation:

Meeting 1: Area Two landholders (11 in attendance, 1 absent)

- Water is not draining at all from behind Woodberry Road properties anymore.
- Concerns over intermittent leaking of the floodgate and lack of understanding of chain of command to respond to complaints.
- Queried current contact details for Hunter Valley Flood Mitigation (HVFM) Scheme enquiries.
- Queried management of Maitland Council's stormwater levy paid by some landholders – can this contribute to private drain clearing due to wider catchment inputs (including residential runoff from other properties who pay the levy).
- Perceived inadequacy of stormwater quality improvement devices (retention/ detention basins) adjacent to Thornton residential and industrial areas. Does Maitland Council audit and monitor these basins? Why are the basins part full all the time, leading to reduction in capacity to capture stormwater?
- Suspected that the MUSIC model results underestimate changes to stormwater runoff. Observations said to exceed modelled runoff.
- Queried whether the landscape elevation has changed over time, i.e. is the elevation declining due to compression and drying of the floodplain?
- Expectation that Council contribute to the cost of drain clearing to assist in draining stormwater from Thornton North residential developments.
- What are the approvals required to proceed with private drain clearing? Are there restrictions to methods able to be used without approval? Implications of SEPP14?

Meeting 2: Area 1 landholders (2 in attendance, 2 absent)

- Complained of HVFM Scheme maintenance and rate of response after complaints are lodged.
- Poor water quality in the lower end of Greenways Creek has been the cause of fish kills. Perceived lack of monitoring of water quality parameters other than dissolved oxygen.
- Perceived inadequacy of stormwater quality improvement devices (retention/ detention basins) adjacent to Thornton residential area. Does Maitland Council audit and monitor these basins?
- Observed impact of Woodberry Road levels on preventing escape of flood water, perceived effect of insufficient capacity of existing culverts, impacts of compression of soil profile and road level raising.

Meeting 3: Area 3 landholders (6 in attendance, 1 absent)

- Observed rushing of water out of Thornton North following rainfall events, velocity of flows damaged lower fences in January floods.
- Concerned about the residential runoff from Thornton carrying contaminants (fertilisers, pesticides, roadway runoff) that accumulates on private farmland and is unable to drain effectively.
- Recent observed reduction in frogs and birds. Increase in weed species water hyacinth and alligator weed.
- Perceived inadequacy of stormwater quality improvement devices (retention/ detention basins) adjacent to Thornton residential and industrial areas. Does Maitland Council audit and monitor these basins? Can more water be retained on MCC land?
- Discussion of cost sharing of drainage maintenance work (preference for all catchment contributors and expectation that Council contribute to the cost of drain clearing), also queried legalities of establishing a drainage union.

Meeting 4: Area 4 landholders (5 in attendance, 1 absent)

- Concerns over poor water quality in open water area impacting on health of nearby humans and livestock. Interest in what other contaminants may be contained in licenced discharge.
- Recent observed increase in water hyacinth, interested in further discussing control options.
- Observed reduction in range of wildlife using open water area.
- Recent observations of higher than historic water levels, back flooding through railway culverts.
- Perceived inadequacy of stormwater quality improvement devices (retention/ detention basins) adjacent to Thornton residential area. Does Maitland Council audit and monitor these basins?
- Very interested in pursuing improved drainage through Maitland Council block. Expectation that EPA, Baiada and Maitland Council contribute to the cost of improving drainage of licenced discharge water and catchment runoff.

Appendix D – Site photos

Figure D.1: Location of photos

Figure D.2: P1 – Woodberry floodgates downstream

Figure D.3: P2 – Woodberry floodgates upstream

Figure D.4: P3 – Greenways Creek looking upstream from floodgates

Figure D.5: P4 – Woodberry Road at Greenways Creek

Figure D.6: P5 – HWC pipeline at Greenways Creek

Figure D.7: P6 – Side drain, east of Woodberry Road

Figure D.8: P7 – Culverts under HWC pipeline access road

Figure D.9: P8 – Greenways Creek in middle of floodplain

Figure D.10: P9 – Dense phragmites on floodplain

Figure D.11: P10 – HWC pipeline

Figure D.12: P11 – Water level logger installation on wooden bridge at Greenways Creek

Figure D.13: P12 – Dense vegetation on floodplain

Figure D.14: P13 – Open water at south-western extent of floodplain, adjacent to railway

Appendix E – Water quality monitoring recommendations

To: Hunter Local Land Services
From: Will Glamore and Duncan Rayner
Subject: Woodberry Swamp water quality monitoring plan

Date: 20th June 2016
Ref: WRL2014125 M20160620

WRL is currently undertaking a hydrologic study of Woodberry Swamp. A recommendation from the hydrologic study (WRL technical report 2016/03) and working group meeting (23rd May 2016) was that further water quality monitoring should be undertaken to quantify the effectiveness of Woodberry Swamp in removing nutrients and pollutants from catchment runoff and the licensed discharge. Previous sampling undertaken by RCA Australia in 2007 (11th April to 5th December 2007) indicated that high nutrient loads discharged from the Baiada Beresfield facility were being removed by Woodberry Swamp. However, nutrient concentrations measured at Woodberry Road exceeded ANZECC (2000) water quality guidelines. Another round of water quality monitoring will provide up to date data to assist in decision making for future management options for Woodberry Swamp.

The proposed sampling locations (Table 1 and Figure 1) overlap with the previous sampling sites, and propose different and additional locations based on present day site understanding. WRL is concerned that, given the flat topography, the waterway at the previously sampled site near the Golf Course may interact with downstream water during dry periods. Therefore, the sampling location at Site 1 (Figure 1) is recommended to be moved further upstream. Sampling at Site 3 will provide an immediate comparison to data from Site 2 as to the effectiveness of the wetland to remove nutrients from the licensed discharge. Although access to Site 3 may be difficult, particularly during wet periods, sampling from the central floodplain area should be undertaken where possible, and the sampling location noted. Site 4 will enable contributions from urban catchment areas to be quantified. Sites 5 and 6 indicated the quality of water being discharged to the Hunter River. Site 7 aims to sample the Hunter River directly and care should be taken not to sample immediately downstream of the floodgates, particularly if the floodgates are discharging (i.e. during a falling tide). The status of the floodgates (open or closed) should be noted when sampling at Sites 6 and 7. Site 8 represents the location used for fortnightly water quality monitoring currently undertaken by Baiada.

Sampling should be undertaken at a fortnightly interval to align with existing Baiada water quality monitoring. Monitoring should be undertaken for 12 weeks to capture a range of environmental conditions. Recommended field and laboratory parameters are detailed below. Following the conclusion of the monitoring program, a brief summary should be supplied which details the sampling methodology, field parameters results, sampling location photographs and laboratory results.

Field parameters:

- Electrical conductivity
- pH
- DO
- Temperature
- Flow
- Chlorophyll-a

Laboratory analysis:

- Total nitrogen (TN)
- Total phosphorus (TP)
- Ammonia nitrogen
- Biological oxygen demand (BOD)
- Chemical oxygen demand (COD)
- Total Suspended Solids (TSS)

Table 1: Proposed sampling locations with indicative co-ordinates (Co-ordinates: GDA 94 MGA 56)

ID	Approx. Easting	Approx. Northing	Location
1	372075	6369539	Weakleys Drive, as access permits. The aim is to ensure that there is no influence from licensed discharge, hence sampling further upstream than previous sampling in 2007.
2	373307	6371188	East railway culvert
3	375034	6372148	Greenways Creek in central area of Woodberry Swamp (Ward Property). Sampling location as access permits.
4	373499	6373361	Thornton North, east of Government Road near Alan and Don Lawrence sports field
5	376785	6371945	Woodberry Road bridge
6	377714	6371359	Upstream of floodgates
7	377802	6371363	Hunter River: Downstream of floodgate, ensuring water originating from Woodberry Swamp is not sampled
8	373379	6371025	Licensed discharge location as per usual fortnightly sampling

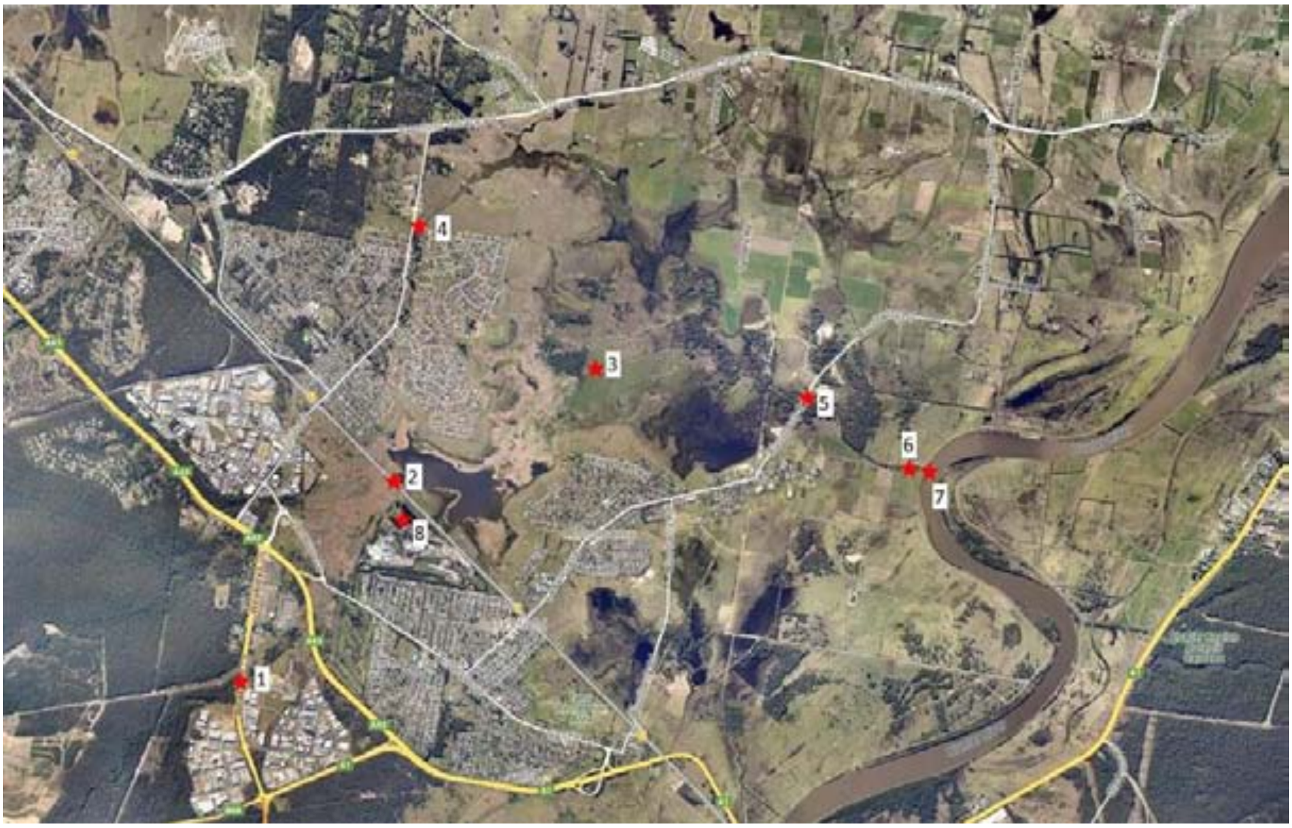

Figure 1: Proposed water quality sampling locations