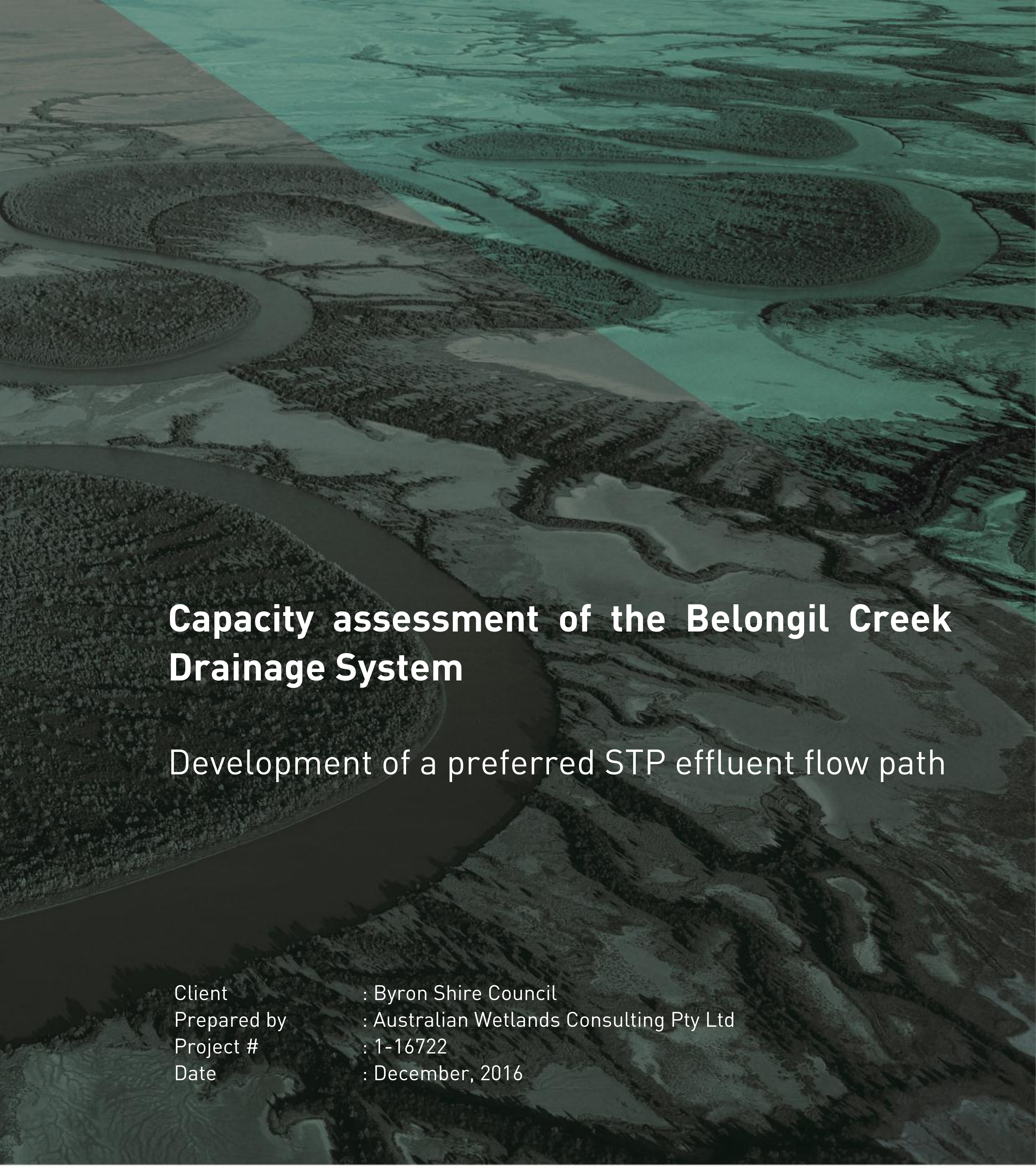

Capacity assessment of the Belongil Creek Drainage System

Development of a preferred STP effluent flow path

Client : Byron Shire Council
Prepared by : Australian Wetlands Consulting Pty Ltd
Project # : 1-16722
Date : December, 2016

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Capacity assessment of the Belongil Creek Drainage System

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Project control

Project name: **Capacity assessment of the Belongil Creek Drainage System**
Development of a preferred STP effluent flow path

Job number: 1-16722-1a
Client: Byron Shire Council
Contact: Peter Rees

Prepared by: Australian Wetlands Consulting Pty Ltd

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20/12/2016	A	Mark Bayley Damion Cavanagh (BMT WBM)	Damian McCann	1 x PDF to Peter Rees
XX/01/2017	B	Mark Bayley Damion Cavanagh (BMT WBM)	Damian McCann	1 x PDF to Peter Rees

Executive Summary

The Byron Bay Sewage Treatment Plant (BB STP) forms part of the Byron Bay Integrated Water Management Reserve (BBIWMR), which currently discharges up to 3ML per day of dry weather flow into the upper Union Drain. On top of this discharge, a large area (24 ha) of regenerating flood plain forest is irrigated with treated effluent – at an approximate rate of 1 ML/day. In recent years the discharge of STP effluent into the upper Union Drainage system has caused significant concern from adjoining landholders. Due to increased development within Byron Bay, effluent inflow rates are projected to increase over the next 5-10 years. As a result of this increase, Byron Shire Council (BSC) seek guidance on a sustainable effluent release pathway – for current BB STP flows and projected 5ML/day and 8ML/day flows. To determine a sustainable effluent release pathway for the BB STP a number of investigations where undertaken:

- A broad scale, catchment wide ecological assessment, focusing on areas directly adjoining the Estuary and drainage system,
- An assessment of the fate of effluent released from the current discharge location since transfer of effluent from the South Byron Sewage Treatment Plant (SB STP) to the BB STP,
- An assessment of drain water levels, rainfall and estuary opening events using 10 water level loggers deployed throughout the catchment,
- An assessment of the geology and presence of Acid Sulphate Soil (ASS) of the Effluent Irrigation Area land west of the BBIWMR,
- The development of two alternative effluent release pathways, and
- Hydrologic, hydraulic and water quality modelling investigations on current and proposed effluent release pathways under current and proposed effluent flows.

Ecologically, the Belongil Creek, ICOLL and drainage system provides a large expanse of high quality habitat for various terrestrial and aquatic species. Swamp forest (large proportion mapped as SEPP 14), mangroves, saltmarsh and regenerating areas with the STP provide high quality habitat for multiple species listed under the TSC Act and EPBC Act. Known breeding habitat for several species such as the Little Tern and Pied Oyster Catcher occurs within the catchment, meaning that conservation of these environments is essential for the sustainability of the local population. Overall the catchment hosts an array of high value ecological features including threatened species habitat (flora and fauna), EECs, SEPP 14 wetland and wildlife corridors (regional and sub regional).

Detailed site analysis of the effluent irrigation area, land to the west of the BBIWMR and Belongil drainage system has inferred that the increase in flows associated with the transfer of effluent from the SB STP to the WB STP in 2006 with the adjoining has resulted in:

- A decrease in artificial estuary opening events,
- A potential increase in water table height west of the BBIWMR, resulting in an increase in the frequency, extend and depth of surface water inundation,
- A reduction in peat fires and acid discharge events, and
- The occurrence of both PASS/ASS within the upper Union Drain area.

The receiving environment for BB STP discharges is the low-lying tidal floodplain of Belongil Creek. Assessing hydraulic impacts in this environment required consideration of the estuarine and meteorological conditions that may prevail in this catchment, including the effects of a variable entrance openings and variable catchment responses to meteorological conditions. The models established for the Hydraulic Capacity Assessment (HCA) include a SOURCE hydrologic model and a linked 1 dimensional (D) / 2D TUFLOW hydraulic model of major drainage channels and overbank floodplain areas. Both models were validated in unison using a mixture of qualitative and quantitative approaches and a good model fit was achieved. As such the models accurately predict the timing and magnitude of catchment flow events, but also in the areas of interest they were able to demonstrate an accurate prediction of water levels for tides within the channels and the influence on catchment runoff events.

For the existing BB STP discharge location and the alternative effluent release Option 1 location, there are significant areas of the floodplain predicted to experience increases in duration of inundation. Generally this inundation has been predicted to occur downstream (to the south) of Ewingsdale Road in the main portion of the floodplain. The flatter channel gradient and influence of tide height/entrance conditions increases the duration of water ponding in this floodplain. The differences in the time of inundation are typically less than 2%. For the he alternative effluent release Option 2 location, the predicted increases in duration are significantly less than for the two other alternatives.

A rapid assessment approach was applied to investigate potential changes in water quality (salinity, nitrogen and phosphorus) in the Belongil Creek estuary resulting from increasing discharge volumes from the BB STP (with discharge quality remaining static). As such the water quality modelling provides ancillary information to the HCA component. The model developed accounts for key flow components (i.e. BB STP, catchment and tidal exchange), pollutant inputs/outputs (i.e. STP, catchment and oceanic exchange) and nutrient processes (i.e. settlement, sediment release and denitrification) and provides a temporal prediction of pollutant concentrations within the estuary. Given that the model is non-dimensional the model predictions are volume averaged. The models used for the assessment were adapted from the Tallow and Belongil Creeks Ecological Study.

The results identify that for salinity, decreasing the BB STP discharge volumes (i.e. to 1 ML/d) increases the average salinity of the estuary over the modelling period. Whilst increasing the discharge volumes to 5 ML/d or 8 ML/d, decreases the average estuary salinity. Similarly with predicted TN and TP concentrations, decreasing the BB STP discharge volumes (i.e. to 1 ML/d) decreases the average total nutrient concentrations in the estuary over the modelling period. Whilst increasing the discharge volumes to 5 ML/d or 8 ML/d, increases predicted total nutrient concentrations within the Belongil Estuary. Peak total nutrient increases of up to 92% are seen for TP for the 8ML/d discharge scenario, but these peaks are short lived and occur at times with either a very low tidal range (due to entrance closure) and/or to a lesser degree dry weather periods which reduce catchment runoff. Considered as a long term median (over the 4+ year modelling period) the TN changes are less than 3% and TP changes less than 2% for the 8ML discharge scenario.

Recommendations

The main recommendation resulting from this study is to provide an alternative effluent release pathway via Option 2 – release into the Industrial Estate drain. While the results of the investigations presented in this report support an alternative effluent release pathway, it is advised that some degree of discharge from the existing release point (EPA 4) continues. This continued discharge is required to ensure that acidic runoff off events and/or peat fires do not occur within the upper drainage catchment - as have occurred in the past. A detailed Environmental Monitoring Plan, complete with triggers and actions is required to inform the delivery of the alternative effluent release pathway. This monitoring plan will provide guidance on the incremental decrease of effluent at EPA 4, and the incremental increase of effluent release to Option 2. The plan will outline key environmental variables to measure, frequency of data collection and triggers which will guide the further increase/decrease of effluent at the two proposed discharged locations (existing and Option 2)

While this report supports the provision of an alternative release pathway, the timeframe to implement this is undecided. Nevertheless, numerous short term actions can be implemented immediately to potential reduction inundation depth, frequency and duration of land west of the BBIWMR:

- Remove concrete lip north of pipes draining the upper Union Drain on Ewingsdale Road,
- Ensure pipes draining the upper Union Drain on Ewingsdale Road are inspected after every decent rainfall events, and cleaned if capacity is impacted by >20%,
- Reduce the weir level from EPA 4 drain within BBIWMR by 100mm or to a level which ensures limited inundation of land west of the Cavanbah Centre, and
- Block drain to the northwest of the irrigation area, ensuring all water draining the BBIWMR travels south.

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1 Introduction

The Byron Bay STP (BB STP) forms part of the Byron Bay Integrated Water Management Reserve (BBIWMR), which currently discharges approximately 3ML per day of dry weather flow into the upper Union Drain. On top of this discharge, a large area (24 ha) of regenerating flood plain forest is irrigated with treated effluent. In recent years the discharge of BB STP effluent into the upper Union Drainage system has caused significant concern from adjoining landholders. Figure 1-1 displays the location of the BBIWMR and the broader study area

Since the closure of the South Byron Bay STP (SB STB), effluent from the entire township now enters the Belongil Creek and drainage system, potentially increasing the frequency of artificial opening events of the Belongil Estuary ICOLL (Australian Wetlands, 2013). Figure 1-2 provides a summary of major activities undertaken by the Byron Shire Council on the upgrade of the Byron township sewage system since the 1980's and 90's.

Currently the BB STP is operating at 72% capacity – approximately 5ML/day, with a design capacity of 6.95 ML/day. Under current land use strategies, Byron Shire Council will need to upgrade the STP to receive up to 10 ML/day by 2025.

The approved EIS for the upgrade of the BB STP predicted no impact to regional groundwater levels. Following development of the BB STP, a post development impact verification project confirmed groundwater behaviour predictions modelled in the EIS. Notwithstanding this, doubt still exists as to the fate and impact of the effluent discharged from the BB STP. In light of this concern, the aim of this report is to investigate the sustainable capacity of the Belongil Creek and drainage system to receive treated effluent from the BB STP. Key objectives of the current study are to:

- Define and determine the <u>sustainable capacity</u> for current and future BB STP release flows in the Belongil Creek
- Determine the impact/s of the current flows (at 3ML/day) compared to the aspirational flows (of 1ML/day) on the drainage system and farmland upstream of Ewingsdale Road
- Assess whether throughput from the BB STP Constructed Wetlands and 24 ha Melaleuca Wetland (BBIWMR) is also charging those drains
- Identify alternative flow path/s for BB STP treated effluent discharge
- Enhance environmental and scenic values (beautification) of the Belongil Catchment.

These objectives will be achieved by undertaking an:

- assessment into the potential options of treated effluent release, including a mix of options
- modelling potential scenarios for BB STP discharge with consideration to
  - o the relative contribution to the flows from the BB STP discharges and rainfall
  - o the impacts of discharges with the Belongil estuary open and closed
- thorough assessment and understanding of project risks
- determination of all regulatory and formal requirements.


AWC
Project: Byron Bay STP alternative effluent release assessment
Figure 1.1: Location of the BBIWMR and broader study site
Legend
Major drains
Marine Park
Belongil Estuary Catchment
BBIWMR
SEPP14 Wetlands
Union Drain
0 200 400 600 m
Date - 16/12/2016
A3 Scale - 1:30000
SOURCE:
Aerial - NearMap Pty Ltd 2016
Study Site - AWC
Care was taken in the creation of this map. AWC should be consulted as to the suitability of the information shown herein prior to the commencement of any works based on the information provided. AWC cannot accept any responsibility for errors, omissions or positional accuracy. There are no warranties, expressed or implied as to the suitability of this map for a particular purpose. However, notification of any errors will be appreciated.

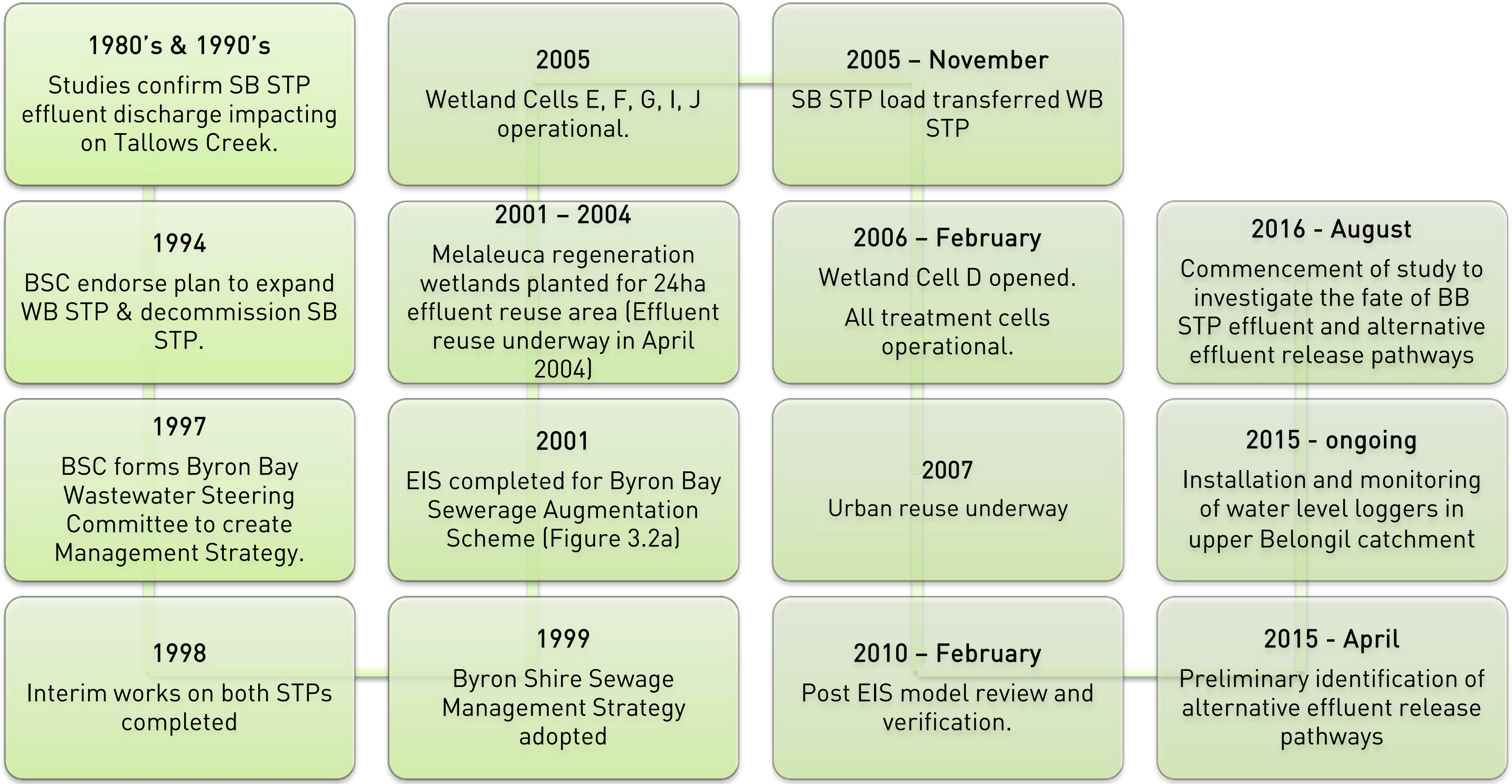


Figure 1-2: Flow diagram of major activities undertaken by the Byron Shire Council on the township sewage systems since 1980's

1.1 Defining the 'sustainable' capacity of the Belongil Creek with regards to effluent release

In the assessment of the current and any future alternative effluent release pathways, it is important to ensure that the sustainability of the Belongil Creek. Sustainability can be defined as capacity to endure, and thus the ability for systems to exist indefinitely. Sustainability within an urban context is often coined "sustainable development" and involves consideration of three factors: social, economic and environmental (Figure 1-3).

Using these three factors, a set of sustainability criteria have been developed to enable assessment of the sustainability of the various STP effluent release pathways/scenarios. These criteria are outlined in Table 1-1 (overleaf), and will be used to evaluate each of the alternative effluent release pathways.

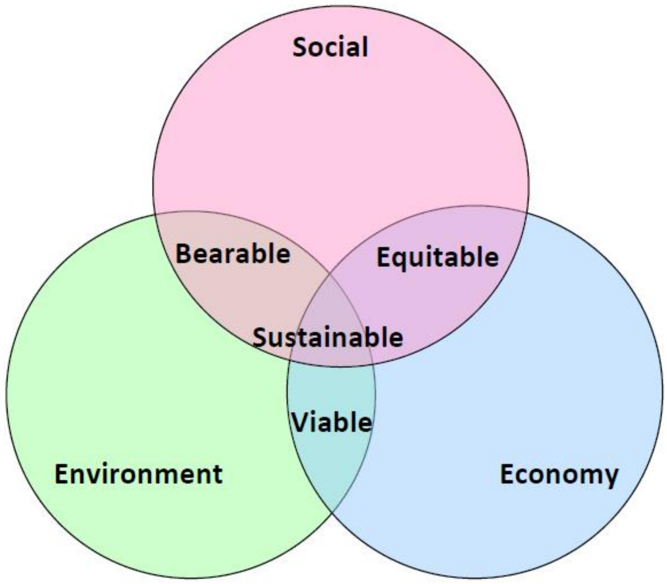


Figure 1-3: Factors governing sustainability

Table 1-1: Preliminary sustainable capacity assessment criteria

Relevant sustainability factor	Sustainability Criteria		
	Aim	Objective	Key assessment method
Social	Achieves the community's aspirations for sewage management in Byron Bay	Meets Council's vision and goals as stated in the Effluent Management Strategy (2006/ Doc #610368)	Qualitative assessment against objectives and recommendations
	Maintenance and improvement of the aesthetic and recreational values of the Belongil Catchment	Water level and conductivity regime of the Belongil Creek/Drain and ICOLL must not affect existing vegetation communities which may affect visual amenity of the Belongil Estuary.	Use of existing water quality models
Economic	Maintain and enhance economic value of the Belongil Estuary and its catchment.	Maintenance of the current and projected economic value of the current land use within the Belongil Catchment	Qualitative landuse value assessment Hydraulic / hydrologic model and water quality model
		Ensure preferred effluent discharge option is within Council's financial capacity.	Council budget
Environmental	Maintain and enhance downstream ecological values of the Belongil Creek, ICOLL and its catchment.	Reduction acid discharge events from the upper catchment: • pH levels within the Belongil Estuary should meet stated water quality objectives	Review past water quality data and known management of ASS on coastal floodplains of NNSW
		No deterioration of existing flora and fauna communities which inhabit the Belongil Creek and ICOLL	Hydraulic / hydrologic model
		Water quality and conductivity profile of the Belongil Creek and ICOLL should meet stated water quality objectives	Water quality model
		Reduction in peat fires	Hydraulic / hydrologic model
		No impact on tidal bird roosting at the mouth of the Belongil Estuary	Hydraulic / hydrologic model
		Meets the objectives and recommendations of the Belongil Estuary MP	Qualitative assessment against objectives and recommendations

2 The Byron Bay STP and the Belongil catchment

The BB STP forms a component of the Byron Bay Integrated Water Management Reserve (BBIWMR), located on a 100ha property off Bayshore Drive in the Belongil Creek catchment (Figure 1-1). The BBIWMR includes a 22ha constructed wetland system and a 24ha Melaleuca wetland effluent irrigation area. Land-use zones within the site include 5A Special Uses, 7A Wetland Zone (SEEP 14) and 7B Coastal Habitat Zone. Site topography is very flat (<2%) and of low relief - with the entire site below 10m AHD. The watertable throughout much of the Belongil Catchment is high, as indicated by the surface drainage system that directs most surface and groundwater flow to the Belongil Creek (Figure 1-1).

Historically, much of the Belongil catchment was waterlogged swamp or wetland, vegetated by wet heath and swamp plant communities. The catchment is low-lying, with most of the area below 4m AHD (ERM, 2001). The natural drainage pattern of the catchment has been altered by human activities such as sand mining in the northern dune system, drainage of land in the western and southern parts of the catchment and urban development in the east (ERM, 2001).

In 1913, following the clearing of wetlands within the catchment, the Union Drain was constructed (hand dug) by the Belongil Creek Drainage Union. The Union drain extends 3 – 4 km across the former wetland area with a network of drains feeding into it, eventually discharging to The Cape Byron Marine Park at the Belongil Beach.

It has been estimated that approximately 80% of the Belongil Creek catchment has been cleared and or drained (for residential, industrial, agricultural and pastoral uses) which has resulted in changes to both the flow and quality of surface and groundwater quality, including issues associated with Acid Sulphate Soils (ERM, 2001).

All land in the low lying areas of the catchment is prone to flooding when the entrance to Belongil Creek estuary is closed. Flood mitigation practices in the catchment have included drainage of wetland areas (as described above) and artificially opening the Belongil Creek estuary entrance to allow surface waters to escape into the ocean. Artificial opening of the estuary entrance has been occurring for approximately 50 years and were historically triggered when the water level at the Ewingsdale Road bridge gauge reached 1.2m AHD. Since 2001, the water level trigger for artificial estuary opening was reduced to 1m AHD following a recommendation in the Belongil Estuary Management Plan (2001) to reduce turbidity following openings. Investigations are currently underway into the potential impacts of the entrance opening regime on system hydrology and ecology.

2.1 Historical Studies within the catchment

2.1.1 Belongil Creek Estuary Processes Study (1997)

Objective: Data compilation study prepared to form the basis for the preparation of an Estuary Management Study for BSC. Belongil Creek Estuarine Management Committee was formed by BSC in 1994, with the objective to "ensure the long-term sustainability of the Belongil Creek, while managing estuarine resources for the community".

Study Area: Study area comprises the 30 ha Belongil creek system (ICOLL) & Cumbebin Swamp and the 2840 ha catchment which surrounds.

Hydrology and Water Quality: During storm events, rainfall runoff is enters the catchment through various drains. Flood levels have been modelled to reach levels of up to 2.6 AHD at the creek mouth. The West Byron STP, Sunny Brand Chicken Farm, Yagers Piggery, domestic rubbish tip, Byron industrial estate and township were all identified as point sources for pollution within the catchment. Over the monitoring period, levels of nutrients and faecal coliforms exceeded the ANZECC water quality guidelines (1992) for the primary contact recreation and protection of aquatic ecosystems (estuarine waters). A detailed assessment of groundwater hydrodynamics and quality was not undertaken. Chlorophyll-a levels were high, indicating eutrophication within the estuary.

Estuary Foreshore and Waterway Usage: Restricted access to majority of the foreshore due to intact riparian vegetation. Access was limited to recreational uses such as canoeing, fishing and occasionally swimming.

Hydrodynamic Processes: The main hydrodynamic processes affecting the opening and closure of the creek were onshore sand transport and catchment flooding. The entrance is exposed to northward littoral drift, caused by dominant south-easterly swells. The mouth of the estuary is breached by either mechanical opening by BSC or by built up floodwaters. Tidal ranges vary throughout the catchment, with average water levels vary from 0.2-1.2 AHD.

Ecology: During the study six vegetation communities, 55 Threatened fauna species, 57 fish species and 7 nationally rare or Threatened plant species were identified to occur currently or in the past. Overall the creek was observed to have high levels of biodiversity and environmental value however fish kills have been recorded in the past after heavy rainfall (low DO and pH).

Conclusion: Belongil Creek ICOLL – medium to poor water quality, water quality decreases after heavy rainfall or when entrance is closed. Increasing developments within the catchment likely to increase the negative effects associated with storm water runoff and waste discharges.

2.1.2 Belongil Estuary Study and Management Plan (2001)

Objective: Create an integrative management plan to "sustain a healthy productive and attractive estuary where balanced and co-ordinated management of resources ensures sustainability of diverse natural systems whilst maintaining or meeting community needs.

Study Area: Belongil Estuary, Cumbebin Swamp and surrounding slopes.

Current pressures on the estuary include: poor storm water quality originating from urban and rural precincts, acid runoff (from rural areas during adverse seasonal conditions) and potentially from point sources of pollution (old landfill site at Butler street, WB STP and Sunnybrand Chicken Factory – circa 2001).

Threatening processes include invasion of exotic species (namely Bitou Bush) and introduction of feral animals (dogs and foxes).

Community perception that wastewater discharged from WB STP has resulted in pollutants being retained in the estuary when the mouth is closed. Results from this study suggest that this community view is not correct and ASS present a much greater risk to ecosystem health. Study into water quality, ASS soils, entrance management, recreation and visual amenity, riparian zone management, flooding, estuary and wetland ecology, cultural heritage, development.

Brief History: Large areas of Cumbebin wetlands cleared in 1960-70s. Construction of drains allowed the agricultural use of low lying previously swampy sites.

Key values: The plant and animal communities of the Belongil Estuary and catchment are diverse and of considerable conservation significance. They include the wetlands of the Cumbebin Swamp and other smaller areas of State significance. Additional areas of conservation importance include floodplain rainforest in the upper catchment (an endangered ecological community), eucalypt and mangrove forest and woodlands, littoral rainforest, saltmarsh and estuary flats. Habitats within the Belongil catchment support over 60 threatened species, including an endangered land snail, several frogs and numerous birds and mammals.

Water/Soil: The Belongil Estuary is impacted by poor quality stormwater. This stormwater originates from urban and rural precincts, acid runoff from rural areas during adverse seasonal conditions, potential point sources of pollution and potential impacts that relate to residential development within the catchment.

The soil profile of the catchment consists of the following soils which may contain potential acid sulfate soils (PASS): estuarine sediments, sandplain and swamp soils. Tulau (1999) identifies the Belongil catchment as a "hotspot" for ASS. Past studies have identified that no lowland sites near the lower estuary were found to contain acid sulfate soils, however several samples found PASS (acidity increase with depth).It is suggested that the "geology of the estuarine and floodplain deposits are complex and cannot be fully characterised without more data".

Urban stormwater management and the artificial opening of the estuary entrance: Poor water quality in terms of ANZECC Guidelines, particularly in relation to DO and faecal coliforms. Surface sediments were not contaminated by organochlorines, hydrocarbons, heavy metals or inorganics.

Management (High priority): reduction of pollutant loads at source, complete Butler Street wetland system.

2.1.3 Byron Bay Sewerage Augmentation Scheme– Environmental Impact Statement [EIS] (2001)

Objective: Assess potential impacts to the environment resulting in the upgrade of the WB STP

Study Area: WB STP, Belongil Creek, Estuary and Catchment

Surface and ground water: Negligible increase in nutrients delivered to the Belongil Estuary, with no net increase in nutrient loads delivered to the estuary post upgrade of the WB STP (achieved via effluent reuse projects). Creation and management of a 24ha effluent irrigation area will result in a decrease in acidic runoff from ASS. While no flooding is predicted within the vicinity of the WB STP as a result of the upgrade, BSC commits to assisting local landholders in drain maintenance. It is predicted that there would be no adverse effect on groundwater resources in the region, or impact on the properties of the surrounding landholders.

Terrestrial and aquatic ecology: With the construction of the 24ha effluent irrigation area, Grass Owl and Acid Frog Habitat was lost. This impact was addressed via the preservation and conservation of land in the north west of the WB STP land. No impact was predicted on aquatic ecology.

Social Benefit and Human Health Risk: Numerous benefits were reported in regards to the upgrade of the WB STP. These mostly included benefits surrounding the closure of the South Byron STP and the inclusion of UV disinfection as part of the proposed upgrade to the WB STP.

Heritage: No currently known sites of Indigenous cultural significance would be affected by the Project. A portion of the proposed pipeline route would pass through the site of the early village of Cavanbah. Archaeological assessment of the section of the pipeline route through Cavanbah would be undertaken prior to construction.

Other Anthropogenic disturbances (Air, Noise & Visual, Traffic): No adverse odor expected, decrease in odor at the South Byron STP site. Increased noise and vehicle traffic during construction phase; will return to normal following construction. Visual impact will be minimal; the proposed Melaleuca regeneration to the south of West Byron STP would enhance the scenic quality.

Conclusion: As part of the proposed upgrade to the WB STP, various construction, operational and monitoring plan where suggested to ensure that predicted impacts were mitigated.

2.1.4 Belongil Creek Entrance Opening Strategy (EOS): Review of Environmental Factors (2005)

Objective: To address the potential impacts associated with the opening of Belongil Creek entrance.

Impacts: Direct impacts include physical damage to dune infauna and flora associated with opening of the entrance using machinery and access routes used by the machinery. These impacts are expected to be minor, however the works will have an impact on threatened species habitat (turtles and Little Terns). In contrast, indirect impacts are likely to be diverse and extensive throughout the catchment. This is due to the extensive low relief wetland system adjacent to the current estuary. Physical impacts are likely to include: lowering of groundwater levels, changes in surface water hydrology of swamps, divergence from the natural breakout range, reduction of areas inundated by floods, increased tidal influence, increased transport of ASS products from the soil profile, increased salt penetration, extreme water quality events, flocculation events, increased marine influence on estuary, increased oxidation of PASS, changes to coastal erosion. These physical changes will impact on the hydrology resulting in flow-on effects on agricultural and urban drainage and vegetation communities. More specifically physical impacts may have the following effects on ecological values: decline in seagrass, reduction in area of non-forested freshwater wetlands, changes to swamp forest vegetation, mangrove increase, loss of sandflats/saltmarsh, change in mangrove diversity, erosion of littoral rainforest at the entrance, direct impact on weed spread, shift from ICOLL to estuarine fish assemblages, fish kills and their associated impacts on fauna habitat.

Threatened species assessment: The report has concluded that the following species are known to or have the potential to occur within the study area: Mitchell's Rainforest Snail, Wallum sedgefrog, Marine turtles, Osprey, Migratory shorebirds, Pied oystercatcher and Little tern

Alternatives: Several alternatives are proposed including: alleviate flooding in the urban and industrial areas of Byron Bay, mitigate fish kills associated with high flow events, protection of ecological communities that have arisen in response to the historical opening regime, mitigate the impacts of ASS runoff.

Long Term Recommendations: Given that many of the draft EOS impacts that trigger an EIS may be effectively mitigated by current initiatives in ASS, stormwater and drainage management, the study recommend that resources may be most effectively used by postponing the commencement of any EIS, until revised management strategies and mitigation strategies have been put in place, and a revised EOS has been drafted. It is recommended that an integrated approach to management and planning be developed as soon as possible. Predicted sea level rise (0.5m by 2100; WBM, 1999) will render artificial entrance opening largely ineffective for the mitigation of flooding in Byron Bay due to possible inundation from the ocean. The EOS should therefore avoid promoting false expectations in the community with regards to "flood proofing" by artificial entrance opening.

Short Term Recommendations: Due to the potentially long time frame required to establish a total catchment plan, the several short term actions are recommended for the interim.

2.1.5 The Byron Effluent Reuse Wetland Scientific Report (2006)

Objective: Seven Chapters that investigate the science and implementation of the effluent irrigation project at the BB STP.

History of the peat acid sulfate soil: The Byron Bay peat-lands are low lying coastal peats that have formed in the interdune swale. Pollen and phytolith records and Charcoal counts indicate peat forming vegetation is composed of Sphagnum, *Cyperaceae* and *Restionaceae* species throughout its history and that the area has experienced an increase in fire activities over the past 5000 years.

Acid sulfate soil distribution: Of particular importance, this study identified the presence of two distinct pyrite layers within the peat profile. This study also demonstrated that there are actionable concentrations of pyrite throughout the entire peat soil profile of the effluent reuse site. It is therefore likely that some acid products will be generated at any time that the groundwater levels are below field capacity. The presence of two pyrite layers poses important management considerations, and these are explored more thoroughly in later chapters. The subsurface pyrite layer was accreted more than 5,000 years ago when sea levels were around 1m higher than present levels. At this time, the wetland was an inland estuary with an environment high in sulfate, iron and organic material – the necessary ingredients for pyrite production.

Acid sulfate soils, pyrite dynamics: The acid sulfate soil mapping programme (Chapter 4) clearly demonstrated the presence of surface pyrite in the waterlogged area in the eastern portion of the effluent reuse wetland, no evidence of significant surface pyrite deposits in the non-waterlogged sites. The presence of surface pyrite in the effluent-logged site meant that effluent irrigation could result in the build-up of potential acidity. Surface pyrite layers were found to form when the peat soil remains waterlogged for extended periods of time, creating highly reducing conditions. Waterlogging for a decade in the eastern portion of the site resulted in a concentrated pyrite layer, pyrite formation is an acid consuming reaction. The almost neutral pH levels and low redox values in the waterlogged eastern portion of the site, in which high concentrations of surface pyrite were measured, bear testimony to the acid consuming nature of pyrite formation. However, when the water table falls after periods of extended waterlogging, this quickly exposes the pyrite layer to atmospheric oxygen, resulting in oxidation and the subsequent liberation of acidity.

Acid sulfate soils: pyrite formation – pot trials: This chapter presented results from a controlled pot-trial experiment that examines some key questions:

1. Does effluent increase the rate of surface pyrite formation?
2. Does the height of the water table affect the rate of surface pyrite formation?
3. Can pyrite formation be suppressed by fluctuating the water tables?

This experiment demonstrated that

- **Effluent promotes the formation of surface pyrite.** Surface pyrite management must therefore be a primary management consideration for the Byron Effluent Reuse Wetland.
- **Ponding water promotes pyrite formation.** The management regime of the wetland should minimise surface ponding, especially for prolonged periods of time.
- **Fluctuating the water table decreases the rate of pyrite formation.** A fluctuating watertable inhibits the rate of surface pyrite formation, and the higher the frequency of

fluctuation, the greater the inhibition. The management regime should aim to maximise the rate of fluctuation.

Melaleuca growth and establishment: Between December 2001 and December 2005, approximately 700,000 Melaleuca saplings were densely hand-planted in the 24 ha Byron Effluent Reuse Wetland with the aim of establishing a Melaleuca wetland that approximates the ecological nature of its predevelopment state

2.1.6 Byron Bay Effluent Management Strategy

Objectives: Objectives of the Byron Bay Effluent Management Strategy include: eliminate surface discharge to Belongil Creek from the West Byron STP; maximise the creation of useful products from effluent reuse projects; link the development of effluent reuse options with the progressive increase of load to the West Byron STP; use effluent to achieve broader environmental objectives e.g. acid sulphate soil remediation and habitat regeneration; understand, monitor and manage the impact of effluent discharge to the Belongil catchment; maximise evapotranspiration as the preferred mechanism for assimilation to the environment; use assimilation pathways and practices to produce effluent surface water run-off that mimics background environmental flows; and prioritise and resource effluent management appropriately.

The Byron Bay Effluent Management Strategy (BBEMS) addresses how objectives in the BBWSC will be achieved. The scheme covers specific projects, effluent reuse potential and timeframes. Three major areas of effluent reuse potential were identified in the development of this strategy and presented in the Program: Urban Reuse Corridor; Regeneration Projects; Rural Lands Projects.

Effluent reuse provisions are identified in this Strategy to address the short-term loading with the transfer of the South Byron STP. This will ensure that there is no negative impact upon the Belongil Creek due to effluent discharge.

Urban Reuse Corridor: The Byron Bay Sewerage Augmentation Scheme required a sewage rising main to be constructed to transfer the existing South Byron STP sewage load to the West Byron STP. Construction of this major rising main provided the opportunity to lay a return effluent pipeline in the same trench. The urban reuse corridor is a strategically significant opportunity for effluent reuse both now and into the future. Potential constraints such as availability of suitable soils and shallow water tables will need to be managed.

Regeneration Projects: The West Byron Melaleuca Wetland Regeneration Project involves the regeneration of native melaleuca wetland on a 24-hectare area in the southwest corner of the West Byron STP site. The project will achieve the objectives of acid sulphate soil remediation, wetland regeneration, habitat restoration and effluent reuse. The combination of effluent reuse potential with other valuable environmental outcomes makes regeneration projects highly desirable. However, the extended period required to establish and mature these projects means that other effluent reuse applications are required in order to achieve the minimum requirement

Rural Lands Projects: Effluent reuse opportunities include irrigation of pasture, crops and forestry in areas that have the most suitable soils for effluent irrigation. Land suitable for rural lands projects exist to the west of the West Byron STP site.

Conclusion: Maximising all effluent reuse opportunities (urban corridor, regeneration projects, and rural lands projects) will help to improve the water quality in Belongil Creek.

2.1.7 Bryon Bay Integrated Water Management Reserve Groundwater Impact Verification (2010)

Objective: The objective of the report was to provide a review of previous studies on modelling used as part of the 2001 Environmental Impact Statement and potential groundwater impact of the BBIWMR on local and surrounding environments of the Belongil Catchment. The primary aim of this report is to verify the predictions made in computer simulation models used to assess the likely impacts of the BBSAS on groundwater levels and quality. The degree of certainty will be assessed by comparing modelled data (PPK 2001) with actual data that has been collected since 1999.

Findings: Comparison of the PPK MODFLOW model (2001) with field data measured between 1999 and 2009 was undertaken, and it can be concluded that the model parameters and outcomes derived by PPK (2001) accurately reflect the hydraulic behaviour of the catchment watertable.

Conclusion: The report draws the following conclusions: Watertable fluctuates in accordance with rainfall events, effluent irrigation or increases in BB STP load has little influence on watertable level; on average, the quality of groundwater the catchment has not decreased since implementation; it is unlikely that the BBIWMR will have any impact on upper catchment flooding due to the extensive network of drains within the BBIWMR and the Belongil catchment (assuming the Belongil Estuary artificial opening strategy is maintained); data collected since 1999 correlates with models used in the BBSAS EIS; and analysis of the watertable within study area demonstrated that on site irrigation practices implemented since 2004 have not had an adverse impact on groundwater quality or the standing water level (SWL) of the aquifer/s.

3 Acid sulfate soils and hydrogeology

Soil on the south-western quarter of the BBIWMR are Holocene aged (<10,000 year old [yo]) clay, silt and peat, while soil over the remainder of the site and to the north, east and south-east of the site are shallow hardened Pleistocene aged (1.6 million yo [Myo] to 10,000 yo) sediments. Most of these geological formations can potentially form acid sulfate soil (ASS), with the entire BBIWMR falling within a "high priority area" for ASS as demarcated by Tulau (1999).

Groundwater beneath the BBIWMR can be classed as an unconfined aquifer (see glossary) and rapidly receives water via infiltrating rain and surface water, discharging to the comprehensive drainage system within the Catchment. The aquifer consists of three main geological units (all alluvial):

- upper sand (top unit) which is extremely permeable (Holocene aged);
- underlying hardened sand (Pleistocene aged 'coffee rock'); and
- a deeper sand unit (Pleistocene aged dune sand).

The upper sand unit is reported as being 2-3 metres thick (from the surface) and is in hydraulic connection with Belongil Creek and local drains and lagoons with a watertable at about 1.0-1.5 metres depth.

The underlying hardened sand contains a dark coloured organic zone and reduced permeability at close to 0 m AHD (reported to be continuous beneath the site). This layer has been cemented in places and has a measured hydraulic conductivity (K, see glossary) in the order of 0.1 m/day (AGC 1997, p2.1). It is therefore hypothesised that this layer may actually act as a barrier to deeper percolation of groundwater and facilitates horizontal shallow migration of groundwater to local discharge points.

The deeper sand unit is reported to consist of interbedded sands, gravels and silty clays above bedrock (reported to be at between 20 and 40 metres depth in the area) with a measured K in the range of 10-50 m/day (PPK 2001, Table 5.17 p103).

The unconfined aquifer beneath the BBIWMR is regionally significant because of its reasonable to fair quality and yield (0.5-2.0 L/sec), however, based on registered users it is not highly used (e.g. In July 2000 there were eight registered private groundwater users in the catchment, ERM (2001)).

Other groundwater users may include registered spear points along the Belongil dune ridge. ERM (2001, p10.24) report this use to be "fairly common" but limited to "watering of gardens". Such occurrence is not expected to influence the hydrogeology either at or surrounding the BBIWMR.

A preliminary assessment of the presence for Acid Sulfate Soils (ASS) has been undertaken across farm land adjacent to the BBIWMR, as shown in Figure 3-1. Previous documentation on the presence of ASS in this area is lacking and there have been general mixed thoughts among stakeholders as to whether ASS is present across this area. The aim of this assessment was twofold:

1. Identify the presence, depth and strength of ASS, and
2. Assess soil and hydrogeology across investigation zone to determine possible connection of groundwater between the BBIWMR and farm land to the west.

As shown in Figure 3-1, the area of investigation is mapped as having a high probability of occurrence of ASS, with Byron Shire Council also mapping the area as Class 2 Acid Sulfate Soils on the Byron Local Environment Plan 2014 (Acid Sulfate Soils Map – Sheet ASS_003). While these maps do not describe the severity of acid sulfate soils, they do provide a preliminary indication that acid sulfate soils could be present in those areas.

3.1 Methods

After determination of probability of ASS occurrence through a desktop assessment (see above), a detailed soil investigation was carried out to including field tests of soil properties, soil sample collection and laboratory analysis. It must be noted that the investigation was not in accordance with the ASSMAC Guidelines (ASSMAC, 1998) in that the density of samples boreholes was reduced and the depth was preliminary only and not specific to any proposed excavation depths.

Nine boreholes were made to a depth of approximately 2.0m, using a Dormer hand auger at the locations shown on Figure 3-1. Each borehole had the following assessment/investigation undertaken:

- Determination of soil properties through field tests including colour, texture and structure through each profile, and
- Soil samples taken:
    - at 500mm increments, or change in soil type in the profile
    - to a depth of 2.5m where possible
    - no sample was taken if the soil was predominantly peat material

The laboratory analysis of soil was undertaken at SCU Lismore to determine the presence of Potential ASS and Actual ASS.

The elevation of each borehole was obtained via LIDAR information taken from the locations of each borehole within a GIS platform.

In accordance with methods outlined in Hirst et al (2009), the saturated hydraulic conductivity (Ksat) of the soil within land adjoining the BBIWMR was assessed at two sites, as shown in Figure 3-1. Saturated hydraulic conductivity of soil defines its ability to transmit water when subject to a hydraulic gradient. In the case of the land adjoining the BBIWMR, this hydraulic gradient can be described as water flow from the paddock through the drainage system or from the groundwater to the surface water within the drains.

The test used can be defined as a modified shallow pit test based on established field based methods outlined in Bouwer and Rice (1983) and Boast and Langebartel (1984) and allows for the rapid assessment of Ksat in shallow groundwater environments.

At each of the sites shown in Figure 3-1, two 50cm x 50cm x 60cm (L x W x D) test pits were dug (Plate 3-1) and a 80cm Odyssey water level logger positioned to record changes in the level of water within the pit. Using a 10L bucket, water within the pit was rapidly bailed out and the logger set to record the level of water within the pit every 5secs. Each pit was assessed three times.

Test pit 1

Test pit 2

Plate 3-1: Photograph of test pits located in land west of the BBIWMR (refer to Figure 3-1.

Date: 9 October 2016
GDA 1994 MGA Zone 56
Date source:
Aerial - NearMap Pty Ltd 2016
Study Site - AWC
Acid Sulfate Soil Risk - NSW Dept Planning and Environment

AWC

Figure 3-1: Borehole locations for ASS preliminary assessment

3.2 Results and discussion

3.2.1 Acid sulfate soil and geology

Appendix A displays bore logs for each bores assessed, showing elevation of soil layers, soil descriptions and the location of samples taken for ASS analysis. A summary of the pertinent information obtained from each bore is displayed in Table 3-2. The bore logs taken from this assessment show that there is typically peat dominated topsoil over the area of investigation. The depth of this layer varies across the site. Beneath the consolidated peat topsoil horizon a layer of peat/sand clay with a very low bearing capacity is common which forms a sloppy mud when trying to extract. A mix of sand layers and/or clay subsoils were encountered that form an aquitard, accentuating the saturated nature of the upper layer. Appendix A displays bore logs and descriptions from all bores 1 through to 6.

The determination of Potential Acid Sulfate Soil (PASS) is dependent on soil texture and values of reduced inorganic sulfur provided by laboratory analysis; these values are provided in Table 3-3. Displayed on the bore logs within Appendix A, soil samples were taken for the laboratory analysis of ASS at all sites. A summary of these results are provided in Table 3-3, with full laboratory results provided in Appendix A.

Sixteen of the 28 samples collected across the nine boreholes indicated the presence of PASS, with many being substantially above the classification value, with PASS present at all boreholes. Generally soil underlying the peat showed signs of the presence of PASS/ASS. This soil was generally classified as a coarse grey/brown sand, often wet and unconsolidated. Comparing these results with that of work undertaken in the preparation of the BBIWMR Environmental Impact Statement (EIS) indicates some small changes to the geological conceptual site model is required.

The Byron Bay Sewerage Augmentation Scheme– Environmental Impact Statement (2001) reported a Holocene peat/mud underlain much of the BB STP area, with a low saturated hydraulic conductivity (kSat) of 0.2m/day). The bore logs conducted as part of this project have confirmed that this low saturated hydraulic conductivity peat/mud layer is not present beneath the effluent irrigation area or the area south of the effluent irrigation area. Rather, the high kSat (25m/day) Holocene sand is present, extending westward to Moran's Hill, and the Upper Union Drain. Additionally, a narrow band of clay is present running parallel with the Upper Union Drain, extending at least 1m below the peat topsoil. An updated geological conceptual model of the BBIWMR and adjoin land is presented in Figure 3-3, showing the approximate location of soil bores, key geographical features and various components of the BB STP. As can be seen on this figure, a highly porous Holocene Sand is present below the irrigation area and wetlands drains/ponds, extending into the farmland to the west of the BBIWMR.

As shown in Figure 3-3, the invert of the Upper Union Drain and Moran's Hill Drain sites at approximately 1.5mAHD, intercepting the Holocene peat layer and extending into, but through, the Holocene Sand layer. Drawing on data and information taken from the Bryon Bay Integrated Water Management Reserve Groundwater Impact Verification study undertaken in 2010, groundwater moves in a westerly and southerly direction from the BBIWMR.

3.2.2 Saturated hydraulic conductivity

Using the data analysis methods outlined in Hirst et al (2009), the Ksat at each of the sites was estimated. As shown in Figure 3-2, the time it took for the test pits to refill with water was short, with each of the pits reaching 80% static water level in under 5 minutes. This rate of water influx, based on Hirst et al (2009), equates to a high Ksat value, with both pits yielding values between 15 and 100 m/day (Table 3-1).

These results are inconsistent with that previously reported for the Holocene Peat Layer, which was reported to have a low Ksat value of 0.2m/day (Byron Bay Sewerage Augmentation Scheme– Environmental Impact Statement, 2001).

Table 3-1: Ksat results from Test pits 1 and 2.

	Pit 1	Pit 2
Depth to water table	16cm	20cm
Pit width and breadth	50cm x 50cm	50cm x 50cm
Pit depth	60cm	60cm
Test 1	>15, <100m day	>15, <100m day
Test 2	>15, <100m day	>15, <100m day
Test 3	>15, <100m day	>15, <100m day

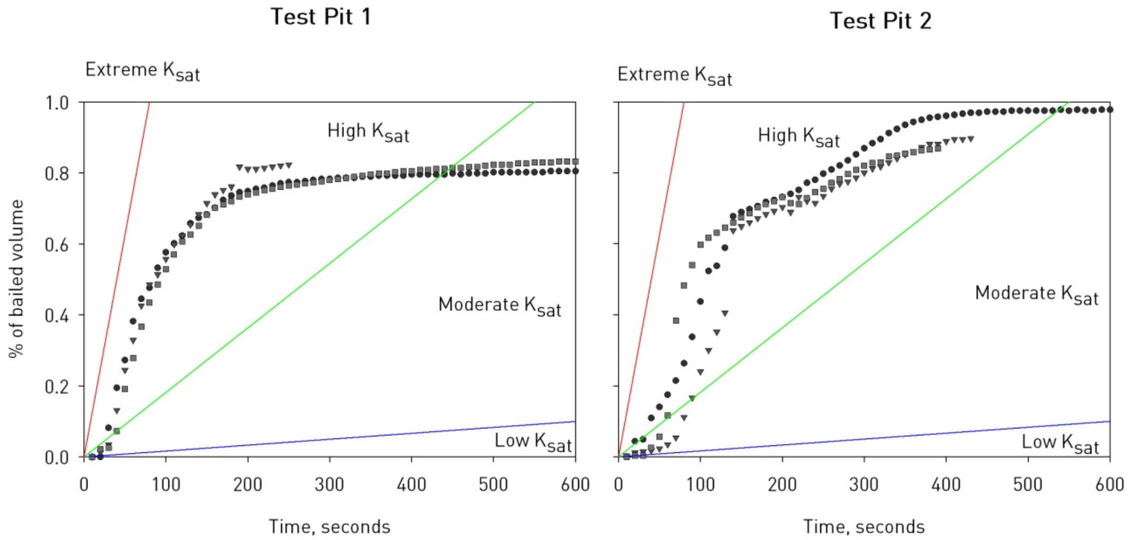


Figure 3-2: Graphs used to estimate Ksat. Different plots on each graph relate to replicate assessments.

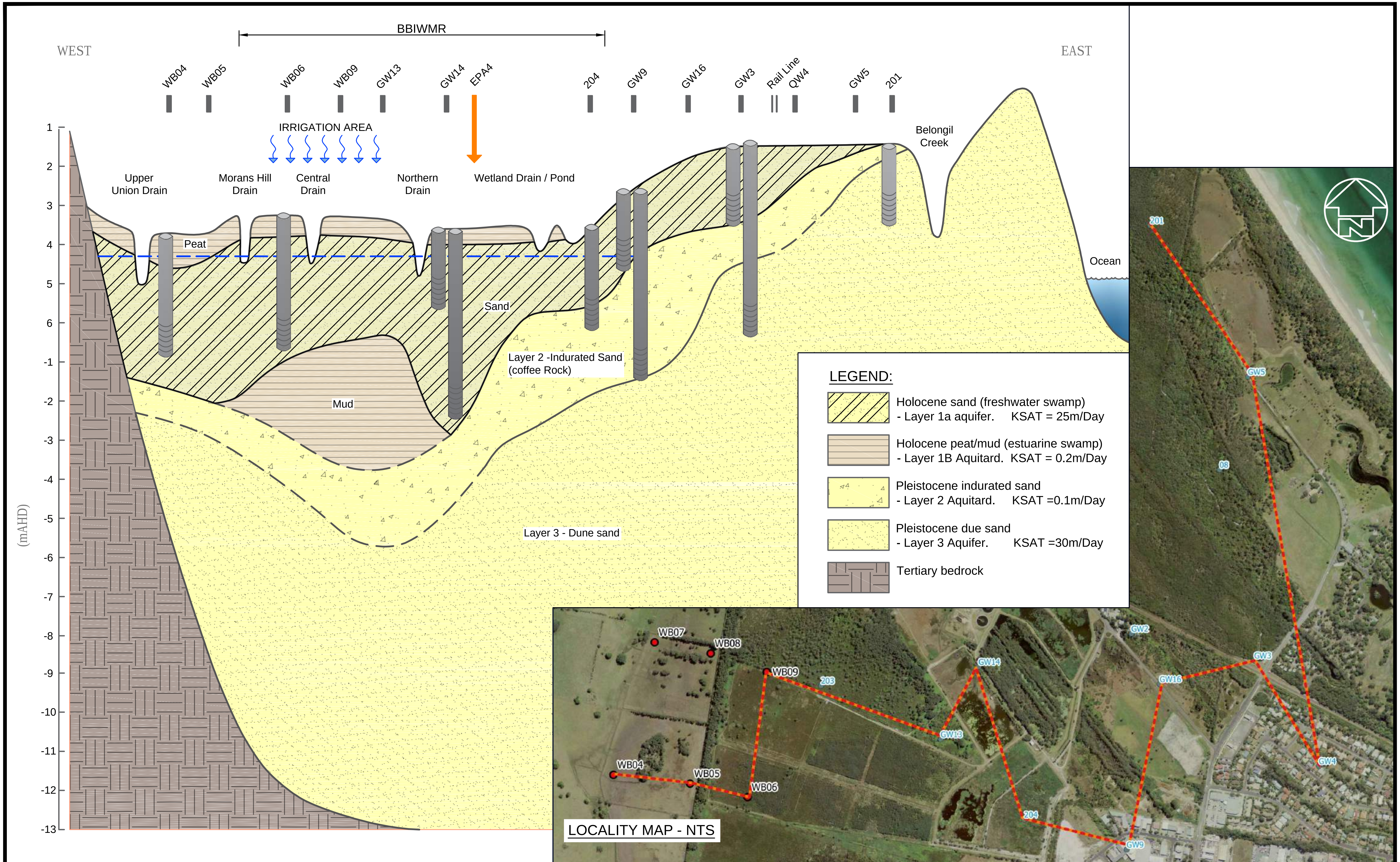
Table 3-2: Basic soil characteristics at each bore

Bore	Elevation (mAHD)		Soil Type	Description
	From	to		
WB01	1.57	1.07	Peat	Dark brown. High organic matter content. Extensive root component in top 200mm
	1.07	-0.43	Sand	Coarse, dark grey. Wetter and less bearing at depth, increase in fine material.
WB02	1.99	1.49	Peat	Dark brown. High organic peat topsoil
	1.49	0.74	Sand	Coarse, dark grey. Abrupt change to coarse grey sand
	0.74	-0.01	Sand	Coarse, brown. Very low bearing. Could not collect samples deeper than 1.5m due to sloppy soil
WB03	2.19	1.39	Peat	Consolidated brown peat with high density roots. Wet.
	1.39	0.99	Peat	Dark drown unconsolidated peat
	0.99	0.19	Sand	Loose/unconsolidated with trace of clay
WB04	1.79	1.49	Peat	Dark brown
	1.49	1.39	Sand	Coarse, dark grey
	1.39	0.49	Clay	Grey/brown fine clay, wet, very low bearing capacity
	0.49	0.29	Sand	Grey coarse sand, unconsolidated. Wet.
WB05	2.09	1.19	Peat	Dark brown
	1.19	0.89	Sand	Coarse, dark grey
	0.89	0.29	Sand	Coarse grey/Brown
	0.29	-0.31	Sand	Coarse grey, compact
WB06	2.79	0.99	Peat	Dark brown peat, roots in top 500mm. Wet. Becoming more loose/unconsolidated with depth
	0.99	0.79	Sand	Grey sand. Wet. Very loose/unconsolidated
WB07	2.16	1.86	Peat	Dark brown peat topsoil
	1.86	1.76	Clay	Mottled grey/orange very stiff clay, variable structure
	1.76	0.16	Clay	Medium grey very stiff clay, Wet
WB08	2.21	1.71	Peat	Brownish/black peat topsoil. Wet.
	1.71	1.31	Peat	Dark brown/grey sand with minor peat. Wet
	1.31	0.21	Sand	Coarse dark grey/brown sand. Wet
WB09	2.44	1.74	Peat	Dark black/brown peaty sand topsoil. Moist.
	1.74	0.44	Sand	Brown sand, loose and wet. Unconsolidated

Table 3-3 Laboratory results - Acid Sulfate Soil (shaded cells infer positive determination of PASS)

Bore	Laboratory sample	Depth, mm	Texture#	Reduced Inorganic Sulphur (% chromium reducible S)	
				(%Scr)	(mole H+/tonne)
WB01	WB - 1 A		Fine	**1.017**	**634**
	WB - 1 B		Fine	**0.840**	**524**
	WB - 1 C		Fine	**1.444**	**901**
WB02	WB - 2 A		Medium	**0.957**	**597**
	WB - 2 B		Medium	**0.171**	**107**
	WB - 2 C		Medium	**0.149**	**93**
WB03	WB - 9A		Medium	**0.242**	**151**
	WB - 9B		Medium	0.024	15
WB04	WB - 4 A		Medium	**0.339**	**211**
	WB - 4 B		Fine	0.042	26
	WB - 4 C		Medium	0.029	18
WB05	WB - 3 A		Fine	**1.159**	**723**
	WB - 3 B		Fine	**0.796**	**496**
	WB - 3 C		Fine	0.064	40
	WB - 3 D		Medium	**0.293**	**183**
WB06	WB - 8A		Coarse	**0.751**	**468**
WB07	WB - 5 A		Fine	0.017	11
	WB - 5 B		Fine	0.013	8
	WB - 5 C		Fine	0.051	32
	WB - 5 D		Fine	**0.100**	**62**
WB08	WB - 6 A		Fine	0.018	11
	WB - 6 B		Fine	0.060	37
	WB - 6 C		Coarse	0.024	15
	WB - 6 D		Coarse	**0.030**	**19**
WB09	WB - 7 A		Fine	0.051	32
	WB - 7 B		Fine	**0.511**	**319**
	WB - 7 C		Fine	0.031	19
	WB - 7 D		Medium	**0.073**	**46**

Classification of Potential Acid Sulfate Soil material if: coarse Scr>0.03%S or 19mole H^+/t; medium Scr>0.06%S or 37mole H^+/t; fine Scr>0.1%S or 62mole H^+/t (Source: EAL results sheet as per QUASSIT Guidelines)



AWC
Australian Wetlands Consulting Pty Ltd
PO Box 2605 / 70 Butler Street
Byron Bay NSW 2481
P (02) 6685 5466 | F (02) 6680 9406
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CLIENT: Byron Shire Council

DO NOT SCALE FROM PLANS, TO BE ADAPTED ON SITE BY CONTRACTOR & CONFIRMED BY PROJECT SUPERVISOR, SIZING, CALCULATIONS, STRUCTURES, & COMPACTION TO BE CONFIRMED BY ENGINEER OR SUITABLY QUALIFIED PERSONS. ENGINEERS CERTIFICATE BY OTHERS.

REV.	ISSUE / AMENDMENTS	DATE
A	FOR DISCUSSION	22/ 11 / 2016

DESIGNED: MB
DRAWN: SS
CHECKED: MB

PROJECT: WEST BYRON SEWAGE TREATMENT PLANT (WBSTP), NSW

DRAWING: CONCEPTUAL SITE MODEL WEST - EAST FIGURE 3.3

DWG No. AWC_1_16722_STP_01

CAD FILE No. 1_16722_BYRONSTP.DWG

REV.

SCALE: NTS

DRAWING CREATED: 10 / 09 / 2016

3.3 Conclusion

The presence of ASS and PASS was confirmed on land within and adjoining the BBIWMR and effluent discharge location on all soils beneath the topsoil – with the exception of a small number of samples of 'clay' located in a lens running north/south alongside Morans Hill Drain. Topsoil across the effluent irrigation area and farm land west of the BBIWMR is dominated by peat, with a high saturated hydraulic conductivity. A high water table was present at all soil bore sites, with indurated sand underlying all soil bores.

An updated conceptual site model of the BBIWMR and adjoining farmland was built. From this updated model it can be seen that there are limited pathways for effluent loss within the upper groundwater system. This is attributed to:

- the indurated sand layer preventing vertical loss of groundwater to the tertiary dune system,
- basalt rock to the west prevents western movement of groundwater,
- the railway track to the north, and
- Ewingsdale road to the south.

Since 1997 no acid discharge events or peat fires has occurred from the Upper Union Drainage catchment – two types of negative environmental events known to have occurred across this area in the past.

4 Assessment of the current fate of effluent delivered to the BB STP, CW and irrigation area

Effluent from the BB STP is lost via four main pathways: 1) discharge to the upper union drain; 2) discharge via irrigation of 24ha of floodplain forest regeneration; 3) discharge to the urban water reuse scheme; and 4) evapotranspiration from the 22ha constructed wetland system and 24ha effluent irrigation area. Drainage of effluent from the BB STP is primarily governed by a weir location within the BBIWMR prior to effluent entering the Upper Union Drain catchment. This weir provides permanent inundation of most land south of the effluent irrigation area and west of the Cavanbah Sports Centre. A secondary hydrologic control for STP effluent draining from the Upper Union Drain catchment occurs at the pipes flowing south within the Union Drain on Ewingsdale Road. In recent years there has been concern and speculation as to the ultimate fate of effluent discharged within the BBIWMR and its influence of the broader hydrology of the Belongil Catchment. This section of the report aims to collate historical information regarding the effluent release from the BBIWMR, artificial Belongil Estuary opening events, Union Drain water levels, local hydrogeology and stable isotope analysis, with the information used to investigate the fate of effluent discharged with the BBIWMR.

4.1 Methodology

A data set spanning from April 2000 to October 2016 was assessed for trends in effluent discharge, effluent irrigation, rainfall and estuary artificial opening events. This data was sourced directly from BSC. Over the last 5 years, numerous water level loggers (Odyssey Capacitance Water Level Loggers, 1.0 – 1.5m length) have been placed in the Union Drain System, one logger (Ewingsdale Bridge) has been deployed for 5 years, while others have only been deployed for 1-2 years (Table 4-1). Three loggers have also been placed in bores within the upper drainage catchment to assess fluctuations in water table movement. Each water level logger had been set to record water level every 10mins, and survey into to mAHD to display water level / water table height in mAHD. Figure 4-1 displays a map, showing the location of these water level loggers, and the date in which they were deployed.

Over the past 10-20 years 'Stable Isotopes' have been used to trace sewage plumes in both aquatic and terrestrial environments. This 'tracing' technique is based on the phenomenon that the source of energy and trophic connectivity within an ecosystem can be traced via stable isotopes. For example, stable nitrogen and carbon isotope ratios from human and animal sewage can be compared to that of the stable nitrogen and carbon isotope ratios within the receiving environment to help determine the flow pathway of effluents within the receiving environment. Samples within a receiving environment that have a 'Human Sewage Signature' indicates that those particular components of the ecosystem are obtaining nutrients sourced from effluent. Over 50 aquatic plant samples were taken within and adjoining the effluent irrigation area for analysis of both carbon and nitrogen stable isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$), at the site shown in Figure 4-1.

Table 4-1: Logger deployment information

Logger Name	Serial Number	Level datum	Date installed	Last download	Date removed
Logger 1	4720	mAHD	29 April 2015	9 June 2016	9 June 2016
Logger 2	4738	mAHD	29 April 2015	Still deployed	30 November 2016
Logger 3	4739	mAHD	29 April 2015	9 June 2016	9 June 2016
Logger 4	4737	mAHD	29 April 2015	Still deployed	30 November 2016
Logger 5	42111	mAHD	29 April 2015	Still deployed	30 November 2016
Logger 6	4740	mAHD	28 April 2015	Still deployed	30 November 2016
Bore North	42110	mAHD	21 May 2015	9 June 2016	9 June 2016
Bore South	42112	mAHD	21 May 2015	Still deployed	30 November 2016
Bore East	4298	mAHD	21 May 2015	Still deployed	30 November 2016
Ewingsdale Bridge	42494	mAHD	3 June 2011	Still deployed	30 November 2016

Project: Byron Bay STP alternative effluent release assessment

Figure 4-1: Location of ydroperiod loggers, effluent discharge points and stable isotope collection points

4.2 Results and Discussion

4.2.1 Assessment of effluent discharge volumes and artificial estuary opening events

Effluent delivery to the BB STP increased in 2006 with the closure of the South Byron STP. As shown in Table 4-2, raw influent into the BB STP increased from median 2ML/day in 1999-2005 to median 4.6ML/day from 2006 onwards. While some of this inflow is reused via the 24ha effluent irrigation scheme or urban reuse (median 0.8ML/day), the majority of the treated effluent is discharged to the environment via the upper union drain (median 3.85Ml/day). Figure 4-2 displays mean monthly effluent flow data between 1999 and 2016, showing high variation in effluent inflow and effluent irrigation volumes, with urban reuse volume relatively uniform over the data collection period. Interestingly, the variation between monthly inflow volumes increases post 2006 which can be attributed to monthly rainfall; increased rainfall results in an increase in STP inflow. This relationship is best illustrated in Figure 4-3, showing a highly significant relationship between monthly rainfall and monthly STP inflow volume. Additional variation in STP inflow can be attributed to school holiday periods when monthly inflow can increase by as much as 1.5ML/day.

When water levels within the Belongil Estuary reach 1.0mAHD at the Ewingsdale Bridge, BSC are permitted (under license from OEH) to artificially open the mouth of the Belongil Estuary to alleviate flood pressures on the CBD of Byron Bay. Pre 2006, artificial estuary opening events occurred on average 5 times a year, generally following >100mm of rain over a 7 day period. Post 2006, artificial estuary opening events have occurred less frequently - an average of 2 times year (Figure 4-2). While estuary opening events have decreased since the transfer of South Byron STP effluent, the rainfall required over a 7 day period to trigger an estuary opening event has appeared to decrease. There are many factors which influence the openings of ICCOLL's, ranging from oceanic conditions, storm surges, longshore drift, sand accumulation and land erosion works. Thus the decrease in the frequency in the artificial estuary opening events may not be wholly attributed to an increase in STP inflow volumes since 2006. However some key observations can be made:

- 7 day accumulated rainfall prior to an estuary opening event post 2006 is less than that pre 2006,
- Water level within the Belongil ICOLL slowly increases if the estuary mouth is closed. This increase can result in levels exceeding 1.0mAHD with no rainfall, generally within 7-10 days, and
- The Belongil Estuary mount is open for longer periods of time post 2006.

From these observations it would appear that since the transfer of the South Byron STP the ~2ML/day increase of treated effluent discharged into the Upper Union Drain has resulted in the more regular unassisted estuary openings. This would have flow on effects for the catchment, including a decrease in flood events within the Byron CBD and likely lower water levels within the lower Belongil Estuary.

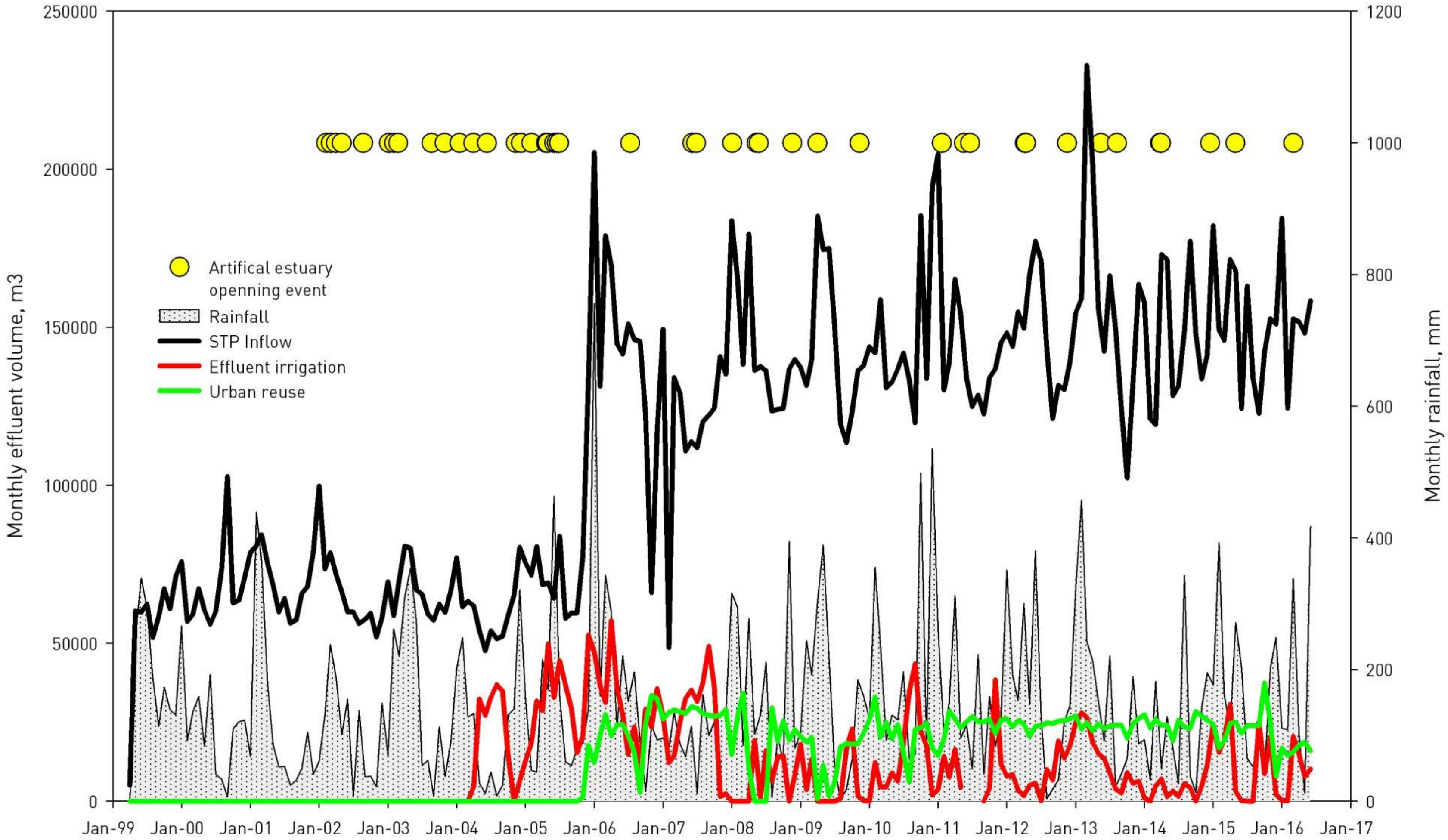


Figure 4-2: BB STP inflow, irrigation and reuse volumes between 1999 and 2016. Artificial estuary opening events also shown.

Table 4-2: Historical effluent delivery to BB STP. All values median ML/day.

Year	Inflow	Irrigation of effluent	Urban Reuse	Discharge to environment
Pre transfer of SB STP				
1999	1.98	0.00	0.00	1.98
2000	2.05	0.00	0.00	2.05
2001	2.22	0.00	0.00	2.22
2002	2.01	0.00	0.00	2.01
2003	2.05	0.00	0.00	2.05
2004	1.92	0.00	0.00	1.92
2005	2.26	1.12	0.00	1.14
Median	**2.05**	**0**	**0**	**2.01**
Post transfer of SB STP				
2006	4.62	1.02	0.79	2.80
2007	4.02	0.79	0.95	2.29
2008	4.39	0.00	0.69	3.71
2009	4.42	0.00	0.58	4.24
2010	4.47	0.43	0.81	3.23
2011	4.42	0.53	0.82	3.07
2012	4.66	0.00	0.81	3.85
2013	5.05	0.14	0.80	4.11
2014	4.73	0.01	0.80	3.93
2015	4.88	0.21	0.79	3.87
2016	5.32	0.15	0.59	4.58
Median	**4.62**	**0.15**	**0.8**	**3.85**

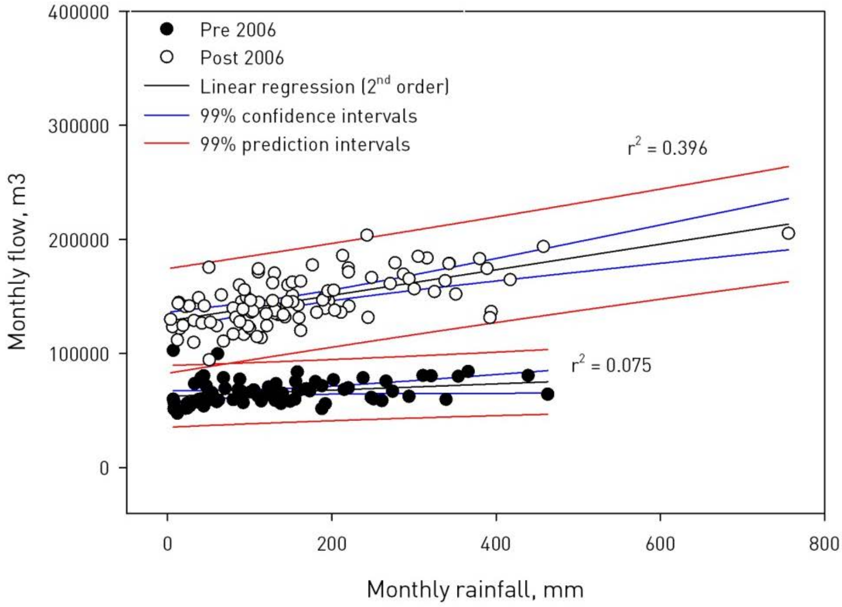


Figure 4-3: Person correlation analysis between rainfall and effluent flow pre and post 2006.

4.2.2 Drain water level assessment

One of the key factors to understanding the influence of the BB STP flows on the hydrology of the catchment is understanding the relationship between the water level within the Union Drain/Belongil Estuary, rainfall, the status of the estuary mouth (open or closed) and the discharge of effluent from the BB STP. As stated in Section 4.1, a network of 10 water level loggers have been established within the catchment, gauging the water level within the drains, creek, estuary and groundwater on an hourly basis (refer to Figure 4-1 for locations of loggers). Data gathered from the network of loggers are displayed graphically in Appendix B. Over the duration of the monitoring period, a number of key observations have been made on the dynamic nature of the water levels within the Union Drain system, Belongil Estuary, rainfall BB STP effluent release:

- Increase in drain and water table level resulting from rainfall,
- Extent of tidal influence into upper drain system, and
- Connection between BB STP effluent flow and drain water levels.

Water levels, groundwater and rainfall

Across all monitoring sites, water levels increase as a result of rainfall. The frequency, magnitude and duration of elevated surface/ground waters as a result of rainfall varies considerably both temporally and spatially. Generally, 50-100mm of rainfall over 2 days will result in elevated ground and surface waters to the extent where extensive flooding occurs across land west of the BBIWMR. This relationship is best illustrated in Figure 4-4, with a series of 50mm + rainfall events in late 2015 which lead to surface flooding. On three occasions between Early November and Late December flooding of the adjoining paddock occurred; preceding the initial two events ~60mm of rainfall was recorded, with 106mm recorded preceding the third event. Interestingly, 60mm of rain falling on the 9/11/2015 resulted in an increase in drain water levels from 1.47 – 1.7mAHD but did not result in flooding of the paddocks. This appears to be the influence of the water level within the drains/groundwater prior to rainfall events. For example, when the drain water level is <~1.4mAHD at Logger 3, 50mm of rainfall will not result in flooding. However, when the water level is >1.7mAHD 50mm of rainfall will result in flooding.

Figure 4-5 illustrates how the water level at Logger 4 increases to a level greater than the drain invert for a period of 4 days following 311mm over two days. The photograph adjoining this graph shows the extent of flooding on the same rainfall event across the land west of the BBIWMR (refer to Figure 4-1 for location and direction of photograph).

While the drainage system of the upper union drain network demonstrably transports effluent efficiently, it is highly likely that since the increased discharge from BB STP in 2006, the regional water table has increased. While this is difficult to demonstrate quantitatively without 'pre 2006' data, the geological cross section presented earlier in Figure 3-3 indicates little pathways for effluent loss outside of the flow under Ewingsdale Road culverts in the Upper Union Drainage system. Furthermore, anecdotal observations by landowners over the past 10 years suggest the water table has increased. This increase in the water table would likely result in an increase in the frequency, duration and depth of inundation resulting from rainfall events owing to the reduced soil store available (in comparison to pre 2006).

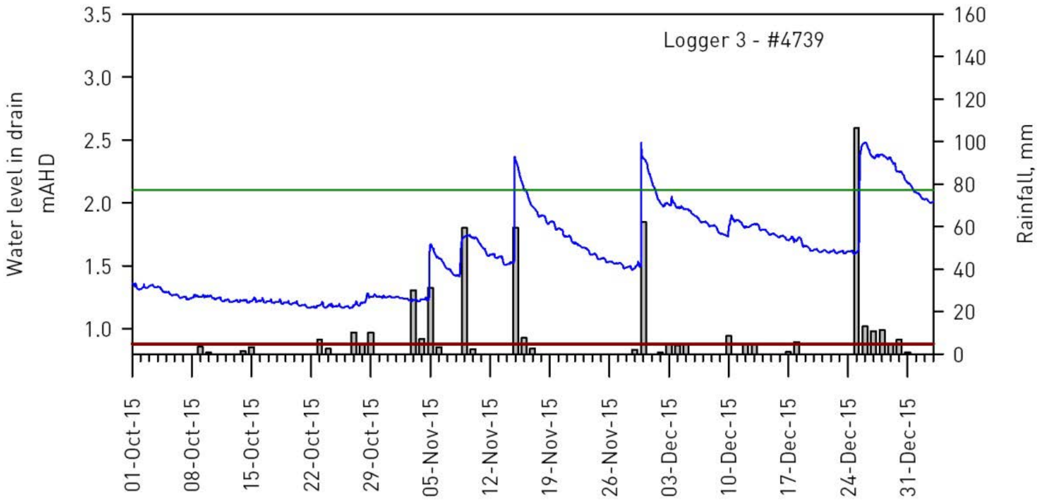


Figure 4-4: Graphical and representation of impact of rainfall events in late June 2015 on water levels in drains. Note location of Logger 3 and photograph on Figure 4-1. The green line represents natural surface level.

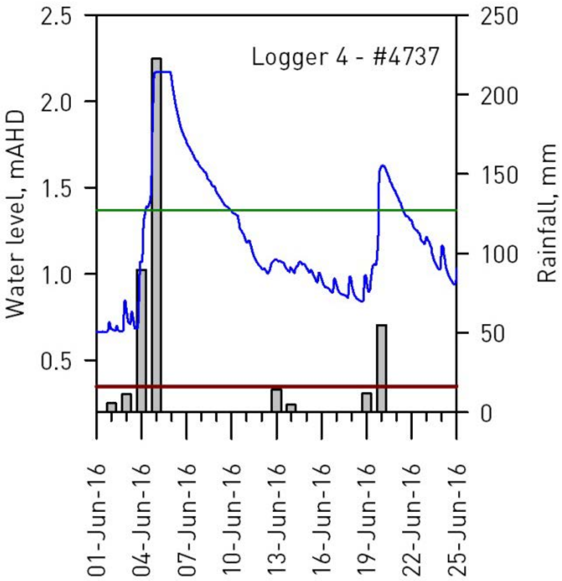


Figure 4-5: graphical and photographic representation of flood events in early and late June 2006. Note location of Logger 4 and photograph on Figure 4-1

Influence of 'closed estuary' on drain system.

Owing to the extremely flat catchment, water levels within the Belongil Estuary substantially influence water levels within the Union and Upper Union drainage system. When the estuary mouth is open, tidal fluctuations in water levels have been recorded north of Ewingsdale Road, at Logger sites 4, 5 and 6. Conversely, when the mouth of the estuary is closed, the level of water within entire Union Drain system rises, as illustrated in Figure 4-6 showing the water level at the Ewingsdale Bridge and the Upper Union Drain over a period with estuary open and closed events. The static water level within the estuary and drainage system appears to be set by the opening status of the estuary mouth and tidal fluctuations.

With an estuary closed event, the water level within the estuary and drainage system incrementally increases 3-5cm per day under non rainfall conditions, reaching a level whereby it overtops the natural sand bar at the estuary mouth OR Council artificially open the mouth of the estuary –as discussed earlier in Section 3.2.1. Under a 'closed' estuary, water levels within the upper union drainage system can be >0.5m when compared to water level under an 'open' estuary regime – however estuary closed events occur only 2-3 times per year and generally for periods <7-10 days.

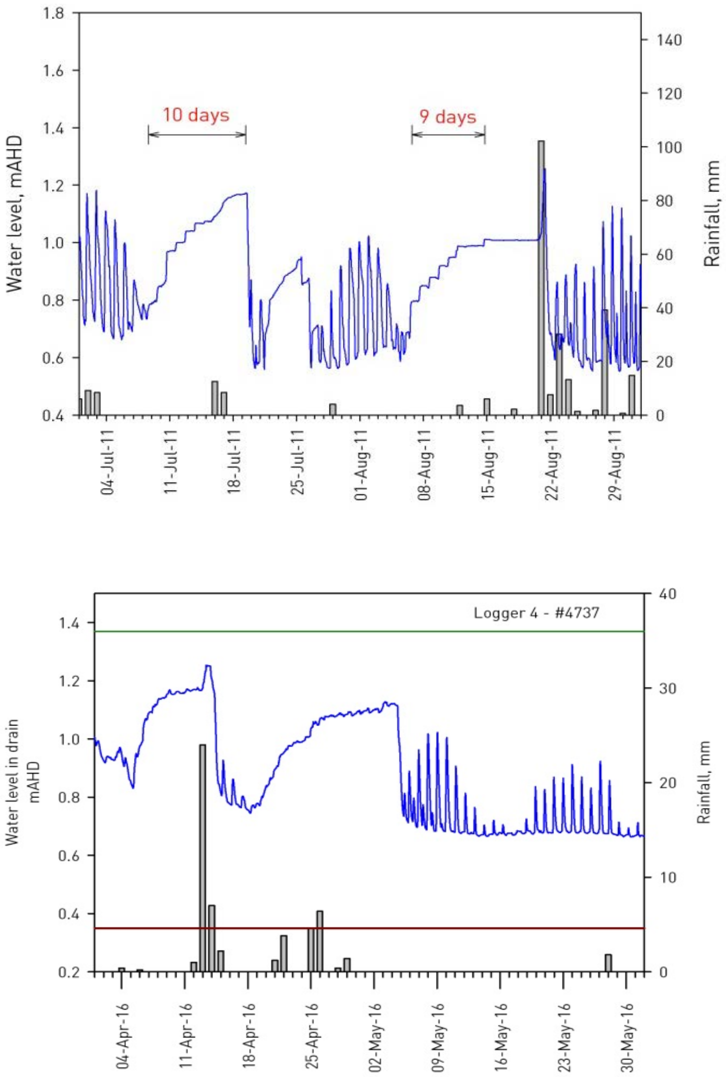


Figure 4-6: Effect of closed estuary mouth on water levels within Belongil Estuary and drain. Logger showing water levels at Ewingsdale Bridge (top graph) and Upper Union Drain (Bottom graph, Logger 4737)

Connection between BB STP effluent flow, irrigation area and drain water levels

Over the past 5-10 years there has been speculation around the effect, if any, of BB STP effluent flow and irrigation on the water levels within Upper Union Drain system. While the EIS (2001) undertaken as part of the BB STP upgrade, work conducted by Bolton (2006) and a post EIS data verification study (AWC, 2010) reported no significant impact to adjoining lands as a result of the upgrade of the BB STP, adjoining landholders remain adamant that there has been an impact. This impact has been defined as:

- more water within the Upper Union Drainage System, and
- increased frequency depth and duration of flooded paddocks.

Unfortunately, all work previous to this study has not included any bores or monitoring sites located on land to the west of the BBIWMR. Additionally, Bolton (2006) investigated the effect of 100m^3/day of irrigation water on surrounding water table levels – significantly less than the mean 370m^3/day irrigation volumes reported in Section 4.2.1 earlier.

It has been reported numerous times that a shallow groundwater mound is present within the BBIWMR, within the vicinity of the constructed wetlands, with groundwater flow moving in all directions but predominantly to the south, west and east (EIS, 2001) owing to the likely influence of the railway line on shallow horizontal groundwater movement.

Appendix B displays water level data from all monitoring points across the Belongil catchment. As can be seen from these figures, the water level in the Upper Union and Union Drainage system, Belongil Creek and shallow groundwater within and adjoining the BBIWMR varies significantly. This variation is largely driven by rainfall, tidal exchange and the opening status of the Belongil Estuary (refer to proceeding section for discussion). As noted in Section 4.2.1, effluent from the BB STP is released to environment via effluent irrigation or direct discharge into the drainage system. Graphs within Appendix B, plot effluent flow alongside drain water level and rainfall for Logger 2 - #4738. As can be seen from this graph, increases in effluent flow generally occur as a result of rainfall and naturally, drain water levels increase in response to rainfall making it difficult to decipher the influence of effluent release on water levels within the drain. However an extract of the data displayed in for Logger 2 - #4738, is provided in Figure 4-7, showing an isolated STP effluent increase of 14ML (compared to 2-3ML/day) on approximately 6th August, 2015 with no corresponding rainfall in the same period. Drain water levels rose in response to this event by approximately 100mm for a period of about 4 days suggesting that effluent discharge does not unduly increase drain water levels.

In previous reports on the assessment of the influence of BB STP effluent on adjoining land uses, STP effluent flow has been estimated at 1-2% of all flows within the Belongil Creek and Estuary. While this is correct, this value is calculated at the Estuary mouth, where tidal exchange and catchment inflow are at their respective maximum. Assessing the influence of BB STP effluent release on catchment flow further up the catchment, within the proximity to it discharge point, provides a somewhat different result. Illustrated in Figure 4-8, catchment flow (data extracted from the results of modelling presented in Section 7) within the Upper Union Drain north of Ewingsdale Road contributes a median 36% of all flows, with the remaining 64% attributed to flow from the BB STP. High or low rainfall periods influence this result considerably, as shown in Figure 4-8, with flow during dry weather being sourced predominantly from the BB STP – often exceeding 90%. During rainfall period, catchment runoff dominates flow in the upper union drainage system, with STP effluent accounting for less than 10% of all flows dependent upon rainfall volumes.

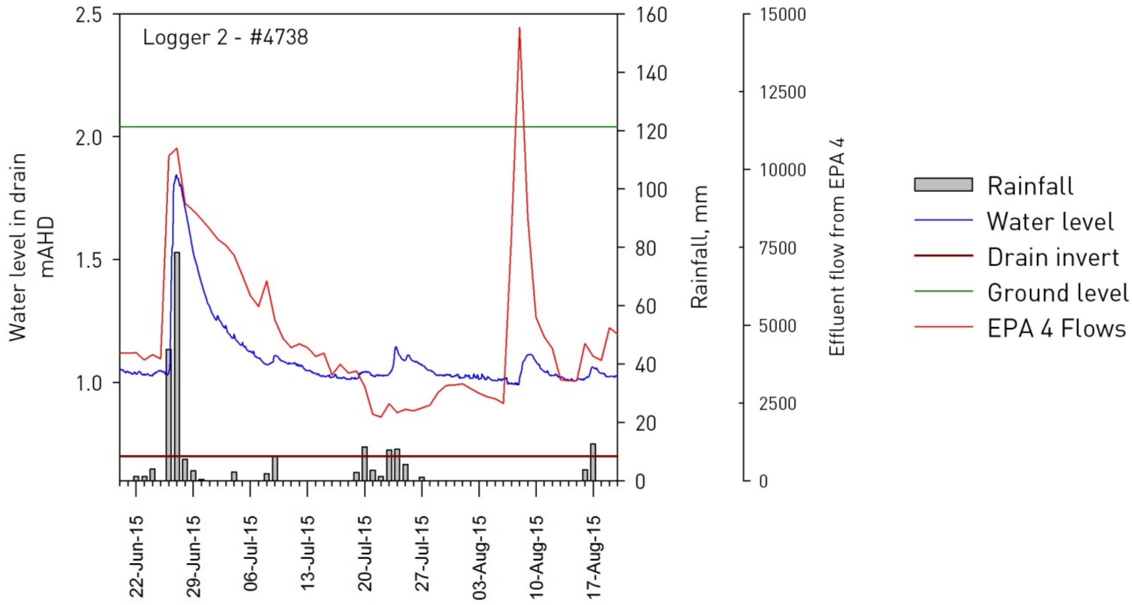


Figure 4-7: Effluent release, rainfall and drain water level

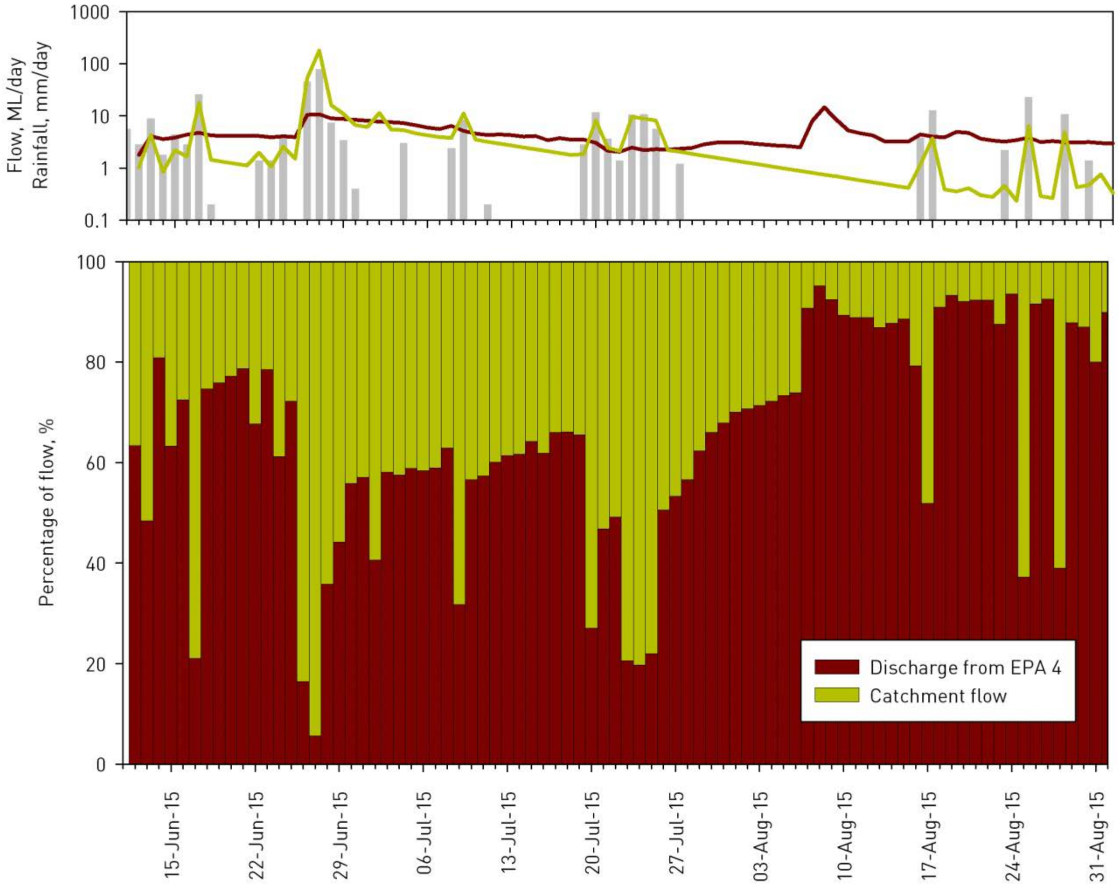


Figure 4-8: Catchment and STP Effluent flow at Upper Union Drain / Ewingsdale Road culvert for select period between June and September 2015. Grey bars represent daily rainfall

4.2.3 Stable isotope assessment

Plants and animals assimilate both stable forms of Nitrogen (N) (14N and 15N) and Carbon (C) (13C and 12C), however they will preference the heavier 15N and 13C where it is available (Mazumder, 2013). Nutrients within human sewage, among other forms of catchment pollution, are usually dominated by these 'heavy' forms for N and C, and as such, ecosystems receiving human effluent may become elevated in the 15N and 13C, relative to the percentage of 14N and 12C.

Results from the stable isotope assessment are provided in Table 4-3, showing little variation in delta 13C values and marginal variation in delta 15N values from the vegetation sampled. Theoretically, trophic groups within ecosystems which are 'impacted' by sewage will have a higher delta 15N and delta 13C values when compared to ecosystems not impacted by sewage. As can be seen from Table 4-3, there is very little difference in 13C values between the sites tested, however there is large variation in 15N values. Site 814, located upstream of the railway line, can be used as a proxy 'control site' – representing a site unlikely to be hydrologically influenced by the operation of the BB STP. At key effluent discharge locations (787-8 – EPA 4, wetland outlet; 802 and 803 – Effluent irrigation outlet), 15N was measured at levels greater than 5, which is reported as being indicative of sites impacted by sewage (Mazumder, 2013).

While the results presented in Table 4-3 do not track 'effluent' from its discharge location through to the Union Drain and Belongil drainage system, it does indicate sewage derived enrichment of the ecosystem within the BBIWMR. This enrichment appears to dissipate prior to entry to the Union Drain and Belongil drainage system, with ecosystem components not showing enriched levels of 15N and/or 13C.

Table 4-3: Results from stable isotope assessment. Refer to Figure 4-1 for locations of samples

SAMPLE ID	%N	%C	d15N	d13C
787	3.85	44.11	10.2	-30.2
788	2.17	41.76	5.9	-30.0
789	3.87	41.48	2.4	-37.4
790	2.99	40.09	2.9	-37.1
791	3.32	39.43	3.4	-32.2
792	1.86	41.50	3.2	-31.4
793	2.56	42.45	4.1	-35.1
794	0.98	46.87	3.4	-29.8
795	1.68	42.41	2.7	-30.0
797	1.57	48.83	1.1	-29.9
798	1.34	52.08	-0.6	-30.0
800	1.17	47.79	-2.1	-27.8
801	0.25	46.52	-0.2	-30.2
802	1.78	47.02	8.8	-31.4
803	3.49	44.23	18.7	-33.4
804	1.87	42.19	4.2	-29.5
805	2.25	37.32	5.1	-31.1
806	1.48	36.06	3.3	-28.6
808	1.41	51.73	-1.0	-32.3
809	1.63	37.68	1.4	-27.4
810	0.72	32.38	1.7	-29.1
811	2.03	41.25	3.9	-29.0
812	0.87	52.78	2.7	-31.5
813	1.06	39.18	3.2	-31.8
814	0.75	45.47	0.0	-33.8
815	1.74	38.65	4.5	-32.3
816	1.26	39.82	-0.7	-26.4

4.3 Conclusion

Since the transfer of the South Byron STP, effluent discharge from the BB STP has increased from a median 2.01ML/day to 3.85ML/day, plus an additional 0.15ML/day used on the effluent irrigation area and a further 0.8ML/day allocated for urban reuse. This increase in discharge can be attributed to the transfer of South Byron STP effluent, plus the apparent increase in flows resulting from storm water infiltration into the sewer system during wet weather. The increase in discharge from the BB STP has resulted in a decrease in the frequency of artificial estuary opening events, reducing from five to six opening events annually to two. Tidal influence when the mouth of the estuary is observed far upstream, with the drainage of the entire catchment influenced when the mouth of the Belongil Estuary is closed.

With the lack of any data on drain and groundwater levels west of the BBIWMR it is difficult to conclusively assess the impact of the increased BB STP flow on the frequency, duration and depth of "flood events". BB STP effluent accounts for a large percentage of flow in the upper catchment, up to 90% during dry weather and reducing down as low as 10% during large rainfall events. As presented in the preceding section, the geology of the land north of Ewingsdale Road creates limited opportunities for effluent losses outside of evapotranspiration or transport through upper union drain system. While the drainage system of the upper union drain network demonstrably transports effluent efficiently, it is highly likely that since the increased discharge from BB STP in 2006, the regional water table has increased. This would result in an increase in the frequency, duration and depth of inundation resulting from rainfall events owing to the reduced soil store available (in comparison to pre 2006).

5 Review and assessment of current flora and fauna values of the Belongil Creek and drainage system

The Belongil Creek, Estuary and Catchment have immense ecological value and social value, with parts of the catchment encompassing the Cumbebin National Park and Cape Byron Marine Park. Furthermore, numerous areas of the catchment are protected under State and/or Federal legislation (e.g. SEPP 14 Coastal Wetlands; EPBC Act). The assessment of current and future effluent release options and volumes must take into account the ecological value of the Belongil Creek, Estuary and Catchment. As defined in Section 1.1, a sustainable effluent release pathway must ensure a balance between economic, social and environmental factors. This section of the report aims to assess the current ecological value of the Belongil Creek, Estuary and its Catchment for the purpose to understand the ecological implications of each wastewater discharge scenario

5.1 Methodology

Two methods where used to assess the current ecological value of the Belongil Creek, Estuary and Catchment:

- Database searches and literature review, followed by
- Field work to ground truth information gained from database searches and literature review.

Prior to field work, searches of the following databases, registers and listings were completed to identify any matters of significance or potential issues:

- Atlas of NSW Wildlife - identify threatened species listed under the *Threatened Species Conservation Act 1995* (TSCA), and *Environment Protection and Biodiversity Conservation Act 1999* (EPBCA) that have records in the local area;
- Protected Matters Search Tool – EPBC;
- SIXMaps Vegetation, Byron Vegetation mapping; and
- Byron Shire Council Local Environmental Plan (LEP) 2014 – Schedule 5;

A review of literature and background studies was also completed to determine constraints or issues relating to:

- Byron Shire Council LEP 2014 (zoning, heritage and general provisions);
- State Environmental Planning Policy No. 44 (Koala Habitat Protection);
- State Environmental Planning Policy No. 14 (Coastal Wetlands); and
- Existing literature on the Belongil Catchment.

Field work for the assessment of the current ecological value of the Belongil Creek, Estuary and Catchment: included:

- Ground truthing of native vegetation present, including description and mapping of the major vegetation communities on the site;
- Identification and mapping of any Endangered Ecological Communities listed under the Threatened Species Conservation Act 1995 (TSC Act), and Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act); and
- Threatened flora and fauna habitat.

5.1.1 Survey Limitations

No targeted Threatened species surveys were conducted. Vegetation communities were classified per class (Keith 2004), due to the large area of study site sufficient data was not collected to determine Plant Community Type (PCT).

5.2 Results and discussion

5.2.1 Existing Flora

A search of the NSW Wildlife Atlas (01/08/2016), based on an area of 10km by 10km centered on the BB STP, confirmed records of 23 Threatened flora species listed under the TSC Act 1995, including 15 species also listed under the EPBC Act 1999 (Table 5.1).

A review of Schedule 1 of the TSC Act 1995 indicates that 11 EECs are recorded to occur within the locality, the following communities are known to or are likely to occur within the study area:

- Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions;
- Littoral Rainforest in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions;
- Lowland Rainforest on Floodplain in the New South Wales North Coast Bioregion;
- Subtropical Coastal Floodplain Forest of the New South Wales North Coast Bioregion; and
- Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions.

Table 5-1. Threatened Flora species recorded in the Locality

Scientific Name	Common Name	Status		Records
		TSC	EPBC	
Allocasuarina defungens	Dwarf Heath Casuarina	E1	E	1,144
Davidsonia jerseyana	Davidson's Plum	E1, 2	E	36
Archidendron hendersonii	White Lace Flower	V	-	24
Xylosma terrae-reginae	Queensland Xylosma	E1	-	8
Cryptocarya foetida	Stinking Cryptocarya	V	V	113
Endiandra floydii	Crystal Creek Walnut	E1	E	1
Endiandra muelleri subsp. bracteata	Green-leaved Rose Walnut	E1	-	7
Owenia cepiodora	Onion Cedar	V	V	1
Tinospora tinosporoides	Arrow-head Vine	V	-	19
Syzygium hodgkinsoniae	Red Lilly Pilly	V	V	7
Syzygium moorei	Durobby	V	V	44
Diuris sp. aff. chrysantha	Byron Bay Diuris	E1,2	-	5
Geodorum densiflorum	Pink Nodding Orchid	E1,2	-	121
Phaius australis	Southern Swamp Orchid	E1,2	E	8
Pterostylis nigricans	Dark Greenhood	V, 2	-	26
Arthraxon hispidus	Hairy Jointgrass	V	V	9
Floydia praealta	Ball Nut	V	V	2
Grevillea hilliana	White Yiel Yiel	E1	-	1
Hicksbeachia pinnatifolia	Red Boppel Nut	V	V	6
Macadamia integrifolia	Macadamia Nut	P	V	5
Macadamia tetraphylla	Rough-shelled Bush Nut	V	V	38
Acronychia littoralis	Scented Acronychia	E1	E	9
Melicope vitiflora	Coast Euodia	E1	-	2
Diploglottis campbellii	Small-leaved Tamarind	E1,2	E	1
V= Vulnerable; E= Endangered; CE= Critically Endangered species pursuant to the TSC Act or EPBC Act				

Vegetation mapping

Mapping of the majority of the site was generally found to be consistent with profile description and extent mapped in Figure 5-1. Vegetation communities were classified as per Plant Community

Class in the NSW Vegetation Information System (VIS) Classification Database (Version 2.0, Office of Environment & Heritage 2012, Keith 2004).

The catchment is largely dominated by Coastal Swamp Forest, namely Broadleaved Paperbark Swamp Forest with patches of Littoral Rainforest and Coastal Freshwater Lagoons scattered throughout. Coastal Freshwater Lagoons are common at the STP site and scattered over sections of pastoral land greater than ~1km from the coast. There is a strip of Mangrove Swamp which follows the southern bank of Belongil creek. A strip of Saltmarsh, up to 100m in width in some section boarders the inland section of the Mangrove Swamp.

Coastal Swamp Forests

Majority of the Coastal Swamp Forests on site are classified as Paperbark Swamp Forest of the Coastal Lowlands of the North Coast. Condition and species composition varies over the study area, however in general the community comprises a low-mid dense paperbark forest, typically 15-20 m tall, with minimal shrub cover and dense graminoid groundcover. The canopy is dominated by Broadleaved Paperbark (*Melaleuca quinquenervia*), Willow Bottlebrush (*Callistemon salignus*), with occasional stands of Swamp Oak (*Casuarina glauca*) and with scattered stands of Swamp Mahogany (*Eucalyptus robusta*). Ground cover is dominated by species such as Bare Twig Rush (*Baumea juncea*) and Tassel Rope-rush (*Restio tetraphyllus*).

Littoral Rainforest

Several stands of Littoral Rainforest exist within the study area, all within 1km of the coast. The community is dominated by a dense canopy of Rainforest trees (Figs, Palms), Tuckeroo (*Cupaniopsis anacardioides*) and Lilly Pilly (*Acmena spp.*). In most stands the understorey is relatively sparse and dominated by herbs and several ubiquitous vines. There are relatively few ferns, although these and epiphytes become common in sheltered locations.

Saltmarsh

The Saltmarsh community within the study area comprises a mosaic of closed to open herbland and grassland dominated by Marine Couch (*Sporobolus virginicus*), Bare Twig Rush (*Baumea juncea*), Common Reed (*Phragmites australis*) and Mangrove Fern (*Acrostichum speciosum*). The community occurs in hypersaline estuarine mudflats subject to occasional tidal inundation.

Coastal Dune Dry Sclerophyll Forest

Sections of Coast Banksia woodland occur on highly elevated land within close proximity to the coast and amongst Swamp Forest. The community comprises an open woodland, with scattered Coastal Banksia, Heath leaved Banksia and Broad-leaved Paperbark. Groundcover dominated by Bare Twig Rush (*Baumea juncea*), Coastal Banksia (*Banksia integrifolia*), Mangrove Fern (*Acrostichum speciosum*), Raspwort (*Gonocarpus spp.*), Tassel Rope-rush (*Restio tetraphyllus*), Blady Grass (*Imperata cylindrica*), with sections of Bracken (*Pteridium spp.*).

Coastal Freshwater Lagoon

Common throughout STP site and occasional elsewhere, comprised of Common Reed grassland on gently undulating plains of Aeolian and estuarine origin. This community has an absent canopy with dense wet heath species dominated by Red-fruit Saw Sedge (*Gahnia sieberiana*), Common Reed

(*Phragmites australis*), Setaria (exotic), Bulrush (*Typha orientalis*) with scattered exotic pines. Pines become dense in some sections (predominantly within the south eastern corner of the STP) creating a dense canopy with thick pine needle ground cover.

Coastal Heath Swamp

There are several patches of coastal heath swamp sparsely scattered throughout the study area. The community comprises a matrix of tall dense sedgeland/fernland and Banksia/Grass Tree heathland. In most stands the sedgeland has an absent canopy and is dominated by Bats-wing Fern (Histiopteris incisa), Tassel Cord Rush (*Restio tetraphyllus*), Swamp Water Fern (*Blechnum indicum*), Red-fruit Saw Sedge (*Gahnia sieberiana*) and Coral Fern (*Gleichenia microphylla*). In some sections Spear Grasstree (*Xanthorrhoea resinifera*), *Leptospermum spp.* and several *Banksia spp*. (fern-leaved & heath-leaved) are also abundant.

SEPP 14 – Wetland

There is a large area (> 300 ha) of SEPP 14 wetland mapped within the study area (Figure 5-2). Much like the rest of the vegetation within the study area, the SEPP14 wetland has experienced various levels of disturbance, depending on location.

Vegetation Condition

The vegetation in the Belongil catchment has been impacted upon by various anthropogenic activities including: clearing, alteration of drainage lines, agricultural practices (such as grazing), urbanisation, increase in pollution from stormwater runoff and entrance opening. It is expected that much of the Belongil catchment was a mosaic of *Melaleuca quinquenervia* forest, freshwater swamps, *Casuarina glauca* forest on slightly higher or more exposed ground, rainforest patches (often with *Melaleuca*) and saltmarsh. Generally, within vegetation stands the condition is moderate-good with weed species relatively sparsely distributed. Typical species include Winter Senna, Lantana, asparagus fern, Coastal Morning Glory and Umbrella Tree. Three listed noxious weed species were recorded:

- Groundsel Bush (*Baccharis halimifolia*);
- Crofton Weed (*Ageratina adenophora*); and
- Bitou Bush (*Chrysanthemoides monilifera subsp rotunda*).

AWC

Project: West Byron STP - Alt. Flow Path

Figure 5-1: Vegetation Communities

Legend

Vegetation Communities

- Coastal Dune Dry Sclerophyll Forests
- Coastal Floodplain Wetlands
- Coastal Freshwater Lagoons
- Coastal Heath Swamps
- Coastal Swamp Forests
- Littoral Rainforests
- Mangrove Swamps
- Maritime Grassland
- North Coast Clay Heathlands
- North Coast Dry Sclerophyll Forests
- North Coast Wet Sclerophyll Forests
- Open Water
- Plantation
- Saltmarshes
- Subtropical Rainforests
- Wallum Sand Heaths

0 100 200 300 400 500 m

N W E S

Date - 09/11/2016

A3 Scale - 1:14000

SOURCE:
Aerial - NearMap Pty Ltd 2016
Study Site - AWC

Project: West Byron STP - Alt. Flow Path

Figure 5-2: SEPP 14 - Wetlands

Legend

SEPP14 Wetlands

0 100 200 300 400 500 m

N W E S

Date - 09/11/2016

A3 Scale - 1:14000

SOURCE:
Aerial - NearMap Pty Ltd 2016
Study Site - AWC

Care was taken in the creation of this map. AWC should be consulted as to the suitability of the information shown herin prior to the commencement of any works based on the information provided. AWC cannot accept any responsibility for errors, omissions or positional accuracy. There are no warranties, expressed or implied as tot he suitability of this map for a particular purpose. However, notification of any errors will be appreciated.

5.2.2 Terrestrial and aquatic fauna

A search of the NSW Wildlife Atlas (01/08/2016), based on an area of 10km by 10km centered on the site returned confirmed records of 57 Threatened fauna species listed under the TSC Act 1995, including 20 species also listed under the EPBC Act 1999 (Table 5.2).

Threatened Fauna

Two confirmed Threatened fauna species, Eastern Osprey (*Pandion haliaetus*) and Pied Oyster Catcher (*Haematopus longirostris*) which are listed under the *TSC Act 1995*, were recorded during the survey. However due to the small survey effort relative to large area of the study site and occurrence of suitable habitat in the area it is likely that the following species occur within the study area:

- Wallum Froglet;
- Olongburra Frog;
- Wompoo Fruit-Dove;
- Superb Fruit-Dove;
- Black-necked Stork;
- Spotted Harrier;
- Pale-vented Bush-hen;
- Beach-stone Curlew;
- Bush-stone Curlew;
- Sooty Oystercatcher;
- Curlew Sandpiper;
- Eastern Curlew;
- Little Tern;
- Glossy Black Cockatoo;
- Eastern Grass Owl;
- Swift Parrot;
- Common Planigale;
- Common Blossom Bat;
- Koala;
- Long-nosed Potoroo;
- Grey-headed Flying-fox;
- Little Bentwing-bat;
- Eastern Bentwing-bat; and
- Southern Myotis.

Migratory/Marine Fauna

Two species, the Rainbow Bee-eater (*Merops ornatus*) and Cattle Egret (*Bubulcus ibis*) listed as Migratory/Marine under the *EPBC Act 1999* were recorded during the survey. It is expected that numerous other species also occur within the study area.

Existing Habitat Values

The suitability of the study area for typical vertebrate fauna groups is described as follows:

Amphibians: The drains and low-lying swamp forest in the study area provide suitable habitat for a range of Threatened amphibian species, including Wallum Froglet (*Crinia tinnula*) and Olongburra Frog (*Litoria olongburensis*). Other common species likely to occur including Peron's Tree Frog (*Litoria peroni*), Tyler's Tree Frog (*L. tyleri*), Bleating Tree Frog (*L. dentata*) and Green Tree Frog (*L. caerulea*).

Reptiles: Habitat for reptiles various throughout the study area, with established litter layer within Littoral Rainforest and drier conditions are more suitable to species such as the Robust Ctenotus, Lace Monitor (*Varanus varius*), and Yellow-faced Whip Snake (*Demansia psammophis*). Species such as the Green Tree Snake (*Dendrelaphis punctulata*), Carpet Python (*Morelia spilota*), Marsh Snake (*Hemiaspis signata*), Burtons Snake Lizard (*Lialis burtonis*) and several skink species are likely to occur over most of the area, both dry and moist.

Birds: A diversity of birds was recorded and is considered typical of the suite of species which occur in coastal swamp forest, wetlands, saltmarsh, rainforest and peri-urban environments. During flowering periods, it would be expected that nectivorous species such as lorikeets, honeyeaters, Wattlebirds and Friarbirds would commonly occur. Drainage line and creek environments provide habitat for the aquatic bird species including Ducks and White Ibis (*Threskiornis moluccus*), White-faced Heron (*Egretta novaehollandiae*) and Egret species, while the open water provides good hunting opportunities for marine raptors such as the Osprey (*Pandion haliaetus*) and White-bellied Sea-eagle (*Haliaeetus leucogaster*). Due to their secluded nature, the sand dunes and beach environments near the mouth of the estuary provide good quality foraging and breeding habitat for several shorebirds including the Pied Oyster Catcher (*Haematopus longirostris)* and Little Tern (*Sternula albifrons*). There is a known breeding location for Pied Oyster Catchers currently sections off on the southern side of the mouth, and a pair was observed during the survey.

Mammals: During the survey, numerous scats likely attributed to macropod species (Swamp Wallaby) were observed along with diggings believed to be that of the Long-nosed Bandicoot were relatively common in the eastern portion of the site. The dense ground cover on site is likely to support species rodent species such as the Bush, Swamp and Black Rats and Grassland Melomys (*Melomys burtoni*). Paperbarks are likely to form part of the larger foraging range for microchiropteran bats, furthermore Banksias, Paperbarks and other flowering trees are likely to provide a nectar source for Grey-headed flying foxes (*Pteropus poliocephalus*) and glider species. Preferred feed tree species for Koala (*Phascolarctos cinereus*), (Swamp Mahogany, Forest Red Gum) are limited to throughout the study area and records in the locality are scarce (Atlas of NSW Wildlife), however the site may be used on occasion by wandering animals for both feeding and shelter.

Aquatic habitat: Mangroves found in the lagoon are particularly valuable as a nursery, providing food and shelter for a great diversity of aquatic macroinvertebrates, small animals, and fish. Native fish that live in in the catchment include freshwater, estuarine and marine species such as the Striped Gudgeon (*Gobiomorphus australis*), Sea Mullet (*Mugil cephalus*), Dusky Flathead (*Platycephalus fuscus*), Luderick (*Girella tricuspidata*), and Sand Whiting (*Sillago ciliata*).

Corridors: The study area is located at the intersection of several wildlife corridors which act to connect wildlife to the north, south and west. These corridors connect the area to Tyagarah NR to the north and Arakwal NP to the east. This connectivity benefits a broad range of fauna assemblages, especially gap-shy woodland birds and arboreals. Habitat links throughout most of the study area could facilitate movement of moderate to highly mobile species. In large sections of the area trees and other habitat links are close enough for gliders and most passerine birds to transverse throughout the site. Pastoral woodland, which is common throughput the study area, increases the risk of predation (eg by foxes and wild dogs) and harassment by dominating species such as Noisy Miners. Ewingsdale Road, which runs west-east, through the centre of the site acts as a biodiversity barrier to many species both physical and behaviourally. The road increases the risk of vehicle collision whilst exposing the species to predators. There are no dedicated fauna underpasses or crossing bridges in place to help facilitate the movement fauna across the highway in the vicinity of the site.

Table 5-2. Threatened Fauna Recorded within the locality

Scientific Name	Common Name	NSW Status	Conservation Status
Crinia tinnula	Wallum Froglet	V,P	
Mixophyes iteratus	Giant Barred Frog	E1, P	E
Litoria aurea	Green and Golden Bell Frog	E1,P	V
Litoria olongburensis	Olongburra Frog	V,P	V
Caretta caretta	Loggerhead Turtle	E1,P	E
Chelonia mydas	Green Turtle	V,P	V
Eretmochelys imbricata	Hawksbill Turtle	P	V
Ptilinopus magnificus	Wompoo Fruit-Dove	V,P	
Ptilinopus regina	Rose-crowned Fruit-Dove	V,P	
Ptilinopus superbus	Superb Fruit-Dove	V,P	
Macronectes giganteus	Southern Giant Petrel	E1,P	E
Macronectes halli	Northern Giant-Petrel	V,P	V
Pterodroma leucoptera leucoptera	Gould's Petrel	V,P	E
Pterodroma neglecta neglecta	Kermadec Petrel (west Pacific subspecies)	V,P	V
Pterodroma nigripennis	Black-winged Petrel	V,P	
Ephippiorhynchus asiaticus	Black-necked Stork	E1,P	
Ixobrychus flavicollis	Black Bittern	V,P	
Circus assimilis	Spotted Harrier	V,P	
Hieraaetus morphnoides	Little Eagle	V,P	
Lophoictinia isura	Square-tailed Kite	V,P,3	
Pandion cristatus	Eastern Osprey	V,P,3	
Grus rubicunda	Brolga	V,P	
Amaurornis moluccana	Pale-vented Bush-hen	V,P	
Burhinus grallarius	Bush Stone-curlew	E1,P	
Esacus magnirostris	Beach Stone-curlew	E4A,P	
Haematopus fuliginosus	Sooty Oystercatcher	V,P	
Haematopus longirostris	Pied Oystercatcher	E1,P	
Irediparra gallinacea	Comb-crested Jacana	V,P	
Calidris ferruginea	Curlew Sandpiper	E1,P	CE,C,J,K
Calidris tenuirostris	Great Knot	V,P	CE,C,J,K
Numenius madagascariensis	Eastern Curlew	P	CE,C,J,K
Onychoprion fuscata	Sooty Tern	V,P	
Sternula albifrons	Little Tern	E1,P	C,J,K
Calyptorhynchus lathami	Glossy Black-Cockatoo	V,P,2	
Glossopsitta pusilla	Little Lorikeet	V,P	
Tyto longimembris	Eastern Grass Owl	V,P,3	
Tyto novaehollandiae	Masked Owl	V,P,3	
Tyto tenebricosa	Sooty Owl	V,P,3	
Carterornis leucotis	White-eared Monarch	V,P	
Stagonopleura guttata	Diamond Firetail	V,P	
Dasyurus maculatus	Spotted-tailed Quoll	V,P	E
Planigale maculata	Common Planigale	V,P	
Phascolarctos cinereus	Koala	V,P	V
Potorous tridactylus	Long-nosed Potoroo	V,P	V
Pteropus poliocephalus	Grey-headed Flying-fox	V,P	V
Syconycteris australis	Common Blossom-bat	V,P	
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	V,P	
Miniopterus australis	Little Bentwing-bat	V,P	
Miniopterus schreibersii oceanensis	Eastern Bentwing-bat	V,P	
Myotis macropus	Southern Myotis	V,P	
Nyctophilus bifax	Eastern Long-eared Bat	V,P	
Scoteanax rueppellii	Greater Broad-nosed Bat	V,P	
Pseudomys gracilicaudatus	Eastern Chestnut Mouse	V,P	
Megaptera novaeangliae	Humpback Whale	V,P	V
Thersites mitchellae	Mitchell's Rainforest Snail	E1	CE
V= Vulnerable; E= Endangered; CE= Critically Endangered species pursuant to the TSC Act or EPBC Act			

5.2.3 Potential ecological impacts resulting from altered catchment hydrology

Changed hydrology and hydraulics have the potential to have severe consequences on the ecological values within a vegetation community, particularly groundwater dependent ecosystems (GDE's). Many species have a 'threshold' or tolerance level to particular conditions, when exceeded these conditions effect the health of that species, in turn altering ecosystem structure. In the Belongil Estuary in particular, the interaction of natural variation, changes in land use and changes brought about by artificial opening of the estuary mouth makes the impacts of any entrance opening strategy difficult to quantify. However, the physical impacts discussed above are known to have the potential to result in the following impacts on ecological values:

- Altered species composition;
- altered species distribution;
- species mortality;
- altered species richness;
- altered species abundance; and
- altered community structure.

A decline in condition of vegetation

In some cases, alternations in the water regime are known to result in a decline in the health of individual plant species. Plants that are present in swamps, wetlands and saltmarshes establish under specific conditions that suit their anatomy and physiology. If the environment experiences a change for an extended period of time, the condition of these species can decline. The severity of this decline in health is dependent on the extent of change.

The anatomy and physiology of plants governs the ability of each species to respond to changes in their environment. An Increase in the duration or depth of inundation may restrict access to sufficient oxygen, and this lack of oxygen in the soil results in lower soil conditions that lead to the development of toxic compounds that can affect plants. In response to a restriction to oxygen plants may initially wilt, drop leaves and branches, and ultimately die if the duration of inundation is sustained. Each plant species responds to inundation differently. For example, common wetland tree species such as *Melaleuca* are unable to respond to extensive and rapid changes in water levels however they tolerate several years of continuous inundation before tree death occurs. Therefore, the impact of a changed water regime may not be recognised until years after a change has been implemented.

Changes in species distribution and abundance

Changes in water regime can change species distribution within a wetland. If changes in hydrology are beyond the ability of a particular species to adapt, the vegetation community may begin to shift, altering the species distribution throughout the ecosystem. A change in species distribution may only occur if there is: another location that meets its water requirements and other conditions such as suitable soil type, an area is available for colonisation and seeds or vegetative parts that are able to reach that location.

Many species can tolerate an increase or decrease in conditions (such as salinity, inundation level) for a short period, however if exposure extends beyond a time period, a negative influence may be experienced. For example, when *M. quinquenervia* is exposed to increased salinity levels (above 10 dS/m) germination percentage is greatly decreased. The species can tolerate these higher salinity levels for short periods however, if salinity is permanently increased, germination percentage will decrease, most likely resulting in dieback of this species, reducing canopy cover and altering the ecosystem structure. (IERM, 2005).

Loss of species or change in species composition

Altered hydrology can change the species composition present at a wetland, in turn transitioning from one vegetation community to another. In some circumstances, more sensitive species may decline, while more tolerant species may increase in abundance (native or exotic). These changes in composition can be short, medium or long term, depending upon the changes that have occurred and the resilience of the species to variability (DEC, 2014). For example, if Paperbark Swamp Forest is inundated for extended periods, canopy species such as *Melaleuca quinquenervia* and *Eucalyptus robusta* may die back. Depending on salinity levels, the ecosystem may transition into a treeless vegetation community such as freshwater wetland or saltmarsh (DEC, 2014).

The discharge of stormwater into saltmarsh communities can alter the salinity regimes, increases nutrient levels and facilitates the spread of introduced species. If a saltmarsh habitat is inundated for an extended period, the community can experience a dieback of saltmarsh species, changing the species composition of the marsh. Common Reed (*Phragmites australis*) spreads rapidly to form extensive stands in tidally isolated saltmarshes and alters the landscape, hydrology, ecology and function of the entire community. Where tides have been excluded from saltmarsh habitats for extended periods, vegetation will change to either freshwater or terrestrial communities (NSW Gov, 2008).

Changes in nutrient loads can also affect ecosystem function downstream from a development. For example, in coastal wetlands an increase in the loads of nutrients (such as nitrogen and phosphorus) and suspended solids entering waterways in runoff after rain are taken up by some types of aquatic plants, particularly macro algae and phytoplankton. When exposed to high nutrients these plants become dominant over plants living on the waterbody floor (seagrasses and benthic microalgae) (OEH, 2013).

Additionally, weeds compete with native wetland species and habitats, and when the community is exposed to changed conditions, they may replace them altogether. Common weeds in coastal wetlands include Lantana (*Lantana camara*), Salvinia (*Salvinia molesta*) and Caulerpa (*Caulerpa taxifolia*), (OEH, 2013).

Impacts to Fauna

When a vegetation community experiences a shift in vegetation composition and structure the habitats of native fauna are also altered. In the past, the Belongil catchment have seen fauna habitat be jeopardised through the clearance of vegetation and alterations in the hydrological and salinity regime of Belongil Creek. (IERM, 2005)

Individual species survive within specific ranges of temperature, water regime and chemical conditions. When these ranges are exceeded the species has several options; adaptation or migration or they will locally die out. As with flora, the sensitivity of a particular species is determined by physiology (e.g. metabolic requirements and tolerances to climatic conditions), ecology (e.g. life history, habitat use, behaviour, dispersal and biotic and abiotic interactions) and genetic diversity.

Changes in the natural water-regime may disrupt natural processes such as triggers (fish spawning), migration etc. resulting in a decline in native fish populations. Species of mammals, birds, reptiles, frogs, fish, invertebrates, fungi, plants and bacteria may all be affected. Altered hydrology can lead to invasion by new species (both native and introduced), as the new water regime provides suitable conditions where they did not exist before (Harding, 2012).

Sensitivity of many species to changes in environment is dependent on the phase of their lifecycle. Frogs are a good example as they have the ability to migrate to favorable conditions, however if the water levels dry rapidly, during the breeding season, tadpoles will not be able to mature past their aquatic phase. In these ways, altered water regime can have significant impacts on a wetland's species composition. Altered water regimes have the potential to influence the habitat of fauna through the depletion of seedbanks through flooding or drying; reducing plant growth and therefore reducing foraging and shelter sources; disrupting pollination, symbiosis and other biological interactions.

Changes in population distributions

Highly mobile species, with the ability to disperse can show significant population-scale changes in distribution in response to changes to the hydrology regime. Migratory birds may also be affected the changes (disruptions to the synchronicity of migration and prey flushes), ultimately altering the timing of environmental cues to migrate (DEC, 2014).

5.3 Conclusion

The Belongil Creek, ICOLL and drainage system provides a large expanse of high quality habitat for various terrestrial and aquatic species. Habitat quality varies throughout the catchment varies, with some sections have experienced high levels of disturbance in the past. However, swamp forest (large proportion mapped as SEPP 14), mangroves, saltmarsh and regenerating areas with the STP provide high quality habitat for multiple species listed under the TSC Act and EPBC Act. Known breeding habitat for several species such as the Little Tern and Pied Oyster Catcher occurs within the catchment, meaning that conservation of these environments is essential for the sustainability of the local population. Furthermore, the following Endangered Ecological Communities (EECs) are known to occur within the catchment:

- Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions;
- Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions;
- Littoral Rainforest in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions;
- Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions,

Overall the catchment hosts an array of high value ecological features including threatened species habitat (flora and fauna), EECs, SEPP 14 wetland, GDE's and wildlife corridors (regional and sub regional). Many values are dependent upon the prevailing hydrological regime and are sensitive to changes in hydrology. Management actions must demonstrably have no adverse effect on these vegetation communities.

6 Identification of alternative flow paths for the discharge of STP effluent

A key output of this project is the identification of a preferred effluent release pathway, which will be determined via assessing a range of effluent discharge scenarios against the sustainability criteria established in Section 1.1. Previous consultation was conducted with BSC on a range of effluent release pathways, with many options being discussed, evaluated and ranked (AWC, 2016). Based on this discussion and process, the two highest ranking alternative effluent release scenarios have been investigated in study (Figure 6-1):

- Existing release site.
- Option 1: Pipe to Ewingsdale Road and discharge west Island Quarry, south Ewingsdale Road.
- Option 2: Discharge to Industrial Estate drainage system.

The hydraulic/hydrologic model and water quality model developed for the study area (refer to Sections 7 and 8) will be post-processed under a range of effluent release scenarios, outlined in Table 6-1 and shown diagrammatically in Figure 6-1 . These models will identify:

- the maximum spatial extent and duration of water inundation resulting from the various effluent release scenarios, and
- the impact of the various release scenarios on the background water quality of the Belongil ICOLL.

Furthermore, the results of the modelling will be compared against key environmental values and threats determined during the targeted environmental assessment (Section 5). Each effluent release scenario will be qualitatively assessed against all of the identified sustainability criteria presented in Section 1.1.

Table 6-1: Effluent release scenarios

Scenario number	Flow scenario	Effluent release#	Release description
1	"Control"	1ML/d	Pre closure of South Byron STP
Do nothing Scenarios			
2a	Current flow	3ML/d	Release at current discharge location (EPA 4), under estuary open and closed and high low rain events
2b	2025 flow	5ML/d	Increased load based on 2025 projected population
2c	2050 flow	8ML/d	Increased load based on 2050 projected population
Various outflow scenarios. Discharge at several locations as per identification of alternative flow paths			
3a	Current	3ML/d	1 ML discharged to Upper Union Drain; 2 ML discharged to Industrial Estate drain, shown as **Option 1** in Figure 6-1
3b	2025	5ML/d	1 ML discharged to Upper Union Drain; 4 ML discharged to Industrial Estate drain, shown as **Option 1** in Figure 6-1
3c	2050	8ML/d	1 ML discharged to Upper Union Drain; 7 ML discharged to Industrial Estate drain, shown as **Option 1** in Figure 6-1
4a	Current	3ML/d	1 ML discharged to Upper Union Drain; 2 ML discharged via **Option 2,** shown in Figure 6-1
4b	2025	5ML/d	1 ML discharged to Upper Union Drain; 4 ML discharged via **Option 2** shown in Figure 6-1
4c	2050	8ML/d	1 ML discharged to Upper Union Drain; 7 ML discharged via **Option 2** shown in Figure 6-1
Notes: #: Assuming 1 ML urban reuse per year			


AWC
Project: Byron Bay STP alternative effluent release assessment
Figure 6.1: Existing and alternative effluent release pathways
Legend
Belongil catchment boundary
Option 1 effluent release pathway
Existing release pathway
Option 2 effluent release pathway
BBIWMR
0 200 400 600 m
Date - 16/12/2016
A3 Scale - 1:30000
SOURCE:
Aerial - NearMap Pty Ltd 2016
Study Site - AWC
Care was taken in the creation of this map. AWC should be consulted as to the suitability of the information shown herin prior to the commencement of any works based on the information provided. AWC cannot accept any responsibility for errors, omissions or positional accuracy. There are no warranties, expressed or implied as tot he suitability of this map for a particular purpose. However, notification of any errors will be appreciated.

7 Hydraulic capacity assessment of the Belongil Creek and Drainage system

A Hydraulic Capacity Assessment (HCA) has been completed across the drainage systems and floodplain of the Belongil Creek catchment. The HCA assesses the potential changes in inundation behavior of the various STP discharge volumes and locations presented in Section 6.

Due to the low lying nature of much of the Belongil Creek catchment and the fact that its drainage lines are extensively tidal it has been necessary to assess the potential effects of varying STP discharges on the capacity of the existing drainage system for a range of estuarine and meteorological conditions. Principally this includes the status of the entrance of Belongil Creek, which in being an ICOLL, varies from fully closed to fully open. The added effect of variable meteorological conditions on catchment flows is another overlay which requires consideration in assessing the longer term capacity of the existing drainage system to convey flows.

7.1 Methodology

The adopted assessment approach has been to complete long term continuous simulation (over a nearly five year period) that represents a range of estuarine and meteorological/catchment conditions that could be considered representative of long term system operation. From this the effects of modification (i.e. scenarios) could be determined.

The HCA has been completed using a number of modelling tools including:

- A SOURCE hydrologic model over the Belongil Creek catchment that provides hydrologic inputs to the hydraulic model; and
- A TUFLOW linked 1 dimensional / 2 dimensional hydraulic model of the floodplain regions and drainage networks.

7.1.1 Hydrology Model Overview

The SOURCE hydrologic model has been constructed using a range of locally specific data including a digital elevation model (DEM) of the catchment, catchment land use mapping and SILO meteorological data. As the Belongil catchment is ungauged, traditional model calibration methods were not possible, as such model parameters were established through a joint validation process with the hydraulic model which involved:

- Qualitative assessment using historical photographs identifying inundation patterns during significant rain events in a particular portion of the catchment; and
- Qualitative and quantitative assessment comparing recorded water levels from a water level logger in the Union Drain to water levels predicted by the hydraulic model.

Model parameters were able to be refined to provide an acceptable validation outcome, indicating that predicted catchment hydrology adequately represented actual catchment hydrology. This validation process was able to be performed across a number of critical sub-catchments of the Belongil Creek system where drainage infrastructure exists, noting that these drains can overflow to the floodplain if water levels exceed the bank full height.

Further detailed descriptions of hydrologic model establishment and validation are provided in Appendix C.

7.1.2 Hydraulic Model Overview

The hydraulic model developed for the HCA has been adapted from the flood model developed for the Belongil Creek Flood Study completed in 2009. The flood study model was modified to allow simulation over long time periods and hence inform the HCA. Key modifications have included:

- Change in model resolution from 10m grid size in floodplain areas to a 25 m grid size in the floodplain areas;
- Accepting hydrology from the SOURCE hydrology model at identified sub-catchment locations in place of the design event hydrology utilised for the flood study;
- Updates to LiDAR in the floodplain regions to make use of newer higher resolution information;
- Incorporating new project specific survey information for key drainage lines on the Union drain and surrounds. This survey information was introduced as 1 dimensional elements within the hydraulic model formulation;
- Incorporation of a tidally varying downstream boundary. Incorporation of this downstream boundary was necessary to inform entrance conditions were during the simulation period. Being an ICOLL the Belongil Creek estuary operates between fully open and fully closed, however, bathymetric data to describe entrance conditions was not available for hydraulic modelling. The use of recorded water levels within Belongil Creek (at the Ewingsdale Bridge) overcomes this data limitation; and
- The West Byron STP flows were introduced into selected drainage channels to assess hydraulic capacity effects and potential floodplain inundation as required.

As identified above the hydrologic and hydraulic models were validated in unison using a range of qualitative and quantitative methods. Adjustments were made within the hydraulic model to ensure accurate representation of catchment flow dynamics.

Further detailed descriptions of hydraulic model establishment and validation are provided in Appendix E.

7.1.3 West Byron STP Discharge Scenarios

To test the impact of the STP flows on the floodplain and estuary three different release locations were tested, including:

- Existing – The exiting discharge location;
- Option 1 – Tributary of Union Drain South of Ewingsdale Road; and
- Option 2 – Industrial Estate Drain.

For each for these locations a total release from the West Byron STP of 3, 5 and 8 ML/day has been modelled. For environmental reasons a discharge of 1 ML/day is maintained at the existing discharge site. For example for the 5ML/day release Option 2, 1 ML/day is released at the existing discharge location and 4 ML/day is released via Option 2 (i.e. in the Industrial Estate Drain).

The STP discharge locations in the hydraulic model are presented in Figure 17-2 (Located in Appendix E). A total of 10 simulations were run, these are outlined in Table 7-1.

Table 7-1 : TUFLOW Simulation Configurations

Simulation Name	Discharge at Existing Location (ML/day)	Additional Output Location	Additional Output Discharge (ML/day)
Existing 1ML Base Case	1.0	N/A	N/A
Existing 3ML	3.0	N/A	N/A
Existing 5ML	5.0	N/A	N/A
Existing 8ML	8.0	N/A	N/A
Option 1 3ML	1.0	Option 1	2.0
Option 1 5ML	1.0	Option 1	4.0
Option 1 8ML	1.0	Option 1	7.0
Option 2 3ML	1.0	Option 2	2.0
Option 2 5ML	1.0	Option 2	4.0
Option 2 8ML	1.0	Option 2	7.0

7.2 Results and discussion

For each of the simulations presented in Table 6-1 the model was run for the period 17/09/2011 to 15/04/2016. Duration and inundation depth greater than 1 cm was recorded. For the existing location, 1ML/day STP discharge the duration of inundation is presented in Figure 7-1. The duration is presented as a percentage. The total simulation duration was 1,672 days or 40,128 hours, so an inundation of 10% indicates that the cell was wet for 4,013 hours of the simulation.

For the 3, 5 and 8ML/day STP discharges the duration of inundation was compared back to the existing 1ML/day base case. Any change in inundation duration for the three locations and three discharge rates are presented in Figure 7-2 through to Figure 7-10. These are presented as a percentage of the total simulation time. For example a value a 1% indicates that for the entire 4.5 year simulation the duration of inundation has increased by 401.3 hours or approximately 17 days.

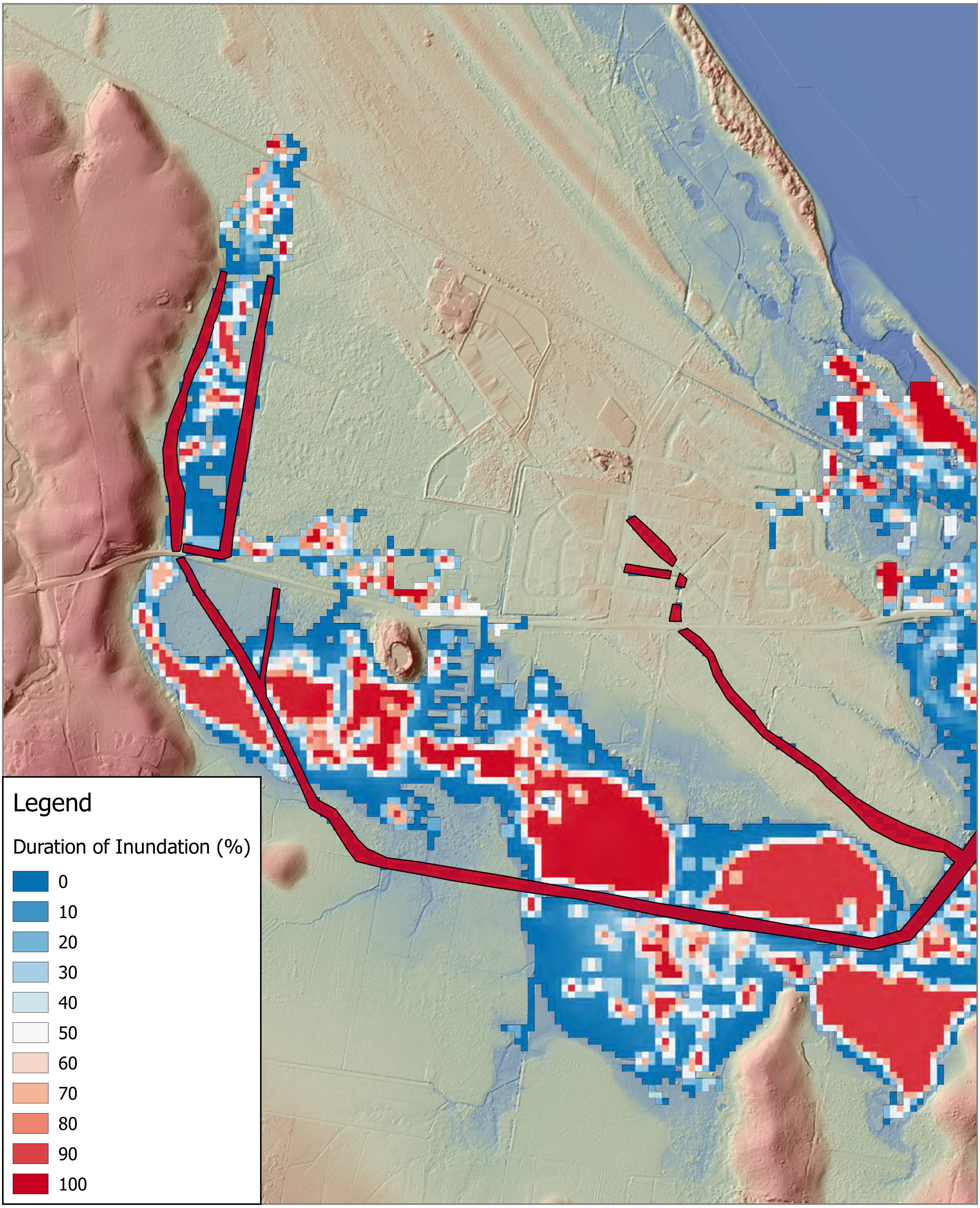
The difference in duration mapping presents a relative assessment of the modelled alternatives, back to a 1ML discharge in the existing output location. If an area, for example the lower Creek or drain is wet 100% of the time, this shows up as a 0% difference in time of inundation, even though the depth of inundation may vary.

For the existing STP discharge location and Option 1 location, there are significant areas of the floodplain which are predicted to experience an increase in duration of inundation. This does not necessarily occur, at the discharge location itself, but rather further downstream. The flatter channel gradient and influences of the tidal level / entrance condition can cause additional duration of water ponding in the floodplain. The differences in the time of inundation are typically less than 2%.

For the Option 2 location, the predicted increases in duration are significantly less than for the two other alternatives.

7.3 Conclusion

Several scenarios were assessed as part of the HCA which included varying outfall locations and/or increases in effluent discharge volumes. Impacts were assessed on a relative basis by comparison back to a 1ML discharge in the existing discharge location. For the existing STP effluent discharge location and Option 1 location, there are significant areas of the floodplain predicted to experience increases in duration of inundation. Generally this inundation has been predicted to occur downstream (to the south) of Ewingsdale Road in the main portion of the floodplain. The flatter channel gradient and influences of the tidal level / entrance condition cause the additional duration of water ponding in these floodplain locations. The differences in the time of inundation are typically less than 2%, or 34 days. For the Option 2 location, the predicted increases in duration are significantly less than for the two other alternatives.



Title:

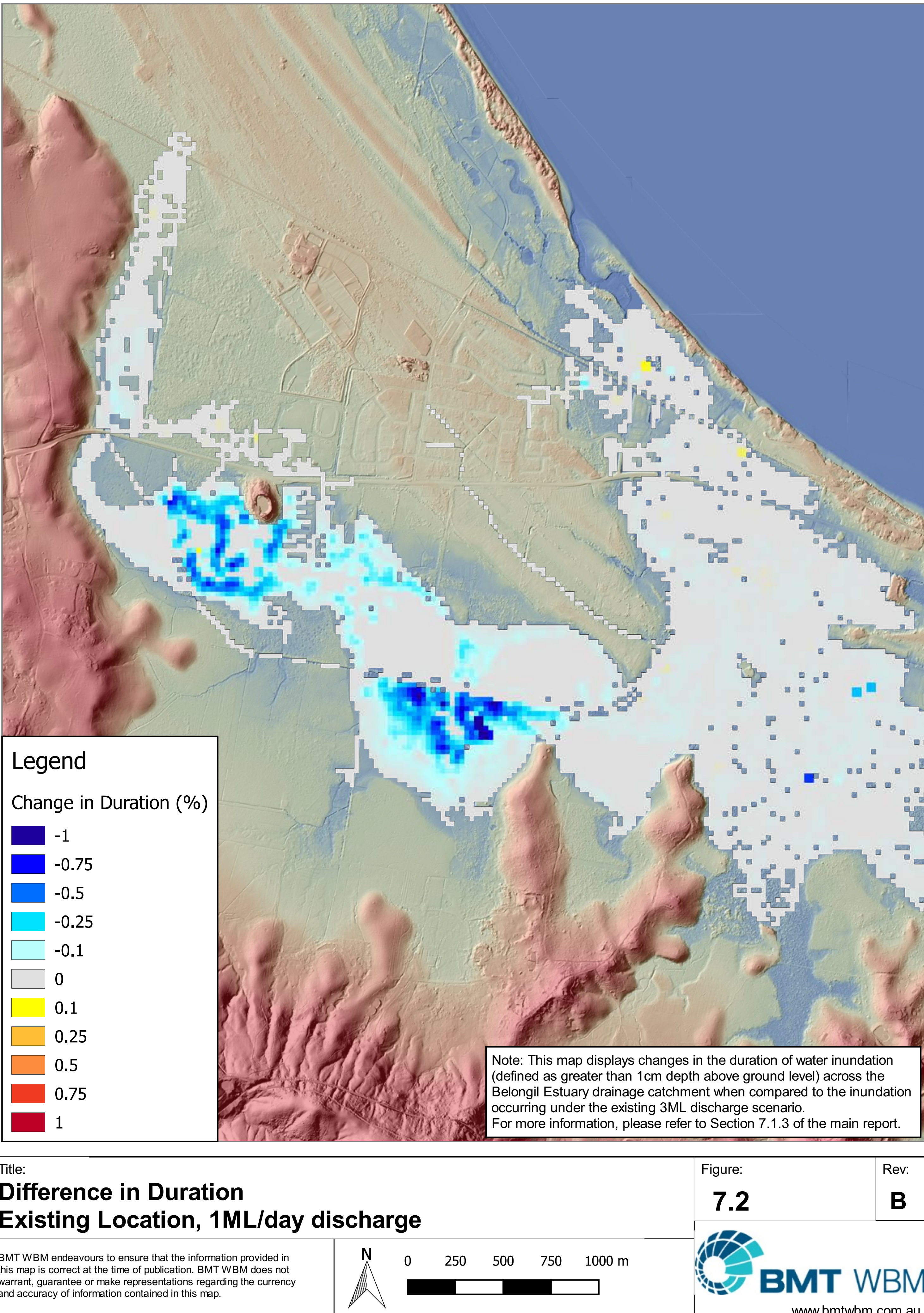
Duration of Inundation
Existign Location, 1ML/day discharge

Figure: 7-1

Rev: A

BMT WBM
www.bmtwbm.com.au

Filepath: "C:\Projects\B22117_Belongil_STP\Mapping\QGIS\HYD_014_duration_ex_1ML.qgs"



Title:
Difference in Duration
Existing Location, 1ML/day discharge

Figure: **7.2**

Rev: **B**

BMT WBM
www.bmtwbm.com.au

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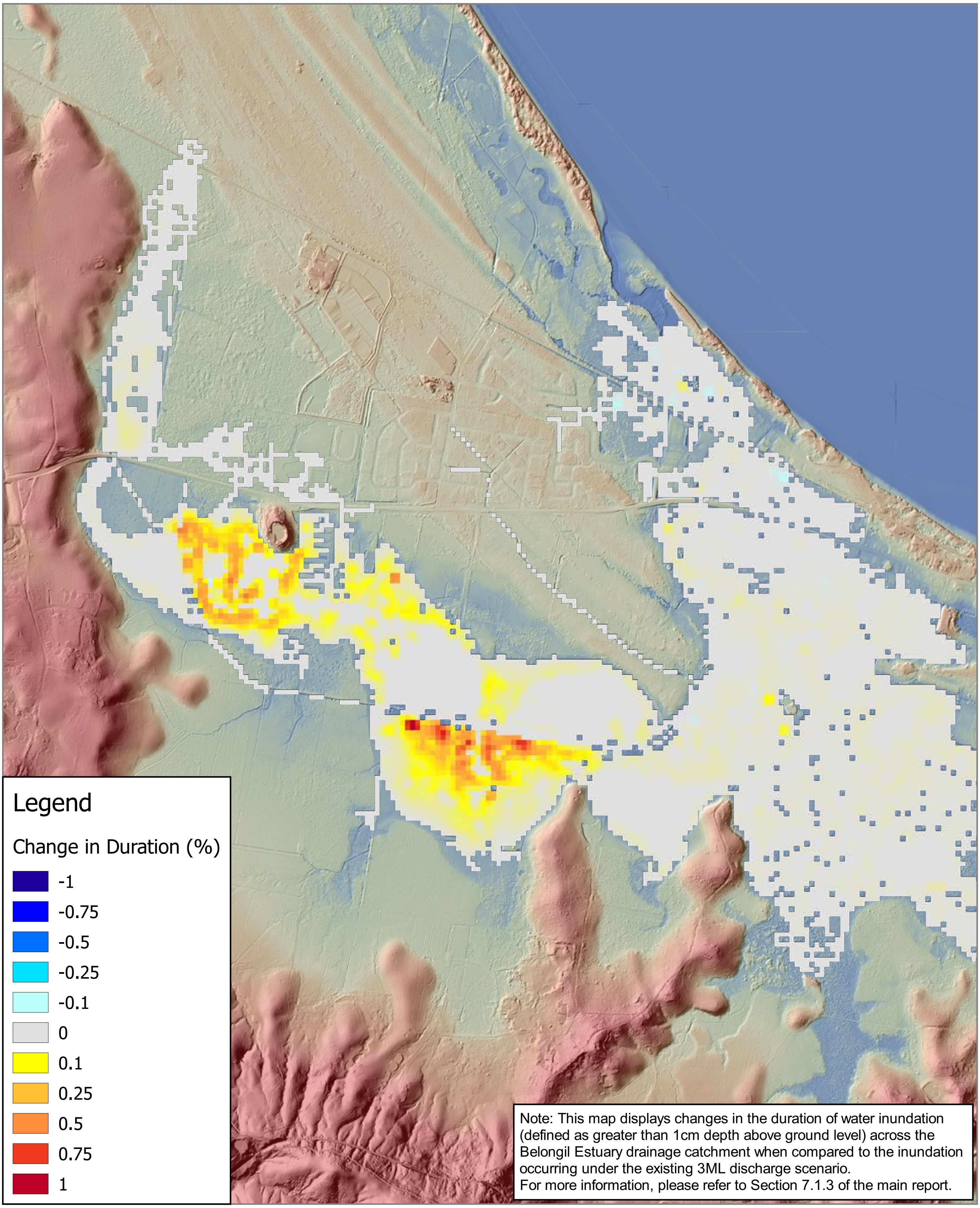

Title:

Difference in Duration
Existing Location, 5ML/day discharge

Figure: **7.3**

Rev: **B**

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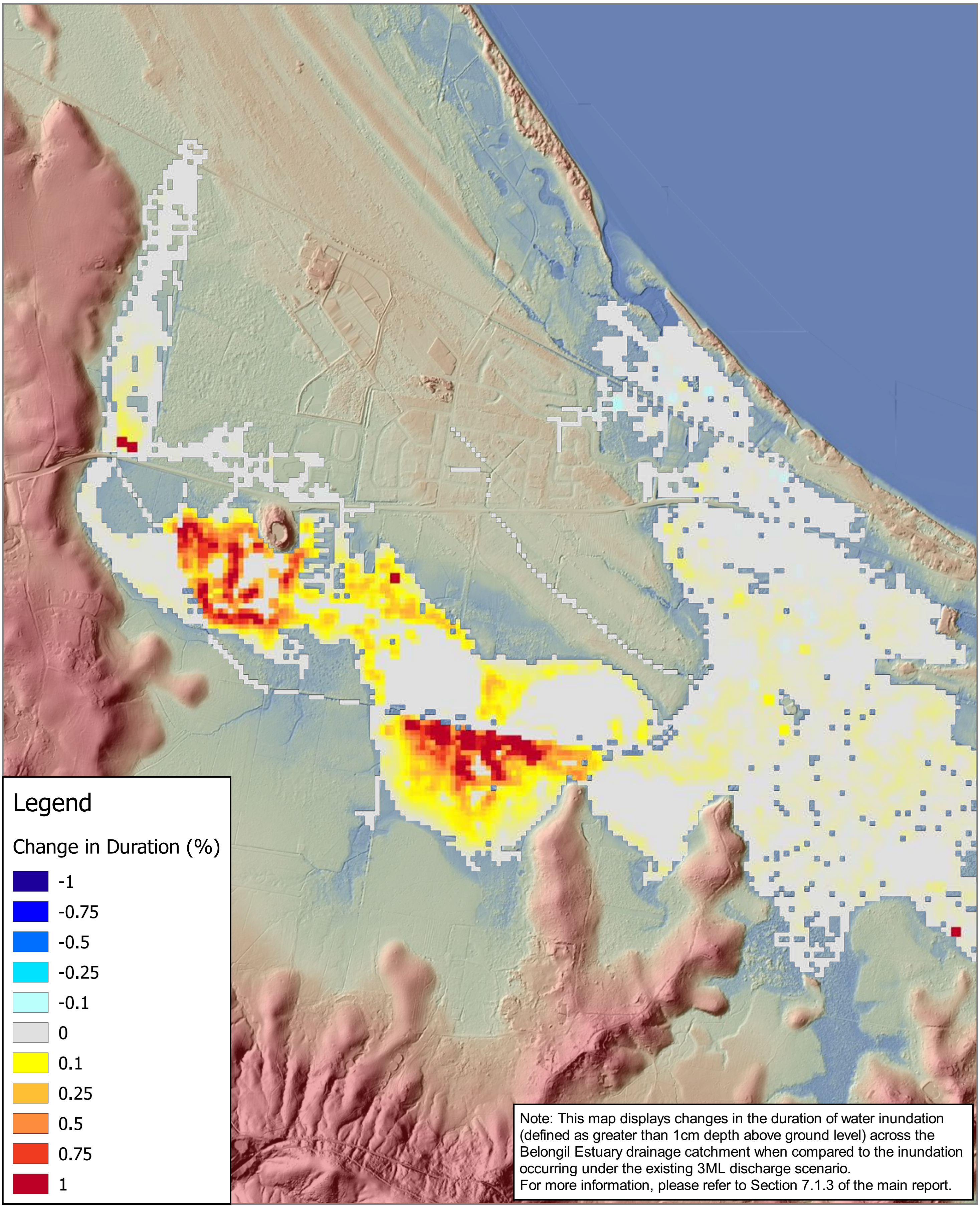

Title:

Difference in Duration
Existing Location, 8ML/day discharge

Figure: **7.4**

Rev: **B**

N

0 250 500 750 1000 m

BMT WBM
www.bmtwbm.com.au

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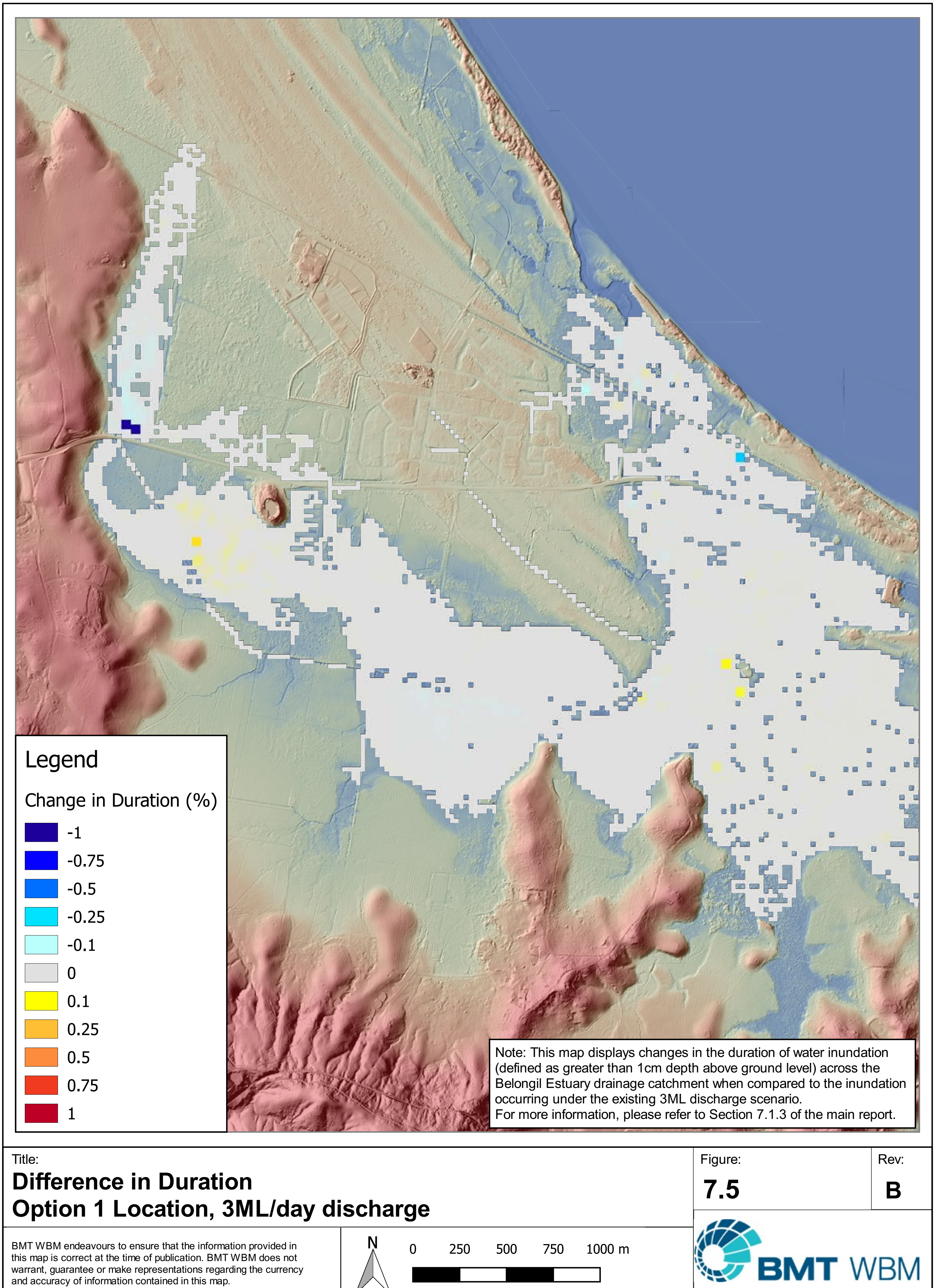

Title:

Difference in Duration
Option 1 Location, 3ML/day discharge

Figure: **7.5**

Rev: **B**

www.bmtwbm.com.au

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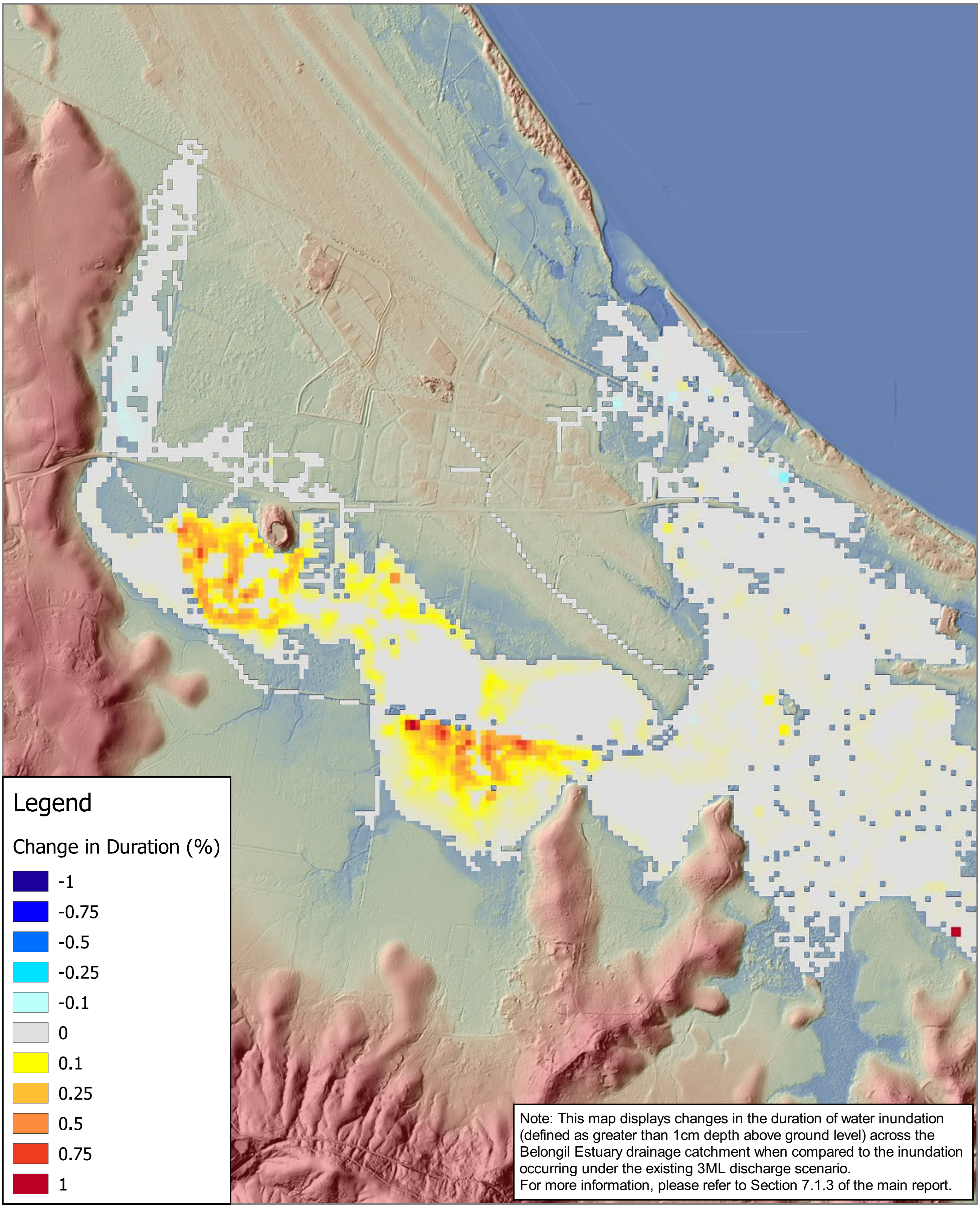

Title:

Difference in Duration
Option 1 Location, 5ML/day discharge

Figure: **7.6**

Rev: **B**

N

0 250 500 750 1000 m

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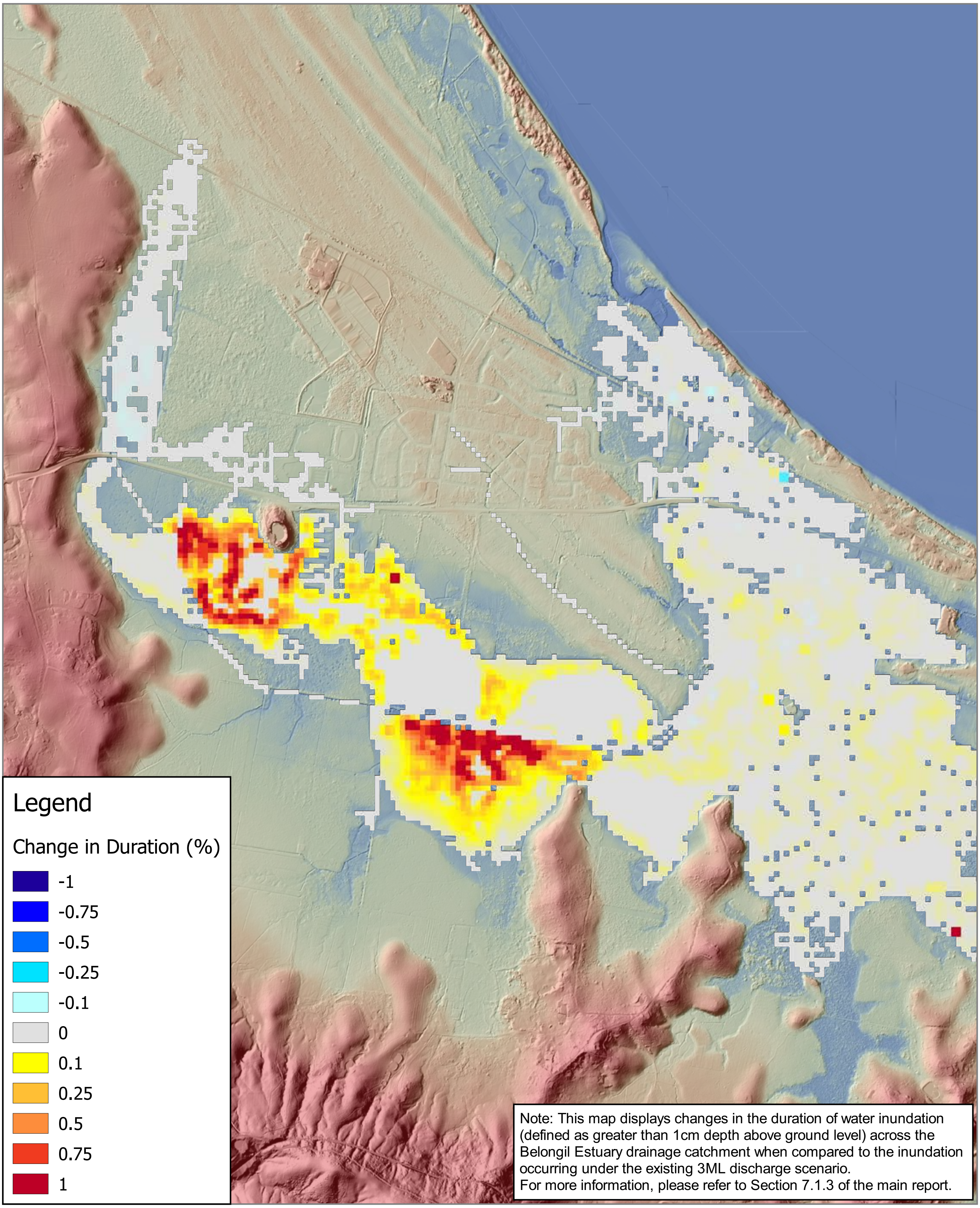

Title:

Difference in Duration
Option 1 Location, 8ML/day discharge

Figure: **7.7**

Rev: **B**

N

0 250 500 750 1000 m

BMT WBM

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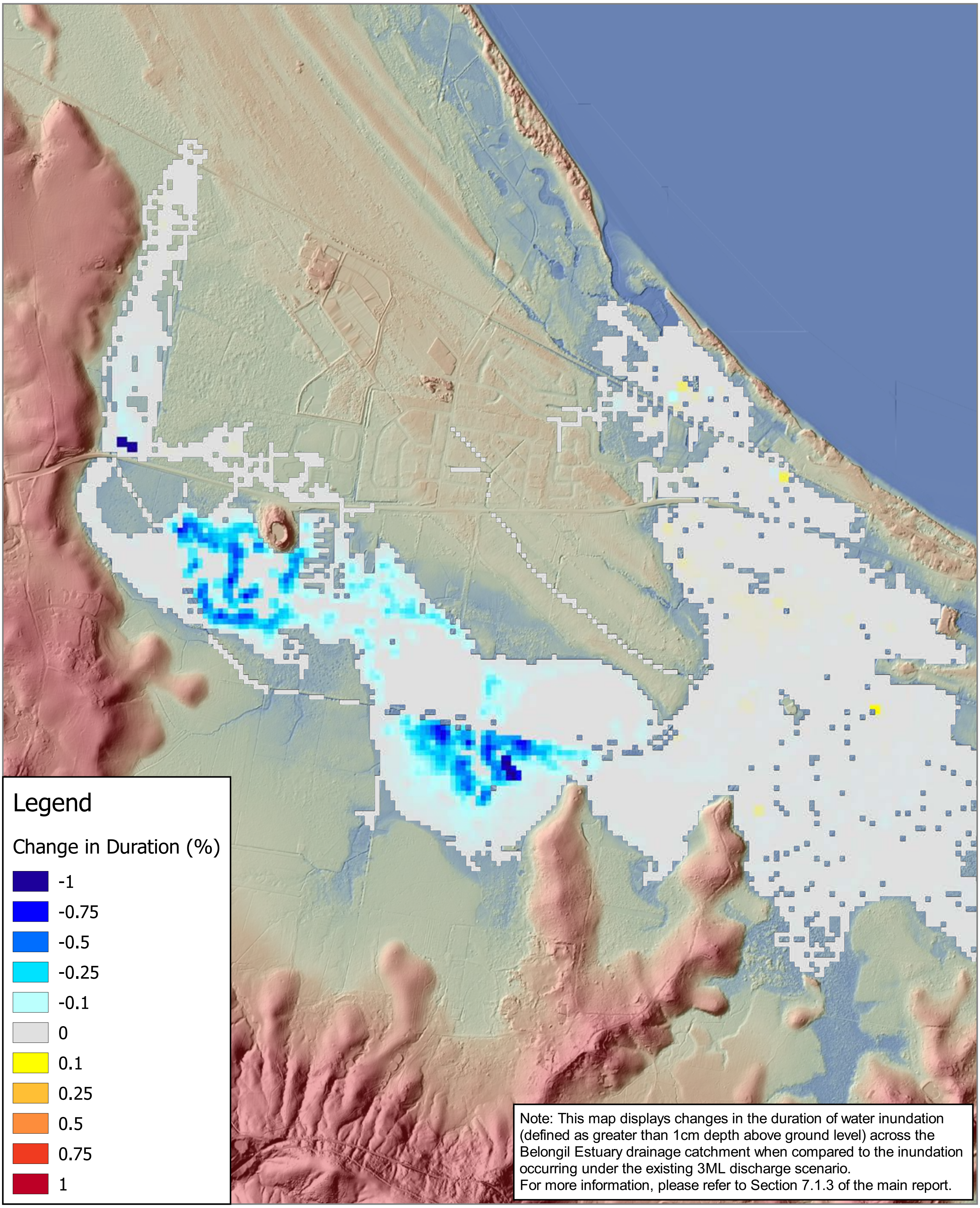

Title:

Difference in Duration
Option 2 Location, 3ML/day discharge

Figure: 7.8

Rev: B

N

0 250 500 750 1000 m

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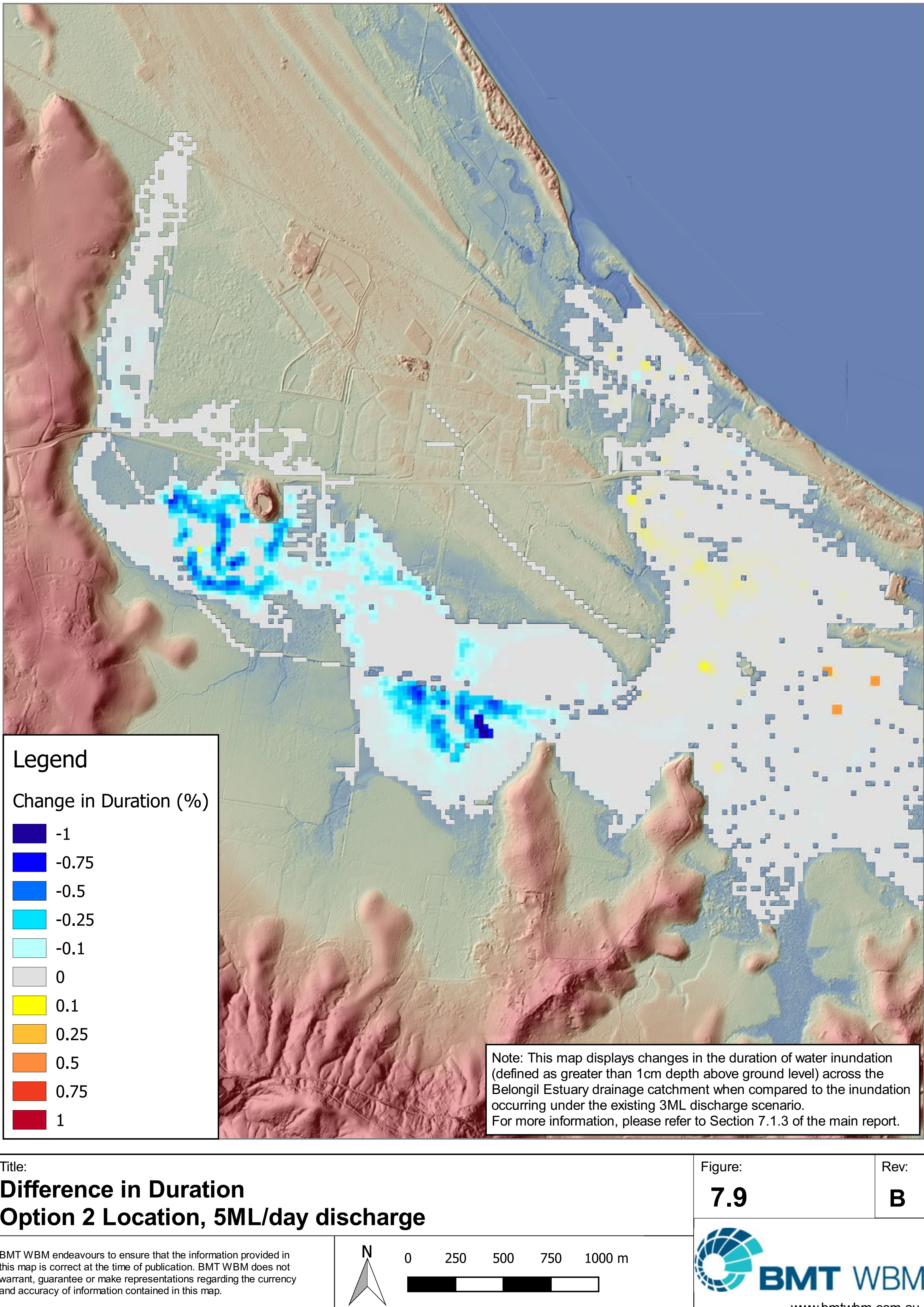
Filepath: "C:\Projects\B22117_Belongil_STP\Mapping\QGIS\20170111\HYD_101_ddur_Op2_3ML.qgs"



Note: This map displays changes in the duration of water inundation (defined as greater than 1cm depth above ground level) across the Belongil Estuary drainage catchment when compared to the inundation occurring under the existing 3ML discharge scenario.
For more information, please refer to Section 7.1.3 of the main report.

Title:

Difference in Duration
Option 2 Location, 5ML/day discharge

Figure: **7.9**

Rev: **B**

BMT WBM
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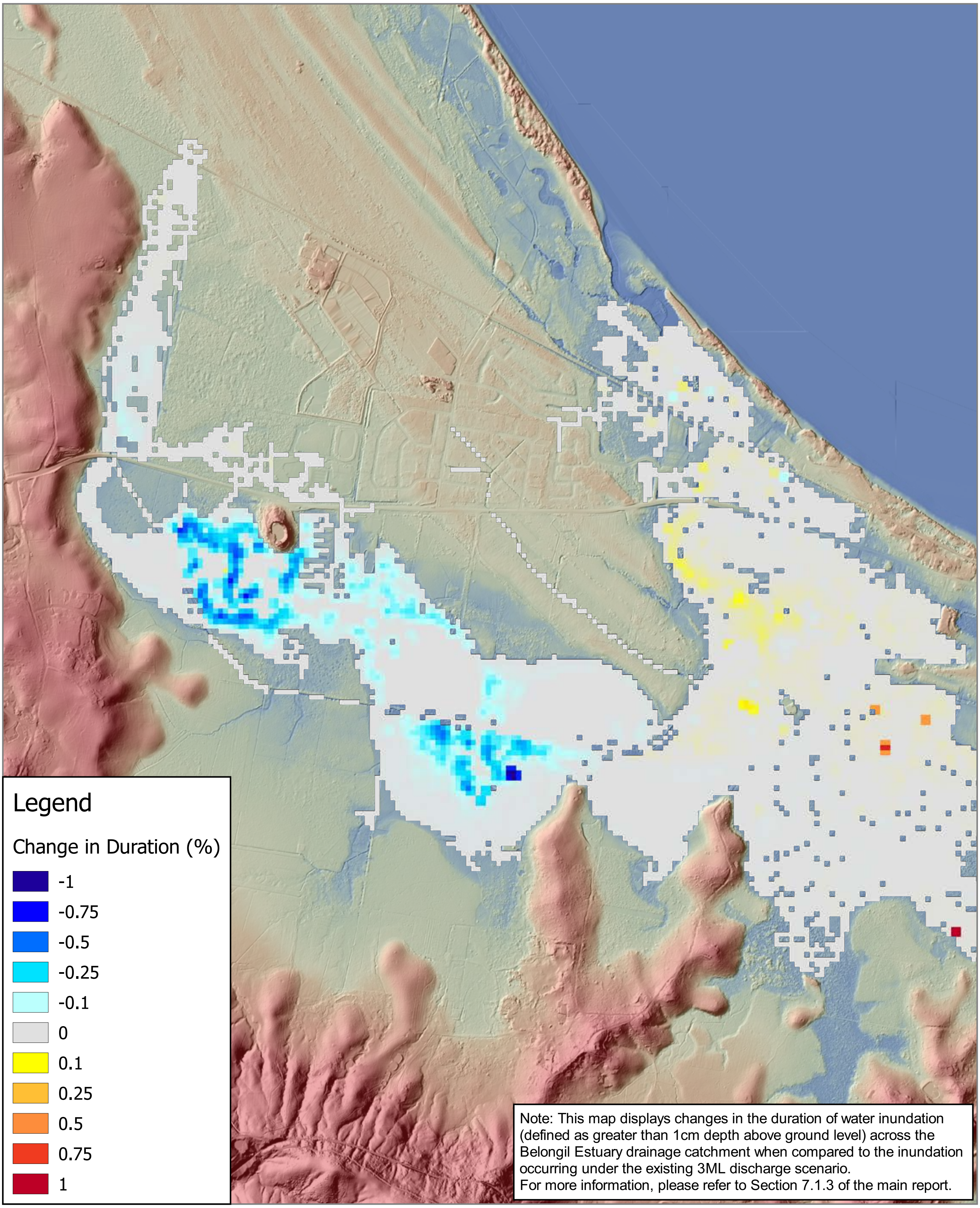
Filepath: "C:\Projects\B22117_Belongil_STP\Mapping\QGIS\20170111\HYD_101_ddur_Op2_5ML.qgs"



Title:

Difference in Duration
Option 2 Location, 8ML/day discharge

Figure: **7-10**

Rev: **B**

N

0 250 500 750 1000 m

BMT WBM

www.bmtwbm.com.au

Filepath: "C:\Projects\B22117_Belongil_STP\Mapping\QGIS\20170111\HYD_101_ddur_Op2_8ML.qgs"

8 Water quality impact assessment of release scenarios of the Belongil ICOLL

In addition to the HCA water quality modelling has been completed to provide an understanding of potential water quality changes within the Belongil Creek estuary resulting from increasing discharges from the West Byron STP.

8.1 Methodology

A rapid assessment water quality model has been developed to ascertain potential impacts to the estuary. The model accounts for key flow and pollutant inputs to the estuary and it is able to provide a temporal understanding (i.e. changes over time) of potential changes in key pollutant concentrations. However, due to its formulation (i.e. it is a non-dimensional model) it cannot provide spatial information (i.e. locations of change). The rapid assessment water quality model has been established to provide an understanding of potential estuarine water quality changes resulting from changes to discharge quantities from the West Byron STP.

The water quality model utilised for this project was originally developed as part of the Tallow and Belongil Creeks Ecological Study prepared by BMT WBM for Byron Shire Council in 2000. This study developed both salinity and water quality models of the estuary that were calibrated to local conditions and observed data. The model itself is a non-dimensional water quality model which provides volume averaged results for modelled constituents, which for this study has included salt and nutrients. The model has been established over a multi-year period where sufficient data exists to allow it to simulate flow and water quality metrics.

The original existing model has been updated to incorporate recorded West Byron STP discharges, modelled catchment discharge data (from the SOURCE model), tidal exchange information specific to the modelling period (derived from recorded tide level information for the estuary) and updated estuarine area and volume relationships derived from the updated Digital Elevation Model for the Belongil Creek estuary and catchment.

The effects of revisions to catchment runoff, tidal exchanges and the estuarine area / volume relationships were validated over a two year period in 1994 and 1995 using available water level and salinity data collated by Manly Hydraulics Laboratory as part of an earlier investigation of the estuary. Model parameters from this validated model were then applied to models established for a later period (i.e. 2011 to 2016) that were utilised for the purposes of impact assessment.

Insufficient nutrient data exists for the estuary to validate the performance of the water quality model over the 2011 to 2016 period, however, as key model parameters relating to nutrients (i.e. settlement, sediment release and biological uptake) have not been changed from the original calibrated model it is considered that the model will still be able to adequately assess nutrient dynamics.

Further detailed descriptions of water quality model establishment and validation are provided in Appendix D.

8.1.1 West Byron STP Discharge Scenarios

The water quality modelling has assessed the following key scenarios:

- Existing Case – Approximately 3ML release per day from the West Byron STP;
- Scenario – 1 ML release per day;
- Future Scenario – 5 ML release per day; and
- Future Scenario – 8 ML release per day.

Unlike the hydraulic modelling, the water quality scenarios are release location independent. The water quality modelling is focused on potential impacts to the estuary as opposed to the drainage channels which have been assessed as part of the HCA. The modelling assumes that water reaches the estuary with the same quality irrespective of release location. Indeed, the water quality utilised for the STP discharges is based on monitored data from the STP wetland itself prior to release to the drainage channels. It is likely that the water quality could change with its extended passage along drainage channels. The extent of these changes is expected to be minimal and STP effluent would be expected to further naturalise given the extensively vegetated nature of the existing and potential discharge paths.

8.2 Results and discussion

8.2.1 Existing Case

Existing case results are included along with the scenario results to allow for comparisons of results. Note total suspended solids were not modelled for the estuary as the West Byron STP (like most modern STPs) contributes very low concentrations (and loads) of suspended sediments to the drainage network.

The results graphs include the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) guideline trigger values for slightly disturbed ecosystems in south east Australia. These Water Quality Objectives (WQOs) are generally recognised by OEH as the default trigger values for estuaries of this type. Locally specific trigger values can be derived, but extensive condition assessment and consultation is required to derive the locally specific environmental values and WQOs for a waterway. This has not yet been done for the Belongil Creek. As such the default trigger values (shown in Table 8-1) are recommended for use where no locally specific guideline values exist. The trigger values apply to waterways experiencing ambient conditions.

Table 8-1: Default trigger values for slightly disturbed ecosystems in south-east Australia (Adapted from Tables 3.3.2 and 3.3.3, chapter 3, ANZECC 2000)

Ecosystem type	Chl-a (μg/L)	Turbidity (NTU)	TP (mg/L)	Sol P (mg/L)	TN (mg/L)	NOx (mg/L)	NH_4 (mg/L)	DO (%sat)	pH
Estuaries	4	0.5-10	0.03	0.005	0.30	0.015	0.015	80-110	7.0-8.5

8.2.2 1 ML, 5 ML and 8 ML scenarios

To assess the 1 ML, 5 ML and 8 ML scenarios the discharges from the West Byron STP were adjusted by differences in the flow volumes. As agreed with Byron Shire Council there was no attempt at scaling of flows from the STP to account for the influence of stormwater infiltration or other potential loading factors. It was also assumed that the STP produced the same quality of effluent as had been determined from the monitored data provided for the period 2011 to 2016.

Results have been presented as both a time-series in Figure 8-1 to Figure 8-3 (over 2012 only to make data more legible) and as box and whisker plots as shown in **Error! Reference source not found.** to **Error! Reference source not found.**. The box and whisker plots utilise data from the full modelling period (i.e. 2012 to 2016).

The box and whisker style plots provide a representation of the median (centre bar within the box), 20th and 80th percentile values (upper and lower bounds of the box), plus an indication of the spread of the data as provided by the "whisker" which extends upwards and downwards from the box and measures 1.5 times the interquartile range (i.e. range between 20th and 50th percentile, or 50th and 80th percentile). Maximum and minimum records, where present in the display range of the graph, are also shown typically by a star. The water quality objective where present is included on the graph as well. This style of graph is useful for understanding the spread of data, particularly for long datasets where there is a reduced variation in the observed results.

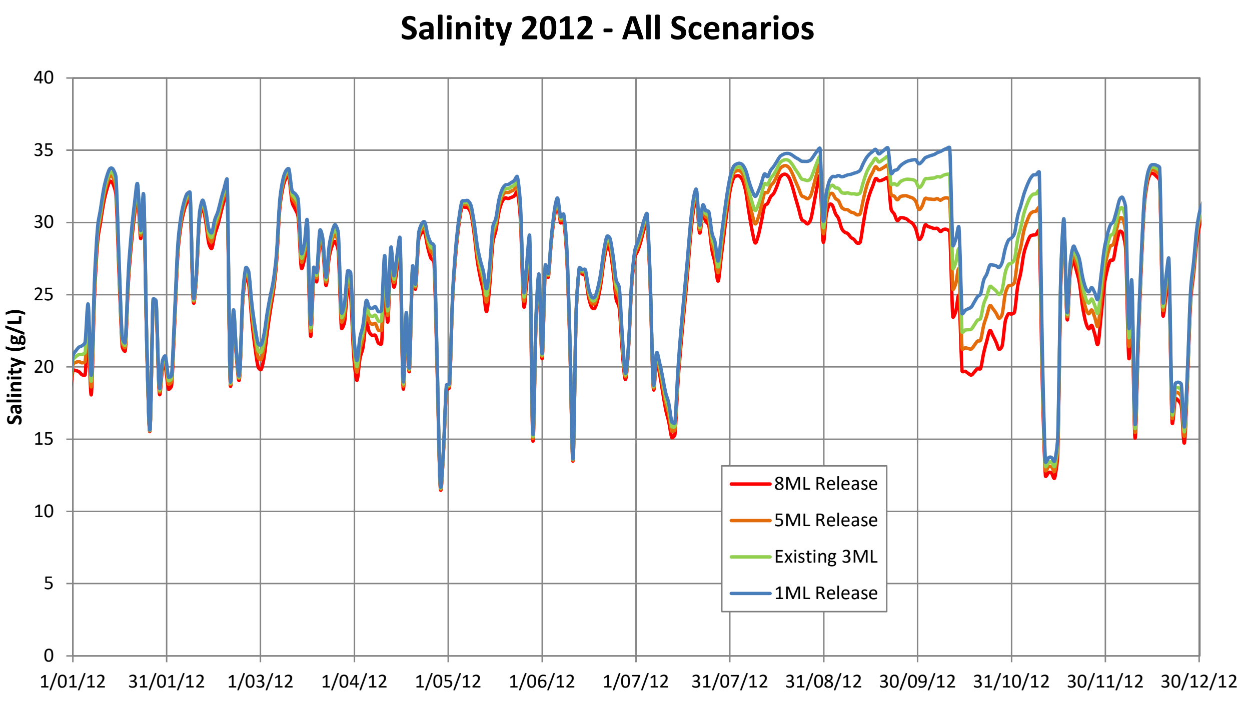


Figure 8-1 : Total Nitrogen Concentrations – All Scenarios

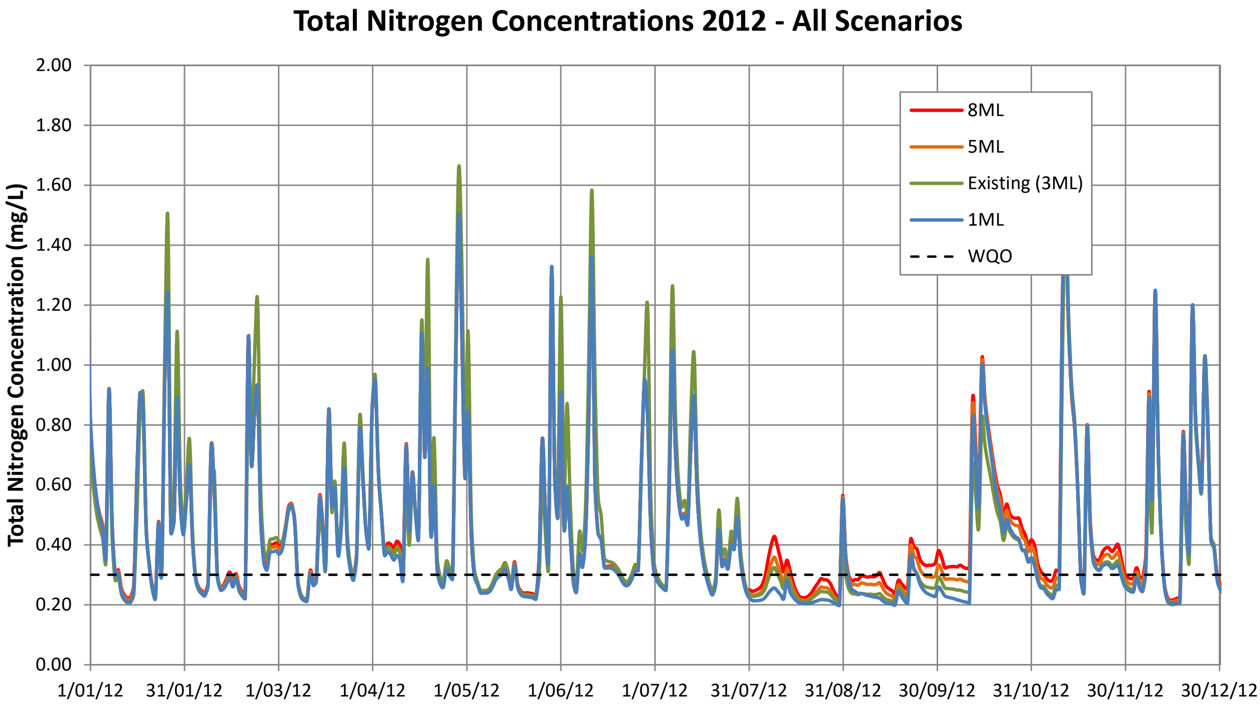


Figure 8-2 : Total Nitrogen Concentrations – All Scenarios

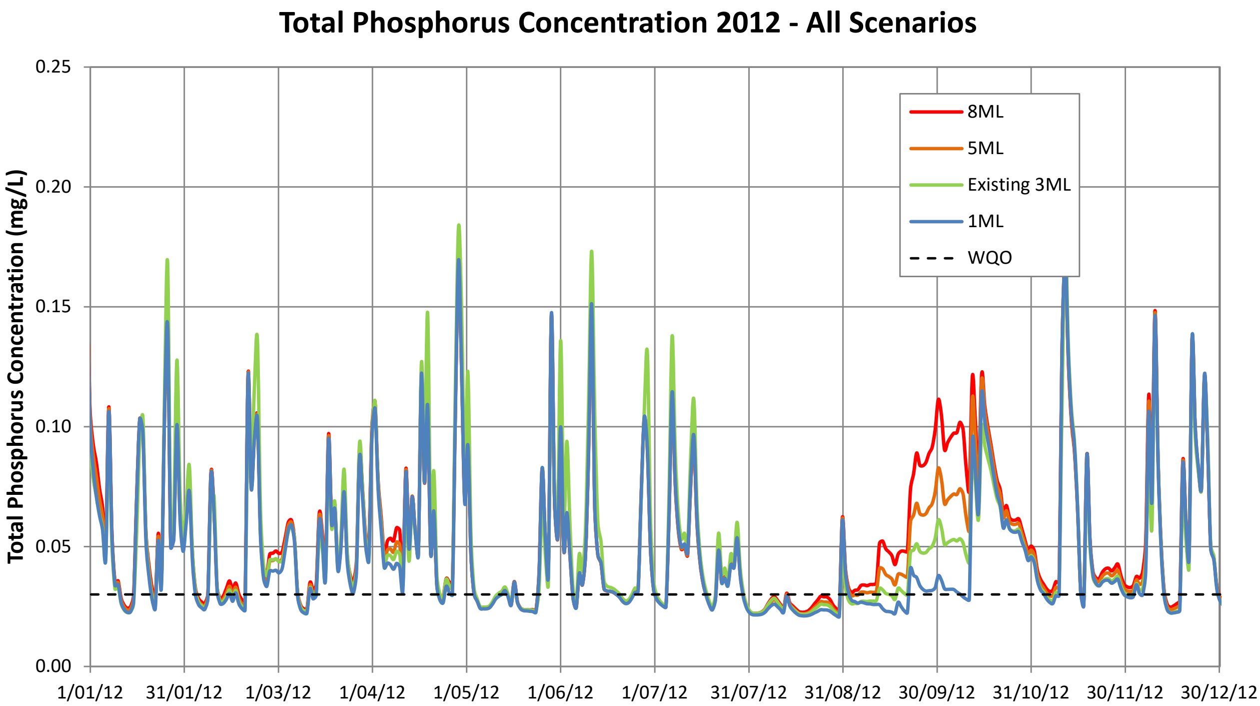


Figure 8-3 : Total Phosphorus Concentrations – All Scenarios

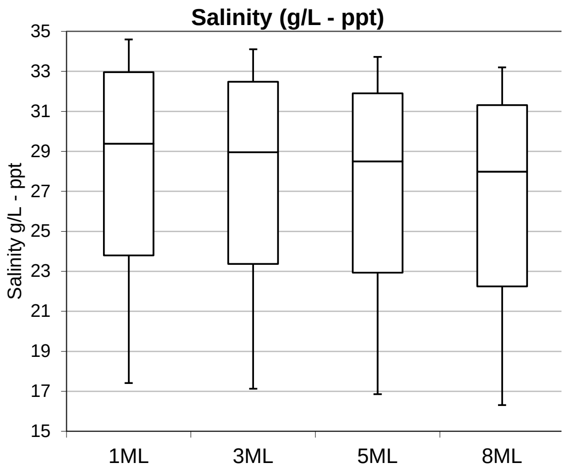


Figure 8-4 : Modelled Salinity concentrations for selected Scenarios

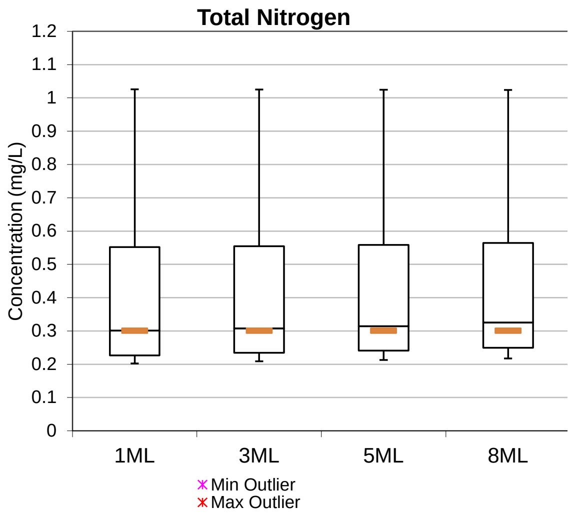


Figure 8-5 : Modelled TN concentrations for selected Scenarios

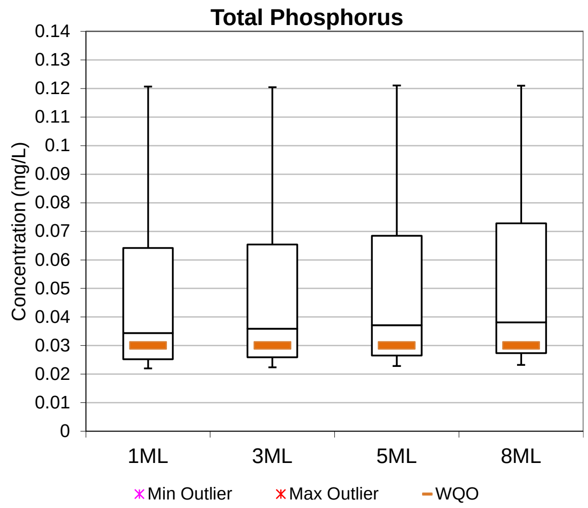


Figure 8-6 : Modelled TP concentrations for selected Scenarios

8.2.3 Salinity

The results identify that for salinity, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) increases the average salinity of the estuary over the modelling period, while increasing the discharge volumes (i.e. to 5 ML/d or 8 ML/d) decreases the average salinity across the estuary.

In terms of the scale of change the following results were obtained (all results are compared to the existing case):

- 1 ML/d resulted in a maximum increase in salinity of 7.9% with a median increase of 1.1% over the modelling period. In terms of modelled salinity concentrations a maximum increase in concentration of 1.9 ppt and median increase in concentration of 0.33 ppt were predicted;
- 5 ML/d resulted in a maximum decrease in salinity of 7.1% with a median decrease of 1.2% over the modelling period. In terms of modelled salinity concentrations a maximum decrease in concentration of 1.7 ppt and median decrease in concentration of 0.32 ppt were predicted;
- ML/d resulted in a maximum decrease in salinity of 16.4% with a median decrease of 3.0% over the modelling period. In terms of modelled salinity concentrations a maximum decrease in concentration of 4 ppt and median decrease in concentration of 0.8 ppt were predicted;

The long term median results are a function of increased or decreased dilution over a longer period within the estuary with a decrease in STP flows results in decreased dilution, etc. The peak values are caused by either a very low tidal range (due to entrance closure) providing opportunity for increased evaporation or dilution in estuary and/or dry weather periods reducing catchment runoff and there salt diluting effects within the estuary.

8.2.4 Total Nitrogen

The results identify that for TN, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) decreases the average TN concentrations of the estuary over the modelling period. Whilst increasing the discharge volumes (i.e. to 5 ML/d or 8 ML/d) increases predicted TN concentrations.

In terms of the scale of change the following results were obtained (all results are compared to the existing case):

- 1 ML/d resulted in a maximum decrease in TN of 17% with a median reduction of 1.1% over the modelling period. In terms of modelled TN concentrations a maximum decrease in concentration of 0.05 mg/L and median decrease in concentration of 0.003 mg/L were predicted;
- 5 ML/d resulted in a maximum increase in TN of 16% with a median increase of 1.1% over the modelling period. In terms of modelled TN concentrations a maximum increase in concentration of 0.05 mg/L and median decrease in concentration of 0.003 mg/L were predicted;
- 8 ML/d resulted in a maximum increase in TN of 39% with a median increase of 2.7% over the modelling period. In terms of modelled TN concentrations a maximum increase in concentration of 0.12 mg/L and median increase in concentration of 0.007 mg/Lt were predicted.

The long term median results are a function of a number of factors including changes in STP plant loadings and estuarine dilution during certain conditions. The effect of increased STP loadings can be seen between the 3 ML/d and 5 ML/d scenarios while the effect of dilution can be seen (as for the salinity scenarios) between the 1 ML/d and other scenarios. Peak values occur when either a very low tidal range (due to entrance closure) and/or dry weather period occurs affecting tidal exchange or catchment flows.

8.2.5 Total Phosphorus

The results identify that for TP, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) decreases the average TP concentrations of the estuary over the modelling period. Whilst increasing the discharge volumes (i.e. to 5 ML/d or 8 ML/d) increases predicted TP concentrations.

In terms of the scale of change the following results were obtained (all results are compared to the existing case):

- 1 ML/d resulted in a maximum decrease in TP of 4% with a median reduction of 0.9% over the modelling period. In terms of modelled TP concentrations a maximum decrease in concentration of 0.003 mg/L and median decrease in concentration of 0.0003 mg/L were predicted;
- 5 ML/d resulted in a maximum increase in TP of 39% with a median increase of 0.8% over the modelling period. In terms of modelled TP concentrations a maximum increase in concentration of 0.02 mg/L and median decrease in concentration of 0.0003 mg/L were predicted;
- 8 ML/d resulted in a maximum increase in TP of 92% with a median increase of 2.0% over the modelling period. In terms of modelled TP concentrations a maximum increase in concentration of 0.05 mg/L and median increase in concentration of 0.0007 mg/L were predicted.

As for TN, the long term median results are a function of a number of factors including changes in STP plant loadings and estuarine dilution during certain conditions. The effect of increased STP loadings can be seen between the 3 ML/d and 5 ML/d scenarios, while the effect of dilution can be seen (as for the salinity scenarios) between the 1 ML/d and other scenarios. Peak values occur when either a very low tidal range (due to entrance closure) and/or dry weather period occurs affecting tidal exchange or catchment flows.

8.3 Conclusion

Several scenarios were assessed as part of the study which included varying outfall locations and/or increases in effluent discharge volumes. Impacts were assessed on a relative basis by comparison back to the existing case (in which approximately 3 ML/d is discharged at the West Byron STP). The model assessed potential changes in salinity, total nitrogen and total phosphorus and results identify that for salinity, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) increases the average salinity of the estuary over the modelling period. Whilst increasing the discharge volumes to 5 ML/d or 8 ML/d, decreases the average estuary salinity. Peak salinity reductions of up to 16% are seen for the 8ML/d discharge scenario, but these peaks are short lived and occur only at time when there is either a very low tidal range (due to entrance closure) and to a lesser degree dry weather periods reducing catchment runoff. Considered as a long term median (over the 4+ year modelling period), salinity changes for all scenarios were less than 3%.

Similarly with predicted TN and TP concentrations, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) decreases the average total nutrient concentrations in the estuary over the modelling period. Whilst increasing the discharge volumes to 5 ML/d or 8 ML/d, increases predicted total nutrient concentrations within the Belongil Estuary. Peak total nutrient increases of up to 92% are seen for TP for the 8ML/d discharge scenario, but these peaks are short lived and occur at times with either a very low tidal range (due to entrance closure) and/or to a lesser degree dry weather periods which reduce catchment runoff. Considered as a long term median (over the 4+ year modelling period) the TN changes are less than 3% and TP changes less than 2% for the 8ML discharge scenario.

Modelling has shown that short term changes in salinity and total nutrient can occur at times when the entrance is obstructed and can be further exacerbated when combined with a low rainfall period (which reduces catchment runoff to the estuary). During these periods, which are typically of the order of weeks to a couple of months, nutrients and salinity levels can increase more noticeably, but would be still be regarded to fall within the range of water quality observed in an ICOLL style estuary.

Without any clear driver for further assessment, more detailed water quality modelling is unlikely to be warranted.

9 Sustainable assessment of effluent release scenarios

Changes in catchment hydrology have the ability to affect the physical & chemical processes within a catchment, which can in turn impact on the various environmental values of the Belongil Estuary. A summary of the potential physical and chemical impacts are listed below:

- Increased flow rate: increased erosion; shallow rooted plants washed away;
- Increased water depth: water depths may exceed threshold levels of many species;
- Increased times of inundation: times of inundation may exceed threshold levels of many species;
- Decreased groundwater table: potential oxidation of ASS/PASS layers and export of acid and drying of peat layers causing fire risks
- Increased/decreased salinity levels: increase in freshwater input into system;
- Increased nutrient loadings; and
- Time that Belongil Creek Estuary mouth is open may in turn increase tidal influences and salinity, whilst reducing tannins in water and water levels within the estuary.

This section of the report assesses the two alternative (+existing) effluent release options presented in Section 6, in light of the sustainability criteria presented in Section 1.1. Each of the proposed two effluent release pathways plus the existing release pathway, have been assessed against the sustainability criteria listed in Table 1-1, this assessment is presented in Table 9-1

Based on the qualitative assessment undertaken in Table 9-1, Release Option 2 provides the most sustainable effluent release option, while providing some degree of continued effluent discharge to the upper drainage catchment. The proceeding section explores the impacts / benefits adopting Release Option 2 as the preferred effluent release pathway.

Table 9-1: Sustainability Assessment of existing and proposed effluent release pathways

<table>
<tr><th rowspan="2"></th><th colspan="2">Sustainability Criteria</th><th rowspan="2">Existing release scenario</th><th rowspan="2">Release Option 1</th><th rowspan="2">Release Option 2</th></tr>
<tr><th>Aim</th><th>Objective</th></tr>
<tr><td rowspan="2">Social</td><td>Achieves the community's aspirations for sewage management in Byron Bay</td><td>Meets Council's vision and goals as stated in the Effluent Management Strategy (2006/ Doc #610368)</td><td colspan="3">All scenarios meet Council's vision and goals as stated in the Effluent Management Strategy</td></tr>
<tr><td>Maintenance and improvement of the aesthetic and recreational values of the Belongil Catchment</td><td>Water level and conductivity regime of the Belongil Creek/Drain and ICOLL must not affect existing vegetation communities which may affect visual amenity of the Belongil Estuary.</td><td colspan="3">Same result for all scenarios, with little change in water quality and conductivity values within the estuary across all proposed effluent flow regimes</td></tr>
<tr><td rowspan="2">Economic</td><td rowspan="2">Maintain and enhance economic value of the Belongil Estuary and its catchment.</td><td>Maintenance of the current and projected economic value of the current land use within the Belongil Catchment</td><td>Potential decrease in agricultural land value from current inundation regime</td><td>Potential decrease in agricultural land value from current modelled inundation regime</td><td>Yes, no increase in inundation to catchment land uses.</td></tr>
<tr><td>Ensure preferred effluent discharge option sits within the financial means of the Council.</td><td>Yes, no change</td><td>Yes, minimal costs</td><td>Yes, minimal costs</td></tr>
<tr><td rowspan="6">Environmental</td><td rowspan="6">Maintain and enhance downstream ecological values of the Belongil Creek, ICOLL and its catchment.</td><td>Reduction of acid discharge events from the upper catchment. pH levels within the Belongil Estuary should meet stated water quality objectives</td><td>No anticipated change, recent WQ data showing limited acidic discharge events</td><td>Due to the similar location of effluent discharge under Option 1, no anticipated change, recent WQ data showing limited acidic discharge events</td><td>Possible change in WQ due to decrease of water table in upper catchment. Can be managed through operational control of effluent release</td></tr>
<tr><td>No deterioration of existing flora and fauna communities which inhabit the Belongil Creek and ICOLL</td><td>Increased inundation of mapped SEPP 14, possibly resulting in impacts to vegetation health and regeneration</td><td>Increased inundation of mapped SEPP 14, possibly resulting in impacts to vegetation health and regeneration</td><td>No increase in inundation across catchment.</td></tr>
<tr><td>Water quality and conductivity profile of the Belongil Creek and ICOLL should meet stated water quality objectives</td><td colspan="3">Same result for all scenarios, with little change in water quality and conductivity values within the estuary across all proposed effluent flow regimes</td></tr>
<tr><td>Reduction in peat fires</td><td>No anticipated increase based on recent absence of peat fires from the upper catchment</td><td>Due to the similar location of effluent discharge under Option 1, no anticipated increase based on recent absence of peat fires from the upper catchment</td><td>Possible increase in peat fires due to drying of the peat layers from a reduction of the water table level. Can be managed through operational control of effluent release</td></tr>
<tr><td>No impact on tidal bird roosting at the mouth of the Belongil Estuary</td><td colspan="3">No anticipated change, estuary mouth is open more frequently which results low water levels and greater bird roosting areas</td></tr>
<tr><td>Meets the objectives and recommendations of the Belongil Estuary MP</td><td colspan="2">Meets the objectives of the Belongil Estuary MP, until effluent release increases, whereby increased inundation occurs that could possibly result in impacts to vegetation health and regeneration of wetlands.</td><td>Partly meets the objectives of the Belongil Estuary MP, however continued effluent release at existing outlet required to maintain water table heights</td></tr>
</table>

9.1 Impacts of the Proposed Flow Path – Option 1.

9.1.1 Inundation

The aim of the alternative drainage flow path is for a stable inundation time to be maintained in response to an increase in the output to 8 ML. Conclusions are drawn on the assumption that the STP will increase its flow to 8 ML.

Existing

All scenario results have been compared back to the existing case result (i.e. average approximately 3 ML/day discharge). The highest inundation times are focused in a section of Paperbark Swamp Forest towards the western section and paddocks along the southern section of the subject area. These areas currently experience a maximum inundation time of 331 hours over the model period.

If the flow is increased to 8 ML the average inundation time would increase substantially. In general, the distribution of inundation will remain stable however the average time would show a dramatic increase. Sections along the western and southern edges of the study area would likely experience an increase of inundation in excess of 1000 hours/model period.

If the existing drainage system is retained, an increased output would likely result in:

- Paperbark Swamp Forest in west (Section B in Figure 9.1): Increased time of in inundation resulting in a change of species composition, including die back of *Melaleuca quinquenervia*. Species such as Common Reed (*Phragmites)* and Bulrush (*Typha*) are likely to become dominant, creating a monoculture and reducing diversity. The vegetation composition is likely to transition from a forested swamp/wetland to a treeless community. Fauna species such as Grey-headed Flying Fox, Common Blossom Bat, several Glider species, Regent Honeyeater, Swift Parrot, Australasian Bittern, Large-footed Myotis, Olongburra Frog and Wallum Froglet, which are highly dependent on Paperbark Swamp Forest, will experience a shift and potential loss in habitat. Existing habitat will remain within the locality for those highly mobile species (such as Black-necked Stork), however it is unlikely that remaining vegetation is sufficient to support all species displaced. Species with low mobility will be exposed to these abrupt changes and those unable to adapt, such as Wallum Froglet and Olongburra frog will not survive. It must be noted that this section of vegetation is mapped as SEPP14 – Wetland and is of high ecological value;
- Paddocks & Wetlands in south (Section C in Figure 9.1): Flooding and inundation times will increase, resulting in a larger extent of open water. This vegetation currently experiences periods of drying, however under the increased output, the vegetation would remain wet for longer periods (if not permanently), species transition to sedges, rushes around the outskirts with deeper areas dominated by aquatic plant species;
- Belongil estuary and surrounding vegetation (Section D in Figure 9.1): There is likely to be little change in inundation and therefore ecological structure will remain stable; and
- Cumbebin Swamp (Section E in Figure 9.1): Slight increase in inundation times and extent of inundation, meaning that some low-lying areas may see a slight transition to contain more wetland species such as an understory of sedges and rushes. Additionally, this area may see a slight shift to a treeless community with a small amount of *Melaleuca quinquenervia* dieback.

AWC

Project: West Byron Bay STP effluent release assessment

Figure 9.1 : Zones within Catchment

Legend

Zones

0 200 400 600 m

Date - 12/01/2017

A3 Scale - 1:7500

SOURCE:
Aerial - NearMap Pty Ltd 2016
Study Site - AWC

Option 1

Option one is likely to experience similar impacts to the existing drainage system.

Option 2

With an output of 8 ML, Option two will experience a slight decrease in inundation times in the western section of the catchment. With an output of 8 ML, the eastern section of the catchment will experience a very slight increase in inundation, however the percentage is much lower than alternative options. Similar to the existing scenario and Option one, the most noticeable impacts will be seen in a section of Paperbark Swamp Forest (Section B) along the western section and in the paddocks along the southern section of the study area (Section C). Overall the impacts would be minimal and the vegetation composition is likely to remain relatively stable. However, the potential exists for the following impacts to occur:

- Paperbark Swamp Forest in west may experience a slight decrease in inundation times. Some sections may experience a decrease in sedge/rush ground cover, with grasses and small herbs becoming more abundant. The dominant canopy species (*Melaleuca quinquenervia*) is able to adapt to such changes and is likely to remain stable.
- Paddocks & Wetlands in the south may experience slightly drier conditions, with time and extent of open water likely to decrease. The extent of change is not likely to result in the transition from wetland to swamp. If no outside influences (land management) are experienced, vegetation such as Common Reed (*Phragmites)* and Bulrush (*Typha*), which are more highly adapted to changes in hydrology and water quality may increase in the area.
- Belongil Estuary and surrounding vegetation: There is likely to be little change in inundation and therefore ecological structure will remain stable; and
- Cumbebin Swamp: Unlikely to experience any significant impacts, however the potential does exist for a slight increase in wetland species.

9.1.2 Salinity

The natural variation of salinity levels within the estuary over the sample period is approximately 22 ppt. Results did show that a large volume discharged from the STP results in a slight decrease in the average salinity, however only by a few percent, unless unusual conditions prevail. When the flow was modeled with an 8ML discharge, estuarine salinity was shown to decrease by ~16%. This occurred during a period of reduced tidal levels (i.e. closure) with dry weather and the time experienced was limited. Modeling results for salinity fall within the natural variation of the estuary (maximum difference between 1 ML and 8 ML is ~6 ppt) and as such, changes in salinity as a result of alternative flow scenarios are not likely to have an impact on the ecology.

The salinity and inundation tolerances of common species within the catchment are identified in Table 9-2. In most scenarios, these conditions will not be exceeded as a result of the proposed flow path (Option two) and as such, conditions are likely to remain stable. However, during times of extreme weather, high rainfall, low rainfall, low tidal range and estuary entrance closure, the risk does exist for salinity and nutrient levels to change for a period long enough to influence aquatic communities within the catchment. As such it is recommended that an adaptive management approach is implemented through the establishment of a monitoring program which would allow for extreme environmental conditions and changes in vegetation structure to be tracked, allowing for quick responses and adaptations in STP flow outputs if required. Monitoring should include a mixture of vegetation transects (focused in areas of SEPP 14) correlated with water data (inundation times, nutrient and salinity levels).

*Table 9-2: Salt tolerance of common species in the area. *Values obtained from Chambers et al, 1995 & Clarke et al, 1970.*

Species	Salinity		Optimum Growth	Water Depth Tolerance
Freshwater wetland species				
Paspalum distichum	4-10 ppt	brackish	freshwater, <4 ppt	tolerant of limited tidal inundation and water logging
Cladium procerum	~< 5 ppt		summer freshwater	large approx 1 m
Cyperus eragrostis	~< 5 ppt		summer freshwater	large approx 1 m
Blechnum indicum	5 ppt	brackish	summer freshwater	
Eleocharis acuta	0 ppt	freshwater	freshwater +nutrient	1.2 m (large tolerance of season flooding) 1 m
Eleocharis dulcis	1 ppt	freshwater	freshwater +nutrient	1.2 m (large tolerance of season flooding) 1 m
Melaleuca quinquenervia	35 ppt	up to seawater	20% seawater + nutrient	
Casuarina glauca	15 ppt	40% seawater	20% seawater + nutrient	
Lepironia articulata	5 ppt	brackish	summer freshwater	
Baumea articulata	0 ppt	freshwater	freshwater +nutrient	0.7 m (large tolerance of seasonal flooding) 0.8 m
Typha orientalis	5 ppt	brackish	summer freshwater	0.8 m (large tolerance of season flooding) 1 m
Salvinia molesta	10 ppt	28% seawater for 5-7 days		floating plant
Myriophyllum aquaticum	< 10 ppt		freshwater +nutrient	
Saltwater wetland species				
Juncus krausii	15 ppt	40% seawater	20% seawater + nutrient	higher saltmarsh
Sporobolus virginicus	35 ppt	<100% seawater	20% seawater + nutrient	medium saltmarsh
Sarcocornia quinqueflora	70 ppt	150-200% seawater	20% seawater + nutrient	low saltmarsh (high tolerance of water logging)
Suaeda australis	35 ppt	100% seawater	20% seawater + nutrient	low - medium saltmarsh
Triglochlin procerum	21-35 ppt	60-100% seawater	20% seawater + nutrient	low - high saltmarsh
Bacopa monnieri	35 ppt	100% seawater		30cm if clear
Aegicerus corniculatum	35 ppt	100% seawater	20% seawater + nutrient	mangroves
Avicennia marina	35 ppt	100% seawater	20% seawater + nutrient	mangroves

**Values obtained from Chambers et al, 1995 & Clarke et al, 1970.*

9.1.3 Nutrients

At most times during year modeling shows only negligible differences in the level of TN and TP between the existing and 8 ML scenario. At some points during the model a difference is notable with nutrient levels in the 8 ML scenario exceeding those with lower output. The 8 ML/d resulted in a maximum increase in TN of 39% with a median increase of 2.7% over the modelling period. Additionally, the 8 ML/d resulted in a maximum increase in TP of 92% with a median increase of 2.0% over the modelling period. Peak values correspond with environmental conditions such as periods of dry weather or low tidal ranges, often caused by estuary entrance closure.

The increases in nutrients illustrated in the model are relatively low, with short lived peaks, however the potential for excessive growth of naturally occurring organisms, such as algae does exist during peak events. Excessive growth of algae can deplete oxygen levels in the water making the water unsuitable for aquatic wildlife. Species such as Common Reed (*Phragmites)* and Bulrush (*Typha*) are also known to out-compete other wetland species in times of increased nutrients. These impacts may be experienced within areas inundated with water, such as within drainage lines, estuary, wetlands and during flooding events within swamp forest. Whilst significant impacts are unlikely, the greatest risk exists when dry weather coincides with entrance closure.

9.1.4 ASS/PASS

Historically, the upper drainage catchment has discharged acidic waters as a result of extensive catchment drainage. In recent years this acidic discharge (or fish kills) has not been recorded, presumably as a result of increased water table heights resulting from a combination of effluent irrigation and increased effluent discharge.

It can be assumed that under the existing effluent release scenario and Option 1 (along with increased effluent flow), that existing and resulting increased water table height will not cause increase in acidic discharge from the upper catchment.

If release Option 1 was adopted in full, there is a potential for increased acidic discharge and peat fires in the upper catchment and fish kills within the Belongil Estuary. As such, there is some degree of 'need' for continued effluent to discharge into the upper drainage system to ensure limited acidic discharge and zero fish kills within the Belongil Estuary. The actual daily volume of discharge required in the upper drainage system to maintain the environmental values of the Belongil Catchment is unknown at this stage.

An incremental decrease in flows to the upper union drain catchment coupled with an incremental increase in flows to Option 2, alongside intensive monitoring (water level, conductivity, pH) to gauge potential impacts to the Environmental Values of the Belongil Estuary and its catchment, is recommended.

9.2 Conclusion

Via the adoption of Option two, it is expected that minimal impacts will occur on ecological structure and function within the catchment. If the existing flow path is maintained, increased output from the STP is highly likely to decrease inundation times in some patches within the catchment, resulting in vegetation shifts, altering habitat values for the many threatened species known to frequent the area.

During times of extreme weather, high rainfall, low rainfall, low tidal range and estuary entrance closure, the risk does exist for salinity and nutrient levels to change for a period long enough to influence aquatic communities within the catchment.

Due to the presence of ASS/PASS in the upper catchment of the Belongil Estuary, the historical occurrence of acid discharge (+associated fish kills within the Belongil Estuary) and peat fires, a continued discharge of effluent form the existing location (EPA 4) is recommended. The exact volume of discharge required to negate acid export events and peat fires is unknown, thus an adaptive effluent release management response is recommend – linked to key monitoring of catchment responses. This adaptive management approach should be implemented through the establishment of a monitoring program which allows for extreme environmental conditions and changes in vegetation structure and groundwater surface water quality to be tracked. Monitoring would inform adaptive management responses, and adaptations in STP flow outputs if required. Monitoring should include a mixture of vegetation transects within key habitat types correlated with water data (inundation times, nutrient, pH and salinity levels). This is detailed further in Section 10.

10 Additional effluent irrigation areas

The 24 ha effluent irrigation area located within the BBIWMR (Plate 10-1) provides a unique pathway for effluent loss (via evapotranspiration) that has the added benefits of environmental rehabilitation. This rehabilitation can provide many benefits to the Belongil Estuary catchment including:

- increased biodiversity,
- a reduction in the exposure of acid sulfate soils,
- a reduction in peat fires,
- improved treatment of effluent and reduction of nutrient loads to the Estuary,
- complete removal of effluent from the Belongil Catchment, and
- the sequestration of carbon.

From the information presented in Section 7 and 9 of this report, the inundation pattern of the Belongil Estuary catchment will change with increased effluent loads and the provision of an alternative effluent release pathway. While increased effluent irrigation areas have not been assessed in this report as a supplementary or alternative effluent discharge pathway, they should be investigated where suitable sites occur and landholders are supportive. Increased effluent irrigation may provide a hydraulic/nutrient buffering capacity for the catchment in times of high effluent production (holidays periods). This could have the potential to reduce nutrient concentrations within the Estuary during periods when the Belongil ICOLL is closed during dry weather – a key time where nutrients within the ICOLL increase as a result of the BB STP effluent discharge (refer to Section 8).

Plate 10-1: Effluent irrigation area within BBIWMR

11 Conclusions and recommendations

This study has investigated the current fate of effluent discharged within the BBIWMR and its influence on the upper catchment drainage system under a range of current and predicted operating regimes. Detailed site analysis of the effluent irrigation area, land to the west of the BBIWMR and Belongil drainage system has inferred that the increase in flows associated with the transfer of effluent from the SB STP to the BB STP with the adjoining has resulted in:

- A decrease in artificial estuary opening events,
- A potential increase in water table heights west of the BBIWMR, resulting in an increase in the frequency, extent and depth of surface water inundation, and
- A reduction in peat fires and acid discharge events.

Ecologically, the Belongil Creek, ICOLL and drainage system provides a large expanse of high quality habitat for various terrestrial and aquatic species. Swamp forest (large proportion mapped as SEPP 14), mangroves, saltmarsh and regenerating areas with the STP provide high quality habitat for multiple species listed under the TSC Act and EPBC Act. Known breeding habitat for several species such as the Littler Tern and Pied Oyster Catcher occurs within the catchment, meaning that conservation of these environments is essential for the sustainability of the local population. Overall the catchment hosts an array of high value ecological features including threatened species habitat (flora and fauna), EECs, SEPP 14 wetland and wildlife corridors (regional and sub regional).

In order to assess the impact of various effluent release scenarios on the Belongil Creek, ICOLL and drainage system and Hydrologic, Hydraulic and Water Quality models where developed. These models ran various effluent release scenarios, including current effluent relapse and projected effluent release (5ML and 8ML) at three locations; Existing discharge point and two alternative locations. For the existing STP discharge location and Option 1 location, there are significant areas of the floodplain predicted to experience increases in the duration of inundation with increase effluent discharge. Generally this inundation has been predicted to occur downstream (to the south) of Ewingsdale Road in the main portion of the floodplain (SEPP 14 wetland area north of Union Drain). The flatter channel gradient and influences of the tidal level / entrance conditions are the cause of additional water ponding in these floodplain locations, though the differences in the time of inundation are typically less than 2%. For the Option 2 discharge location, the predicted increases in duration are significantly less than for the two other alternatives.

From a water quality perspective, modelling results identify that for salinity, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) increases the average salinity of the estuary over the modelling period, while increasing the discharge volumes to 5 ML/d or 8 ML/d, decreases the average estuary salinity. Peak salinity reductions of up to 16% are seen for the 8ML/d discharge scenario, but these peaks are short lived and occur only at time when there is either a very low tidal range (due to entrance closure), or to a lesser degree, during dry weather periods. Considered as a long term median (over the 4+ year modelling period), salinity changes for all scenarios were less than 3%.

Similarly with predicted TN and TP concentrations, decreasing the West Byron STP discharge volumes (i.e. to 1 ML/d) decreases the average total nutrient concentrations in the estuary over the modelling period, while increasing the discharge volumes to 5 ML/d or 8 ML/d, increases predicted total nutrient concentrations. Peak total nutrient increases of up to 92% are seen for TP for the 8ML/d discharge scenario, but these peaks are short lived and at time when there is either a very low tidal range (due to entrance closure), or to a lesser degree, during dry weather periods. Considered as a long term median (over the 4+ year modelling period) the TN changes are less than 3% and TP changes less than 2%.

Overall the water quality modelling completed for this project has identified that the future scenarios result in minor change to the long term median total nutrient and salinity concentrations of the estuary. This outcome is a function of the high level treatment effected at the Byron STP and subsequent extended travel time of treated effluent through the partially vegetated Union drainage system.

Modelling has shown that short term changes in salinity and total nutrient can occur at times when the entrance is obstructed and can be further exacerbated when combined with a low rainfall period (which reduces catchment runoff to the estuary). During these periods, which are typically of the order of weeks to a couple of months, nutrients and salinity levels can increase more noticeably, but would be still be regarded to fall within the range of water quality observed in an ICOLL style estuary.

Without any clear driver for further assessment, more detailed water quality modelling is unlikely to be warranted.

11.1 Recommendations

The main recommendation resulting from this study is to provide an alternative effluent release pathway via Option 2 – release into the Industrial Estate drain. While the results of the investigations presented in this report support an alternative effluent release pathway, it is advised that some degree of discharge from the existing release point (EPA 4) continues. This continued discharge is required to ensure that acidic runoff off events and/or peat fires do not occur within the upper drainage catchment - as have occurred in the past. Unfortunately the minimum volume of effluent required to be released from the existing release point (EPA 4) is unknown at this stage. As such an effluent release transfer and monitoring program will need to be developed. This monitoring program should be developed to monitor ground and surface water levels, pH and conductivity on an hourly basis at a minimum of two sites. The results from this monitoring should be used to inform the ultimate volumes of effluent discharged into the current and proposed disposal pathways.

Whilst ecological impacts associated with Option 2 are predicted to be minimal, monitoring sites should be established to validate modelling and inform adaptive management. It is recommended that vegetation transects are established within the areas mapped as SEPP 14, focusing on sections that are predicted to experience the highest increase in inundation times. Byron Shire Council currently conducts monitoring of vegetation structure (via transects) within Belongil Estuary. The data collected in these transects should be utilised in addition to monitoring recommended above. Regular monitoring is essential to validate modeling and ensure that changes to flow regimes are not affecting ecological structure within the catchment.

While this report supports the provision of an alternative release pathway, the timeframe for implementation is undecided. Nevertheless, numerous short term actions can be implemented immediately to potentially reduce inundation depth, frequency and duration of land west of the BBIWMR:

- Remove the concrete lip north of pipes draining the upper Union Drain on Ewingsdale Road,
- Ensure pipes draining the upper Union Drain on Ewingsdale Road are inspected after every decent rainfall events, and cleaned if capacity is impacted by <20%, and
- Reduce weir level from EPA 4 drain within BBIWMR by 100mm or to a level which ensures limited inundation of land west of the Cavanbah Centre.

A detailed Environmental Monitoring Plan, complete with triggers and actions is required to inform the delivery of the alternative effluent release pathway. This monitoring plan will provide guidance on the incremental decrease of effluent at EPA 4, and the incremental increase of effluent release to Option 2. The plan will outline key environmental variables to measure, frequency of data collection and triggers which will guide the further increase/decrease of effluent at the two proposed discharged locations (existing and Option 2)

While increased effluent irrigation areas have not been assessed in this report as a supplementary or alternative effluent discharge pathway, they should be investigated where suitable sites occur and landholders are supportive.

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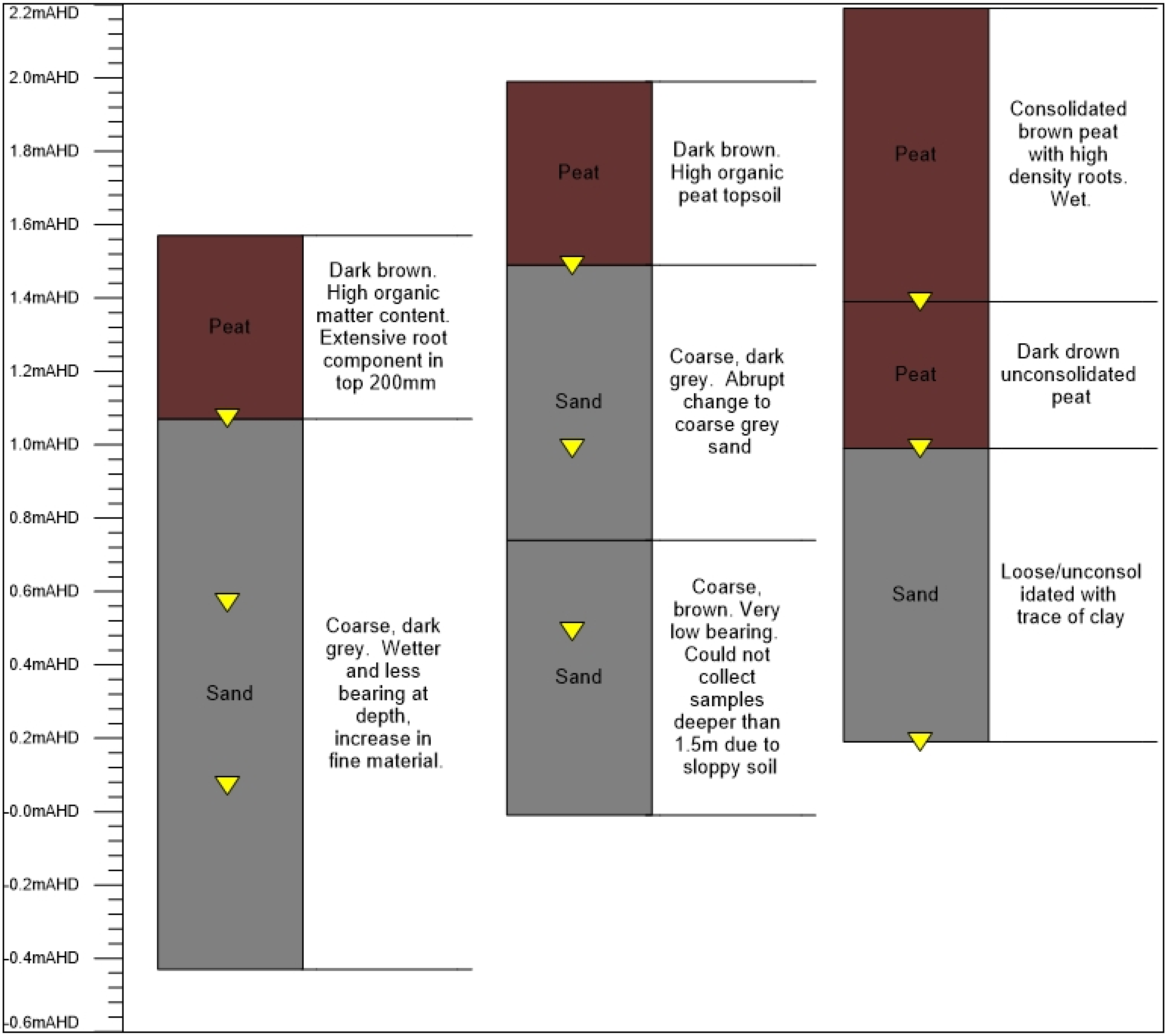
13 Appendix A – Soil bore logs and ASS results

West Byron STP Alternative Flow Path Investigation

Client: Byron Shire Council
Field work date: 14 & 17 Sept 2016
Project: West Byron STP Alternative Flow Path Investigation
Job Number: 1-16722
Staff: Jesse Munro
Drill type / method: Hand auger

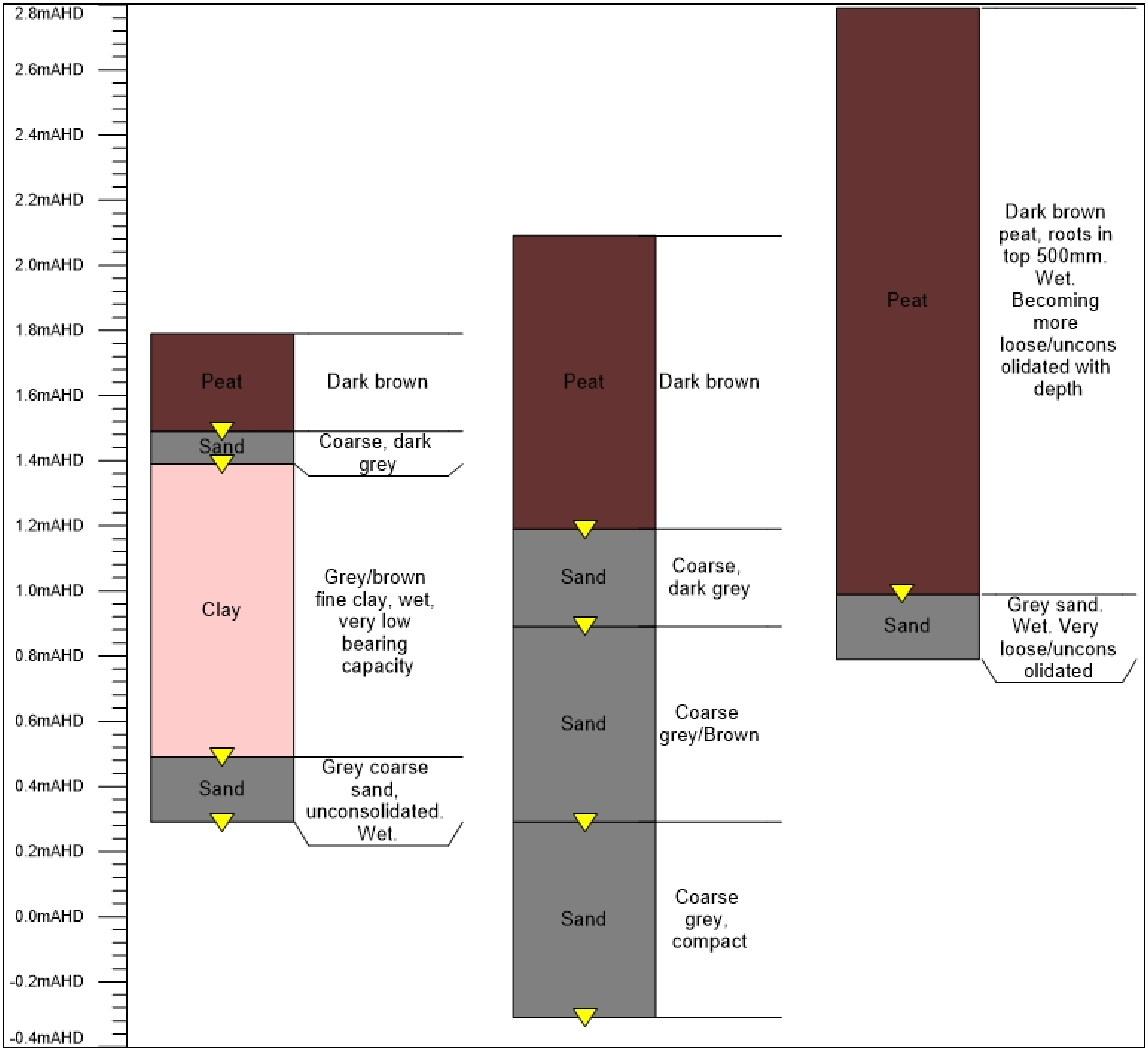


Bore ID: WB-01 WB-02 WB-03

Units of mesaure: mAHD approximate
Yellow triangle represents approximate location of ASS sample
Red line indicates minimum depth to ASS as defined by >19 mole H^+/tonne

West Byron STP Alternative Flow Path Investigation

Client: Byron Shire Council
Field work date: 14 & 17 Sept 2016
Project: West Byron STP Alternative Flow Path Investigation
Job Number: 1-16722
Staff: Jesse Munro
Drill type / method: Hand auger



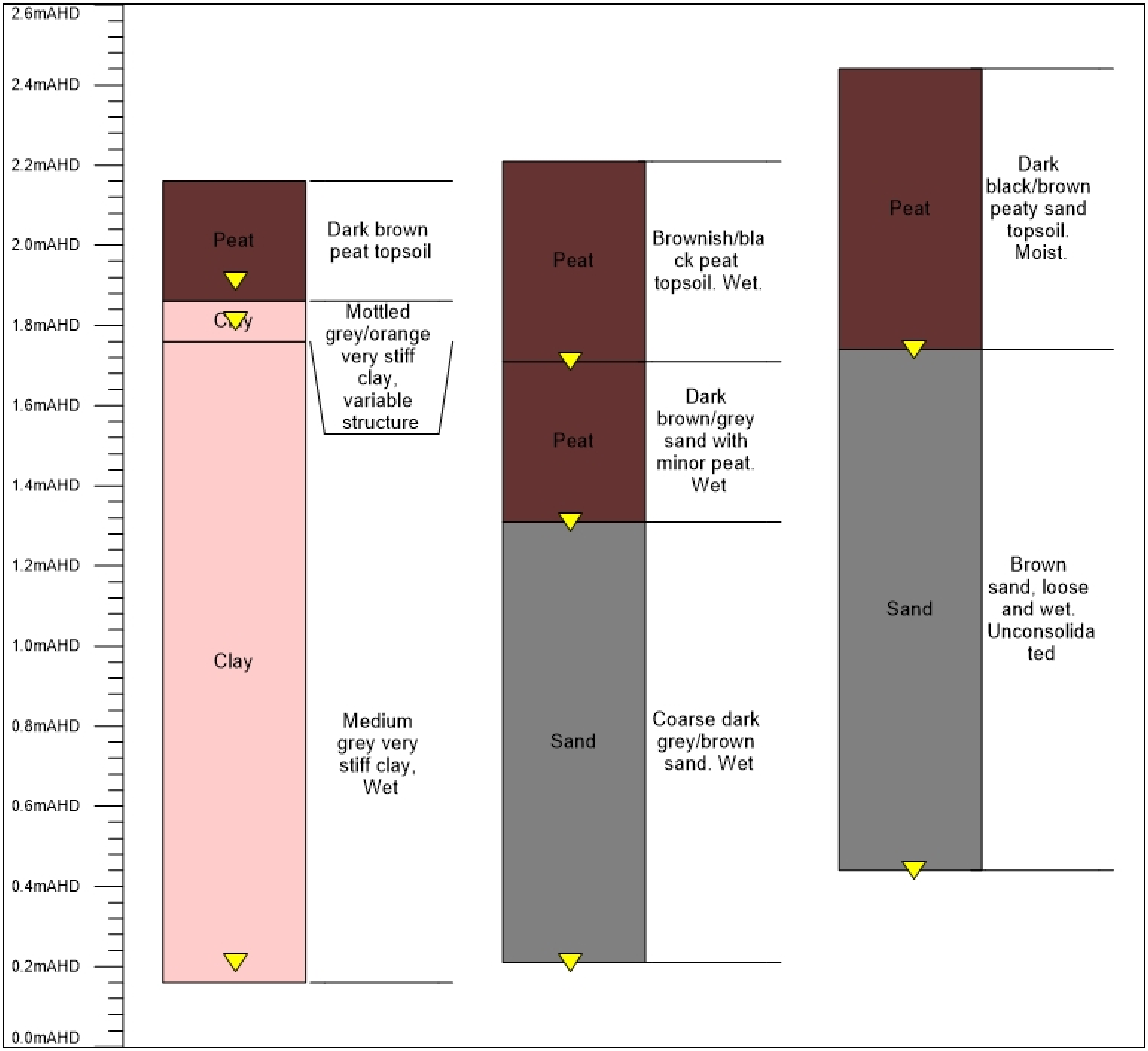
Bore ID: WB-04 WB-05 WB-06

Units of mesaure: mAHD approximate
Yellow triangle represents approximate location of ASS sample
Red line indicates minimum depth to ASS as defined by >19 mole H^+/tonne

West Byron STP Alternative Flow Path Investigation

Client: Byron Shire Council
Field work date: 14 & 17 Sept 2016
Project: West Byron STP Alternative Flow Path Investigation
Job Number: 1-16722
Staff: Jesse Munro
Drill type / method: Hand auger

AWC



Bore ID: WB-7 WB-8 WB-9

Units of mesaure: mAHD approximate
Yellow triangle represents approximate location of ASS sample
Red line indicates minimum depth to ASS as defined by >19 mole H^{+}/tonne

14 Appendix B – Water level logger graphs

15 Appendix C – Detailed methodology on hydrologic model.

15.1 Introduction

This section outlines the catchment modelling completed by BMT WBM. The catchment modelling was completed as a key component of the study to provide catchment flows. Flows were determined at numerous locations within the catchment (such as flows to the Union Drain) as well as an overall flow to the Belongil Creek estuary itself. This hydrologic data has been used to inform both a hydraulic model and a water quality model, as described in later sections of this report.

The catchment modelling results have been verified by qualitative and quantitative means as described in Section 17.6. It should be clearly stated that the validation process applied is not a traditional calibration where modelled flows are compared to a recorded flow set at a gauging station. This was not possible as there were no gauged flow stations in the catchment. The validation process applied has been done to ensure that the model provides an adequate reflection of the timing and magnitude of flows in the catchment. This increases confidence in use of the model for the study.

15.2 Model Framework

The SOURCE quantity and quality modelling framework simulates current catchment characteristics and responses, in addition to evaluating the impacts of specific changes, such as the addition of point source flows. SOURCE is not one model, but a framework in which groups of different models can be selected and linked such that the most suitable model to describe a particular aspect of a catchment can be developed and applied.

For the Belongil catchment, the SIMHYD hydrology module (see Figure 15-1) has been utilised as it is a commonly applied hydrologic model which has been applied by BMT WBM successfully in smaller coastal catchments in similar investigations in northern NSW.

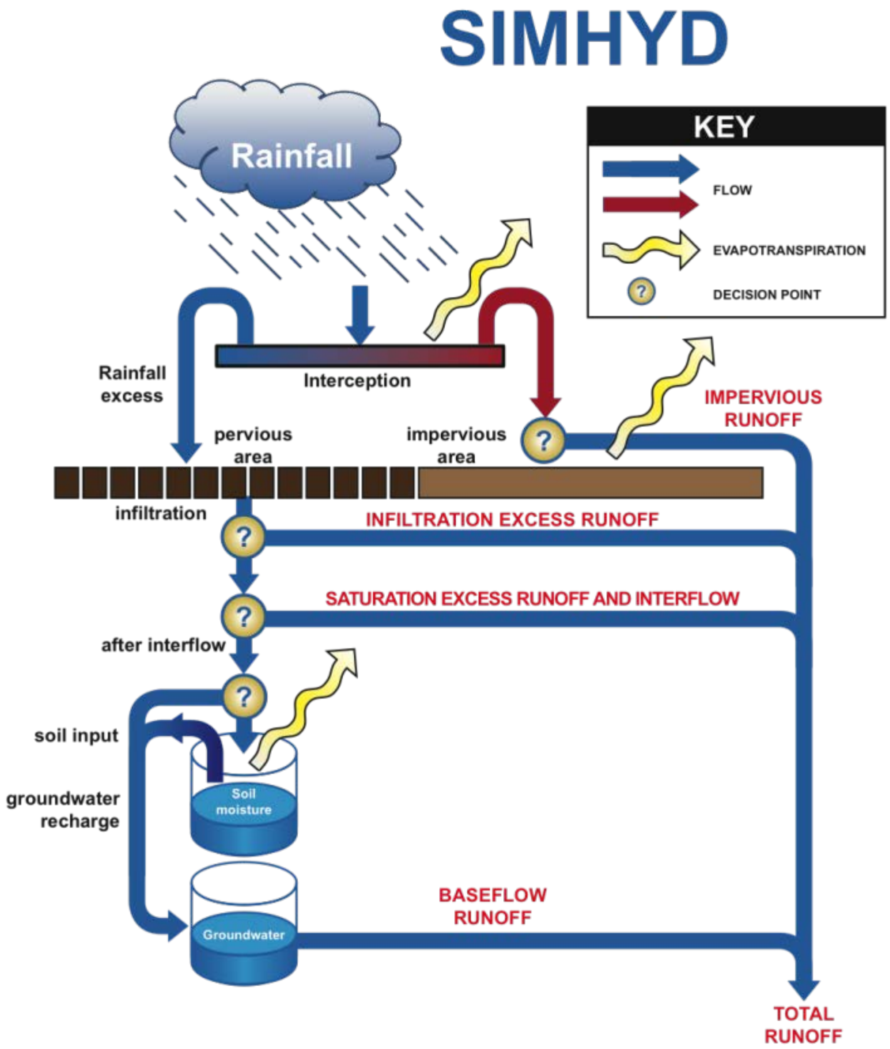


Figure 15-1: Overview of the SIMHYD Model

15.2.1 Data Requirements for a SOURCE Model

The SOURCE modelling framework requires a number of data sets including:

- A digital elevation model (DEM) for sub-catchment delineation;
- A land use map to provide a basis for functional unit definitions;
- Climate data (daily rainfall and evaporation data);
- Water quality data and/or Event Mean Concentration (EMC) / Dry Weather Concentration (DWC) data for pollutant export model parameterisation (if available);
- Hydrologic data for model calibration or validation (if available); and
- Point source (e.g. wastewater treatment plant) flow and quality data if applicable.

The following section summarises the data used to construct the Belongil SOURCE model.

15.2.2 Digital Elevation Model (DEM)

The DEM is discussed in Section 17.3.3 which overviews the hydraulic model construction process. From the DEM sub-catchments are identified and applied within the SOURCE model as described below.

15.2.3 Sub-catchment Map

A sub-catchment map for Belongil Creek was utilised from previous flood modelling completed by BMT WBM within the same catchment for Byron Shire Council. This earlier sub-catchment map was verified against:

- Computer generated sub-catchments were developed from a more recent 1m gridded LiDAR (circa 2012);
- The most current drainage layers from Byron Council, showing trunk drainage and stormwater asset locations such as culverts;
- Site specific knowledge of the 'lay of the land' and observations of local drainage paths, particularly in the vicinity of the West Byron STP.

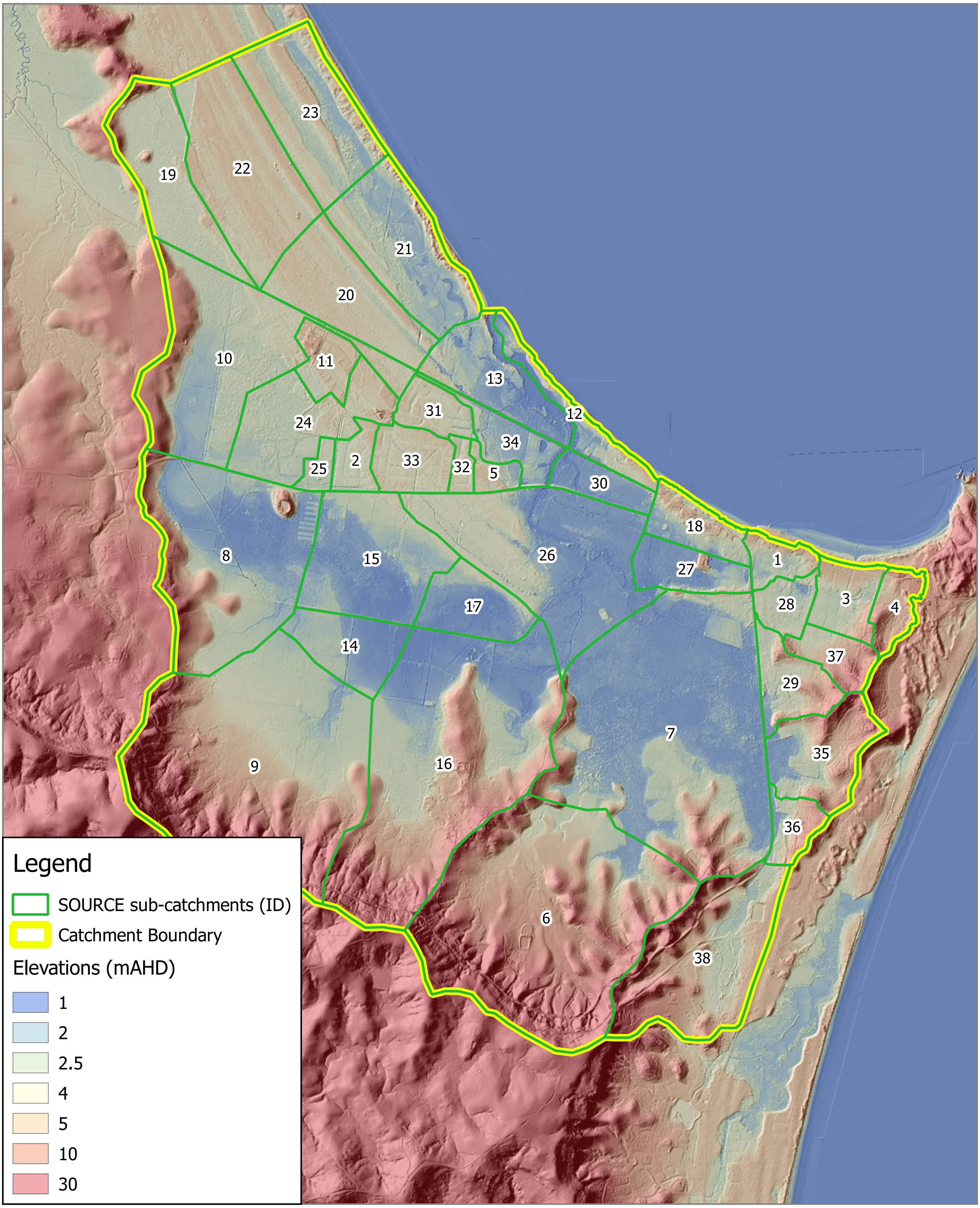
The resultant sub-catchment map contains 38 sub-catchments and is shown in Figure 15-2. These sub-catchments are used to provide hydrologic inputs to the hydraulic model as described in Section 1.3.1.

Land Use

A land use data set for the Belongil Creek catchment was developed from the State-wide Land Use Mapping Program completed by the NSW Government. This dataset contains over 500 detailed land use classes which are grouped under 14 major categories. This data was modified from the original to reduce the total number of land uses (Functional Units) to 8. The data reclassification is shown in Table 15-1. Total areas for each land use are shown in Table 15-2. The land use map used in the SOURCE model is shown in Figure 15-3.

As can be seen in Figure 15-3 the Program mapped the existing Belongil Fields Conference and Holiday Centre as an urban land use. This centre and adjoining lands may become part of the proposed West Byron Development. This proposed development is approximately 108 ha and would comprise a mixture of land uses including residential (low to medium density), conservation, light industrial and open space.

For the purposes of the current study, no modifications to the State generated land use layer have been made. However, significant development such as the proposed West Byron could influence surface and groundwater interactions, surface peak flows and discharge volumes, as well as water quality (depending on applied mitigation within the development).



Title:

Belongil Creek SOURCE Subcatchment Map

Figure: **15-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Table 15-1 : Functional Units Used in SOURCE Based on Land Use Type

Functional Unit	Major Land use Category	Detailed Land use Class
Forest	Conservation Area	National park
		Private conservation agreement
		State forest
		Tree lot
	Special Category	Foreshore protection - vegetated fore dune (coastal feature)
	Tree & Shrub Cover	Hardwood plantation
		Native forest
		Native forest - regeneration
		Native woody shrub
		Softwood plantation
		Tree lot - exotic species
		Windbreak or tree corridor
	Urban	Urban recreation
	Wetland	Floodplain swamp
		Floodplain swamp - back swamp
		Floodplain swamp - billabong
		Mangrove
		Mudflat
		Swamp
Grazing	Grazing	Degraded land (salt site, eroded area)
		Grazing
		Recently cleared land
		Sown, improved perennial pastures
		Sown, improved perennial pastures
		Volunteer, naturalised, native or improved pastures
Horticulture	Horticulture	Building associated with horticultural industry
		Nursery
		Orchard - tree fruits
		Orchard - tree fruits - irrigated
		Pecan, macadamia and other nuts
		Shade house or glass house (includes hydroponic use)
		Tea Tree Plantation
		Tea Tree Plantation - irrigated
Intensive Use	Cropping	Cropping - continuous or rotation
	Intensive Animal Production	Horse stud and/or horse breeding facilities
		Intensive animal production - poultry
	Mining & Quarrying	Derelict mining land
		Mine site
		Quarry
	Power Generation	Electricity substation
		Energy corridor
	Special Category	Farm Infrastructure
	Transport & Other Corridors	Aerodrome/airport
		Communications facility
	Urban	Abandoned urban or industrial area
		Industrial/commercial
		Landfill (garbage)
		Sawmill
		Sewage disposal ponds
		Surf club and/or coastal car parking facilities
Road	Transport & Other Corridors	Road or road reserve
Rural Residential	Urban	Alternate life style community under multiple occupancy
		Cemetery
		Rural residential
		Small to medium forested or wilderness blocks with isolated residential buildings.
Urban	Urban	Area recently under development for urban, commercial and/or industrial uses
		Caravan park or mobile home village

Functional Unit	Major Land use Category	Detailed Land use Class
		Government and private facilities
		Residential
		Surf club and/or coastal car parking facilities
Water	River & Drainage System	Aquaculture
		Drainage channel
		Drainage depression in cropping paddock
		Drainage or water supply channel
		Farm dam
		Irrigation dam
		Irrigation supply channel
		Marina
		Prior stream
		River, creek or other incised drainage feature
		Water supply pressure reservoir including water filtration plant
	Special Category	Beach
		Cliff/rock outcrop
		Sand spit/estuarine sand island
	Wetland	Floodplain swamp - billabong

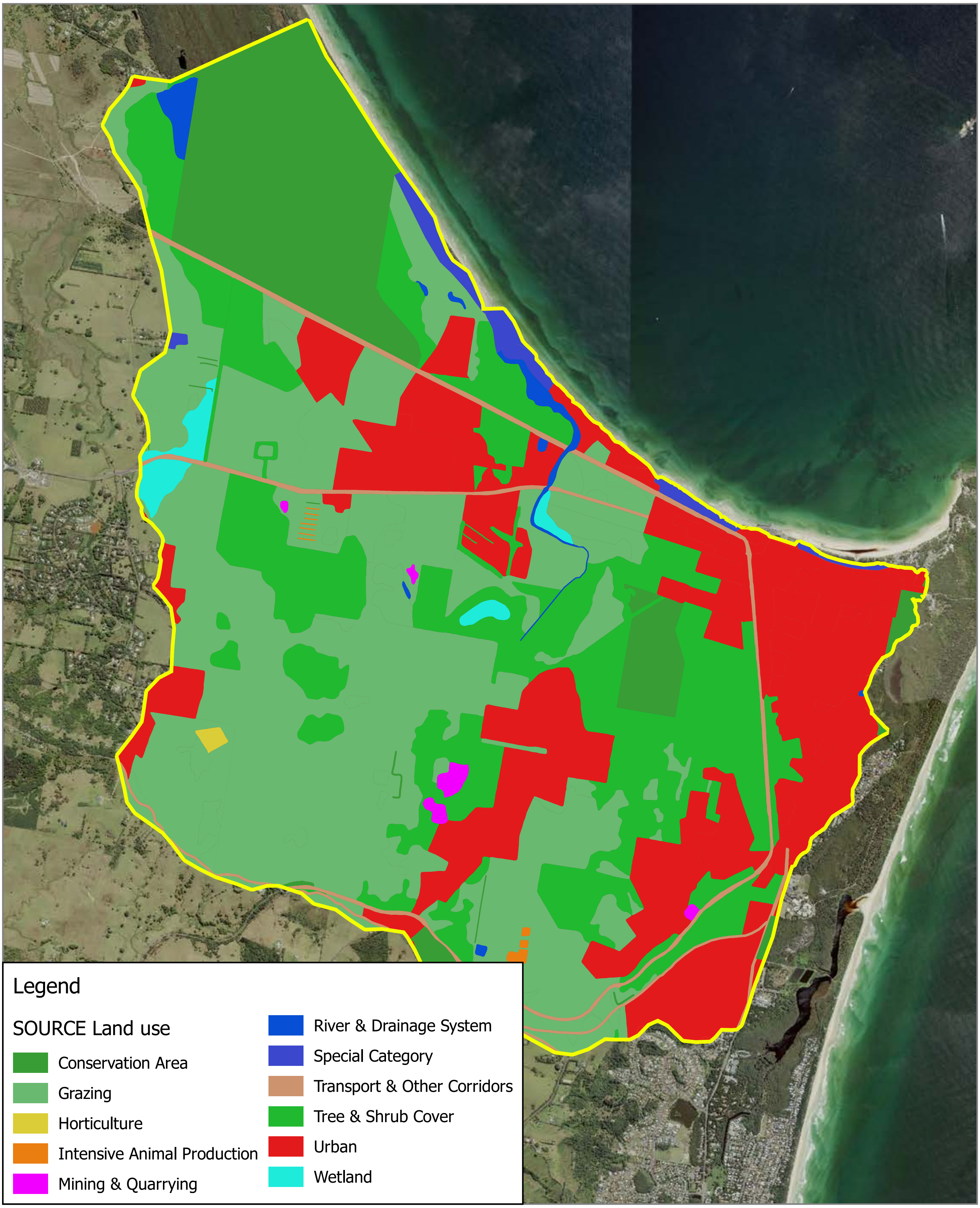
Table 15-2 :Land Use Area Breakdown

Functional Unit Name	Current Land use	
	Area (ha)	Percentage of Total (%)
Forest	1,178	40.0%
Grazing	1,069	36.3%
Horticulture	3	0.1%
Intensive Use	182	6.2%
Road	26	0.9%
Rural Residential	197	6.7%
Urban	261	8.9%
Water	32	1.1%
Total	2,947	100.0%

Rainfall and Evapo-transpiration

Rainfall and potential evapo-transpiration (PET) data imported to the SOURCE model domain is processed to produce a single time-series for each sub-catchment.

Daily rainfall and potential evapotranspiration (PE) data for the SOURCE model was sourced from the Bureau of Meteorology (BOM) SILO gridded datasets for the catchment over the period 1st January 1990 to 1st July 2016. Table 15-3 includes yearly total rainfall and PE data for a randomly selected Belongil Creek sub-catchment. As the SILO data is supplied as a gridded GIS dataset, each grid point provides a unique rainfall and PE dataset. As such varying rainfall and PE datasets are applied to each catchment from the gridded SILO datasets.



Title:

Belongil Creek SOURCE Land use Map

Figure: **15-3**

Rev: **A**

N

0 1000 2000 m

BMT WBM
www.bmtwbm.com.au

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Table 15-3 : Annual Rainfall and Evaporation

Year	Annual Rainfall [A]	Annual PE
1990	**1,736** [B]	1,527
1991	1,634	1,626
1992	1,327	1,531
1993	1,344	1,542
1994	**1,897**	1,529
1995	1,377	1,482
1996	**2,033**	1,521
1997	1,534	1,553
1998	1,373	1,539
1999	**2,877**	1,428
2000	1,241	1,493
2001	1,453	1,552
2002	1,209	1,597
2003	**1,870**	1,497
2004	1,298	1,586
2005	1,569	1,598
2006	**2,425**	1,544
2007	1,319	1,557
2008	**2,030**	1,465
2009	**2,046**	1,558
2010	**2,354**	1,389
2011	1,629	1,430
2012	**1,803**	1,496
2013	**1,945**	1,499
2014	1,267	1,496
2015	**1,897**	1,493
2016 (Partial)	965	732
Mean (26 Years)	**1,711**	**1,520**

[A] Taken from sub-catchment 12 of the model
[B] Bold blue text indicates values above the 26 year average rainfall

Hydrology Parameters

The hydrology component of Belongil Creek SOURCE model has been parameterised using the SIMHYD rainfall-runoff model. SOURCE has procedures for calibrating the SIMHYD parameters whereby it utilises an internal numeric optimiser to bring modelled results as close as possible to observed (i.e. 'real') data.

As the Belongil Creek catchment has no flow gauging stations an alternate method has been applied. This method has two parts as described below:

- Qualitative assessment using photographs that identify inundation patterns during significant rain events in a particular portion of the catchment; and
- Qualitative assessment comparing recorded water levels from a water level logger in the Union Drain to water levels predicted by the hydraulic model (described later in this section).

The process of model 'validation' by comparing predicted water levels (from the hydraulic model) to observed water levels in the Union drain is not a typical optimisation method. Essentially the predicted water levels and shape of runoff hydrographs were compared to observed water level data and adjustments made to hydrology model parameters to provide for a better model fit.

Further details of this process and outcomes are described in Section 17.6. The adopted hydrology parameters are included in Table 15-4.

Table 15-4 : Adopted SIMHYD Parameters

Parameter	Adopted Value
Impervious Threshold	1 mm
Rainfall Soil Interception Store	3.4 mm
Pervious Fraction	See below
Soil Moisture Store Coefficient	40 mm
Infiltration Shape	3
Infiltration Coefficient	300
Interflow Coefficient	0.41
Recharge Coefficient	0.6
Baseflow Coefficient	0.08

Pervious fractions adopted within SimHYD are provided below:

- Forest – 100%
- Grazing – 100%
- Horticulture – 100%
- Intensive Use – 35%
- Road – 35%
- Rural Residential – 90%
- Urban – 65%
- Water – 0%

The model was initially parameterised using procedures outlined in Chiew and Siriwardena (2005). However, as part of the validation, adjustments were made to certain parameters to increase runoff volume timing. This was achieved through specific adjustments to the Soil Moisture Store Coefficient (SMSC), recharge coefficient and infiltration coefficient. Generally, parameters were modified within suggested ranges identified within SOURCE.

It is recognised that hydrology parameters would vary between sub-catchments depending on a range of factors, but due study limitations in respect of validation, parameters have been applied to all sub-catchments.

Outcomes of the validation process completed within the hydraulic model are outlined in Section 17.6.

Pollutant Export Parameters

SOURCE supports a limited range of pollutant generation processes. For the Belongil Creek catchment model an Event Mean Concentration (EMC) / Dry Weather Concentration (DWC) pollutant generation process was selected. The use of EMC/ DWC is common in many daily time step catchment water quality models. It does have the limitation that it cannot be used to model water quality for particular storm events. This model does however facilitate the estimation of long term or mean annual pollutant exports and should be interpreted in this way.

In the present study, literature values have been used to derive and allocate EMC/DWC values for each land use represented by the model and apply these EMC/DWC values across the entire catchment area. As more information is collated and data analysis is undertaken in the catchment, it would be possible to modify EMC/DWC values for individual land uses in individual sub-catchments.

Extensive research and analysis of local water quality data has been carried out by Chiew and Scanlon (2002) to determine land use based EMC and DWC values for the south-east Queensland region. The median values from this study have been used, and are shown in Table 15-5.

Table 15-5: Adopted EMC and DWCs for TSS, TN and TP

Land Use Name	TSS		TN		TP	
	EMC (mg/L)	DWC (mg/L)	EMC (mg/L)	DWC (mg/L)	EMC (mg/L)	DWC (mg/L)
Forest	20	10	1.5	0.4	0.06	0.03
Grazing	260	10	2.08	0.7	0.3	0.07
Horticulture	300	10	1.95	0.7	0.32	0.07
Intensive Use	550	10	5.2	0.7	0.45	0.07
Road	130	7	1.6	1.5	0.28	0.11
Rural Residential	130	10	1.6	0.7	0.28	0.07
Urban	130	7	1.6	1.5	0.28	0.11
Water (Rainfall)	0	0	0	0	0	0

Point Sources (Quantity)

The Belongil Creek SOURCE model contains the West Byron STP. A time series of flow from the STP was obtained from the Byron Shire Council and applied as a point source within the hydraulic model (refer to Section 1.3.1). It was not necessary to add this flow to the hydrology model as it was able to be added within the hydraulic model (either approach would yield the same outcome and results).

Effluent release data for the west Byron STP (at site EPA5 minus allowances for seepage and evapotranspiration losses in the wetland areas) is presented in Figure 15-4. Flow modifications for the purposes of modelling scenarios with different release volumes were performed by addition or subtraction of flows to the existing daily flows. No attempt was made to scale flows for scenarios.

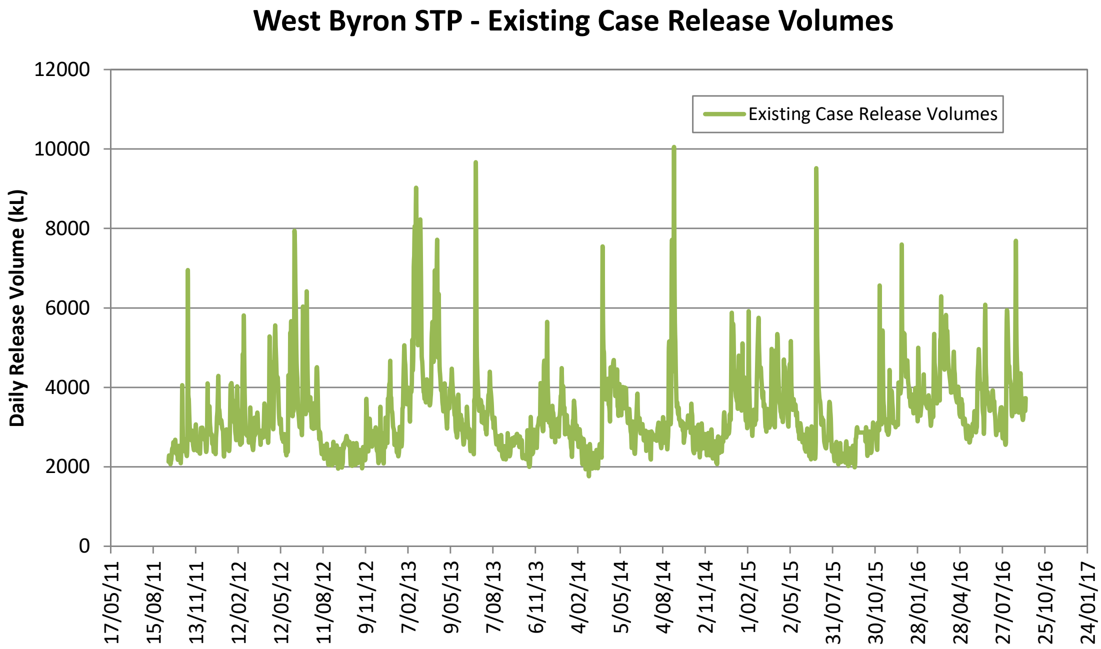


Figure 15-4: Daily West Byron STP Effluent Release Volumes

Table 15-6 : Annual West Byron STP Effluent Release

Year	Flow (ML/y)
2011 (partial)	290
2012	1,120
2013	1,290
2014	1,150
2015	1,200
2016 (partial)	790

Point Sources (Quality)

The Belongil Creek SOURCE model contains the West Byron STP. Recorded water quality data from EPA 3 was used to create a time series of water quality being discharged from the STP. Given that the recordings were made within the STP itself, they do not account for the additional nutrient processing which would be expected with travel down the Union drain prior to entry to the Belongil Creek estuary.

Byron Shire Council supplied the water quality monitoring data. The data has been presented in Figure 15-5.

Table 15-7 presents key statistics relating to the effluent quality data. It is noted that pollutant concentrations are low for STPs and show little peakiness with median and average values being quite similar. The wetland treatment system appears to be effective in reducing pollutant concentrations. Table 15-8 presents calculated pollutant export loads which combines measured discharge and quality datasets.

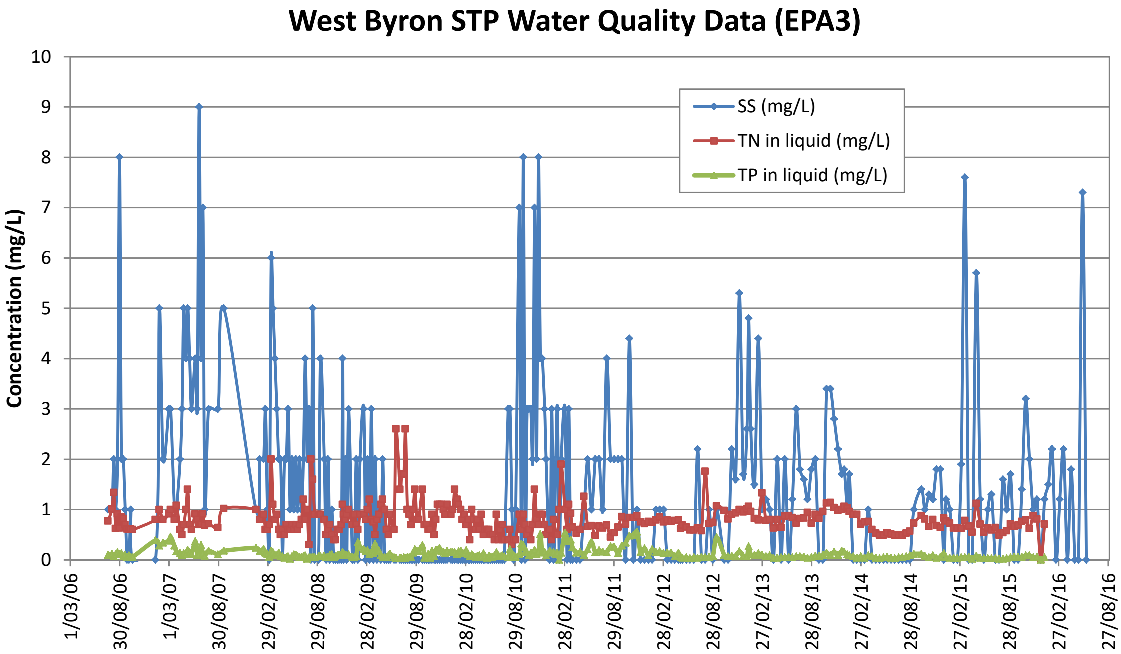


Figure 15-5 : West Byron Effluent Quality Data

Table 15-7: West Byron STP Effluent Quality Statistical Metrics (Available Data)

Parameter	Mean	Median	25th Perc	75th Perc	90th Perc
TSS (mg/L)	1.87	1.70	0.04	3.00	4.00
TN (mg/L)	0.80	0.76	0.60	0.90	1.10
TP (mg/L)	0.12	0.09	0.06	0.15	0.22

Table 15-8: West Byron STP Pollutant Export Loads (Available Data)

Year	TSS (kg/y)	TN (kg/y)	TP (kg/y)
2011 (partial)	352	228	99
2012	762	899	128
2013	2,327	1,157	115
2014	643	770	78
2015	1,568	807	57
2016 (partial)	861	490	37
Total	**6,514**	**4,353**	**514**

15.3 Model Validation

Model validation is described further within the Hydraulic modelling section. With respect to the hydrology model, as described earlier in this section, adjustments were made to the hydrology parameters via a qualitative process involved the hydraulic model. Essentially the hydraulic model provided insight as to whether the timing and quantity of flow being predicted from the hydrology were appropriate.

15.4 Model Results

The SOURCE model has been developed using available data. As previously mentioned, limited flow and water quality data is available to make an accurate prediction of flows and pollutant loads from the catchment. Flows presented in this section are suitable for use in this study, taking into considerations its limitations.

The final Belongil Creek SOURCE model layout is shown in Figure 15-6. The figure shows the individual sub-catchments, and drainage linkages through to the Belongil Creek estuary and ultimately a discharge to the Byron Bay embayment.

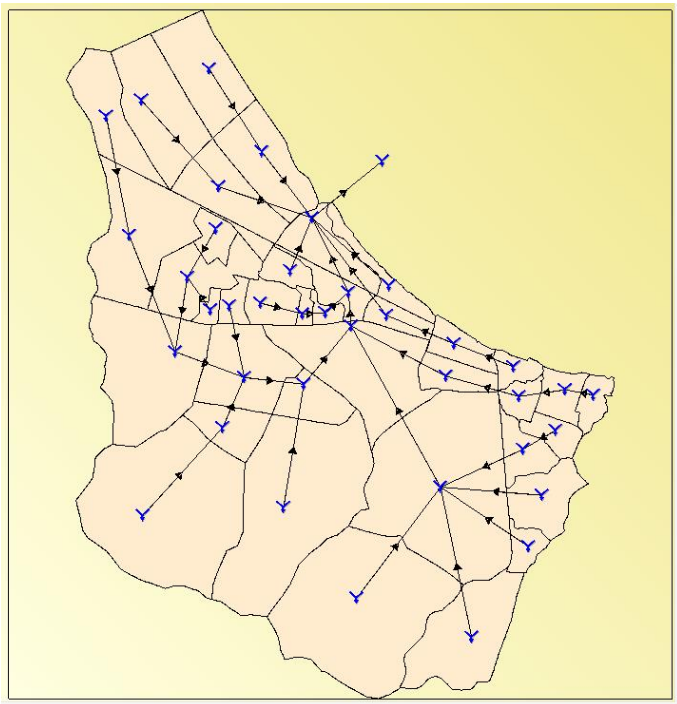


Figure 15-6: Belongil Creek SOURCE Model

Within the SOURCE model estimated flows and constituent loads can be extracted at any node, link or sub-catchment in the model domain. A range of predicted values (flows and loads) are provided in the following sections.

15.4.1 Catchment Flows

Modelled annual flows as delivered from the Belongil Creek catchment are provided in Table 15-9. This table also shows the mean annual flows from the Belongil Creek catchment.

Table 15-9: Modelled Annual and Mean Annual Flows to Belongil Creek (1990 –2016)

Year	Flow (ML)	Year	Flow (ML)
1990	28,300	2004	19,000
1991	25,900	2005	24,200
1992	14,200	2006	47,100
1993	16,100	2007	14,300
1994	33,700	2008	34,700
1995	18,300	2009	38,700
1996	35,500	2010	41,800
1997	20,800	2011	22,700
1998	17,500	2012	30,900
1999	54,000	2013	35,600
2000	14,500	2014	15,400
2001	23,100	2015	28,600
2002	16,300	2016 (partial)	17,100
2003	33,200	**Mean Annual**	**27,200**

15.4.2 Pollutant Export

Modelled annual pollutant loads as delivered from the Belongil Creek catchment are provided in Table 15-10. This table also shows the mean annual pollutant loads to Belongil Creek.

Table 15-10: Modelled Annual and Mean Annual Pollutant Loads from Belongil Creek (1990 –2016)

Year	TSS (T/y)	TN (T/y)	TP (T/y)
1990	3,510	46	5.0
1991	2,920	39	4.0
1992	1,720	22	2.0
1993	1,950	25	3.0
1994	3,930	52	5.0
1995	2,240	29	3.0
1996	4,750	61	6.0
1997	2,480	33	3.0
1998	2,070	27	3.0
1999	6,690	87	9.0
2000	1,820	23	2.0
2001	3,200	40	4.0
2002	1,950	26	3.0
2003	4,450	57	6.0
2004	2,260	30	3.0
2005	3,270	42	4.0
2006	5,310	71	7.0
2007	1,800	23	2.0
2008	4,470	57	6.0
2009	5,240	67	7.0
2010	5,560	71	7.0
2011	2,560	34	4.0
2012	3,940	51	5.0

Year	TSS (T/y)	TN (T/y)	TP (T/y)
2013	4,750	60	6.0
2014	2,060	26	3.0
2015	3,530	46	5.0
2016 (partial)	2,080	27	3.0
Mean Annual	**3,400**	**44**	**4.5**

15.4.3 Comparisons of Catchment and STP flows

Presented in

Table 15-11 are effluent releases from the West Byron STP and catchment flows to Belongil Creek flows as predicted by the SOURCE model. The data indicates (that over the four year period) the STP contributed less than 5% of the total outflow to the Belongil Creek estuary with the remainder being catchment runoff.

Table 15-11: Comparison of Catchment and STP Flows to Belongil Creek

Year	Catchment Flow (ML)	STP Flow (ML)	% STP Contribution to Total Flow
2012	30,900	1,120	3.5%
2013	35,600	1,290	3.5%
2014	15,400	1,150	6.9%
2015	28,600	1,200	4.0%
4 yr Avg.	**27,625**	**1,190**	**4.5%**

15.4.4 Comparisons of Catchment and STP loads

Presented in Table 15-12 is available pollutant loading data for the West Byron STP and Belongil Creek catchment as predicted by the SOURCE model. West Byron STP loads have been calculated by combining measured effluent discharge volumes and monitored pollutant concentrations (at EPA3). The data identifies that the STP pollutant loading is substantially lower than the predicted catchment loading and in the case of total nutrients represents around 2% of the total current contribution (for the period 2012 to 2015).

Table 15-12: Comparison of Catchment and STP Pollutant Loadings to Belongil Creek

Year	Catchment TSS (T/y)	STP TSS (T/y)	Catchment TN (T/y)	STP TN (T/y)	Catchment TP (T/y)	STP TP (kg/y)
2012	3,940	0.8	51	0.9	5.4	0.13
2013	4,750	2.3	60	1.2	6.4	0.12
2014	2,060	0.6	26	0.8	2.8	0.08
2015	3,530	1.6	46	0.8	4.8	0.06
4 yr Avg.	**3,570**	**1.3**	**46**	**0.9**	**4.9**	**0.10**

15.4.5 Assumptions and Limitations

The SOURCE hydrology and pollutant export model has a number of limitations as outlined below:

- Hydrology models are normally calibrated and validated through a process that compares modelled catchment flows to recorded catchment flows. The Belongil catchment has no flow gauge hence traditional means of calibration (model optimisation) are not available. It would be useful to consider installing a flow gauge to collect daily flows within suitable parts of the catchment, which is difficult given that it is mostly tidal.
- Model validation has been performed through qualitative measures as were able to be established by the study team to ascertain and confirm model performance.
- EMC/DWC values specific to South East Queensland have been applied within SOURCE for the purposes of calculating catchment pollutant exports. Locally derived values would improve model accuracy. It is noted that STP loads are low in comparison to catchment contributions and as such improvements to the EMC/DWC values are unlikely to significantly affect study outcomes in this instance.

16 Appendix D – Detailed methodology on water quality model.

This section outlines the water quality modelling completed by BMT WBM. The water quality modelling provides ancillary information to the hydrologic and hydraulic modelling work. It has been established to provide an understanding of potential water quality changes within the Belongil Creek estuary resulting from increasing discharges from the West Byron STP.

A rapid assessment water quality model has been developed to ascertain potential impacts to the estuary. The model accounts for key flow and pollutant inputs to the estuary and it is able to provide a temporal (i.e. changes over time) understanding of potential changes in key pollutant concentrations. However, due to its formulation it cannot provide spatial information (i.e. locations of change), such functionality is in the realm of more complex 1 and 2 dimensional water quality models. Within estuaries normally 2 dimensional water quality models are utilised provided there is sufficient information to build and calibrate them.

The rapid assessment water quality model provides a useful insight into potential system changes without excessive data demands, and can be used to identify the need for further modelling.

16.1 Model Framework

To assess whole of system changes in water quality, a rapid assessment non-dimensional water quality model has been built for the Belongil Creek estuary. The model has been established over a multi-year period where data exists to adequately describe estuary function, catchment inputs and the West Byron STP effluent flows and loads (refer to Figure 16-1). The periods selected also allow for elements of traditional model calibration.

Previously, BMT WBM as part of the Tallow and Belongil Creeks Ecological Study completed for Byron Shire Council developed a non-dimensional water quality model for the Belongil Creek estuary. This box model has been reinstated, updated and applied for use in this study as described in the following sections.

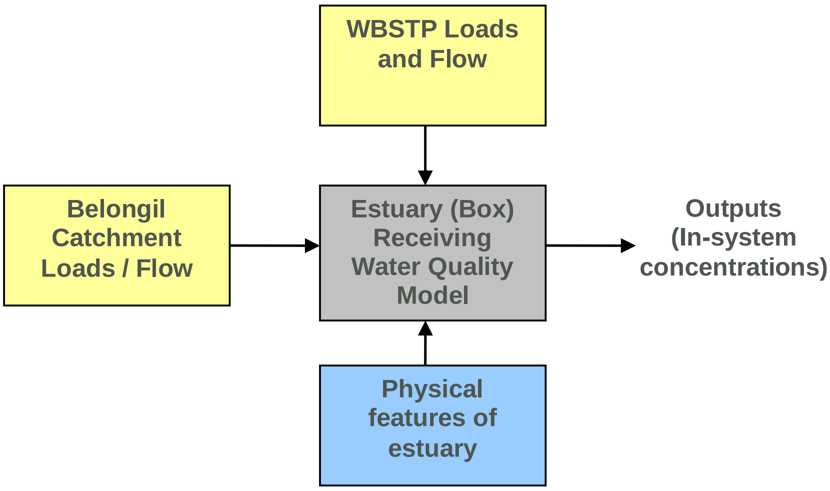


Figure 16-1: Schematic of the rapid assessment water quality model

Other features of the model include:

- Daily time-step operation; and
- Allowances for key processes such as settlement, sediment release, biological uptake and denitrification.

1.1 Data Requirements

Key datasets used to inform the water quality model include:

- West Byron STP discharge data;
- Belongil Creek water quality data;
- Catchment discharge data;
- Volumetric data for the Belongil Creek estuary; and
- Belongil Creek tidal data.

1.1.1 West Byron STP discharge data

West Byron effluent release and water quality data has been obtained from Byron Shire Council for a period extending from September 2011 to July 2016. This effluent release and water quality data is presented in Sections 0 and 0.

1.1.2 Belongil Creek water quality data

The following datasets were identified in respect of water quality:

- Belongil Creek (at Ewingsdale Road bridge) salinity logging. Data compiled by Byron Shire Council and available over June 2011 to April 2016;
- Belongil Creek salinity logging. Data compiled by MHL as part of the Belongil Creek Water Quality Monitoring project completed for the Department of Land and Water Conservation (MHL, 1997). Salinity monitoring period included 1994 and 1995. This data was previously obtained by BMT WBM as part of the Tallow and Belongil Creeks Ecological Study;

- Periodic Creek monitoring associated with entrance opening events. Typically these monitoring activities occur up to three or four times per year, but are always associated with entrance opening events and as such do not represent suitable ambient monitoring; and
- Belongil Creek monitoring associated with the Belongil Estuary Entrance Management Reports Stage 1 (AWC, 2008). Water quality data presented in this report was available over the period of 2007 to 2008. This data did not align with any period where water level logging data was available.

1.1.3 Catchment discharge data

Catchment inputs to the estuary will be obtained from the SOURCE hydrology and pollutant export model. The model has been established using locally specific information and runs over the period of 1990 to 2016. Model establishment and results are further described in Section Appendix E.

1.1.4 Volumetric data

Estuarine bathymetry data, LiDAR and drain survey information has been used to determine estuarine volume at different water levels. All bathymetry, LiDAR and survey have been incorporated into a digital elevation model of the estuary in a GIS package. The DEM has been interrogated using the GIS package to identify estuarine volumes at different water levels.

Accurate estimation of estuarine volume is important within the water quality model to be able to identify accurate concentrations of constituents such as salt and nutrients.

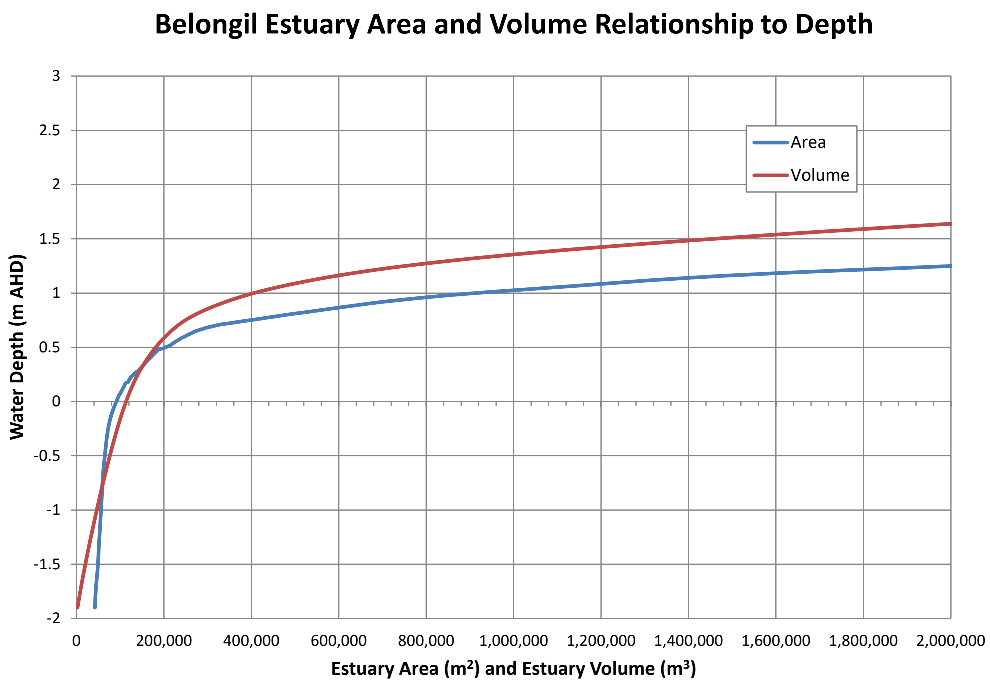


Figure 16-2: Estuary area and volume relationships with water elevation

1.1.5 Belongil Creek tidal data

A key input to the water quality model has been tide level data. Tide level data is used in the model to calculate the quantity of tidal exchange happening over each daily period. As the Belongil Creek estuary mouth is subject to periods of partial or complete closure, daily tidal exchange can vary significantly. As such a methodology was identified to determine daily tidal exchange based on logged water level data within the Belongil Creek estuary.

Two long term tide level records were identified:

- Data obtained from the Manly Hydraulics Laboratory for the Belongil Creek Water Quality Monitoring Project which recorded tide levels from December 1994 to December 1996 (MHL, 1997). This data was logged in the lower estuary several metres downstream (closer to mouth) than the Belongil Creek bridge (refer Figure 16-3).
- Data obtained from Byron Shire Council in the Belongil Creek at the Ewingsdale Road bridge. This data is collected as part of ongoing estuary monitoring work by way of period contracts. Several datasets were obtained and compiled to produce a water level time-series which extends from June 2011 to April 2016 (refer Figure 16-4).

1.1.6 Establishment

Using the abovementioned datasets the salinity and nutrient models developed as part of the Tallow and Belongil Creeks Ecological Study (WBM Oceanics, 2000) were updated. Based on availability of key datasets, the models operate from September 2011 to April 2016.

The key updates to the pre-existing models were made to the following aspects:

- Tide exchange – by use of daily tidal levels in the creek at either the MHL or Council recordings site. Algorithms were derived to convert daily tidal levels into an estimation of tidal exchange to account for the variability in tidal exchange in an estuary with a variable entrance;
- Runoff volumes – these were updated to the latest hydrologic model output from SOURCE; and
- STP volumes – these were updated to the information provided by Council for the periods of interest.

Previously established (calibrated) parameter values for nutrient processes including settlement, sediment release, biological uptake and denitrification were not modified.

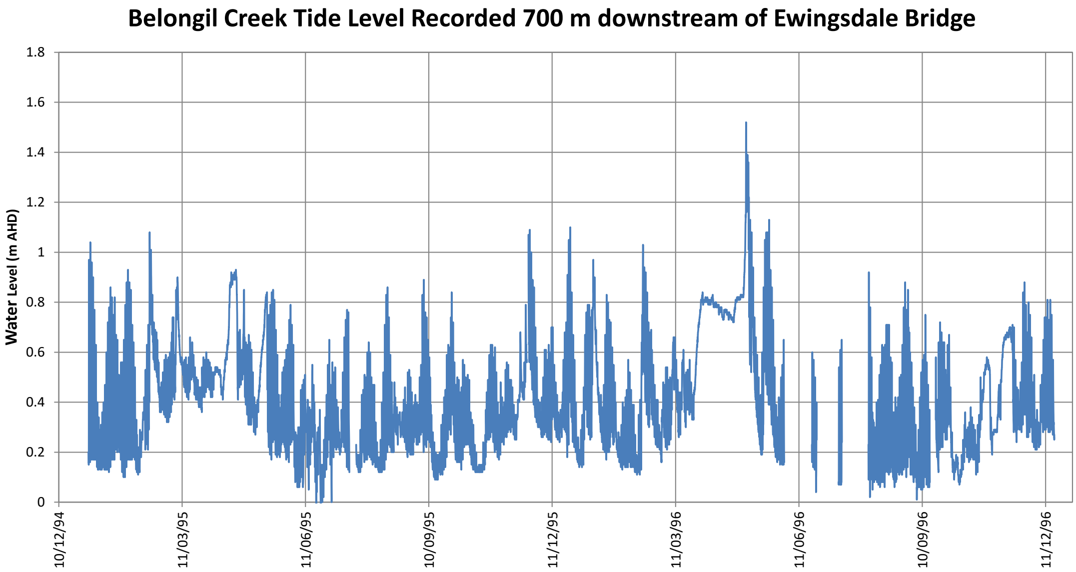


Figure 16-3: Recorded tide levels in Belongil Creek 700 m downstream of Ewingsdale Bridge

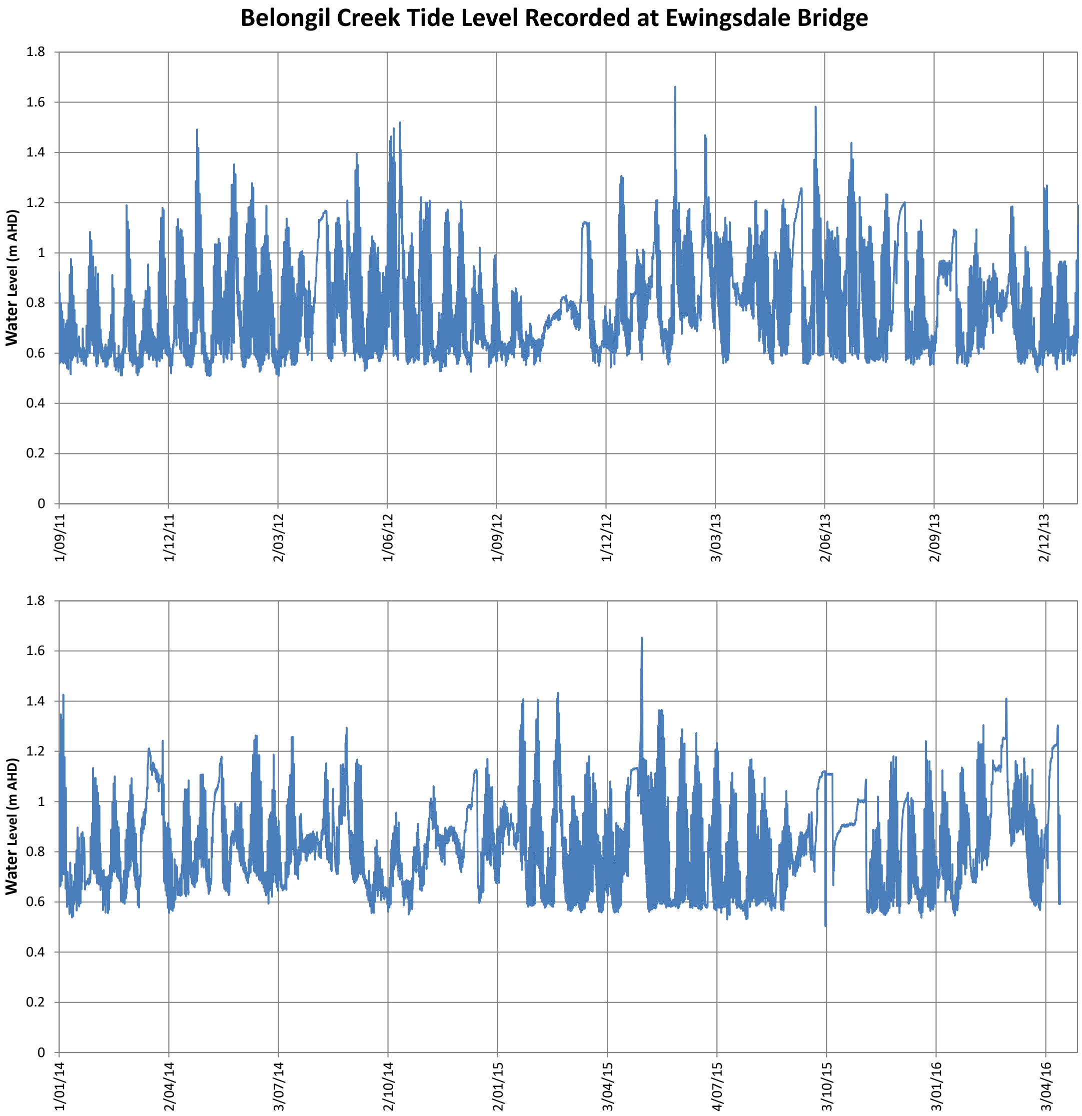


Figure 16-4 : Recorded tide levels in Belongil Creek at Ewingsdale Bridge

1.2 Model Validation

The performance of the salinity model has been verified with available water quality for the estuary. Logged salinity is the only available long term water quality dataset which could be used for model validation purposes. Two salinity datasets are available for model validation, including the MHL dataset covering a two year period (1994 to 1995) and a shorter period at the Ewingsdale Road Bridge crossing. The MHL recording site is several hundred metres downstream towards the entrance from the bridge recording site.

Figure 16-5 and Figure 16-6 have been provided to identify model performance over two differing year long periods. The first validation period occurs in 1995 where an MHL recorded salinity dataset has been used. The second validation period occurs in 2013-14 where a Council recorded salinity dataset has been used. The results identify:

- A sound match of observed and modelled data over 1995. The model matches salinity dynamics for the duration and is able to capture step changes in water quality associated with events such as entrance closures and opening.
- A less sound fit was achieved over the 2013-14 period with differences in the predicted 'ambient' salinity and a lower ability to identify step changes in data.

Despite the poorer fit observed for the 2013-14 period, the model is considered to be adequate. Validation of these models requires the use of an observed dataset in a location which is broadly representative of conditions throughout the estuary (as the model assumes complete mixing). The MHL recording location appears to be such a location, while the Council recording site appears to be too far upstream and is overly influenced by freshwater flows. This would explain the models general over-estimation of salinity throughout the estuary. The validity of the observed data over November and December 2013 period is also questionable, as the data suggests the estuary is totally freshwater for several weeks which is considered unlikely as rainfall over this period was not exceptional (Oct 13 – 73mm, Nov 13 – 196 mm and Dec 13 – 36 mm).

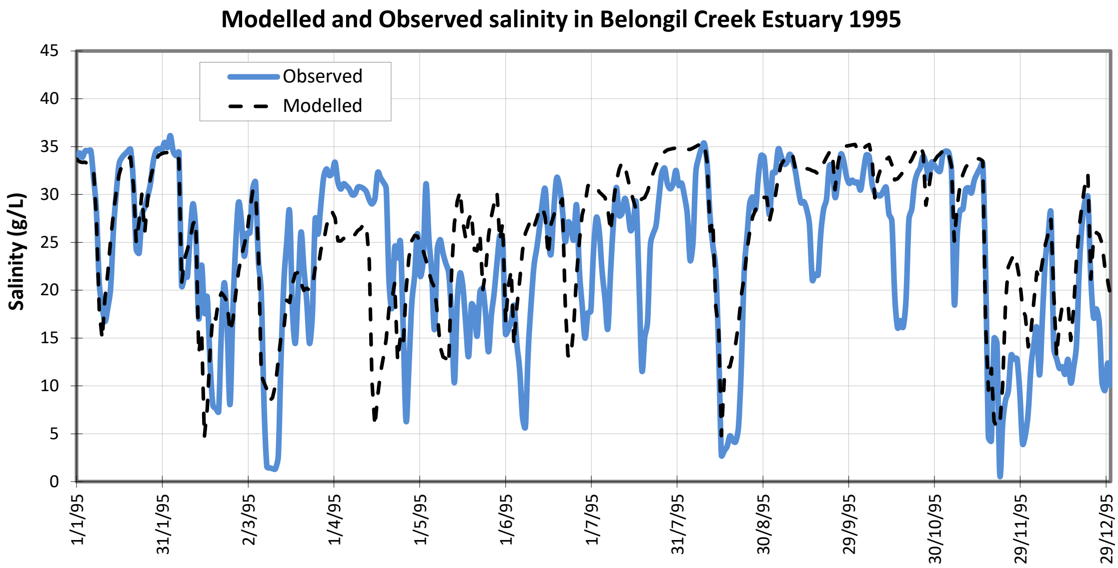


Figure 16-5: Model Validation Period 1995 - MHL Recorded Salinity Data

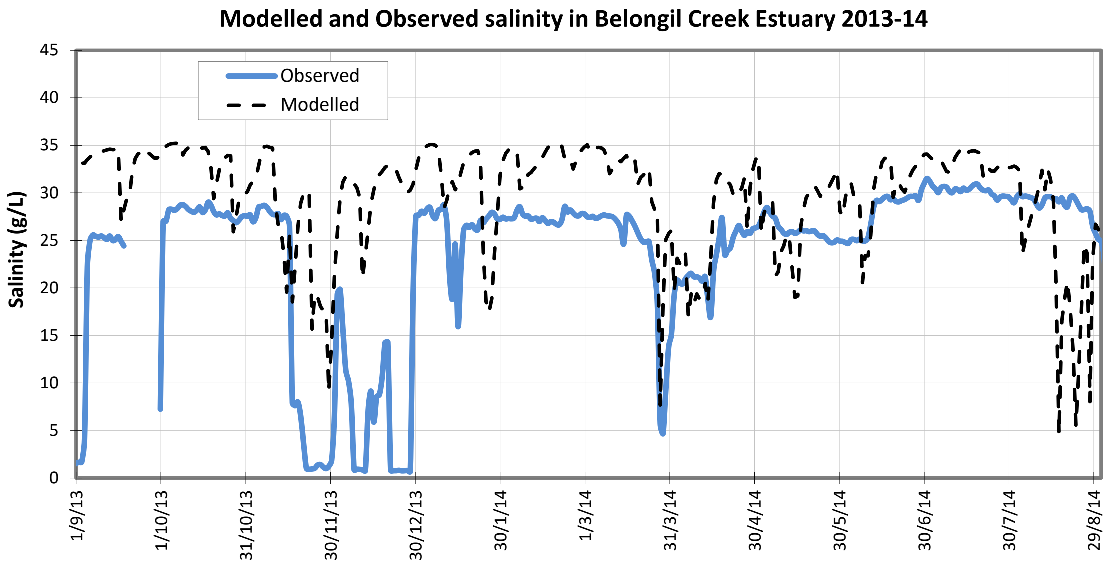


Figure 16-6 : Model Validation Period 2014 - Council Recorded Salinity Data

The model validation process indicates that the salinity data provides an adequate representation of likely salinity conditions based on available information. The outcome indicates that the model provides accurate representation of both inflows (STP and catchment inputs) and tidal exchange processes, all of which determine estuarine salinity on a daily basis.

The validation process identifies that the key driver of water quality in the estuary, i.e. the water balance, is accurate and as such estimates of nutrient dynamics should also be accurate. Other specific nutrient processing model parameters previously developed through the Tallow and Belongil Creeks Ecological Study have been retained in the current model as there was insufficient data available to provide a better calibration dataset. However, no validation was possible for nutrients as no long term water quality data was available for the estuary over the periods which the model was able to be established.

1.2.1 Water Balance

A water balance was performed for the estuary taking into consideration modelled catchment inputs, West Byron STP effluent releases and modelled tidal exchange. A water balance was performed over 2012 to 2015 (i.e. 4 years) to identify the relative contributions of flow to the estuary. Figure 16-7 identifies that the key contributor of water to the estuary is the tide (68%), followed by catchment flows (31%) followed lastly by STP discharges (1%). As such the dominant factor controlling water quality in the estuary will be tidal exchange capacity. Hence if tidal exchange is increased, it will play an even more significant role in moderating water quality.

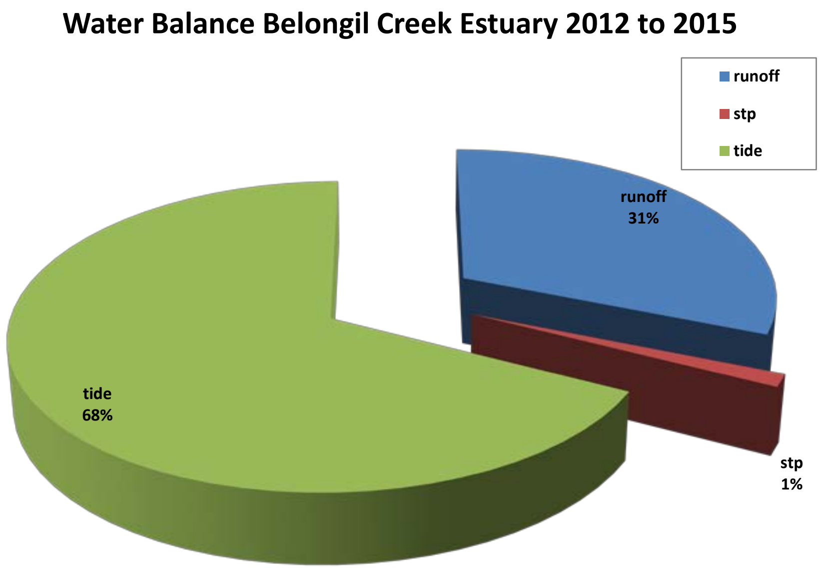


Figure 16-7: Water Balance Belongil Creek Estuary

1.3 Assumptions and Limitations

The water quality models have the following key limitations and assumptions:

- The water quality model is a volume averaged model which assumes complete mixing occurs through the estuary on each daily time step. This is a limitation of the model as complete mixing is unlikely to occur in the estuary volume in each daily time step. Operating in this fashion the model is unable to provide spatial representation of changes in water quality.
- Model performance has been verified using salinity dynamics only. There was no ability to verify model performance against long term water quality datasets. It is however expected that the model should perform adequately as it was previously calibrated to local conditions including salinity and water quality data as part of a previous study.
- Catchment flows are derived from the SOURCE model which is uncalibrated. The SOURCE model however did go through a qualitative refinement process to match predicted flows against observed datasets (i.e. water levels and inundation extents). While not a complete calibration, model performance is adequate for the purposes of this study. Additionally catchment flows are a smaller contributor of flow volume to the estuary than tidal exchange volume and the effect of inaccuracies in the catchment flows are diminished accordingly.
- EMC/DWC values specific to South East Queensland have been applied within SOURCE for the purposes of calculating catchment pollutant exports. The use of non-site specific parameters may introduce some error into the predicted catchment pollutant inputs to the estuary.

17 Appendix E – Detailed methodology on hydraulic model.

For the purposes of the Hydraulic Capacity Assessment (HCA) potential changes in inundation behaviour with varying STP discharge rates and locations has been assessed. Due to the low catchment relief and largely tidally influenced floodplain it has been necessary to assess potential changes under a range of estuarine and meteorological conditions, e.g., estuary mouth open and closed, and also during wet and dry periods.

The adopted assessment approach has been to complete long term continuous simulation (over a nearly five year period) that represents a typical range of estuarine and meteorological/catchment conditions and could be considered representative of longer term system operation. From this the effects of modification (i.e. scenarios) can be determined.

17.1 TUFLOW Hydraulic Modelling Framework

The two-dimensional (2D) and one-dimensional (1D) hydraulic modelling software package TUFLOW has been used for all hydraulic modelling in this study. A brief description of the program is provided below.

TUFLOW solves the full 2D shallow water equations based on the scheme developed by Stelling (1984) and improved by Syme (1991) and Syme (1999). The solution is based around the alternating direction implicit finite difference method. A square grid is used to define the discretisation of the computational domain.

TUFLOW models have been successfully checked against rigorous test cases (Syme 1991; Syme, Nielsen, and Charteris 1998), and calibrated and applied to a large range of real-world tidal and flooding applications.

17.2 Hydraulic Modelling background

The Belongil Creek Flood Study was undertaken for Byron Shire Council by SMEC Pty Ltd and completed in 2009. The purpose of the flood study was to define the catchment flood behaviour and associated risk to the towns of Byron Bay and Ewingsdale. A TUFLOW hydraulic model was created as part of the Flood Study.

Following the completion of the Flood Study, BMT WBM completed the Belongil Creek Floodplain Risk Management Plan (FRMS). As part of the FRMS a number of updates were made to the TUFLOW hydraulic model (BMT WBM, 2015).

The updated TUFLOW model created for the FRMS was used as the basis of the hydraulic modelling presented below. A number of updates were made to this model for the purpose of this HCA. The updates to the TUFLOW model for the purpose of the HCA are outlined in the section below.

17.3 Hydraulic Model Updates

17.3.1 Simulation Period

In order to capture the influences of the STP flows, it was necessary to revise the model approach from short duration event based modelling (which is typical of flood modelling), to modelling a longer continuous period. In order to keep the simulation times manageable a number of other changes were required, as described further below. The actual simulation period selected extends from 17/09/2011 to 15/04/2016, a period of 1,672 days (approximately 4.5 years). This period was selected based on availability of key datasets such as tidal water level data.

17.3.2 Cell Size

The FRMS hydraulic model was designed to run a limited number of shorter duration (typically <1 day) flood events. However, for the hydraulic capacity assessment the model was required to run for a much longer period, i.e. approximately 5 years. In order for the runtimes of the longer term simulation to be manageable, the cell size of the model was increased to reduce the computational load. The FRMS modelling utilised a cell size of 10 m, for the HCA a cell size of 25 m was utilised. This allowed for continuous long term simulation to be completed (for the existing case and identified scenarios) within the timeframe of the project.

17.3.3 Digital Elevation Model

Since the original flood study model (SMEC, 2009), revised LiDAR (elevation) data was collected in October 2012. Since the flood study model had been built and calibrated with previous data, not all flood modelling was updated to the 2012 Lidar. For the HCA the 1m LiDAR collected in 2012 has been used as the primary elevation data source for the floodplain areas.

Additional survey data is incorporated in a number of areas, including:

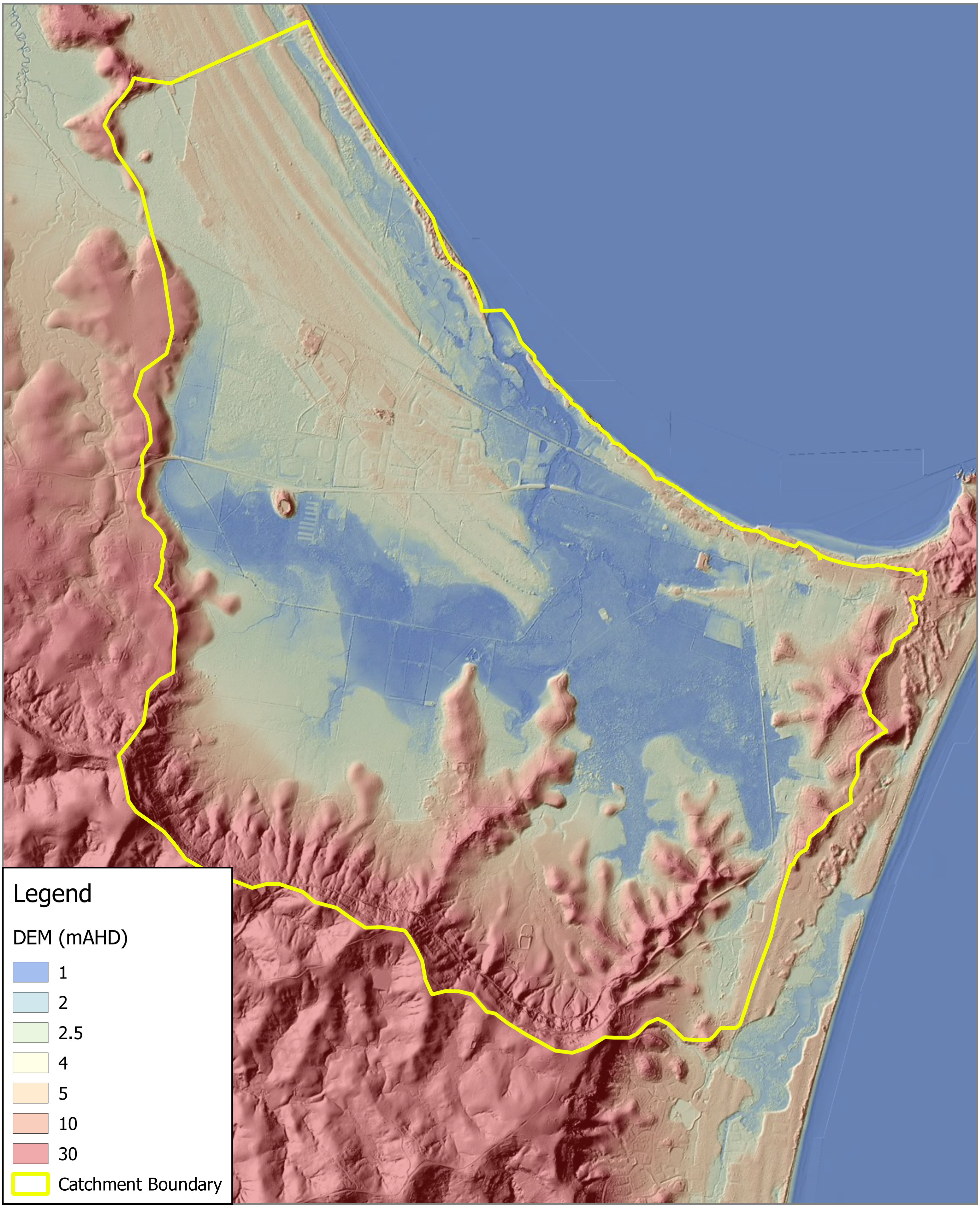
- Hydrosurvey of the Creek, this data was collected by the Department of Public Works and Services in 1997.
- Cross-sectional survey include in the FRMS model; and
- Additional cross-section survey collected by AWC (see Section 1.3.2).

An updated DEM of the catchment is provided in

Figure 17-1.

1.3.1 Revised Boundaries

As part of the SMEC (2009) Flood Study a hydrologic model was created in the XP-RAFTS software. As the XP-RAFTS model cannot account for groundwater effects or water quality and these elements are important to this study, the SOURCE modelling framework was utilised to provide catchment hydrology and water quality datasets (refer Appendix D). Therefore, for the HCA the TUFLOW hydraulic model was configured to use the SOURCE inflow locations and boundary data as opposed to the XP RAFTS boundaries utilised in the Flood Study and FRMS.



Title:

Updated Digital Elevation Model for the Belongil Creek Catchment

Figure: **17-1**

Rev: **A**

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17.3.4 New 1D survey

AWC collected additional survey of the drains within the study area. This was included into the model as 1D sections, which is linked to the 2D areas on the floodplain. The updated 1D locations are presented in

Figure 17-2.

A number of 1D sections outside of the area of interest (e.g. pipes and culverts within the Byron Bay township) were removed from the HCA hydraulic model, to provide for faster computational runtimes and better model stability. These modifications would have no significant effect on the accuracy of the model in floodplain regions.

17.3.5 Extent

The downstream boundary condition of the original Flood Study and FRMS was modified for this project. This was done as insufficient data on entrance bathymetric changes exists over any period, and would have presented a significant limitation for the continuous simulation modelling approach.

The status of the entrance plays a large role in determining water levels within the estuary downstream of the discharge location (i.e. upper estuary and Union drain). To overcome this key potential limitation, water level data recorded at the Ewingsdale Bridge (see Section 1.3.3) has been applied to drive estuarine hydraulics as a downstream boundary condition. This approach overcomes the need for detailed entrance bathymetric datasets to drive the tidal exchange component of the hydraulic model.

Due to the reconfiguration of the hydraulic model with a revised downstream boundary location a revised hydraulic model area was required. The revised hydraulic model boundary is presented in in

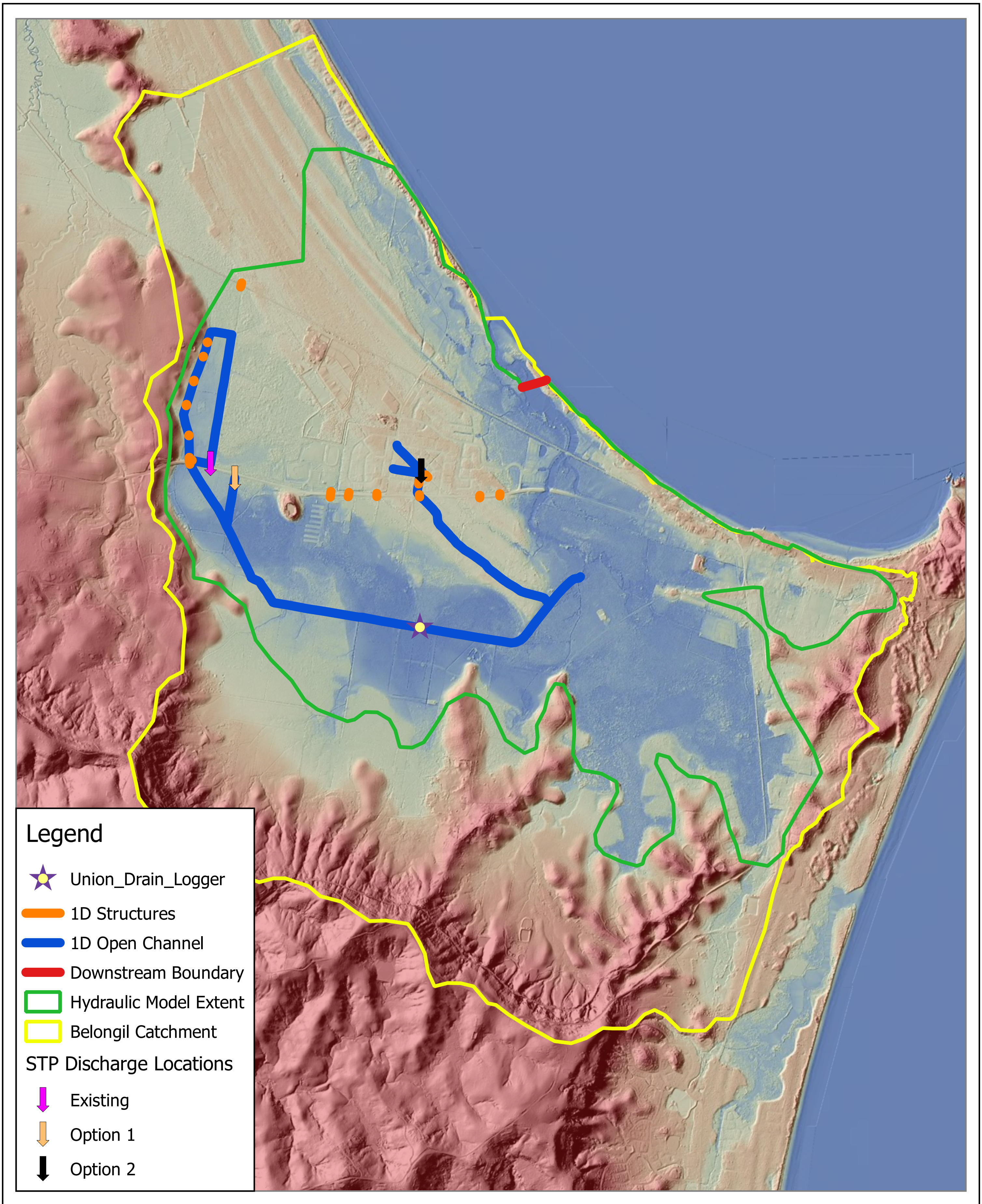
Figure 17-2.

17.4 Boundaries

For the HCA the simulation is run continuously for a period from 17/09/2011 to 15/04/2016, a period of 1,672 days (approximately 4.5 years). This period was chosen as all relevant boundary conditions are available;

- Downstream water levels at Ewingsdale Bridge (for the estuary);
- Catchment flows from SOURCE model; and
- STP discharge data.

Each of these boundaries is described further below.



Title:

Hydraulic Model Configuration

Figure: **17-2**

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17.4.1 Downstream Water Levels

A water level recorder has been operated at the Ewingsdale Bridge crossing of the Belongil Creek estuary since 2011. The water level recorder is owned by Byron Shire Council but has been operated by third parties since installation as part of an ongoing entrance opening monitoring program.

Water levels are recorded hourly and a datum corrected version (to m AHD) from 3 June 2011 to 15 April 2016 was provided to BMT WBM by AWC for use in this study. This water level is applied as the downstream boundary of the hydraulic model in the location presented in

Figure 17-2.

The water level ranges from 0.50 to 1.66 m AHD with a mean value of 0.78 m AHD. The time series data is presented in Figure 17-3.

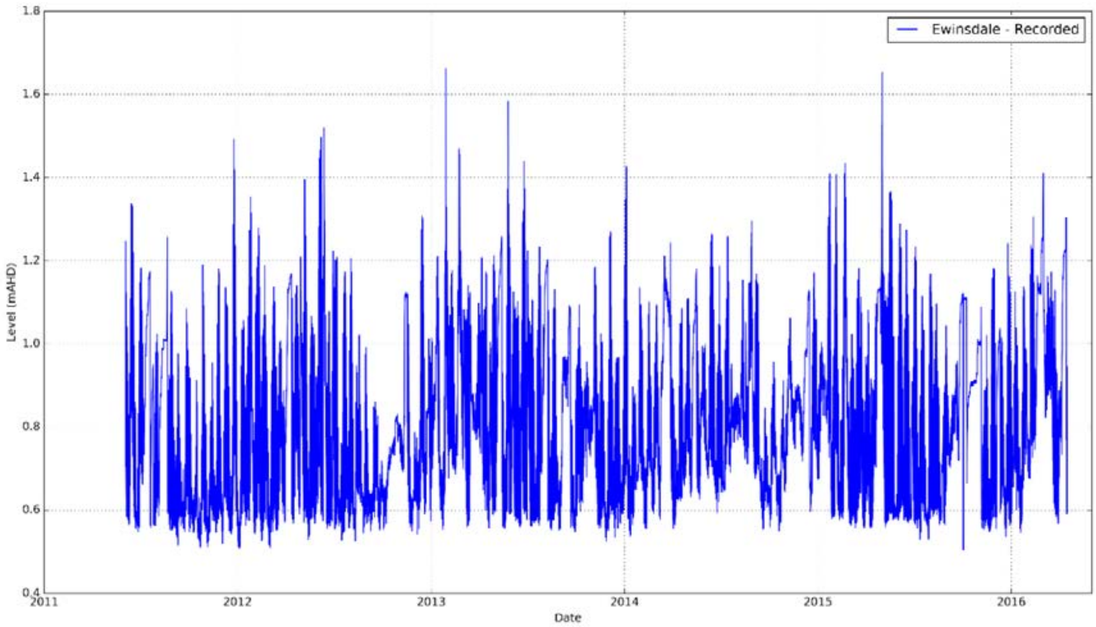


Figure 17-3: Downstream Water Level Data

17.4.2 Catchment Flows

The catchment flows have been generated from the SOURCE model as described in Appendix D. The catchment flows are applied as a mixture of 1D and 2D boundaries, with 1D boundaries applied in the drains and 2D boundaries applied in other areas.

17.4.3 STP Flows

Byron Shire Council provided daily flows from the West Byron STP at site EPA5 minus allowances for seepage and evapotranspiration losses in the wetland areas. For the existing case modelling these are applied as a flow boundary to the 1D channel as shown in

Figure 17-2.

The STP flow data is recorded daily and commences 17 September 2011 and concludes on 15 September 2016. The time series boundary for the existing case data STP flows is presented in

Figure 17-4.

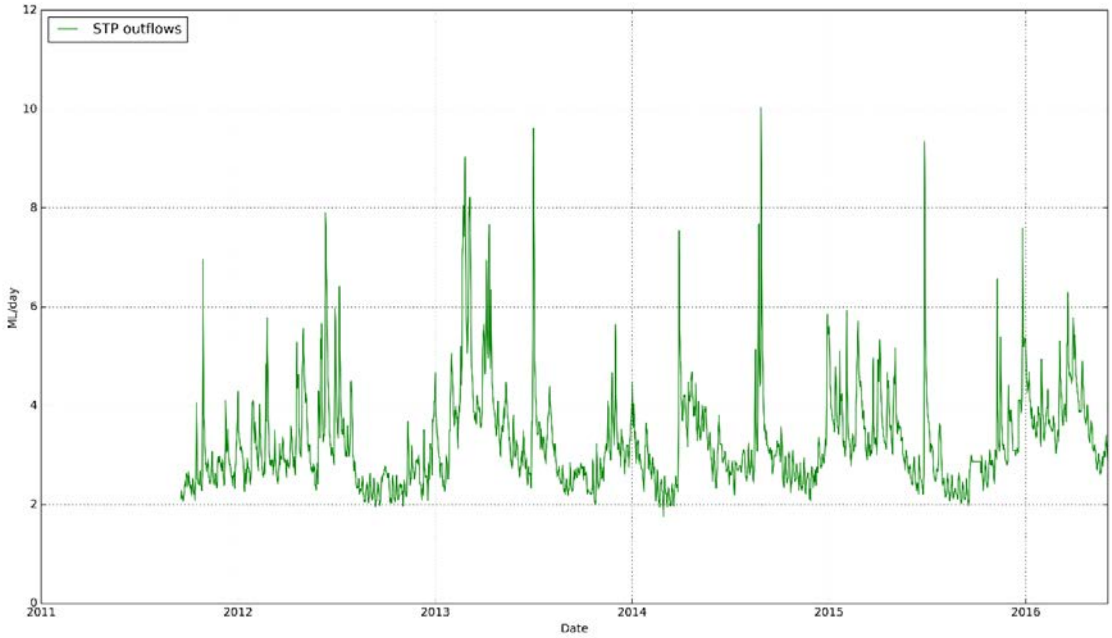


Figure 17-4: STP Flow Boundary Data

17.5 Hydraulic Model Parameters

This section describes the hydraulic model parameters used for the HCA modelling.

17.5.1 Manning's Roughness

The Manning's n values are consistent with those used in the FRMS as presented in Table 17-1. A number of smaller drains were included in the model as 1D model sections. These drains were not included in the FRMS and have been included with a Manning's n value of 0.08 based on photos and site inspection.

Table 17-1 : Adopted Manning's n Values

Land Use Category	Manning's n
Medium Grass Floodplain	0.055
Roads - all road reserve	0.013
Short Grass / Bare Earth	0.03
Residential	0.03
Buildings	1.0
Forested	0.15
Water Bodies	0.025
Creek Lower (2D)	0.025
Unmaintained Floodplain	0.12
Basins	0.03
Swamp	0.08

17.5.2 Structures

There are a number of hydraulic structures included in the hydraulic model. Most notable for the HCA are the culverts in the drains and underneath Ewingsdale Road. These culverts are known to periodically experience blockage and are maintained in a cleared state by Byron Shire Council. Detailed records of these blockages over time are not available, hence, for the purpose of the HCA, these culverts have been assumed to be unblocked.

17.6 Model Validation

To calibrate a hydraulic model, the typical approach is to use calibrated hydrologic inflows and recorded downstream water level to drive the hydraulic model and then compare to observed water levels and flows within the hydraulic model. As the Belongil Creek catchment has no flow gauging stations an alternate method has been applied. This method has two parts as described below:

- Qualitative assessment using photographs that identify inundation patterns during significant rain events in a particular portion of the catchment; and
- Qualitative assessment comparing recorded water levels from a water level logger in the Union Drain to water levels predicted by the hydraulic model.

The process of model 'validation' by comparing predicted water levels (from the hydraulic model) to observed water levels in the Union drain is not a typical optimisation method as it assumes that the hydrologic inputs had been calibrated, which was not possible in this instance.

To overcome this limitation, a number of hydrologic and hydraulic model iterations were performed manually whereby both water levels and the shape of runoff hydrographs were compared to observed water level data (in Union Drain). Over numerous model runs a sufficiently accurate validation was achieved.

Figure 17-5 provides approximate location details of the inundation photos and the location of the water level recorded in the Union drain.

Figure 17-5 Validation Data Locations

17.6.1 Photo Record of Inundation Events

A number of photos of representing inundation in the floodplain have been provided to or taken by AWC and third parties. Whilst it has not been possible to obtain an inundation level that could be used for model validation, they do allow for a qualitative comparison of extent of inundation.

The exact timing of the photos is unknown in relation to the inundation events, however, the key information they have provided are the existence of a flow connection between the drain lines and 'paddock' and the general extent of inundation. The inundation events resulted from rainfall as follows

- April 2009 - Approximate rainfall totals – 2 April 10mm, 3 April 67mm, 4 April 58 mm and 5 April 12 mm. Refer Figure 17-6; and
- May 2009 - Approximate rainfall totals – 42 mm 19th May, 8 mm 20th May, 136mm 21st May, 132 22nd May and 32 mm 23rd May. Refer Figure 17-7; and
- June 2016 – Approximate rainfall totals - 3 June 9 mm, 4 June 45 mm and 5 June 166 mm. Refer Figure 17-8.

Figure 17-6: Photo Inundation: April 2009 (Source, Tidswell)

Figure 17-7: Photo Inundation: May 2009 (Source, Tidswell)

Figure 17-8: Photo Inundation: June 2016 (Source AWC)

17.6.2 Model Representation of Inundation Events

The hydraulic model operates over a period from 2011 to April 2016 and as such does not allow for inundation mapping of these events, however, a visual comparison of inundation extent for a flood event in January 2013 was undertaken (refer Figure 17-10). During this event the following approximate rainfall totals were recorded at Cape Byron Lighthouse 39 mm on the 27th January, 90 mm on the 28th January and 29 mm on the 29th January.

This inundation shows that the model predicts significant inundation in the floodplain area to the north of Ewingsdale Road which is consistent with the provided photographs.

Union Drain Logger Data

The water level logger in Union Drain has a record from the 12/03/2013 through to 26/09/2014 and then again from 15/10/2015 through to 15/04/2016. This is presented in Figure 17-9 below, noting that the x-axis is from 2011-2016 as per the Ewingsdale Bridge data and the STP flows.

The vertical datum of this water level logger was adjusted by application of a vertical shift of 0.17m. This was done to bring predicted water levels at the Union drain in line with those recorded at the Ewingsdale Bridge during periods when both recorders would have been expected to demonstrate matching water levels, e.g. during periods of entrance closure.

There appears to be a difference in datum between the 2013-2014 data period and the shorter 2015-2016 period. Therefore, the time-series validation has been conducted using the longer 2013-2014 data set.

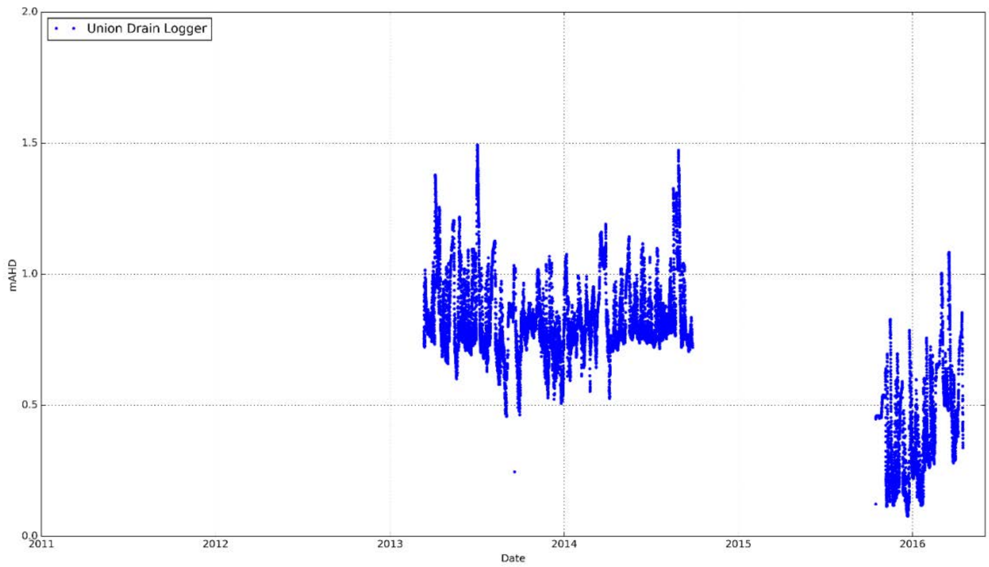
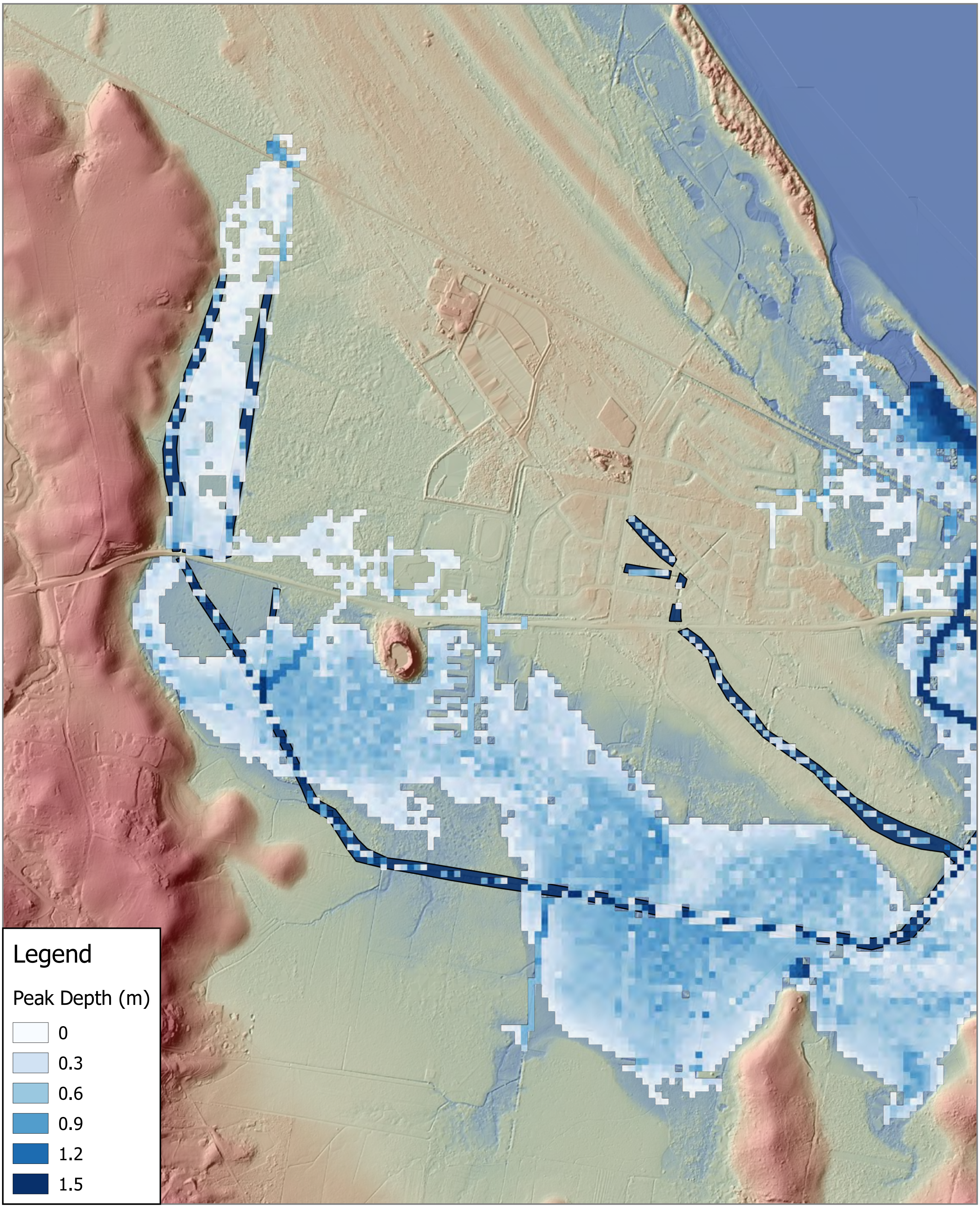


Figure 17-9: Datum Shifted Union Drain Logger Data



Title:

Peak Inundation Depth
January 2013

Figure: **17-10**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Comparisons of observed and modelled water levels in the Union Drain at the logger location are provided in Figure 17-11. The upper left panel represents the observed v's modelled water level, the upper right panel presents a variation on a cumulative frequency type graph which aims to demonstrate the alignment of observed and predicted water levels at different water depths. The lower panel is a time-series of observed versus modelled water level within the Union Drain.

For the performance measures described above the values calculated for the period 12/03/2013 through to 26/09/2014 are:

- Nash Sutcliffe Coefficient of Efficiency (NSE) for hourly data, 0.64;
- The percent bias, -3.3;
- The Root Mean Squared Error (RMSE), 0.09; and
- Correlation of determination (R^2), 0.76.

The above indicators are consistent with a good model fit with observed data, and indicate that the model is suitable for the purpose of the HCA.

In particular the model performs well on the upper sections of the tidal cycle and also during the flood peaks. Over a longer period it would appear that the union drain "clogs up" over time, presumably with vegetation and / or sediment.

For example in Figure 17-12, which shows the modelled and observed water levels in Union drain over a 4 month period from June 2013 to October 2013. Throughout June and July the minimum water level observed is approximately 0.8 m AHD. However, after an entrance close at the start of August and subsequent opening around the 10th of August, the water levels at the bottom of the tide drop down to approximately 0.5 m AHD.

The result appears to indicate that a "flushing" of the drain has occurred and more tidal propagation is occurring up the Union Drain. Over a longer period, this seems to be varying. Accordingly, the hydraulic model has been configured to provide an intermediate position, with the model over-predicting the tidal range during some periods, but under-predicting for others. It is noted that this largely affects the lower water level values (typically below 0.8 m AHD) which are likely to be contained entirely within the Union Drain. For the HCA which also considers inundation in the floodplain, water is only able to leave the Union drain at higher elevations (above 0.8 m AHD) and as such is more important to considerations of floodplain inundation. It is reiterated that the model performs better for the higher water levels which have an overall greater significance in this investigation.

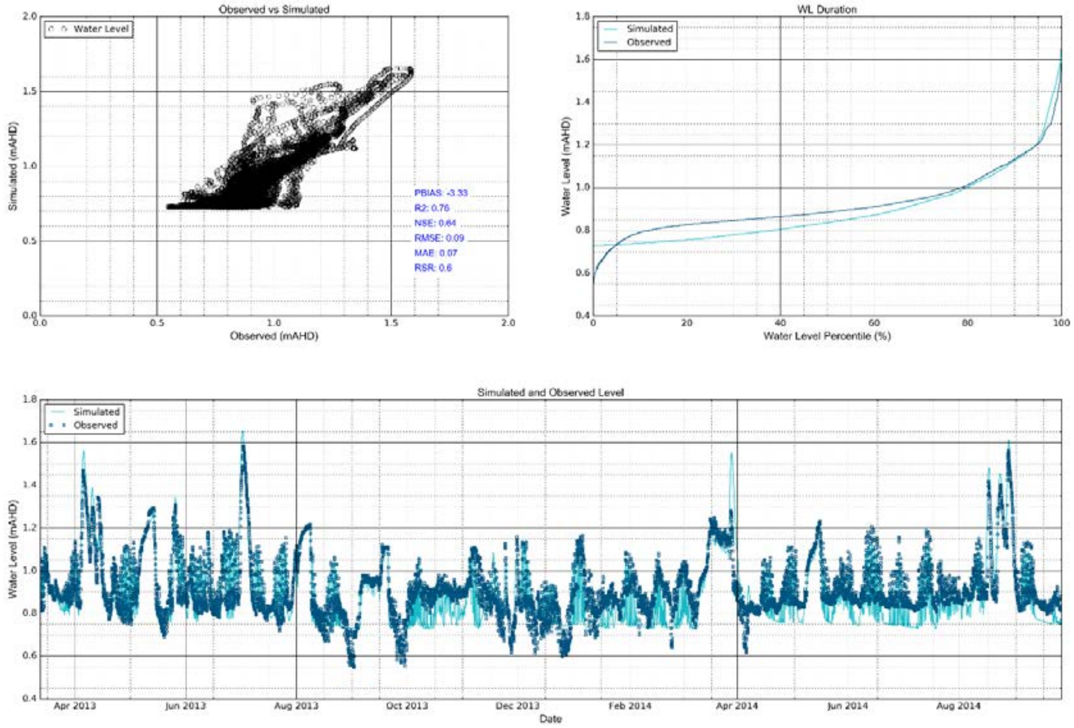

Figure 17-11: Water Level Validation – 2013 to 2014

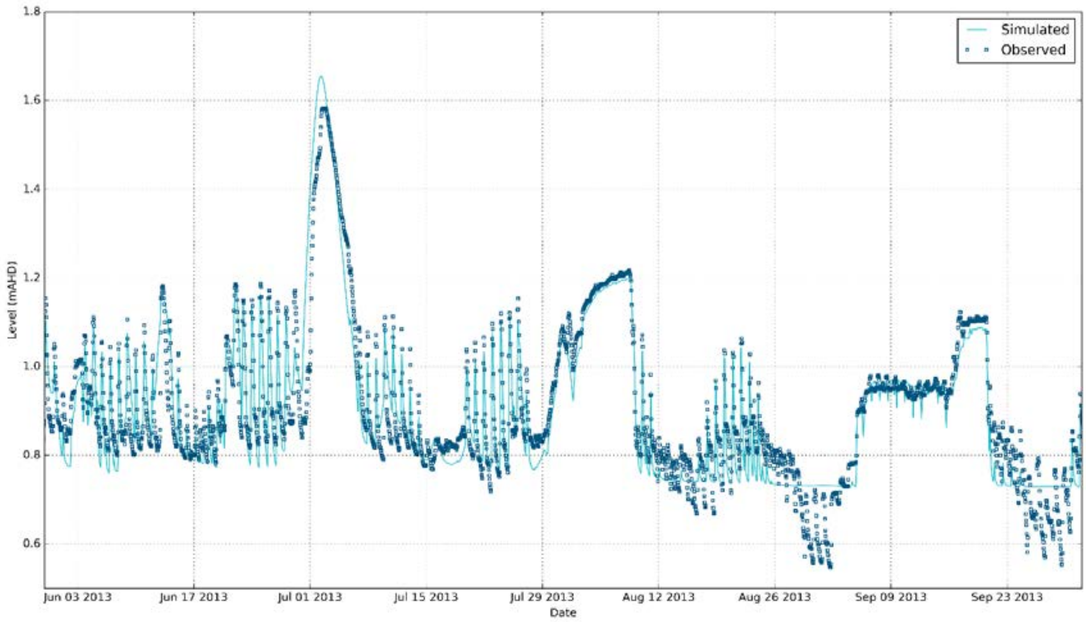

Figure 17-12: Water Level Validation – June to September 2013

17.6.3 Effect of Land Use Change

The proposed West Byron development would influence land use styles in this portion of the overall Belongil catchment. This could influence surface and groundwater interactions, surface peak flows and discharge volumes, as well as water quality (depending on applied mitigation within the development).

This may have implications for the long term drainage capacity of the existing drainage line that bisects the proposed West Byron development site. To identify if there are likely to be capacity issues, water level results for the 8ML discharge at Option 2 (which directs the maximum amount of STP effluent through the drain) were extracted from the model run at two locations along this drainage line. The two points of extraction coincide with locations where actual drain survey data was obtained for use in the study and as such provide an accurate representation of the existing drain profile at these locations. The locations of the extraction / survey points are shown on Figure 17-2.

Extracted water level data across the approximately 5 year modelling period has been processed to derive 25th, 50th and 75th percentile values, and an observed maximum water level across the entire period. The results are plotted within the drain profile as shown in Figure 17-13 and Figure 17-14. It can be seen that for median flows (50th percentile), the drains have ample capacity to convey increased flows. It is worth noting that even the maximum (peak) flood flows from events that occurred during the modelling period did not exceed the drain capacity.

These results indicate that the use of the Option 2 release point is appropriate to the 2050 timeframe and potentially beyond.

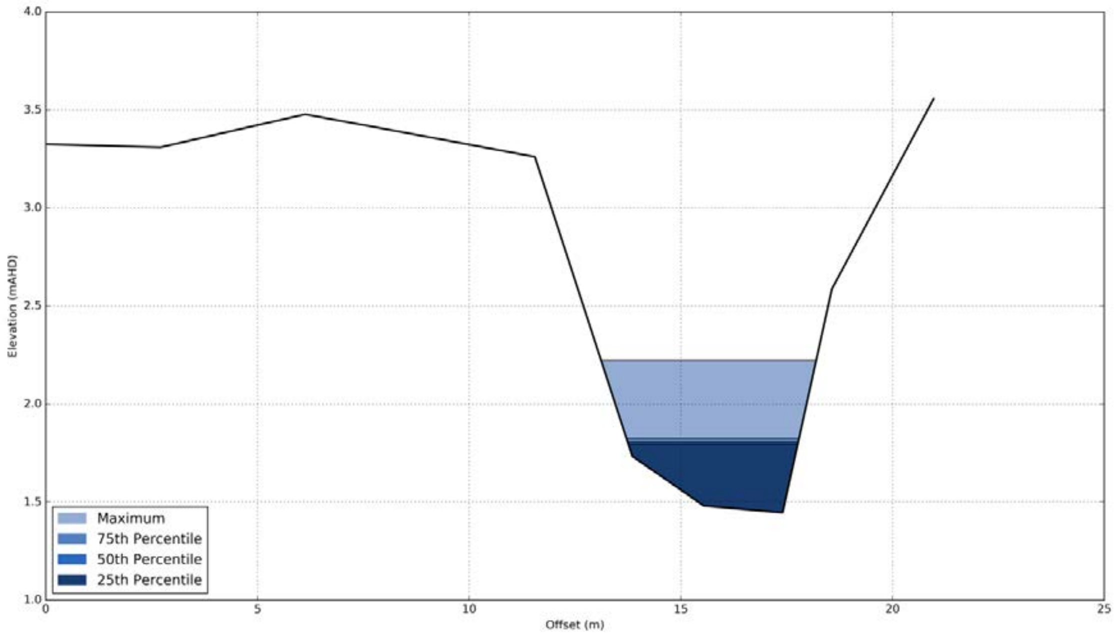

Figure 17-13: Modelled water level data at Location 1

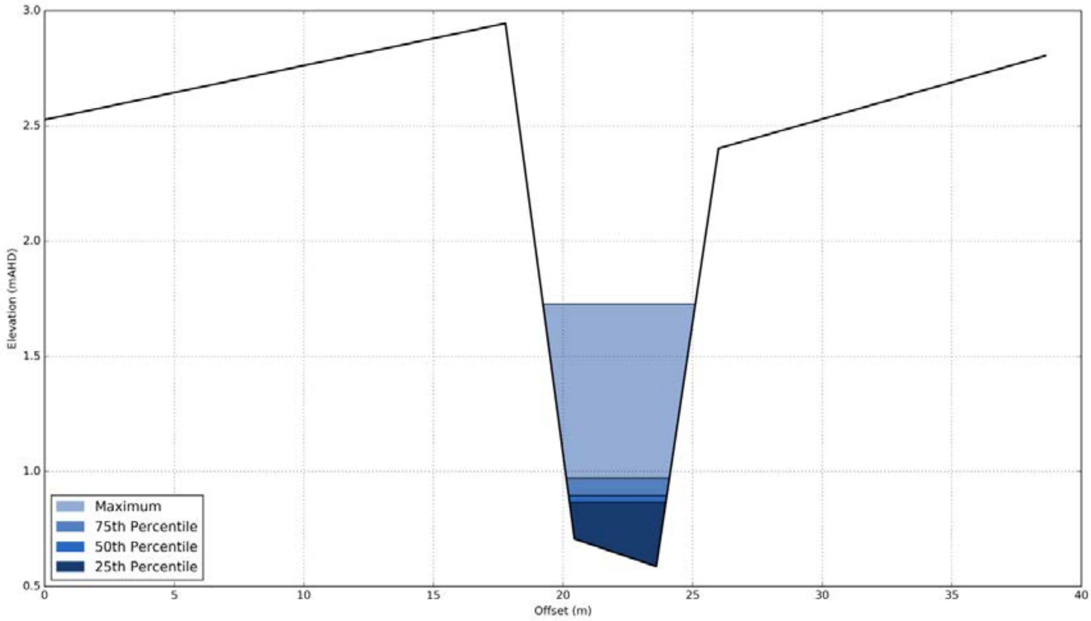

Figure 17-14: Modelled water level data at Location 2

17.7 Assumptions and Limitations

The interpretation of the inundation and difference in inundation maps presented in the report should be completed with an appreciation for the limitations in their accuracy. While the points below highlight these limitations, it is important to note that the results presented provide an up-to-date methodology and set of models.

- The updated hydraulic model has not has not been fully calibrated;
- The DEM has been generated from LiDAR data with an unknown vertical accuracy. In areas of dense vegetation or standing water the LiDAR elevations are likely to have been based on interpolation.
- No soil infiltration or evaporation is applied to the hydraulic model. Allowance for these is made in the hydrology model. In some locations within the floodplain, where the DEM is "bumpy" due to high vegetation cover, water ponds for the remainder of the simulation.
- The estuary mouth is not modelled directly (i.e. the sediment transport is not included in the hydraulic model). The modelling assumes that changes in the flows from the STP do not alter the open / closing regime at the entrance. STP flows are estimated to account for around 5% of the total flows from the catchment to the estuary (for the existing case).

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