Woy Woy Peninsula
Flood Study

Final Report

Gosford City Council **March 2010**

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1 FOREWORD

The NSW State Government's Flood Prone Land Policy provides for the development of sustainable strategies for managing the occupation and use of floodplains from a risk management hierarchy perspective. The policy has the primary objective '*to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.*' NSW Government (2005)

Under the Policy, management of flood prone land falls under the responsibility of Local Government. State Government subsidies support works to reduce potential flood damage and personal danger in existing developed areas. The State also provides specialist technical support to assist Councils to ensure that the management of flood prone land is consistent with flood risk, with a view to ensuring that development does not cause an increase in potential liability.

The Policy provides for technical and financial support by the State Government through the following sequential stages:

1. Flood Study – Determines the nature and extent of the flood problem.
2. Floodplain Management Study – Evaluates management options for the floodplain with respect to both existing and future development.
3. Floodplain Management Plan – Involves formal adoption by Council of a plan of management for the floodplain.
4. Implementation of the Plan – Involves construction of flood mitigation works, where viable, to protect existing development.
   – Uses planning controls to ensure that future development is compatible with flood hazards.

The Woy Woy Peninsula Flood Study encompasses stage one of this management process. This study has been prepared by DHI Water and Environment Pty Ltd for Gosford City Council to describe and quantify flood behaviour under present catchment conditions. The flood study will form the basis for floodplain management options with the end result being the application of ecologically sensitive planning and development controls.

2 EXECUTIVE SUMMARY

The Woy Woy Peninsula urban area is bounded by Brisbane Water to the north and east, Broken Bay to the south, and Brisbane Water National Park to the West. The study area is approximately 13km^2 as shown in Figure 1. Much of the area is prone to nuisance flooding, especially from long-duration rainfall events. Flooding occurs in road reserves and in private property, where it remains until it infiltrates or evaporates. Generally this nuisance flooding may remain for a couple of days. However, during very wet periods the groundwater table can rise such that flooding remains for several weeks.

This flood study was undertaken to determine the existing flood behaviour of flood prone areas for a range of flood risk levels from the 50% Annual Exceedance Probability (AEP) event through to the Probable Maximum Flood (PMF). Flood behaviour was determined for flood prone areas using mathematical modelling tools developed specifically for the study. Catchment groundwater behaviour, runoff generation, overland flow, channel flow and pipe flow were calculated using the MIKE SHE modelling software. The model allows a distributed, physically based approach to rainfall runoff, with rainfall time series applied directly to a two dimensional grid representation of the catchment surface.

The model was calibrated to the 1988 storm event using flood depths obtained from community consultation and council maps indicating areas historically prone to flooding.

Design rainfall intensities and temporal patterns for the required range of flood risk events were obtained and applied to the model. The flood model predictions indicate that in many areas of the catchment the groundwater table rises to the ground surface, preventing infiltration of rainfall and creating significant areas of ponded water. The existing flow channels and stormwater drainage conduits can be effective at removing this water if the ponded areas are connected to the drainage system and the drainage system is operating effectively.

Plans showing flood depth, flood hazard classification and other results from the design flood events are presented in Figure 13 to Figure 55.

The developed flood modelling tools and reported flood behaviour for existing catchment conditions can now be used as the basis for developing a Floodplain Risk Management Plan for flood prone land in the catchment. The hydraulic model developed for the flood study may generally be used to assess the hydraulic impact of any proposed structural flood mitigation works on flood behaviour.

3 GLOSSARY OF TERMS

The majority of this glossary is based on the glossary of terms published in the New South Wales Government Floodplain Management Manual (2005).

Annual exceedance probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood of discharge 500 m^3/s has an AEP of 5%, it means that there is a 5% chance of (that is one-in-20 chance) of a peak flood discharge of 500m^3/s or larger occurring in any one year (see average recurrence interval).
Australian height datum (AHD)	A common national plane of level corresponding approximately to mean sea level.
Average recurrence interval (ARI)	The long term average number of years between the occurrence of a flood as big, as or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Aquifer	An underground layer of water-bearing permeable rock or unconsolidated material from which water can be extracted.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The land area draining through the main stream, as well as tributary streams to a particular site. It always relates to an area above a particular location.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local heavy rainfall. Often defined as flooding which peaks within 6 hours of the causative rain.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, lake or dam and/or overland flooding associated with major drainage before entering a watercourse and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood liable land	Is synonymous with flood prone land (i.e.) land susceptible to flooding by the probable maximum flood (PMF) event. Note that the term flood liable land now covers the whole of the floodplain not just that part below the flood planning level as indicated in the 1986 Floodplain Development Manual (see flood planning area).

Flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
Floodplain	Area of land, which is subject to inundation by floods up to, and including the probable maximum flood event, that is, flood prone land.
Floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
Floodplain risk management plan	A management plan developed in accordance with the principles and guidelines of the NSW Government Floodplain Management Manual 2001. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept of the 1986 Floodplain Development Manual.
Flood planning levels (FPLs)	Are the combinations of flood levels and freeboards selected for the planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. The concept of flood planning levels supersedes the “standard flood event” of the 1986 Floodplain Development Manual.
Flood prone land	Is land susceptible to flooding by the probable maximum flood (PMF) event. Flood prone land is synonymous with flood liable land.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk is divided into 3 types, existing, future and continuing risks. They are described below. **Existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **Future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **Continuing flood risk:** the risk a community is exposed to after flood risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing risk is simply the existence of flood exposure.

Flood storage areas

Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity and loss of flood storage can increase the severity of flood impacts by reducing the natural flood attenuation. Hence it is necessary to investigate a range of flood sizes before defining flood storage areas.

Floodway areas

Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels.

Freeboard

A factor of safety typically used in relation to the setting of floor levels, levee crest levels etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement and other effects such as "greenhouse" and climate change. Freeboard is included in the flood planning level.

Geographical information systems (GIS)

A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.

Groundwater

Water that is located beneath the ground surface in soil pore spaces and fractures of lithologic formations.

Hazard

A source of potential harm or a situation with a potential to cause loss. In relation to the NSW Floodplain Management Manual 2005 the hazard is flooding which has the potential to cause damage to the community.

Hydraulics

The term given to the study of water flow in waterways, in particular, the evaluation of flow parameters such as water level and velocity.

Hydrogeology

The study of the distribution and movement of groundwater in soil and rock layers beneath the surface of the earth

Hydrograph

A graph that shows how the discharge or stage/flood level at any particular location changes with time during a flood.

Hydrology

The term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

Local overland flooding

Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

Mainstream flooding

Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

Major drainage

Councils have the discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of the NSW Floodplain Management Manual, major drainage involves:

- The floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once the system capacity is exceeded; and/or
- Water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
- Major overland flow paths through developed areas outside of defined drainage reserves; and/or
- The potential to affect a number of buildings along the major flow path.

Mathematical/computer models

The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

Minor, moderate and major flooding

Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood.

Minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to flood.

Moderate flooding: low-lying areas are inundated requiring the removal of stock and or the evacuation of some houses. Main traffic routes may be covered.

Major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

Modification measures

Measures that modify either the flood, property or the response to flooding.

Peak discharge

The maximum discharge occurring during a flood event.

Piezometer

Small diameter water well that is used to measure the hydraulic head of groundwater in aquifers

Probable maximum flood (PMF)

The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF should be addressed in a floodplain risk management study.

Probable maximum precipitation (PMP)	The greatest depth of precipitation for a given duration meteorologically possible over a given size of storm area at a particular location at a particular time of the year, with no allowance made for long term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.
Probability	A statistical measure of the expected chance of flooding. (see annual exceedance probability).
Runoff	The amount of rainfall that actually ends up as stream flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
Survey plan	A plan prepared by a registered surveyor.
Topography	A surface which defines the ground level of a chosen area.
Unconfined Aquifer	Aquifer with an upper boundary being the water table or phreatic surface.
Water surface profile	A graph showing the flood stage at any given location along a water course at a particular time

4 INTRODUCTION

Historically, the Woy Woy Peninsula has been prone to low level, nuisance flooding, especially from long-duration rainfall events. Much of the Peninsula is flat and low lying with little surface gradient to allow for stormwater runoff. Drainage problems are frequently caused due to the lack of watercourses and well defined overland flow paths. The sand dune ridge system over which the residential areas lie at times contains a high groundwater table that prevents infiltration of flood water and localised areas of less pervious soil also restricts infiltration. In the past, flooding has been observed to occur in road reserves and in private property, where it remains until it infiltrates or evaporates. Generally this nuisance flooding may remain for a couple of days. However, during very wet periods the water table can rise such that flood inundation in local areas remains for several weeks.

The recognition of these flooding issues has prompted Gosford City Council (GCC) to prepare a detailed flood study to identify the various causes of flooding on the Woy Woy Peninsula.

DHI Water and Environment Pty Ltd (DHI) was commissioned to determine the flood behaviour for the various design flood events for present catchment conditions. Overland flood behaviour will be described by the nature and extent of flooding through the estimation of design flows, levels and velocities.

A staged approach to the study was adopted. Firstly, data collection was undertaken to collate historical flood information including historical rainfall and flood level data and also to collect relevant information to describe the physical size and nature of the catchment and the stormwater asset. Secondly, a combined groundwater/hydraulic modelling tool of the catchment was developed and validated using the historical storm data. Finally the validated hydraulic model will be used in conjunction with design rainfall conditions to estimate design overland flooding behaviour in the catchment for a range of risk levels for existing catchment conditions. The developed model can be used to investigate various management options to assist in determining sustainable Floodplain Risk Management Strategies for the catchment floodplain.

5 CATCHMENT DESCRIPTION

The study area is approximately 13km^2 in size and is bounded by Brisbane Water to the North and East, Broken Bay to the South, and Brisbane Water National Park to the West. An overview of the study area is provided in Figure 1. Over 80% of the study area consists mainly of a series of low lying beach ridges with intervening swales, where ground levels vary between 4m and 6m AHD. The remaining study area backs onto the National Park and Blackwell Mountain and is typically of higher elevation with rocky outcrops.

The majority of the catchment is characterised by predominantly low-medium density urban development. Many areas on the Peninsula are not serviced by piped drainage systems, kerb and gutter infrastructure nor have effective overland flow paths. As a result, overland flow is prone to gather in local sags in the street network. Where these sags are unrelieved, or the capacity of the stormwater pits is insufficient, stormwater runoff will pond until it reaches a level where it can flow overland.

The inherent series of low lying beach ridges and intervening swales trend northeast to southwest, parallel to the present shoreline at Ocean Beach and at right angles to the prevailing refraction pattern of southeast swell waves entering Broken Bay (Cook, 1998). Figure 2 shows the ridges and swales in the form of topography. The local hydrogeology is controlled by this beach ridge system, within which an unconfined shallow aquifer exists. Groundwater flows are evident towards shorelines in the north, east and south fed by the groundwater mound located in the central western region. This groundwater mound fluctuates with rainfall and has a response time of between 1 and 3 days (Conacher Travers, 2005). While soils on the Peninsula are fairly coarse sands, and infiltration should be rapid, the presence of podsol soils can often impede the transition of water from the surface to the groundwater table, causing surface ponding and waterlogging. Podsol soils have a B Horizon dominated by the accumulation of compounds of organic matter, aluminium and/or iron which is also called 'coffee rock'. This hydraulic conductivity of these layers is much less than that of the course sands. There is little information on the spatial extent of these podsol soils, only limited point information from bore and pit excavations.

6 STUDY APPROACH

6.1 Objectives

The objectives of the Woy Woy Peninsula Flood Study, derived from the Study Brief and in accordance with the NSW Floodplain Development Manual (2005), are as follows:

- Develop an integrated 2D hydraulic modelling system for the definition of flood behaviour on the Peninsula. The model should account for infiltration of surface flows to groundwater, dynamically linking the groundwater and surface water system;
- Define the variation of flood behaviour over particular durations in terms of flood levels, depths, extents, velocities and flow rates for a full range of flood events, under existing catchment conditions;
- Investigate design flood events for six (6) design flood events including the: 1 in 2 year (50% AEP), 1 in 10 year (10% AEP), 1 in 20 year (5% AEP), 1 in 100 year (1% AEP), 1 in 200 year (0.5% AEP) and Probable Maximum Flood (PMF) for Existing and Future catchment conditions;
- Define the hydraulic categories (floodway, flood-fringe or flood storage) and the provisional hazard categories (low, high) for events nominated in consultation with the Committee; and
- To assess the potential impact of elevation of tailwater levels as a result of climate change;

6.2 Broad Steps

In undertaking the above, the study involved:

- Reviewing and compiling all available flood related data for the study
- Defining the study area specifically taking into account where boundaries need to be located in order to ensure the validity of all model results within the study area
- Undertaking a community survey of residents in the catchment to collect historical information describing overland flows and community opinion regarding drainage in the catchment
- Determining the likely extent and behaviour of historical overland flows by reviewing the compiled data and feedback from the resident survey
- Identifying structures and factors that influence floodplain flow paths
- Identifying properties and general areas at risk from flooding under particular flood conditions
- Providing the analytical tools for the future investigation and assessment of flood mitigation options and management measures

7 DATA

Relevant reports and physical data have been collated for the study from a variety of sources. The data includes various background information and data essential for the development and validation of the modelling tools.

7.1 Previous Relevant Studies

The following presents a review and summary of previous studies (provided by Council) within the area, in order to identify information relevant to the Woy Woy Peninsula Flood Study. The information contained in these reports is very diverse and has been further classified into those containing;

- General background information;
- Information related to groundwater, incorporating the UTS Stormwater Infiltration Project and the Gosford - Wyong Joint Water Supply Scheme; and
- Catchment drainage studies.

7.1.1 General Background Studies

***The Origin and Development of the Umina - Woy Woy Beach Ridge System, Broken Bay, NSW,* (Hails, 1969),** attempts to review the formation of the beach ridges and intervening swales that are inherent on the Peninsula. The orientation of these formations suggests that the ridges were formed parallel to the predominant fronts of the refracted south-easterly swell waves, when the sea level was higher than at present. Development of the ridge system was dependant on several inter-related coastal processes. These included wave, current and tidal action, seasonal changes in the beach and offshore profiles, availability and rate of supply of sand, and the configuration of the adjacent bedrock coastline.

***Stormwater Infiltration Experiments on a Sandy Area in Eastern Australia,* (Matuzic et al, 2001)** provides background information on the geography and geology of the Woy Woy region, as well as possible flooding mechanisms. Localised areas of impervious soil preventing infiltration was cited as one cause of flooding. During installation of some of the infiltration devices, the water table was found to be higher than the required excavation. This could indicate that the infiltration devices effectiveness may be significantly reduced. An infiltration device at Mackenzie Avenue was installed in an impervious layer of coffee rock, probably making it ineffective. At several device sites the pit water levels remained elevated for several days indicating the presence of a perched water table possibly caused by organic podsols or other impermeable layers in the soil.

The Brisbane Water Foreshore Study undertaken by **Posford Pavry Sinclair & Knight (1975)** provides background information on the existing condition and uses of Brisbane Water and provides a set of guidelines for the use and development of the Foreshore. The study includes a history of the area, a physical description of the waterway, current moorings, structures and services as well as navigation and dredging.

The Brisbane Water Flood Study: Compendium of Data **(PWD, 1991)** constitutes the first phase of the Brisbane Water Flood Study. The report was prepared to provide a convenient reference for historical flood data and identifies sources and details of storm information. The report includes a summary of main flood events commencing from the first recorded on the 28th May 1889 to the 4th Feb 1990 with the most severe being that of the 25th May 1974. Flood levels on houses fronting Brisbane Water for the May 1974 event have been collated.

The *Central Coast February 1992 Flood Event*, MHL (1992), presents a detailed summary of data collected in the Gosford-Wyong region for the February 1992 flood event. It gives a brief outline of the meteorological conditions that were responsible for the storm and lists the resultant flood behaviour. Data contained in the report include:

- Creek maximum height profiles;
- Synoptic charts;
- Rainfall hyetographs - with associated locality maps;
- Maximum rainfall intensities;
- Intensity-frequency-duration plot;
- 24 and 48 hour rainfalls;
- Water level hydrographs;
- Rainfall/water level over plots; and
- Maximum height records.

This report indicated ARIs of the rainfall recorded at the Woy Woy pluviograph were approximately 30yr for 24hr (260mm), 60yr for 48hrs (382.5mm) and 30yr for 72hr duration (382.5mm).

Land use investigation Woy Woy Peninsula conducted by **Andrews Neil Environmental Pty Ltd (2005)** identifies past and current land uses that may have had the potential to influence groundwater quality. Two general land use scenarios were identified. The first, area source, involved typical residential activities that may create an area source for potential contamination of groundwater. These activities included the use of pesticides, herbicides and fertilizers and the removal of lead based paint. Such sources may be of short duration and intermittent, however, the cumulative nature of such activities can impact on groundwater quality.
The second scenario involved site specific activities such as closed landfills and underground storage tanks where the source of potential contamination is more localised. These sources of contamination are likely to be of longer duration, if not permanent. Using this information and the known direction of groundwater flow, proposed bore locations that were considered to produce water with a low risk of contamination were identified.

The ***Brisbane Water Estuary Processes Study***, currently being conducted by **Cardno Lawson Treloar (2007a),** details progression of the Brisbane Water Estuary Processes Study. The report describes the study approach including the data and modelling systems applied, together with the outcomes of the analysis. Water levels in Brisbane Water are determined for the full range of flood and ocean events that may occur due to various natural physical processes. It has been found that flooding behavior can be influenced, either separately, or by a combination of, catchment runoff, rainfall falling directly onto Brisbane Water, elevated ocean levels (as a result of storm surge and king high tides) and local winds. To a minor extent flooding was also found to be affected by sediment shoals that alter ocean entrance conditions near Ettalong.

7.1.2 Groundwater studies

Extensive research has been carried out by various organisations in regards to the Woy Woy Peninsula groundwater system. The **Woy Woy Infiltration Project** initially commenced due to the increasing need for alternative options for stormwater management. The project involved the installation of stormwater infiltration devices at several locations on the Peninsula. The project had the dual aim of reducing waterway pollution by filtering stormwater and trapping pollutants

near their source, and assessing the potential for reducing peak runoff and flow volumes (O'Loughlin et al, 1998).
A second project termed the **Gosford-Wyong Joint Abstraction Scheme** was more recently carried out to investigate using treated abstraction water from the Woy Woy shallow sand aquifer to supplement the reticulated potable water supply. This was carried out through drilling and various testing at exploratory bore sites.

The following provides a brief summary of the major reports that have been carried out by various organisations. The numerous reports have been separated based on the two projects described above; however it is important to note that there is a significant degree of overlap with specific regard to the involvement of Larry Cook and Hydroilex.

Woy Woy Infiltration Project

Assessment of Alternative Stormwater Drainage Systems for the Woy Woy Peninsula, undertaken by **O'Loughlin (1997)**, assesses possible drainage methods for developed areas on the Peninsula. The use of infiltration systems and other forms of on-site stormwater flow reduction measures are investigated and recommendations in regards to further research are made. These involve the investigation of groundwater and soils, field trials of infiltration devices and additional surveys on stormwater infiltration devices and design procedures.

The following relevant statements have been summarized from this report. Humate horizons comprising dark brown to black water soluble organic substances were recorded between 0.3 and 1.5 deep in many bore localities. Humate development is closely controlled by fluctuating water table and can results in impregnation and cementation of beach sands. As well as aquifer recharge from rainfall, there is recharge from the runoff from the western escarpment sandstones. The presence of standing water for some time after heavy rains raises questions about the permeability of the soils and possible high water tables. The infiltration systems should be effective for floods up to 5yr ARI.

***Potential for Stormwater Infiltration on the Woy Woy Peninsula*, (O'Loughlin at al, 1998)** follows on from the recommendations of O'Loughlin, (1997**).** The Hydrogeology and soils of the Woy Woy region were analysed and groundwater patterns and fluctuations determined. The results indicated that infiltration of stormwater runoff should be effective over most of the Peninsula with the exception of localised areas of sand and humic podzols which contain semi-impermeable sands cemented with organic compounds. These are generally found in the geology units of Qamp, Qamh-5 and Qamh-4.

The study indicates the Woy Woy Peninsula topsoil consists of 10-30cm of dark brown loose sand to sandy loam. The texture of the sand can increase to loam where organic matter is high. The topsoil overlays 30cm of grey loose sand and in depressions a black soft organic stained sandy pan. The pan consists of quartz sand grains coated and weakly cemented with black organic compounds. Sometimes the pan can be up to 50cm thick. This material especially would occur in poorly drained swales and depressions.

Plans are proposed for trials of infiltration systems and recommendations of sites, types of devices, and monitoring programs are provided.

Hydrogeological Assessment - Stormwater Infiltration Study Woy Woy Peninsula, Volumes 1 & 2, undertaken by **Cook (1998)** provides a baseline assessment of hydrogeological conditions for the Peninsula, assessing a series of alternative, on-site storm water disposal systems. The findings conclude that infiltration of stormwater presents a promising option for dealing with the Peninsula's drainage problems.

The broad objective of the study was to undertake a detailed analysis of groundwater conditions, which included;

- assessing local hydrogeological conditions;
- monitoring water levels and establishing hydraulic gradients and directions of groundwater flow;
- measuring the hydraulic conductivity of the subsurface; and
- determining the chemistry and assess quality of groundwater

In order to achieve these objectives, work primarily comprised of the construction of a series of piezometers, followed by geophysical bore logging and water level measurement and monitoring.

The majority of boreholes penetrated a 0.1 to 0.4m thick layer of humic rich sandy soil. Silty Sands were detected between 0.7 and 3.8m in Bore WW14, 2.0 and 3.0m for Bore WW9 and 2.3 and 3.7m for Bore WW10. Coffee rock, peaty sand, peat and wood were recorded in several bores (WW5, WW6, WW7, WW generally below 4m.

Amongst other conclusions, the report uses the information determined to identify flooding hot spots and suggests that stratigraphic control may be largely responsible for localised flooding. Further recommendations for monitoring are made.

***Woy Woy Stormwater Infiltration Devices – Design Drawings*, (Kinhill Brown & Root, 1999)** details the infiltration structures to be installed at various locations on the Peninsula. The plans include the exact location and design calculations for the structures as well as the setout table and location of survey marks. Seventeen infiltration devices have been installed at fourteen locations. The infiltration devices are different sizes and types, and generally consist of some minor stormwater pipe collection which directs flow to grated drainage pits.

***Pollution Removal by Stormwater Infiltration in the Woy Woy Peninsula*, (UTS, 1999a)** details the installation of stormwater infiltration devices at several locations on the Woy Woy Peninsula. Stormwater movements and pollutant removal in areas where devices are located are combined with equivalent processes in areas where conventional drainage systems are in place. The project also included monitoring of rainfall, water table position and pollutant levels in collected runoff and groundwater. This allowed for comparison over time and between areas where infiltration is employed.

The infiltration devices generally consisted of 12m by 3m gravel trenched feed by 100mm diameter perforated pipe which was in turn feed by a grated 1.2m square pit. The was a high standing water table at device WW7 Gwendolen Ave during installation which was probably related to the coffee rock found at 5m depth.

***Stormwater Infiltration for the Woy Woy Peninsula*, UTS (1999b),** provides a status update on the infiltration project. It reflects on the work completed so far, describes the investigation, design and construction stages of the trial project and navigates toward the monitoring and evaluation phases. The report presents new sampling results, discusses and documents the construction process and presents an overview of the instillation of monitoring equipment at the trial sites.

The infiltration device WW5 Mackenzie Ave is not expected to be effective due to installation on top of low permeability coffee rock. In photographs of device installation show coffee rock appears to be at only 1m depth. This is much lower than bore logs show. Soil tests at each device location show the combined levels of silt and sand are all below 2%, however the areas with the larger flooding problems appear to have the higher clay contents. The pits were designed to handle 50% AEP storm event.

Report on Stormwater Infiltration Study Woy Woy Peninsula January 1999 to June 2000 **(Cook, 2000)** presents the results of work carried out on the project between December 1998 and June 2000. Objectives were to commission the test stormwater infiltration devices, compile a comprehensive database incorporating water quality, water level and rainfall measurements and to assess hydraulic and environmental efficiency of test infiltration devices.

Stormwater and Groundwater Analysis from the Woy Woy Peninsula**, (Brisbin and Stevens, 2001),** examines laboratory results from the infiltration zone in order to examine the link between rainfall and catchment runoff and the quality of groundwater. This information was used to assess the performance of the Atlantis System, Gravel Infiltration Units and Permeable Pavements that were used in the Woy Woy Infiltration Project.

Report on Stormwater Infiltration Study Woy Woy Peninsula June 2000 to October 2001 **(Cook, 2002)** provides recommendations on the feasibility of a water sensitive urban design pilot project on the Woy Woy Peninsula. Furthermore it provides recommendations on the preparation of a floodplain risk management study utilising Water Sensitive Urban Design principles for the B and C (to be discussed in the following section)Woy Woy catchments. It is suggested that this study could provide a strategic blueprint for better roads, drainage, streetscape and urban design in all flat sandy areas.

Gosford-Wyong Joint Abstraction Scheme

Stratigraphic Analysis of Woy Woy Peninsula **(Cook, 2005)** presents the main interpretation from geophysical logging of the boreholes located on the Peninsula. The interpretation successfully identifies a stratigraphic control in the area and data obtained provides a framework for production bore drilling, groundwater modeling, and management.

Woy Woy Peninsula Sand Aquifer System Numerical Modelling of Groundwater Abstractions**, (Mackie, 2005),** details the development of a computer based numerical model that represented the aquifer system. The model is to be used to consider various groundwater management strategies. The two major objectives were to

- Assimilate available geological and hydrogeological data, development and calibration of an advective flow model
- Testing of various GCC pumping strategies, inclusion of salt water interface to examine potential landward migration of the interface, and reporting of findings.

Comprehensive figures included exploration and test bore locations, base and thickness of the sand aquifer and registered spear and bore locations

Desktop Review and Geotechnical Investigation, Proposed Bores, Various Locations, Umina Beach and Woy Woy**, (Douglas & Partners 2005),** details the results of a desktop review and geotechnical investigation carried out in the vicinity of the newly installed groundwater abstraction bores. Investigations undertaken indicated that the subsurface profile is generally comprised of medium dense, dense or very dense sands. Some very loose and loose sands are however, predominant in the upper 5-6m also occurring as thinner layers at depth.

Ecological Assessment of Proposed Groundwater Extraction from Woy Woy Peninsula**, (Conacher Travers, 2005),** presents on an assessment of the proposed groundwater extraction on the local environment, particularly in regards to Groundwater Dependant Ecosystems and locally occurring threatened species, populations and ecological communities.

Hydroilex (2005b) produced a series of 22 reports entitled ***Test Drilling and Aquifer Testing***, for the Gosford-Wyong Joint Water Authority. These reports contain test drilling and aquifer testing of various bores as part of the Gosford-Wyong council's Water Authority Joint Water Supply Scheme. The series of reports are structured identically with an introduction, information on bore construction, aquifer testing (which includes a constant rate pump test), assessment of potential interference, water quality testing and conclusions and recommendations.

***Woy Woy Peninsula Sand Aquifer System Numerical Modelling of KBR Options*, (Mackie 2006), reviews work that** Kellog Brown and Root Pty Ltd (KBR) produced to consider further options for resource exploitation. These included re-instatement of previously constructed runoff infiltration structures across the peninsula and injection of treated sewerage effluent at strategic locations. Both options were to be designed to elevate groundwater storage within the sand aquifer thereby providing an increased resource for subsequent utilization. Further numerical modeling of the aquifer system was undertaken to generate an output for KBR.

7.1.3 Personal communication with Larry Cook

Notes containing data and information for the development of a groundwater computer model were collated by Larry Cook. The work was conducted on behalf of Mackie Environmental Research as part of the Gosford-Wyong Councils Water Authority Joint Water Supply Scheme. The aim of the informal document was to provide the necessary information for development of a numerical model which could be used to assess the pumping capabilities of the borehole scheme. Data include a review of the local and regional geology, drilling and bore logging results.

Woy Woy Borefield, a further informal data report written by **(Cook, 2007),** compiles individual and composite hydrographs as well as daily rainfall data and bore registers. The name, location and ground level elevation of each monitoring bore are described, while hydrographs plot the elevation of the water surface against daily rainfall.

Manually recorded daily rainfall from the Everglades Golf Club and Umina Bowling Club are supplied. Manly Hydraulics Laboratory (MHL) have rainfall gauges with automatic recording in the Gosford Area. These are to be investigated further for application in the hydrodynamic and hydraulic modelling.

7.1.4 Drainage Studies

Historical flooding on the peninsula has been largely accredited to the failure of implemented drainage systems. Due to the sandy nature and low gradient of the Peninsula drainage pipes have a tendency to become blocked with sediment, leading to localised flooding. In response to this problem a large number of drainage studies have been completed by various consultants. The Peninsula was divided into a number of catchments, designated A to Q.

***Report Stormwater Investigations to Catchment Blackwall Mountain, Springwood Street, Waitangi Street, Warrigal Street, Wyalong* Street, Memorial Avenue, Umina,** conducted by **Giammarco Engineering (1989)** investigates the extent of stormwater flooding in severe flood events, particularly those experienced in April 1988 and January 1989. The report gives a general description of the catchment and flooding behavior and recommends strategies and drainage options to resolve and relieve flooding problems. It is reported that there have been written complaints from affected residents about flooding. It is concluded that the developed residential area needs an urgent drainage management program and strategy to cater for the 100 year Average Recurrence Interval (ARI) event.

***Woy Woy, Umina, Ettalong Peninsula, Drainage Strategy Study*, (Webb McKeown & Associates, 1992)** was commissioned by Gosford City Council to assist in planning possible future trunk drainage works and in the preparation of a development control plan. The report states that development on the peninsula over the last 50 years has resulted in an inadequate stormwater drainage system and increased housing density has contributed to increased flows, reducing the effectiveness of the existing system.

Ross-Rowan Catchment, Woy Woy Channel to Ocean Beach Road, Trunk Drainage Management Study and Management Plan **(Webb McKeown & Associates, 1993)** is a trunk drainage management study and plan for the Ross-Rowan Catchment. It includes a review of the existing drainage system and presents trunk drainage options with cost estimates, impacts and benefits of proposed works.

Woy Woy Peninsula Catchments 'B' and 'C' Drainage Study**, (Webb McKeown & Associates, 1993)** details a further drainage investigation and concept design for catchments B and C at Woy Woy. The study includes background information, design criteria and methods, drainage options and recommendations.

Woy Woy Peninsula - Catchments 'P' and 'O' Drainage Investigation - Draft Report (Issue 1)**, (Patterson Britton & Partners, 1997)** identifies conceptual drainage options for catchments P and O at Woy Woy and recommends the preferred drainage concepts. The study covers catchment characteristics and a history of development as well as the existing drainage problems in the region. An investigation of current stormwater management practices and detailed modelling was undertaken for which a number of alternative drainage concepts were examined. These included open channel systems, piped drainage systems and a retarding basin combined with piped drainage systems.

Drainage Investigation Veron Road / Dulkara Road Catchment Umina / South Woy Woy**, (Kinhill Engineers, 1999),** investigates the extent of stormwater flooding and develops a drainage management plan to solve or relieve identified flood problems in the catchment. The existing system capabilities were investigated using the ILSAX model and a number of feasible options were developed to achieve council's stated design standard. The majority of flow problems investigated were found to be caused by development in natural flow paths and often where piped drainage system was capable of conveying only the 100% or 50% AEP event. Solutions investigated mainly involved structural measures such as piped system upgrading and construction of detention basins.

Woy Woy Peninsula Catchments 'D' and 'E' Drainage Study **(Ivan Tye and Associates, 2000)** details further drainage investigations and prepare a concept design for catchments D and E. The 1% AEP capacity trunk drainage options for catchment are investigated.

Everglades Lagoon System Precinct, Plan of Management **(KBR, 2005)** provides the framework for the short, medium and long term management of the Everglades Lagoon System Precinct

7.2 Cadastral and Topographic Data

Gosford City Council provided cadastral base information in GIS digital format for use during the study.

A topographic TIN was supplied by Council based on an Aerial Laser Survey (ALS) conducted in 2007. Two metre contour data was also supplied.

Aerial photography has been provided for 1997, 2005 and 2007.

7.3 Groundwater Data

Piezometer locations have been provided in GIS layer format. Larry Cook has provided a large amount of data for direct use in building the MIKE SHE model.

7.4 Stormwater Drainage Network

Various drainage plans and data have been collated by Council and provided in electronic format. Data includes;

- Stormwater investigation studies
- Drainage and WAE (work as executed) documents
- Drainage inspection plan in hard format showing pit inspection records (% blockage)
- GIS layers for pit and pipe infrastructure

It has been advised by Council that the majority of the design plans have not been provided with WAE (work as executed) documents. As a result, these plans cannot be relied on for accurately representing the stormwater network.

7.5 Historical Flood Information

In order to establish the behaviour of overland flooding in the catchment it is important to establish the history of overland flooding in the study area.

Two sources for spatial flooding information were obtained from council:

- Source 1 – GCC maps with flood affected areas defined with blue highlighted areas. Documents file names were: img-928152836.pdf, img-928152858.pdf, img-928152918.pdf, img-928152937.pdf, img-928153003.pdf, img-928153021.pdf, img-928153039.pdf, img-928153058.pdf.

- Source 2 – 'Black Spot' flooding locations defined in Figure 4a and 4b from a previous unknown drainage study. Documents file names were: north-001.tif & R_south-001.tif.

This information has been amalgamated into a single map as shown in Figure 3 and it was used to assist in model calibration.

7.6 Historical Stream Gauge Information

No water level gauges or flow gauges exists within the study area or nearby. This can be problematic for model calibration. Emphasis was placed on calibrating to the flooding information described in the section above and flood levels obtained from the community consultation.

7.7 Historical Rainfall Data

For calibration of the flood model, historical rainfall records were obtained from Manly Hydraulics Laboratory, the Bureau of Meteorology (BOM) and Silo Data Drill (http://www.nrw.qld.gov.au/silo/datadrill/). Details of the data useful for calibration are given in Section 9.

8 COMMUNITY CONSULTATION

8.1 Introduction

The following information details the outcomes from the Woy Woy Peninsula community consultation program. Such a consultation program is important in order to obtain flood related information from the community as well as to gather support and promote flood awareness.

8.2 Methodology

In order to obtain as much historical information about flooding on the peninsula as possible, the community representative, Sheelagh Noonan was initially consulted. Two strategies, firstly an indirect and then direct were devised as explained below.

8.2.1 Indirect

Initially, a brief summary of the minutes from the August Floodplain Risk Management Committee (FRMC) were published in the Peninsula Times on the 2nd October 2007. A press release was issued in both the Express Advocate on the 10th October and the Peninsula Times on the 16th October appealing to members of the community who may have information on flood related issues or permanent marks from previous floods. Copies of the newsletter and questionnaire could be easily obtained from Woy Woy and Umina Public libraries or downloaded from Council's website. There were a limited number of responses from this general appeal. However, as members of the community were keen to provide information, the responses were very detailed.

8.2.2 Direct

Information on past flooding events obtained from Council was combined with the results of preliminary flood modelling to determine geographic areas that were particularly flood prone. Using the cadastral database in the Geographical Information System (G.I.S), these areas were mapped and a mail out containing a brief newsletter and questionnaire was sent out. Additionally, completed surveys from the *Brisbane Water Flood Study* conducted by Cardno Lawson Treloar were obtained and useful information regarding flooding of the Brisbane Water foreshore was retained.

On 11th October 2007, 1,886 community newsletters and accompanying questionnaires were posted out to the targeted properties on the Peninsula. A copy of the newsletter and questionnaire are included in Appendix A.

8.3 Results

By the 29th October 2007, which marked the end of the consultation period, a total of 178 questionnaires were returned. This translates to a return rate of approximately 9.4%, comparing well with other surveys of this nature. The responses were evenly spread across the Peninsula as shown in Figure 3. This highlighted the success of specifically targeting the mail out to flood prone areas and was a beneficial methodology in that the information returned well represented the Peninsula spatially.

It is important to note that many of the questionnaires were returned without being completed. However, 50% of the respondents provided information that was of direct use to the flood study such as photographs of past flood events, and details of flooding frequency, depths and extents.

Community members identified as potentially having more detailed information on past flood events were contacted for follow up interviews. After conducting 20 interviews only one permanent flood mark had been identified in the form of a nail hammered into a telegraph pole near 4 Cogra Rd. This marks the maximum height of the flood waters for the April 1988 event.

Significant flooding events identified by the community included:

- August 1972
- 1st May 1974
- 1984
- March 1986
- 1st April 1988
- February 1990
- March 1991
- February 1992
- 1st May 1998
- April 1999
- 1st June 2007

The community was able to provide information for the May 1974, April 1988, February 1990, February 1992 and June 2007 events however the **April 1988** event was the only event with enough data to be useful for model calibration. This event was the largest flood event noted by the residents since 1972, with the possible exception of 1974 although there were limited responses from residents who lived in Woy Woy during that event. The 1974 event also was heavily dominated by storm surge which is not the focus of this study.

Based on the community comments, peak flood depths for the 1988 event have been estimated as shown in Table 1.

Table 1 - Estimated Peak Water Depths for 1988 Flood Event

Site Number	Location	Resident Comment	Estimated 1988 Peak Depth (mm)
1	Intersection, Wharf Rd and North Burge Rd	2002 flooding estimated 200 mm from photos	>200
2	78 Dunalban Ave	600mm in 1990 – in 1988 slightly less	500
3	30 Shepard St	Halfway up car window	800
4	20 Ridge St	Pooling only when stormwater inlets get clogged	<150
5	Lone Pine Ave	calf muscle depth between 73 Lone Pine avenue and Shepard st	400
6	306 Blackwall Rd	30cm over entire yard and adjoining properties.	300
7	12 Shepard St	46 to 50cm deep in road gutter	500
8	28 Ross St	photo provided	600
9	58 Watkin Ave	1990 worst flooding	500
10	140 Paton St	36cm deep over my block	360
11	132 Paton St	1ft under the house	300
12	18 Darley Rd	Houses flooded to window level	500
13	4 Cogra Rd	water over floor by 90mm	400
14	39-51 Karloo Rd	5ft deep from paling fence blocking flow	1500
15	28 Waratah Ave	150 mm 3 times yearly	>150
16	3 Forest Rd	30cm deep spread across the road	300
17	10 Dulkara Rd	Up to 0.75m in streets	750
18	61 Boronia Ave	30cm deep in back lane	300

9 MODELLING

The MIKE SHE model was selected as the model of choice for this study due to its unique ability to simulated surface water and groundwater in an integrated way. This was crucial due to the significance of elevated groundwater level as a flooding mechanism. For full details of the MIKE SHE theory and functionality see DHI (2008). The MIKE SHE version 2008, Service Pack 2 was used.

Model development was conducted in two stages:

1. Long Term Model: Construct and calibrate a model focusing on groundwater to understand the long term fluctuations of the water table. This model was run for 100 years to examine the significance of flooding related to elevated water table and to derive a suitable antecedent water table elevation surface for the event model.

2. Event Model: Upgrade and intensify the Long Term Model to focus on surface water flooding. This model was calibrated to the 1988 flood event and then run with the design events.

9.1 Long Term Model

9.1.1 Model Setup

The MIKE SHE model was setup with the following configuration:

- Model Grid spacing: 100m for speed to allow 100yr simulation runs.

- Historical rainfall data from:

  - 1/1/1906 - 1/12/1964: Silo Data Drill Rain data for Longitude 151.35 degree, Latitude 33.50 degrees.

  - 1/12/1964 – 1/1/2007: BOM Rain Gauge 061318 Woy Woy (Everglades Country Club)

- Reference Evapotranspiration estimates based on FAO56 method from Silo Data Drill for Longitude 151.35 degree, Latitude 33.50 degrees.

- Overland Flow: MIKE SHE's finite difference method based on the topographic Triangulated Irregular Network (TIN), sampled onto 100m grid.

- Unsaturated Zone: MIKE SHE's 2 Layer Method with 50% of area impervious with the remainder having the following characteristics:

  - Water content at saturation: 0.3

  - Water content at field capacity: 0.2

  - Water content at wilting point: 0.05

  - Infiltration hydraulic conductivity: 5.5e-005 m/s

- Saturated Zone:
    - Lower level (bedrock) as per Mackie (2005)
    - Specific Yield of 0.37 as per Mackie (2005)
    - Boundary conditions of Fixed Head type at ocean boundary of 0mAHD. Elsewhere (i.e. western escarpment) zero flux.

9.1.2 Model Calibration

Horizontal hydraulic conductivity of the aquifer was adjusted until simulated water table levels were similar to observed levels at a number of bores. The calibrated horizontal hydraulic conductivity is shown in Figure 4. The calibrated horizontal hydraulic conductivity was significantly lower than that measured by the field tests by Hydroilex (2005b). The reason for this could be related to the overestimation of the depth to bedrock. Also bore logs have shown that a relatively impermeable layer exists in some areas at 5m depth. These layers could result in significantly lower effective hydraulic conductivity than measured. The spatial extents of these relatively impermeable layers are unknown so they could not explicitly be incorporated into the model.

A sample of calibration results are shown in Figure 5 with the measured water levels shown as circles. The calibration is reasonable and adequate for the purpose understanding the long term behaviour of the water table and for simulating the water table during flood events. The errors could be due to heterogeneity of some of the model inputs and parameters including horizontal hydraulic conductivity, specific yield, unsaturated zone water holding capacity and rooting depth.

Note that the purpose of the model is for estimating potential flooding impact of elevated groundwater and therefore the model should not be used for any other purpose (e.g. water supply planning) unless further development and calibration is carried out.

9.1.3 Model Runs and Results

The calibrated model was run for 100 years (1906 to 2007) using historical rainfall data to obtain an understanding of the frequency and duration that the water table may come to the ground surface. The water level at Bore WW5 was used as an indicator of this due to its location toward the centre of the study area. These levels are presented in Figure 6. Based on this figure there were 18 years out of the 100 years that the water table reached the ground surface. Figure 7 shows a duration curve of this data and it shows the water table is at or above the ground surface at WW5, approximately 3% of the time.

Table 2 compares the modelled water table with historical flood events as conveyed by the residents during the community consultation. The table shows that of the 11 community noted flood events since 1972:

- 4 had the modelled water table above the ground during the same year.
- 4 more had the modelled water table near the ground (within 0.5m) during the same year.
- 3 remaining had the modelled water table about 1m below the ground during the same year.

Also, of the 5 community noted largest floods since 1972 (1974, 1988, 1990, 1992 and 2007):

- 3 had the modelled water table above the ground during the same year.

- 2 more had the modelled water table near the ground (within 0.5m) during the same year.

Based on this information it could be summarised that; of all noted historical floods, 40 to 70% maybe exacerbated by elevated groundwater levels and of the largest noted historical floods, 60% to 100% maybe exacerbated by elevated groundwater levels.

9.1.4 Antecedent Water Table Levels for Event Modelling

Initial groundwater levels over the study are required as an input to the Event Model. Experience shows that adopting median antecedent conditions (e.g. for soil moisture/rainfall losses or reservoir water levels) for flood risk modelling generally leads to an underestimate of flood risk. However, adopting a high antecedent condition (e.g. worst case) can lead to an over estimate of flood risk. An analogous example to setting the initial groundwater level is selecting the antecedent water level in a large reservoir when determining the flood frequency of downstream flooding. Joint probability analysis generally shows that adopting Full Supply Level (i.e. assuming the reservoir is always full before a flood event) is conservative, resulting in an overestimation of flood levels for a certain level of risk (e.g. 1% AEP). Adopting the median water level (occurs 50% of the time) results in underestimation of flood levels. This is due to the nonlinear relationship between antecedent conditions and flood risk and the significance is dependent on having a relatively large reservoir capacity relative to the flood flows. Previous flood studies by DHI generally show that an antecedent condition that approximates the 80th percentile occurrence gives similar flood risk estimates to a more thorough study involving complex joint probability analysis. Based on this, for the design event modelling, the initial ground water level equivalent to 80th percentile occurrence has been adopted. This is shown in Figure 7 when the groundwater table is 0.55m below the ground at WW5 or 4mAHD on Figure 6. Figure 6 also supports this approximation by showing a significant number of events where the groundwater table reaches the surface when the antecedent level was near 4m AHD just before the sharp rainfall driven rise to the surface. For example see 1988, 1990 and 1998 in Figure 6. Based on this analysis the water table levels across the study area simulated just before the 1988 event (which approximate the 80th percentile level at WW5), will be adopted as the antecedent groundwater levels for the design event modelling. This surface in the form of depth below ground is shown in Figure 8.

To put Figure 8 input into perspective: The saturated zone is modelled with a specific yield of 0.37. This equates to 370mm of water storage capacity per vertical meter of soil profile. Therefore, areas in Figure 8 that have the water table within 0.5m of the ground level have less than 185mm of storage capacity ignoring any horizontal groundwater movement. Therefore, if more than 185mm of rainfall occurs during a design event, the water table will rise to the ground surface and ponding will occur. This ponding will continue to increase in depth with further rainfall if surface drainage does not disperse it. Ponding can also occur if the rainfall intensity exceeds the infiltration capacity defined for each land use in Section 9.2.1.

Table 2 - Comparison of modelled groundwater levels and community noted historical floods since 1972.

Year	Modelled Peak Groundwater Elevation (mAHD)	Modelled Groundwater Above Ground	Historical Flood
1972	4.13	Within 0.5m	Yes
1973	3.73		
1974	4.68	Yes	Yes
1975	4.43		
1976	4.48		
1977	4.14		
1978	4.70	Yes	No
1979	4.12		
1980	3.13		
1981	3.71		
1982	3.84		
1983	4.47		
1984	4.28	Within 0.5m	Yes
1985	4.41		
1986	4.12	No	Yes
1987	4.09		
1988	4.74	Yes	Yes
1989	4.82	Yes	No
1990	4.82	Yes	Yes
1991	3.93	No	Yes
1992	4.21	Within 0.5m	Yes
1993	3.13		
1994	3.38		
1995	3.22		
1996	3.52		
1997	3.69		
1998	4.60	Yes	Yes
1999	4.49	Within 0.5m	Yes
2000	3.84		
2001	3.62		
2002	3.52		
2003	3.94		
2004	2.99		
2005	2.91		
2006	1.98		
2007	4.01	No	Yes

9.2 Event Model

9.2.1 Model Setup

The Event Model was developed by increasing the detail of the Long Term Model defined above. The model resolution was increased to 10m to allow more precise calculation of surface flooding flows and depth.

Digital Elevation Model
The TIN was sampled onto a 10m grid and is shown in Figure 2.

MIKE SHE simulates overland flow in two dimensions and the interaction with the piped stormwater network is calculated interactively. Overland flow paths are developed without the prior assumptions of the direction and size of the flow path as would be required in a 1D overland flow approach. This approach also eliminates issues with additional overland flows paths that may occur for more extreme events that can potentially be underestimated or missed entirely using a 1D approach.

Land Use

Based on land zoning GIS data, vegetation GIS data and aerial photographs, a land use map was produced to define five different land use zones relevant to the modelling. These areas are:

- Trees on sand
- Trees on rocky slopes
- Grasslands
- Roads
- Urban lots

A plan showing the derived land use map is shown in Figure 9. To calibrate the model, the hydraulic roughness (Manning's 'n') and the infiltration hydraulic conductivity for these zones were varied.

Buildings were not modelled explicitly as obstructions to overland flow but are incorporated into the calibration of the Manning's n. The overland flow velocities in the study area are generally small due to the ponding nature of the study area, however there are some steep areas where velocities maybe higher and obstructions by buildings and fences etc maybe more significant. It is not possible to represent these fine scale obstructions in the model and therefore care must be taken in interpreting the results in the steeper areas where flow is concentrated.

A number of infiltration pits exist in the study area. These were represented in the model as 10 x 10m areas with a drainage potential (infiltration hydraulic conductivity) of 200mm/hour.

Open Channel Drainage System

Three open channels were incorporated into the model (MIKE11 component) as shown in Figure 10. The cross section and structure details for these channels were acquired from previous studies, measured from the TIN and field measurements.

A number of water bodies/ponds exist in the Everglades Golf Course. For the calibration and design events, their initial water levels were set to 2.7mAHD, which is the crest of the current outlet weir.

Pipe Drainage System

On review of the available data the approach for the integration of the stormwater system into the model was to:

1. Only model the stormwater drains that were identified from the recent drainage inspection (R. Ausorp, GCC) as effective (i.e. not blocked);
2. Adopt the stormwater infrastructure levels in the WAE drawings where they are available;
3. Where drains are functional but have no WAE level information, adopt the corresponding DEM level for the lintel/grate level and a representative average pit depth;
4. Inspect and modify the pipeline levels over the included length to ensure that the pipes generally slope towards the outlet.

Figure 10 shows the assumed current (2008) effective network which is included in the model (MOUSE component).

For the calibration event (1988) it was assumed that no effective piped drainage network existed. This is supported by the fact that major pipe drainage works have taken place since this event and in many cases as a result of this event.

9.2.2 Model Calibration

General Approach

In the absence of any gauged water level/flow data, the calibration of model operation became a two-stage process. In the first instance, the model was calibrated against the peak water level data available for the 1988 storm event. Then secondly, the extents of significant inundation were compared to known flooding 'hot spots' shown in Figure 3. This was an iterative process, which followed the steps listed below:

1. Develop rainfall hyetographs for calibration event.
2. Apply rainfall to the MIKE SHE model and compare modelled peak water levels to historical peak water level and inundation areas.
3. Adjust model parameters and return to step 2 (depending on the rate of convergence to historical values).

The model parameters were fine-tuned until a reasonable fit with the historical data was reached for the calibration event.

Note, the model was not fully developed or validated outside the study area boundary and therefore data outside the boundary should be ignored.

Calibration Event

The storm event of 1988 was used to calibrate the model. For this event, 311mm of rainfall fell in the 72 hours after 9:00AM 29/04/1988. This equates to an average intensity of 4.3mm/hr which is approximately a 7% AEP ***rainfall event.*** High antecedent water table levels probably exacerbated the flooding and it is estimated that this event may have been a rarer ***flood event*** than the rainfall AEP considering this event is the largest observed in over three decades. Approximately 570mm of rainfall fell in preceding 40 days leading to elevated water table conditions.

The temporal patterns for the calibration storm event were taken from the nearest available pluviograph gauge that was available at the time, Peats Ridge (BOM Gauge 61351). This temporal pattern was scaled by the daily rainfall measured at Everglades Golf Course (BOM Gauge 61318). Figure 11 shows the cumulative hyetograph from Peats Ridge and the scaled hyetograph for Woy Woy used during calibration modelling.

The Brisbane Water boundary condition was a constant water level of 0.9mAHD which approximates Mean High Water Spring (MHWS). This was set for the MIKE11 Channels and MOUSE pipe network.

Model roughness and hydraulic conductivity coefficient maps were based on the land use map defined above. Initial roughness and conductivity estimates were based on values applied in previous studies for similar areas. Fine-tuning of the roughness map formed part of the calibration exercise. The model was run for the 1988 storm event numerous times, adjusting model parameters until the model levels approximated the peak water levels recorded. The resulting roughness and infiltration hydraulic conductivity values are given in Table 3.

Table 3 - Adopted Roughness Values and Infiltration Hydraulic Conductivity

Land Use	Adopted Manning's 'n'	Infiltration Capacity		Comments
		(m/s)	(mm/hr)	
Roads Lots	0.035	$6.9 \cdot 10^{-6}$	25	Includes road side permeable areas
Urban Lots	0.040	$2.77 \cdot 10^{-5}$	100	Includes permeable (e.g. grass) and impermeable areas (e.g. driveway)
Grassed Surfaces	0.070	$5.55 \cdot 10^{-5}$	200	Open space areas (e.g. sport fields) primarily consisting of grass
Trees on sand	0.080	$5.55 \cdot 10^{-5}$	200	
Trees on Rocky Areas	0.070	$6.9 \cdot 10^{-6}$	25	
Open Channels				
Drain North	0.014	-	-	Smooth rectangular concrete channel.
Etttalong Creek	0.04	-	-	Highly vegetated. 'n' value from Chow (1959) for dense weeds, high as flow depth
Main Channel	0.04	-	-	

A comparison of the modelled and recorded peak water levels for the 1988 event is presented in Table 4. This shows that a reasonable match of the observed peak water levels has been obtained for most observed data locations considering the approximate community estimation of depth. The largest error was at Calibration Point 14 (39-51 Karloo St) where a steep drainage path runs through residential lots. A resident estimated a water depth of 1500 mm upstream of a paling fence which is a local feature not accounted for in the model given the 10x10m grid resolution. Therefore the model results are not applicable to areas where fine scale features such as fences significantly affect flows.

Figure 3 shows the modelled maximum water depth for the calibration event along with the properties reported as being overland flow affected. The model demonstrates a reasonable agreement with the affected areas in the central and north east of the study area. There are some areas where the model does not simulate significant flooding but there are reportedly flood affected properties. Possible causes of the differences are:

- The flood affected areas noted in the database may not be a comprehensive data set;
- Affected areas which are not residential property may not have been reported either by Council or the community;
- Effective stormwater drainage networks may exist in areas with over estimated flood depths
- Adopted antecedent water table levels maybe not being fully representative in all areas.

Table 4 - Modelled and Observed Peak Water Depths for 1988 Storm Event

Calibration Point	Location	Estimated Observed 1988 Depth (mm)	Modelled Depth (mm)	Modeller Remarks	Difference (mm)
1	Intersection, Wharf Rd and North Burge Rd	>200*	223	At intersection	OK
2	78 Dunalban Ave	500	375	In street	-125
3	30 Shepard St	800	700	Deepest point in street	-100
4	20 Ridge st	<150	60	In front of house	OK
5	Lone Pine Ave	400	490	Deepest point in street	+90
6	306 Blackwall rd	300	220	Measured in backyard	-80
7	12 Shepard St	500	750	Deepest point in street	+250
8	28 Ross St	600	800	At road intersection	+200
9	58 Watkin Ave	500	450	In front of house	-50
10	140 Paton St	360	580	In front of house	+220
11	132 Paton St	300	380	In street	+80
12	18 Darley Rd	500	460	Deepest point in street	+40
13	4 Cogra Rd	400	530	In front of house	+130
14	39-51 Karloo Rd	1500	450	Deepest point in street	-1050
15	28 Waratah Ave	>150	550	In front of house	OK
16	3 Forest Rd	300	280	In NW corner of block	-20
17	10 Dulkara Rd	750	890	In street	+140
18	61 Boronia Ave	300	200	40 m NW of house	-100

Overall, the calibration was considered satisfactory. Further improvement of the model calibration could be achieved by further model analysis for future flood events. The calibrated model was then used to estimate design flood conditions.

9.3 Design Event Model Runs and Results

The calibrated MIKE SHE model was used to simulate overland flood behaviour for a range of design events.

The initial ground water level was defined is discussed in section 9.1.

Design storm rainfall depths for the study area estimated using ARR (Pilgrim, 2001) are presented in Table 5 below. The Probable Maximum Precipitation (PMP) values were determined using the Bureau of Meteorology's Bulletin 53 (BOM, 2003). Due to the relatively small study area, an areal reduction factor of one and no spatial variation in the rainfall was adopted.

Table 5 - Design Rainfall Intensities (mm/hr)

Duration	Frequency (AEP)					
	50%	10%	5%	1%	0.5%	PMP
15 min	77.09	111.82	128.63	167.28	184.17	600
30 min	54.81	80.38	92.75	121.31	133.84	440
1 hr	37.5	55.66	64.44	84.83	93.82	320
2 hr	24.97	36.97	42.78	56.25	62.18	245
3 hr	19.57	28.94	33.48	43.99	48.61	197
6 hr	12.89	19.01	21.98	28.84	31.85	130
12 hr	8.5	12.51	14.45	18.94	20.91	33
24 hr	5.44	8.18	9.5	12.6	13.97	33
48 hr	3.39	5.22	6.1	8.19	9.12	24
72 hr	2.5	3.91	4.59	6.21	6.93	13.4

In addition to the layout used in the calibration a storm water drainage system and a number of drainage pits have been included in the model.

In the first instance, a range of storm durations were simulated for the 1% AEP event in order to determine the storm duration most representative of the critical storm duration for the catchment. Once the critical storm duration was determined the remaining design events were simulated.

Design rainfall temporal patterns derived from Australian Rainfall and Runoff were applied to the 2D surface representing the catchment. Spatial variability of the rainfall over the catchment was not considered necessary given the relatively small catchment size.

Flow exchanges between the catchment surface and the sub-surface stormwater pipe network were automatically calculated by the model. All pit inlets (grates and lintels) were assumed to have no blockage for the base design case. Blockage of pits inlets was considered separately as part of the model sensitivity testing.

The Brisbane Water boundary condition was a constant water level of 0.9mAHD. This is equivalent to the 1% exceedance level for the long term tide cycle in the area. This was set for the MIKE11 Channels, MOUSE pipe network and MIKE SHE overland flow.

Critical Storm Duration

A range of storm durations from 15 minutes through to 72 hours were simulated for the 1% AEP flood event in order to determine the critical storm duration for the catchment. Peak flood levels at 23 representative sites were extracted from the model results. See Figure 12 and Table 6 for the representative site locations.

Table 6 – Representative Locations

Point No.	Easting (m)	Northing (m)	Ground Elevation (mAHD)
1	343407	6291860	2.84
2	342509	6291701	3.08
3	343601	6292590	4.06
4	343930	6293030	2.37
5	344360	6292880	4.02
6	344750	6291980	2.93
7	343547	6291404	4.37
8	343370	6291070	4.51
9	343220	6290720	4.27
10	342555	6290130	3.61
11	343990	6290590	5.26
12	343910	6290090	5.65
13	344017	6290361	5.24
14	344210	6289760	4.07
15	345170	6290140	1.54
16	345414	6290688	4.16
17	345450	6290970	4.18
18	344442	6290935	5.06
19	343090	6291170	4.28
20	342542	6292264	0.98
21	342872	6290240	4.73
22	342790	6291440	1.05
23	343500	6290879	4.88

Peak flood depths for the 1% AEP flood at this range of sites for the various tested storm durations are presented in Table 7. This table shows the critical duration as 48 or 72 hours with one location of 1hr. However the 72hr event is the most common critical duration and the difference between the 72 hour event depth and the maximum modelled depth is generally small. The 1 hour critical duration indicated at Location 17 is probably due to its small steep upstream catchment from Blackwall Mountain. The large difference in critical duration is a concern however the difference in depth compared to the 72 hour event is small (30mm). There are other similar areas around Blackwall Mountain and the western side of the study area, which have small steep contributing catchments. It is likely that the critical duration of these areas may be significantly shorter than the 72 hours. It is feasible to include these areas in this broader flood study, however the results from these areas must be treated with caution.

On the basis of this, the 72 hour event was adopted as the critical duration.

Table 7 - 1% AEP Flood Event Peak Depths

Location	Event Duration (hrs)											
	0.25	0.5	1	2	3	6	12	24	48	72	Max.	Critical Duration
	Depth (m)											
1	0.09	0.13	0.18	0.23	0.16	0.17	0.21	0.36	**0.50**	0.42	0.50	48
2	0.01	0.01	0.06	0.06	0.01	0.04	0.08	0.09	0.10	**0.12**	0.12	72
3	0.11	0.12	0.13	0.11	0.07	0.21	0.38	0.47	**0.54**	0.51	0.54	48
4	0.15	0.18	0.19	0.19	0.11	0.25	0.37	0.50	0.53	**0.54**	0.54	72
5	0.14	0.17	0.18	0.17	0.07	0.00	0.00	0.22	0.45	**0.50**	0.50	72
6	0.04	0.07	0.15	0.12	0.02	0.01	0.01	0.02	0.03	**0.15**	0.15	72
7	0.20	0.32	0.36	0.35	0.27	0.43	0.59	0.65	**0.68**	0.63	0.68	48
8	0.04	0.08	0.10	0.10	0.03	0.30	0.38	0.45	**0.49**	0.47	0.49	48
9	0.35	0.46	0.51	0.52	0.41	0.75	0.88	0.83	**0.93**	0.87	0.93	48
10	0.08	0.10	0.07	0.01	0.20	0.35	0.44	0.47	0.49	**0.51**	0.51	72
11	0.04	0.08	0.10	0.07	0.01	0.20	0.33	0.44	0.48	**0.52**	0.52	72
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.10**	0.10	72
13	0.15	0.19	0.21	0.20	0.14	0.14	0.21	0.31	0.45	**0.51**	0.51	72
14	0.24	0.33	0.42	0.36	0.17	0.06	0.16	0.32	0.56	**0.69**	0.69	72
15	0.02	0.02	0.02	0.02	0.01	0.11	0.18	0.27	0.32	**0.35**	0.35	72
16	0.20	0.23	0.25	0.23	0.16	0.26	0.33	0.45	0.56	**0.61**	0.61	72
17	0.23	0.36	**0.43**	0.43	0.39	0.32	0.33	0.28	0.35	0.40	0.43	1
18	0.35	0.39	0.41	0.40	0.32	0.27	0.35	0.48	0.63	**0.68**	0.68	72
19	0.14	0.19	0.20	0.19	0.16	0.18	0.34	0.41	**0.45**	0.43	0.45	48
20	0.05	0.14	0.21	0.28	0.21	0.21	0.36	0.64	0.58	**0.60**	0.64	72
21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**	0.01	72
22	1.62	1.62	1.62	1.62	1.62	1.70	1.79	1.82	1.76	**1.88**	1.88	72
23	0.00	0.02	0.05	0.05	-0.01	0.22	0.30	0.33	**0.36**	0.35	0.36	48

A summary of peak water depths for representative locations is presented in Table 8 for existing urban development and Table 10 for future urban development. A summary of peak water elevations for representative locations is presented in Table 9 for existing urban development and Table 11 for future urban development. Corresponding maps are shown in Figure 13 to Figure 36. Maps of the peak velocity are not presented because the velocities are generally very low due to the ponding nature of the study area.

The model simulates water depth and flows to the boundary of the study area however the results are shown only to the edge of the cadastral lots along the foreshore. It should be noted however, that these simulated levels do not include any elevated flood risk on the foreshore areas due to high ocean levels from causes such storm surge. Design flood levels for Brisbane Water have already been established as part of the Brisbane Water Flood Study (Cardno Lawson Treloar 2007b), and were devised based on high ocean levels. These values need to be superimposed over the design flood levels derived in the present study from catchment flooding to provide an overall envelope of design flood levels.

Future urban development was simulated by decreasing the infiltration capacity from 100mm/hr to 25mm/hr for landuse defined as 'Urban Lots'. The difference between the existing and future urban results are zero in most cases and less than 100mm in all cases because the reduced infiltration rate of 25mm/hr of the urban lots is only exceeded by rainfall intensity from the 100yr and PMP events. Even in these events the flooding depth does not generally increase because in the flooded areas the groundwater table is already at the ground surface when higher rainfall intensity occurs and therefore the infiltration capacity effectively becomes zero anyway.

Table 8 - Summary of Peak Water Depths – Design Flood Events - Existing Urban Development

Location	AEP					
	50%	10%	5%	1%	0.5%	PMP
	Water Depth (m)					
1	0.00	0.08	0.15	0.42	0.58	0.81
2	0.03	0.07	0.09	0.12	0.14	0.51
3	0.23	0.31	0.39	0.51	0.54	0.68
4	0.29	0.46	0.52	0.54	0.55	0.56
5	0.00	0.13	0.25	0.50	0.55	0.61
6	0.00	0.01	0.02	0.15	0.29	0.42
7	0.39	0.53	0.57	0.63	0.65	0.82
8	0.34	0.41	0.43	0.47	0.50	0.61
9	0.75	0.80	0.82	0.87	0.88	1.04
10	0.45	0.48	0.49	0.51	0.51	0.66
11	0.24	0.40	0.46	0.52	0.54	0.63
12	0.00	0.00	0.00	0.10	0.18	0.50
13	0.12	0.27	0.34	0.51	0.57	0.69
14	0.05	0.27	0.40	0.69	0.86	1.13
15	0.14	0.25	0.30	0.35	0.36	0.43
16	0.25	0.39	0.50	0.61	0.63	0.71
17	0.00	0.00	0.27	0.40	0.42	0.48
18	0.21	0.43	0.52	0.68	0.73	0.75
19	0.24	0.36	0.38	0.43	0.45	0.56
20	0.59	0.60	0.61	0.60	0.68	1.35
21	0.00	0.00	0.01	0.01	0.01	0.63
22	1.73	1.83	1.83	1.85	1.92	3.99
23	0.23	0.31	0.32	0.35	0.37	0.43

Table 9 - Summary of Peak Water Elevation – Design Flood Events - Existing Urban Development

Location	AEP					
	50%	10%	5%	1%	0.5%	PMP
	Water Elevation (mAHD)					
1	2.85	2.92	2.99	3.26	3.42	3.65
2	3.11	3.15	3.17	3.21	3.22	3.59
3	4.29	4.37	4.45	4.57	4.60	4.74
4	2.66	2.83	2.88	2.91	2.91	2.93
5	4.02	4.15	4.27	4.52	4.56	4.63
6	2.93	2.94	2.95	3.09	3.23	3.35
7	4.76	4.90	4.94	4.99	5.01	5.18
8	4.85	4.93	4.95	4.99	5.02	5.13
9	5.02	5.07	5.09	5.13	5.15	5.31
10	4.06	4.09	4.10	4.11	4.12	4.27
11	5.50	5.67	5.72	5.78	5.80	5.89
12	5.65	5.65	5.65	5.75	5.84	6.15
13	5.36	5.52	5.59	5.76	5.82	5.94
14	4.12	4.34	4.47	4.76	4.93	5.20
15	1.67	1.79	1.84	1.88	1.89	1.96
16	4.41	4.55	4.67	4.78	4.80	4.87
17	4.18	4.18	4.45	4.58	4.60	4.66
18	5.27	5.49	5.58	5.74	5.79	5.81
19	4.52	4.63	4.66	4.71	4.73	4.84
20	1.58	1.58	1.59	1.58	1.66	2.33
21	4.73	4.74	4.74	4.74	4.74	4.99
22	2.73	2.83	2.83	2.88	2.92	3.24
23	5.11	5.19	5.20	5.23	5.25	5.31

Table 10 - Summary of Peak Water Depths – Design Flood Events - Future Urban Development

Location	AEP					
	50%	10%	5%	1%	0.5%	PMP
	Water Depth (m)					
1	0.00	0.08	0.16	0.42	0.60	0.84
2	0.03	0.07	0.09	0.12	0.16	0.53
3	0.23	0.31	0.39	0.51	0.54	0.68
4	0.29	0.46	0.52	0.54	0.55	0.57
5	0.00	0.13	0.25	0.50	0.55	0.61
6	0.00	0.01	0.02	0.15	0.29	0.42
7	0.39	0.53	0.57	0.63	0.65	0.82
8	0.34	0.41	0.43	0.47	0.50	0.61
9	0.75	0.80	0.82	0.87	0.89	1.04
10	0.45	0.48	0.49	0.51	0.51	0.66
11	0.24	0.40	0.46	0.52	0.54	0.63
12	0.00	0.00	0.00	0.10	0.18	0.50
13	0.12	0.27	0.34	0.51	0.57	0.69
14	0.05	0.27	0.40	0.69	0.87	1.13
15	0.14	0.25	0.30	0.35	0.36	0.43
16	0.25	0.39	0.50	0.61	0.63	0.71
17	0.00	0.00	0.27	0.40	0.42	0.49
18	0.21	0.43	0.52	0.68	0.73	0.75
19	0.24	0.36	0.38	0.43	0.45	0.56
20	0.59	0.60	0.61	0.60	0.68	1.47
21	0.00	0.00	0.01	0.01	0.01	0.63
22	1.73	1.83	1.83	1.92	1.92	3.99
23	0.23	0.31	0.32	0.35	0.37	0.43

Table 11 - Summary of Peak Water Elevation – Design Flood Events - Future Urban Development

Location	AEP					
	50%	10%	5%	1%	0.5%	PMP
	Water Elevation (mAHD)					
1	2.85	2.92	3.00	3.26	3.44	3.68
2	3.11	3.15	3.17	3.21	3.25	3.61
3	4.29	4.37	4.45	4.57	4.60	4.74
4	2.66	2.83	2.88	2.91	2.91	2.94
5	4.02	4.15	4.27	4.52	4.56	4.63
6	2.93	2.94	2.95	3.09	3.23	3.35
7	4.76	4.90	4.94	4.99	5.01	5.18
8	4.85	4.93	4.95	4.99	5.02	5.13
9	5.02	5.07	5.09	5.13	5.16	5.31
10	4.06	4.09	4.10	4.11	4.12	4.27
11	5.50	5.67	5.72	5.78	5.80	5.89
12	5.65	5.65	5.65	5.75	5.84	6.15
13	5.36	5.52	5.59	5.76	5.82	5.94
14	4.12	4.34	4.47	4.76	4.94	5.20
15	1.67	1.79	1.84	1.88	1.89	1.96
16	4.41	4.55	4.67	4.78	4.80	4.87
17	4.18	4.18	4.45	4.58	4.60	4.67
18	5.27	5.49	5.58	5.74	5.79	5.81
19	4.52	4.63	4.66	4.71	4.73	4.84
20	1.58	1.58	1.59	1.58	1.66	2.35
21	4.73	4.74	4.74	4.74	4.74	5.01
22	2.73	2.83	2.83	2.92	2.92	3.26
23	5.11	5.19	5.20	5.23	5.25	5.31

Model Sensitivity

A range of model simulations were simulated in order to understand the sensitivity of the developed modelling system to key model parameters and also to determine the ranges of uncertainty in the model. The sensitivity runs were undertaken for the 72 hour 1% AEP design flood event with future urban development. The sensitivity scenarios that were tested were:

- Low Sea Level Rise: 0.55m increase in the boundary water levels and a 0.2m increase in the antecedent groundwater surface.
- High Sea Level Rise: 0.91m increase in the boundary water levels and a 0.4m increase in the antecedent groundwater surface.
- High Antecedent Groundwater: Equivalent to 90 percentile water table levels as discussed in Section 9.1.4. This was approximated to a 0.25m increase in the water table across the model area compared to the water table used in the design events.
- Low Antecedent Groundwater: Equivalent to 50 percentile water table levels as discussed in Section 9.1.4. This was approximated to a 0.58m decrease in the water table across the model area compared to the water table used in the design events.
- Blocked Stormwater Network: Full blockage of culverts in MIKE11 model and stormwater network inlets in MOUSE model.

The difference in water levels compared to the base case are shown in Table 12 and Figure 37 to Figure 41. These outputs show the model has:

- Moderate sensitivity to Sea Level Rise with an average 50mm increase for the Low Sea Level Rise Scenario and an average 90mm increase for the High Sea Level Rise Scenario.

- Moderate sensitivity to Antecedent Groundwater Levels with an average 50mm increase for the High Antecedent Groundwater Scenario and an average 200mm decrease for the Low Antecedent Groundwater Scenario.
- High sensitivity to the Blocked Stormwater Network in some areas with increases in water levels of up to 1.75m but many areas insensitive with the increase in water level less than 30mm.

Table 12 - Model Sensitivity Analysis

Location	Base Run Depth (m)	Scenario				
		Low Sea Level Rise	High Sea Level Rise	Low Antecedent Groundwater	High Antecedent Groundwater	Blocked Stormwater Network
		Water Depth Difference (m)				
1	0.42	-0.09	0.10	-0.37	0.04	1.33
2	0.12	0.02	0.16	-0.05	0.02	0.41
3	0.51	0.03	0.05	-0.23	0.03	0.25
4	0.54	0.00	0.00	-0.20	0.00	0.00
5	0.50	0.05	0.05	-0.40	0.05	0.05
6	0.15	0.13	0.15	-0.15	0.13	0.18
7	0.63	0.00	0.03	-0.15	0.00	0.02
8	0.47	0.00	0.02	-0.09	0.02	0.01
9	0.87	0.01	0.02	-0.09	0.01	0.00
10	0.51	0.00	0.01	-0.04	0.00	0.00
11	0.52	0.02	0.04	-0.22	0.03	0.01
12	0.10	0.12	0.23	-0.10	0.15	-0.01
13	0.51	0.07	0.10	-0.33	0.08	0.03
14	0.69	0.21	0.29	-0.54	0.24	0.00
15	0.35	0.01	0.03	-0.15	0.01	0.00
16	0.61	0.01	0.01	-0.31	0.01	0.08
17	0.40	0.01	0.02	-0.40	0.01	0.07
18	0.68	0.05	0.05	-0.37	0.05	0.00
19	0.43	0.00	0.03	-0.14	0.00	0.01
20	0.60	0.49	0.59	0.00	0.02	0.64
21	0.01	0.00	0.00	-0.01	0.00	0.00
22	1.92	0.33	0.69	-0.15	-0.05	1.62
23	0.35	0.00	0.02	-0.09	0.00	0.01
Average	**0.52**	**0.06**	**0.12**	**-0.20**	**0.04**	**0.21**

Provisional Flood Hazard Estimation and Floodplain Hydraulic Categorisation

Flood Hazard Categorisation has been undertaken for the Future Development Design Events. Flood categories have been assessed and mapped according to guidelines prescribed in the NSW Floodplain Development Manual. Hazard categories were analysed by assessing the flow velocity and depth at each model grid cell over the course the model simulation and classifying the peak combination of velocity and depth using criteria described in Appendix L of the NSW Floodplain Management Manual (2005). Plans mapping the hazard are presented in Figure 42 to Figure 47.

A floodplain hydraulic classification for the Future Development Design Events as per the guidelines in the NSW Floodplain Development Manual is provided in Figure 48 to Figure 53. Floodways were identified by plotting flow vectors (arrows indicating direction and magnitude of flow) and manually drawing polygons around areas with noticeable flow rates (e.g. greater than $0.2m^3/s$ per 10m cell). Flood Storage areas were defined as those areas with a depth of water greater than 0.2m outside Floodways. Flood fringe areas were the remaining areas with water depth greater than 0.01m.

Additional Design Event

At GCC's request, an additional design event was modelled based on 100yr ARI (1% AEP) with Future Development, 0.91m Sea Level Rise (1.81mAHD tailwater) and 50% blocked stormwater network. The 50% blockage was simulated by reducing the cross sectional areas of all culverts and pipes by 50%. The results are presented in Figure 54 and Figure 55.

10 COMMENTS FROM PUBLIC EXHIBITION

There was one comment to the public exhibition of the flood study report. Mr Gordon Kershaw of 65 Glen St, Umina Beach was concerned that his property may be classed as being in a flood zone even though he has lived on the property for 40 years and never been flooded.

DHI's response to this comment is:

The digital elevation model of the area shows the ground level outside the front door of 4.7mAHD and in the gutter in front of the house of 4.3mAHD. Figure 3 shows the modelled depths for the 1988 Flood event are 0.2m outside front door and 0.6m in the road gutter. In the back yard the depth decreases to 0.05m due to the topography sloping to the front yard. The 1988 event could be classed in the order of a 1 in 30yr event. The flooding modelled at 65 Glen St could be regarded as minor. It is quite possible that no water entered the house during 1988 if it is even slightly raised.

Figure 3 also shows that GCC records indicate that the front half of 65 Glenn St is flood affected. This supports the model findings.

Also, Roy King of 12 Shephard Street, Umina Beach submitted a questionnaire response at the community consultation stage of the study. He stated people paddled a canoe along most of Connex Street during the 1988 flood event. Connex Street is one street to the east of Glen St with similar elevation and long section profile (lower in the middle). It is likely Glen St would have been under similar inundation to Connex Street in 1988.

Therefore there is evidence to support the model results that indicate 65 Glen St is probably subject to minor flooding. No adjustments have been made to the modelling or reported results based on this submission.

11 ACKNOWLEDGEMENTS

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A P P E N D I C E S

A P P E N D I X   A

Community Consultation

Community Consultation

A.1	Community Newsletter
A.2	Community Questionnaire
A.3	Press Release
A.4	Press Story

Woy Woy Peninsula Flood Study Community Newsletter

October 2007

DHI Water·Environment·Health has been engaged by Gosford City Council and jointly funded by the NSW State Government, Department of the Environment and Climate Change to undertake a flood study for the Woy Woy Peninsula. The study is part of Council's Floodplain Management Program which aims to reduce the impact of flooding on the community

Flooding on the Peninsula

Council records show that many areas on the Woy Woy Peninsula are prone to flooding. Flooding is due to a variety of causes. It may be the result of long duration rainfall events, storm tides and the effects of groundwater. Ponded water generally remains on the ground surface for several days until it infiltrates into the ground or evaporates.

Do you live in the study area?

As part of the Woy Woy Peninsula Flood Study, an investigation of the history of past flooding in the catchment is required. The study area comprises the Woy Woy Peninsula bounded by Brisbane Water to the north and east, Broken Bay to the south, and Brisbane Water National Park to the west.

The Current Study

In order to address the flooding on the Peninsula, Gosford City Council has commenced a process to investigate floodplain management strategies in accordance with guidelines set out in the New South Wales Floodplain Development Manual. As part of the process the Flood Study will include a detailed investigation of the existing flooding behaviour on the Woy Woy Peninsula. Information about past flooding events will be combined with the results of computer models to describe the depth and extent of flooded areas.

We need your help!

For the success of the project we require your direct input to provide any information that you may have on historical flooding events. This can be through providing us with photographs, flood levels, and any other relevant information that you may have. If you feel you would like to participate in a personal follow up interview please indicate this preference on the attached questionnaire providing details so that we may contact you. It would be greatly appreciated if you could assist the study by completing the questionnaire, and returning it to DHI Water·Environment·Health at the reply paid address by the 29th October 2007. If you have any information on flooding in the study area, or thoughts on important flood related issues we would like to hear from you!

Who to contact for more information

To find out more about the Flood Study for the Woy Woy Peninsula, or to obtain additional questionnaires or further information please contact:

Miss Cath Acworth
DHI Water and Environment Pty Ltd
PO Box 626
Broadway, NSW 2007

Phone (02) 9213 5700
Fax: (02) 9213 5701
Email: caa@dhigroup.com

Ms Sheelagh Noonan
Peninsula Residents Association Inc

Phone: 0419 609 942

We thank you kindly for your participation in this study.

Woy Woy Peninsula Flood Study
Community Questionnaire

Flooding on the Woy Woy Peninsula varies within the catchment and is influenced by a variety of different factors. We are aware that a questionnaire was sent out last year as part of the Brisbane Water Foreshore Flood Study. However, please note that this current study seeks to specifically determine all flooding behavior on the Peninsula and your knowledge of any flooding events would be greatly appreciated. Please complete as many of the questions as possible and return the questionnaire to the reply paid address below. The information that you provide will remain confidential and be used for the study only and will not be released in any other form.

Name: ________________________________Contact Telephone Number:_________________

House Number _______Street Name____

PART A - GENERAL INFORMATION

1. What is your property?
(Tick one or more boxes)

a. House [ ]

b. Apartment [ ]

c. Business [ ] Type: ____

d. Commercial [ ] Type: ____

e. Vacant Land [ ]

f. Other [ ] Type: ____

2. How long have you owned, lived, conducted business at or had knowledge of this property?

_________ Months

_________ Years

PART B - FLOOD EXPERIENCE

Significant flooding on the Woy Woy Peninsula is known to have occurred on several occasions. Some of these events include **May 1974, April 1988, February 1990, February 1992** and more recently in **June 2007**. If you have information on these flood events or any other flood event, please answer the following questions:

3. Have you ever experienced a flood at the property or witnessed flooding in the area?

a. Yes [ ]

b. No [ ]

4. On average, how often would you experience flooding, and which floods can you remember?

How often?____

Year________________ Month_________________ comments________________________________

Year________________ Month_________________ comments________________________________

Year________________ Month_________________ comments________________________________

5. In the biggest flood that you have experienced, was your property flooded above the floor level of the main residence?

a. No [ ]

b. Yes [ ]

If yes, what was the depth of water over the floor?____

6. How long were the floodwaters over your property for in the largest flood?

a. Less than 1 hour [ ]

b. 1 hour to 3 hours [ ]

c. 3 hours to 12 hours [ ]

d. More than 12 hours [ ]

7. What information can you provide on past floods?

a. Information on extent or depth of floodwater at particular locations [ ]

b. Permanent marks indicating the maximum flood level for particular floods [ ]

c. Photographs or video footage of flooding that you are willing to lend to Council to be copied and returned to you [ ]

d. Information on flow directions and speeds [ ]

e. Information on activities that may have affected flow paths [ ]

8. If you have information on any past floods, please describe precisely where you observed this flooding from (be as specific as possible). Please give a brief explanation of the flooding in terms of <u>depth</u> and <u>extent</u> if possible.

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9. If possible, could you draw a free hand sketch on the back of the questionnaire showing road names and the approximate location and extent of the flooding that you have experienced? Any other details that you could provide would be greatly appreciated.

Please send this completed questionnaire to:

Reply address: DHI Water and Environment Pty Ltd
Reply Paid 626
Broadway NSW 2007

For further information about the Woy Woy Peninsula Flood Study, please contact:

Miss Cath Acworth
DHI Water and Environment Pty Ltd
PO Box 626
Broadway, NSW 2007

Phone: (02) 9213 5700
Fax: (02) 9213 5701
Email: caa@dhigroup.com

Ms Sheelagh Noonan
Peninsula Residents Association Inc

Phone: 0419 609 942

We thank you kindly for your participation in this study

Woy Woy Peninsula Flood Study
Press Release
September 2007

Gosford City Council has initiated a comprehensive study of flooding on the Woy Woy Peninsula. The study area comprises the Woy Woy Peninsula bounded by Brisbane Water to the north and east, Broken Bay to the south and Brisbane Water National Park to the west.

The first stage of the study will investigate past flooding events on the Peninsula. We are currently appealing to anyone who may have information on flood levels from previous floods or flood related issues on the Woy Woy Peninsula to visit Council's Website at http://www.gosford.nsw.gov.au/news_events/interest. The website provides comprehensive information on the study as well as a questionnaire on historical flooding on the Peninsula. If you have any information which you feel would be useful for the study it would be greatly appreciated if you could complete and return the questionnaire to a reply paid address. Please note that the questionnaire will also be made available from Woy Woy and Umina Public Libraries and will be posted to a number of residences on the Peninsula

This flood study is part of Council's Floodplain Management Program which aims to reduce the impact of flooding on the community and any feedback on flooding or flood related issues would be highly appreciated. If you have any other information or photos of previous flooding in the study area or would like more information, please contact:

- Ms Cath Acworth, DHI Water and Environment Pty Ltd, (02) 9213 5700, caa@dhigroup.com
- Mr Jim Gowing, Gosford City Council, Flooding & Drainage Planning Engineer, (02) 4325-8818, jim.gowing@gosford.nsw.gov.au
- Ms Sheelagh Noonan - Peninsula Resident's Association Inc, 0419 609 942