HYDRAULIC AND HYDROLOGICAL MODELLING FOR COMPLEX DESIGN IN A PEAT AREA

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ABSTRACT

Addison Development is an 80ha development in Takanini, South of Auckland. This area is well known as a peat area with the unique geological characteristics of flat contours, high ground water table and peat soil substrate. The development in this area is a challenge in terms of stormwater management due to the complex site constraints.

This paper primarily focuses on the application of hydraulic and hydrological modelling as a robust tool to aid the comprehensive stormwater management design for the 4th stage of Addison Development. The design consists of 42 raingardens and a reticulation network with pipe sizes up to 2300mm diameter for stormwater treatment, detention and conveyance. HEC HMS model was used at the preliminary design stage to investigate the practicability of using raingardens for the stormwater detention function. During the detailed design stage, MOUSE (MIKE URBAN) model was used to optimise the size of the reticulation network and to simulate the peak water levels in various rainfall events. The advantages of each modelling tool are also discussed in this paper.

KEYWORDS

HEC HMS, MOUSE, Flat Contours, Peat Area, LSM, at source treatment

PRESENTER PROFILE

Bronwyn Rhynd is a Director of Stormwater Solutions Consulting Ltd and is an environmental engineer with broad experience in environmental and civil engineering projects. Her expertise is in the water resource area with a focus on stormwater treatment, disposal and management. Bronwyn has been involved in projects requiring project management, erosion and sediment control, flood and flow regulation, wastewater and stormwater treatment and disposal, assessment of effects for both new and existing projects.

William Li is an Environmental Engineer with 4 years of professional experience in New Zealand. Key project experience includes stormwater treatment, disposal and conveyance design, network reticulation design, environmental effects assessments, flood assessments and hydrological and hydraulic modelling.

1 INTRODUCTION

Addison Development is an 80ha development in Takanini, South of Auckland. This area is well known as a peat area with the unique geological characteristics of flat contours, high ground water table and peat soil substrate. The development in this area is a challenge in terms of stormwater management due to the complex site constraints.

This paper covers the application of an “at source” stormwater treatment development that has a piped conveyance system to cater for rainfall events up to and including a

100yr ARI. The complex hydraulic and hydrological modelling that was applied to the design of the conveyance system will be presented along with constraints of the catchment and site that led to the best practical application for conveyance of treated stormwater runoff.

1.1 BACKGROUND

The 80 ha Addison development in Takanini has been staged to meet the demands of Auckland's residential market and development capacity. The first three stages that have been developed adopted the traditional cesspit and pipe conveyance with overland flow paths that utilise roads and parklands. The fourth stage of development within this very flat peat area presented a challenge from a conveyance and treatment perspective.

The construction started for the initial stage of Addison in 2000 with the first houses completed, and residential communities established, in mid 2002. The fourth stage at Addison has just been granted 224C with house construction due in the later part of 2010.

The fourth stage of the development is referred to as the Avenues and is situated in the eastern sector of the Takanini South Catchment. This catchment has a comprehensive discharge consent and also a catchment management plan (CMP) that was varied as part of the application of a best practical approach to the conveyance, treatment and discharge of stormwater runoff.

The initial design stages for the Avenues stormwater management started in 2006, with granting of a variation to the Auckland Regional Council (ARC) discharge consent in 2007. Close liaison with the Papakura District council (PDC) and ARC ensured that the needs of the regulatory authority were incorporated within the design components of the development

1.2 CATCHMENT DESCRIPTION

The Takanini South sub-catchment associated with the Avenues development is referred to as the Racecourse Catchment, reflecting the nature of the land use prior to the residential development and associated plan change. The contributing catchment is in the order of 170ha which requires conveyance of stormwater to the ultimate receiving environment of the Puhurehure Inlet during rainfall events up to and including 100yr event.

The contributing catchment has a very small slope, between 0.2% and 0.6% which falls towards the North Island Main Trunk (NIMT) railway line, with ground contours almost parallel to the Railway Line. Therefore, it presents constraints on the development with respect to developing roading infrastructure for the site.

The subsurface conditions of peat require recharge to be included in all design aspects with cognisance of the high ground water table. These conditions impact on the viability of both stormwater treatment options and construction techniques.

The catchment has a mixed use zoning however the majority is residential development. Bruce Pulman Park, a recreational facility, is situated in the south eastern extremity with a commercial area proposed in the central portion (of the catchment).

1.3 PROPOSED DEVELOPMENT OF THE CATCHMENT

The Addison Avenues development is near the extremity of the catchment however the outliers (for this stage of development) are both residential developments of similar nature. The conveyance system requires connectivity to the central system for these developments.

A conveyance system is to provide for treated runoff therefore any development discharging to this centralised conveyance system is to provide treatment within its boundary or in a sub-catchment facility. The catchment management plan variation has developed a “tool box” approach for options of treatment however not the design of such devices or options.

The Avenues is based on an “at source” or “local sub-catchment” approach to treatment and conveyance of runoff. The “local sub-catchment” management, or LSM, design is based on small sub catchments of up to 1 ha discharging runoff, via surface flow, to a swale and raingarden for treatment. There are no cesspits for collection within the management system. All roof runoff is discharged initially to recharge pits and overflow into a conveyance system, without the need for treatment due to cladding selection.

This LSM approach also allows for surface detention of large rainfall event runoff. A design criterion for this event is that the top water level will not encroach across the road centreline or into any lot boundary during 100yr ARI rainfall event. This was achieved with detailed design of the management of runoff taking into consideration the surface storage and hydraulic response of the raingarden and swales during various rainfall events.

1.4 CONSTRAINTS IN TERMS OF STORMWATER MANAGEMENT

The very small slope that falls towards the west with ground contours almost parallel to the railway line proved to be challenging to have overland flow paths without large quantities of earthworks.

The subsurface conditions are predominantly peat based with high ground water table. The winter ground water level is between 0.5m to 1.0m below the ground surface, whilst the average summer level is 1.5m below the ground surface. This ground water table needed to be regenerated with recharge pits to ensure shrinkage of peak did not occur and settlement monitored for a long period post construction.

If a conventional stormwater management approach was to be implemented for the conveyance network design, this main trunk line (central conveyance) that discharges to the receiving environment will have maximum depth to invert of over 6m. This will require tremendous excavation and reinforcement to ensure the safety of working in the low strength organic soil conditions. The associated cost with this would make the entire development uneconomical.

1.5 STORMWATER SOLUTIONS

A shallow main trunk line option has then been developed to address the construction issues associated with installation of deep pipelines. A key objective of the option is to lift pipe inverts along the trunk line reach by using stormwater ponds. The shallow main trunk line layout is shown in Figure 1.

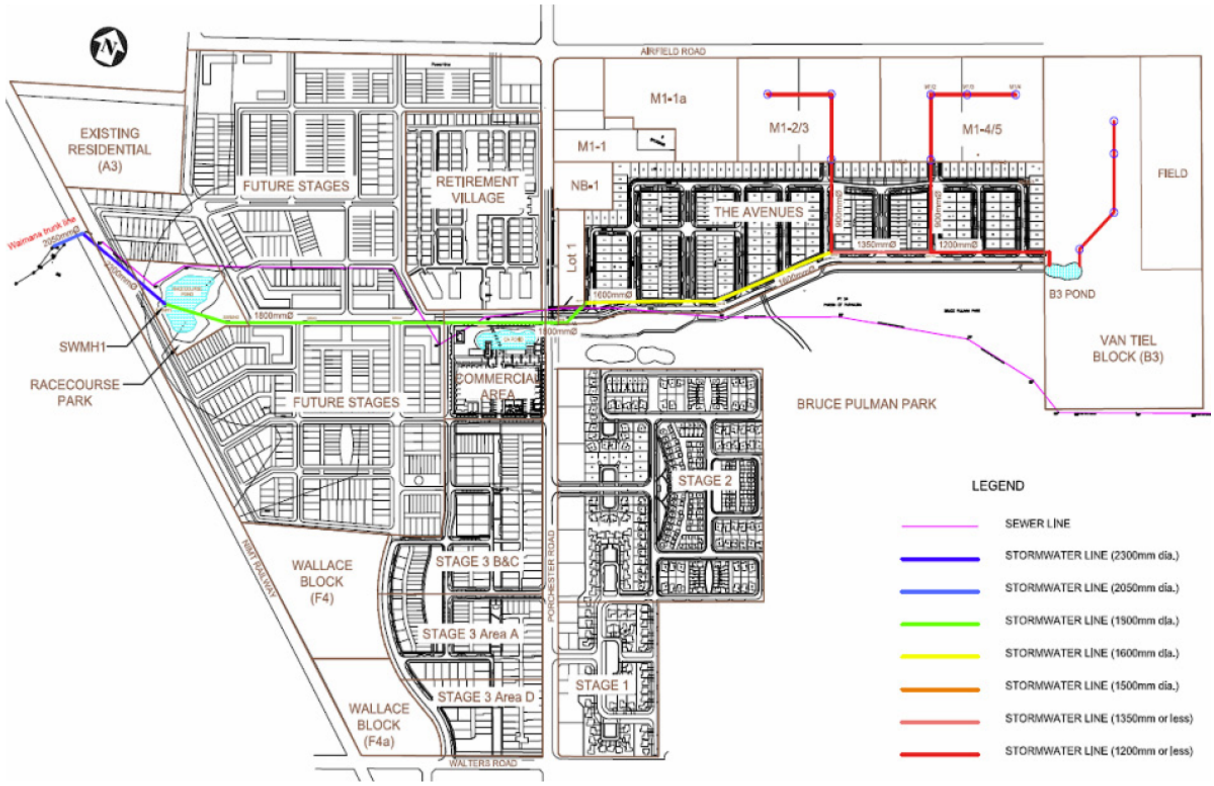

Figure 1: Shallow Main Trunk Line Plan View

For The Avenues development, it is proposed to create 'hump and hollow' (or LSM) within the site to address the following site constraints:

- 0.2% existing slope
- Maximum earthwork cut and fill of no more than 0.5m due to the low strength organic soil substrate and high ground water table

42 subcatchments will be formed. Each has a raingarden for stormwater treatment and also temporary storage during large rainfall events.

To assist the assessment of the overall performance of the proposed stormwater management system, we used HEC HMS and MOUSE modelling software packages.

2 HEC HMS MODELLING

During the preliminary design stage, hydrological modelling was undertaken to assess the critical conveyance aspects of the proposed stormwater management for The Avenues catchment.

The modelling software package used is HEC HMS, which is the hydrologic modeling system developed by US Army Corps of Engineers. The selection of this software is due to the following considerations:

- ARC TP108 is recommended through ARC TP10
- Guideline adopted for hydrological and hydraulic analysis for the Takanini South Stormwater Catchment Management Plan (CMP)

- It is the industry wide accepted standard for hydrological and hydraulic analysis
- It is commonly used at the CMP's starting stage or preliminary design stage
- It does not require too much detailed information to set up and run

2.1 OBJECTIVES

The key objectives of this modelling exercise are as follows:

- To simulate the conveyance system in various rainfall events
- To assess the water depths and duration of temporary ponding within the road reserve and the adverse effects on surrounding land uses.
- To assess available grades and indicative sizing of the main trunk line

2.2 MODELLING INPUT

The modelling input was based on the preliminary design layout available at that time. The catchment runoff parameters, such as initial abstractions, curve numbers and time of concentrations (or lag time) were established in accordance with ARC TP108 guidelines.

2.2.1 RAINFALL

The following rainfall events and rainfall depth have been modelled:

- 5yr ARI 24hr event, 122mm
- 10yr ARI 24hr event, 146mm
- 10yr ARI +10%, 160.6mm
- 100yr ARI 24hr event, 222mm
- Probable maximum precipitation (PMP) event, 649mm

The 24hr rainfall depths up to and including 100yr ARI are as per Papakura District Development Code Table 1-4, whilst the PMP rainfall depth is based on Water and Soil Technical Publication No.19.

It is to be noted that the pipe network is sized to accommodate the 10yr ARI + 10% design flow, as per PDC's requirements for this development.

2.2.2 INITIAL ABSTRACTION (IA)

The initial abstractions used for impermeable and permeable catchments are 0 and 5, respectively.

It is to be noted that CMP used an initial abstraction of 15mm for lot impervious area, due to the consideration of groundwater recharge via soakage pits. However, our assessment has taken a slightly more conservative approach to exclude this water loss.

2.2.3 CURVE NUMBERS (CN)

The CN values used for the impermeable and permeable catchments are 98 and 61, respectively. These values are chosen to reflect the peat subsoil nature and are consistent to those used in CMP.

2.2.4 TIME OF CONCENTRATION (TC) AND LAG TIME

HEC HMS model uses lag time to reflect the runoff travel time from a catchment to immediate downstream node.

The lag times used for the impermeable and permeable catchments are 2 and 7 minutes, respectively. These values tend to be shorter than the minimum 10 minutes as per standard ARC TP108 guideline. However they were adopted in consultation with PDC modelling team.

2.3 MODELLED RESULTS

2.3.1 10YR ARI RAINFALL EVENT

The piped network is sized for unattenuated 10yr ARI + 10% design flow. This PDC design requirement introduced an allowance for climate change which in turn lowered the future flood risks. Therefore, the conveyance system will have sufficient capacity for up to and including 10yr ARI rainfall events.

2.3.2 100YR ARI RAINFALL EVENT

All raingarden outlets were designed using manhole riser with scruffy dome to prevent large debris entering the conveyance system. Due to the rounded and raised nature of a scruffy dome it is highly unlikely that any debris would remain on the grated cover resulting on full blockage of the outlet will become fully blocked. However, in consultation with PDC during a 100yr ARI event, partial blockage of the raingarden outlets to the piped network is required to be considered.

A 50% operation capacity of the raingarden outlets has been assumed for the 100yr rainfall event. Runoff in excess of network capacity will become temporary surface ponding prior to discharge.

Key modelled results are as follows:

- Surface ponding contained within subcatchments.
- Maximum ponding depth on road 130mm
- Maximum ponding depth on private land 30mm
- Duration of ponding above road less than 3 hours

2.3.3 PMP EVENT

The PMP event was established, as presented in Section 2.2, with the modelled results for this event as follows:

- Some overflow from one subcatchment to another, however all runoff will be contained within the site
- Maximum ponding depth on road 200mm
- Maximum ponding depth on private land 100mm
- Duration of ponding above road less than 5 hours.

It is to be noted that no inlet or pipe blockage has been taken into account for this scenario.

2.4 OUTCOMES

The modelled results show the flood mechanism of the proposed stormwater management for The Avenues development.

- During the 100yr ARI event, all surface runoff can be safely attenuated by temporary ponding within the road reserve within the site. Maximum water depth on the road surface and private land does not adversely affect amenity or cause public hazard. No overland flow will occur across Porchester Road.

- During the extreme event, being the probable maximum precipitation (PMP) event, ponding depth will increase until overflow from one subcatchment to the next occurs via road reserve. The storage provided within the subcatchments results in maximum flood ponding no higher than approximately 150mm above the design 100yr flood level, and relatively small flows across Porchester Road.

- Provision of earth work design to ensure that any overflow is shallow with low velocities in a southerly direction towards Bruce Pulman Park.

- Provision of 300mm freeboard above the top water level during a 100yr ARI event is recommended by PDC for all building finished floor levels, ensuring protection to the built environment during the large and extreme events.

The modelled outcomes support the proposed stormwater management for The Avenues development, which has been regarded as a Local Subcatchment Management (LSM) approach and recommended for adjacent catchments east of Porchester Road.

3 MOUSE MODELLING

During the detailed design stage, the optimisation of the main trunk line design has become critical in terms of constructability and minimising costs. A detailed hydrological and hydraulic model has been constructed using MOUSE modelling software package to assist this design.

3.1 OBJECTIVES

The key objectives of this modelling exercise are as follows:

- To represent the hydrology of the site as well as other contributing catchments

- To represent the hydraulic components of the drainage system, including inlet and outlet structures

- To assess the piped network capacity and freeboard during the 10yr + 10% and 100yr ARI 24 hour rainfall events

- To optimise the main trunk line sizes and slopes

- To assess the surface ponding during the 100yr ARI event

3.2 MODELLING INPUT

The detailed MOUSE model has been developed based on the following information:

- The downstream as-built MOUSE model from culvert under North Island Main Trunk (NIMT) railway line to Pahurehure Inlet, obtained from PDC

- The proposed stormwater management for The Avenues development
- The prevision of future development of other contributing catchments to NIMT railway line culvert

3.2.1 CATCHMENTS

The catchment areas and impervious coverage are based on the following information:

- The proposed site plan for The Avenues development
- Maximum possible development for the remaining catchments as per the District Plan

The initial loss and SCS curves used in MOUSE model for pervious and impervious areas are as per HEC HMS model.

3.2.2 RAINFALL

The MOUSE Model uses Papakura District Council standard 24 hour rainfall data, and ARC TP108 rainfall pattern, as per HEC HMS model. Both 10yr + 10% and 100yr ARI rainfall events have been modelled.

3.2.3 PIPE HYDRAULICS

The following details are imported to the model to reflect the hydraulic components of the drainage system.

- Main trunk line sizes and levels from NIMT railway line culvert to eastern extremity of The Avenues development
- Proposed stormwater ponds along main trunk line
- Drainage system within The Avenues development
    - All piped network sizes and levels
    - Surface storage within the road reserve, as per the proposed contours plans.
    - Outlet structures of raingardens
- Connections from other contributing catchments to the main trunk line

3.3 MOUSE MODELLING OUTCOMES

3.3.1 10YR + 10% ARI

During the 10yr + 10% ARI event, the main trunk line needs to have the gravitational flow capacity without surcharge to accommodate the peak discharge from the contributing catchment. The main trunk line sizes and slopes have then been adjusted accordingly to optimise the sizes.

3.3.2 100YR ARI

During the 100yr ARI event, the raingarden outlet configurations have been modelled with two scenarios, being 50% operational and full flow capacity, for specific purposes:

- Scenario 1: 50% operational capacity, to assess the peak water level and duration of ponding within raingarden and surrounding areas

- Scenario 2: 100% operational capacity, to assess the minimum free board within the main trunk line

The Scenario 1 modelled results show that the maximum water depth above the raingarden surface will be no more than 400mm, which results in no more than 100mm water depth above road centre line for approximately 30 minutes. The short period of the submergence and the extent of ponding during this extreme event has been accepted by PDC, and the predicted peak water levels have been adopted to determine the minimum floor levels of adjacent residential lots.

The scenario 2 has been modelled to optimise the main trunk line sizes to ensure minimum freeboard of no less than 200mm below the manhole lids along main trunk line.

The modelling results have formed part of the supporting documents for engineering approval application to PDC.

The modelling outcomes prove that the proposed stormwater management system is the best practical solution for the site, and this management approach has become the guideline for future development of the remaining Racecourse Catchment.

3.3.3 MAIN TRUNK LINE CHARACTERISTICS

The main trunk line characteristics that have been developed by using the design criteria outline in previous sections, are as follows:

- Length 1.6km

- Pipe sizes range from 1350mm to 2300mm diameter

- Minimum slope 0.35%

- Maximum depth to invert 4.8m

4 DISCUSSION

4.1 HEC HMS VS. MOUSE

4.1.1 DATA INPUT

HEC HMS model does not require reticulation network details to simulate the precipitation-runoff processes. It is ideal for initial stage stormwater management feasibility study or preliminary catchment wide analysis, with the absence of network details.

MOUSE model can simulate the performance of the hydraulic components for the entire reticulation network, which make it more robust to assess the flow conditions of the conveyance system in various scenarios.

4.1.2 REPRESENT STORMWATER COMPONENTS

HEC HMS model has the capability to simulate the hydraulic function of stormwater components to a certain extent. For example, it is capable of modelling the dynamic balance of flows entering and exiting a storage basin. However, it cannot simulate the back water effects to upstream devices.

MOUSE can model the sub-critical and super-critical flows within the network system, which allows flows to exit and then re-enter any stormwater devices as driven by water heads. This is particularly useful in assessing the back water effects to upstream stormwater devices.

4.2 COMPARISON OF MODELLED RESULTS

The main focus is to compare the 100yr peak water depth and ponding duration within the road reserve of the Avenues development. In general, the modelled results are similar and regarded as a good representation of the stormwater management system (URS independent peer review).

The flood extent modelled by MOUSE is slightly less than that modelled by HEC HMS. It is due to the optimisation of the piped network design and the utilisation of close design liaison with the external earth work design team.

4.3 FURTHER USES OF MOUSE MODEL

The MOUSE model has also been used to verify the as-built stormwater system. We have recently re-modelled the 100yr ARI event using the as-built network and surface storage and satisfied the performance of the current built stormwater management system.

The re-modelled 100yr water levels within each raingarden are close to the design levels. They are adopted to determine the adjacent lot finished floor level, as part of the supporting documents for PDC 224(c) application (compliance of subdivision consent conditions).

5 CONCLUSIONS

The Avenues development is a challenge in terms of stormwater management due to the complex site constraints, such as flat contours, high ground water table and low strength organic peat soil substrate.

The stormwater conveyance to the receiving environment was developed to support the local sub-catchment management (LSM) approach within the Avenues. At source stormwater treatment is provided within each sub-catchment and the piped network (conveyance system) receives treated stormwater runoff. The success of this approach has provided a guideline for future development of the surrounding catchments.

HEC HMS and MOUSE, two modelling software packages, have been used to assist the stormwater management design of the conveyance system. HEC HMS was used at the preliminary design stage when the internal reticulation network details were not available. The model input has then been transferred to MOUSE model to simulate the flow conditions of the conveyance system during the detail design stage, and to assist optimising the main trunk line (central conveyance) design.

The application of HEC HMS and MOUSE modelling for the Avenues stormwater management has proved that these hydraulic and hydrological modelling software packages are the robust tools for the variation/optimisation of ongoing design, as well as verification of as-built situation.

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