2D FLOODPLAIN MODELLING FOR THE ALEXANDRA CANAL CATCHMENT FLOOD STUDIES

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City of Sydney Council has prepared the Alexandra Canal Catchment Flood Study and Floodplain Risk Management Study. The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces. A SOBEK 1D/2D floodplain model was established representing the pits, pipes, channels, buildings, ground elevations and landuses. Flood modelling showed inundation of roads at many locations across the catchment as overland flow is trapped at low points due to topography, blockage of overland flowpaths by buildings, and limited capacity of the drainage network. The highly developed nature of the catchment limited opportunities to implement stormwater detention facilities to mitigate inundation. A long-term option comprising substantial additional trunk drainage pipelines required to achieve 20 year ARI capacity in the drainage network across the catchment was examined. Smaller reaches of the overall system were also examined for application in the short to medium term. A significant amount of redevelopment is occurring within the catchment, predominantly the conversion of industrial / commercial warehouse buildings into residential apartments. The catchment-wide flood model has been used extensively for assessment of these developments to satisfy Council's Interim Floodplain Management Policy, particularly with respect to floor levels, basement entries, and potential impact to neighbouring properties. For individual developments, the flood model is refined with a child grid (to improve model resolution) and updated with detailed ground survey (combined with the aerial laser scanning elevations of the base model) as well as other local hydraulic controls.

1 INTRODUCTION

The Alexandra Canal Catchment Flood Study (ACCFS) [1] and the Alexandra Canal Catchment Floodplain Risk Management Study & Plan (FRMSP) [2] prepared by Cardno for The Council of the City of Sydney (Council) were adopted by Council on 17 March 2014. These reports form a comprehensive floodplain risk management plan for the catchment in accordance with the NSW Government's Flood Prone Land Policy and the Floodplain Development Manual.

The floodplain management 'process' for the identification and management of flood risks comprises several stages:

- Flood Study - Determines the nature and extent of the mainstream and overland flood problem.
- Floodplain Risk Management Study – Evaluates floodplain management measures for the floodplain in respect of both existing and proposed development.
- Floodplain Risk Management Plan – Involves formal adoption by Council of a management plan for the floodplain.
- Implementation of the Plan – Implementation of actions to manage flood risks for existing and new development.

A number of previous flood assessments have been undertaken for parts of the Alexandra Canal Catchment but not as a single whole of catchment model. Similar studies have been prepared or are in preparation for other catchments within the Council Local Government Area (LGA).

2 ALEXANDRA CANAL CATCHMENT

The Alexandra Canal Catchment, shown in Figure 1, is located a couple of kilometres south of the Sydney central business district. The catchment covers an area of about 13.8 km^2 of which about 11.9 km^2 is within the City of Sydney, representing its largest catchment (about 43% of the area of the LGA). It includes the suburbs of

Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park.

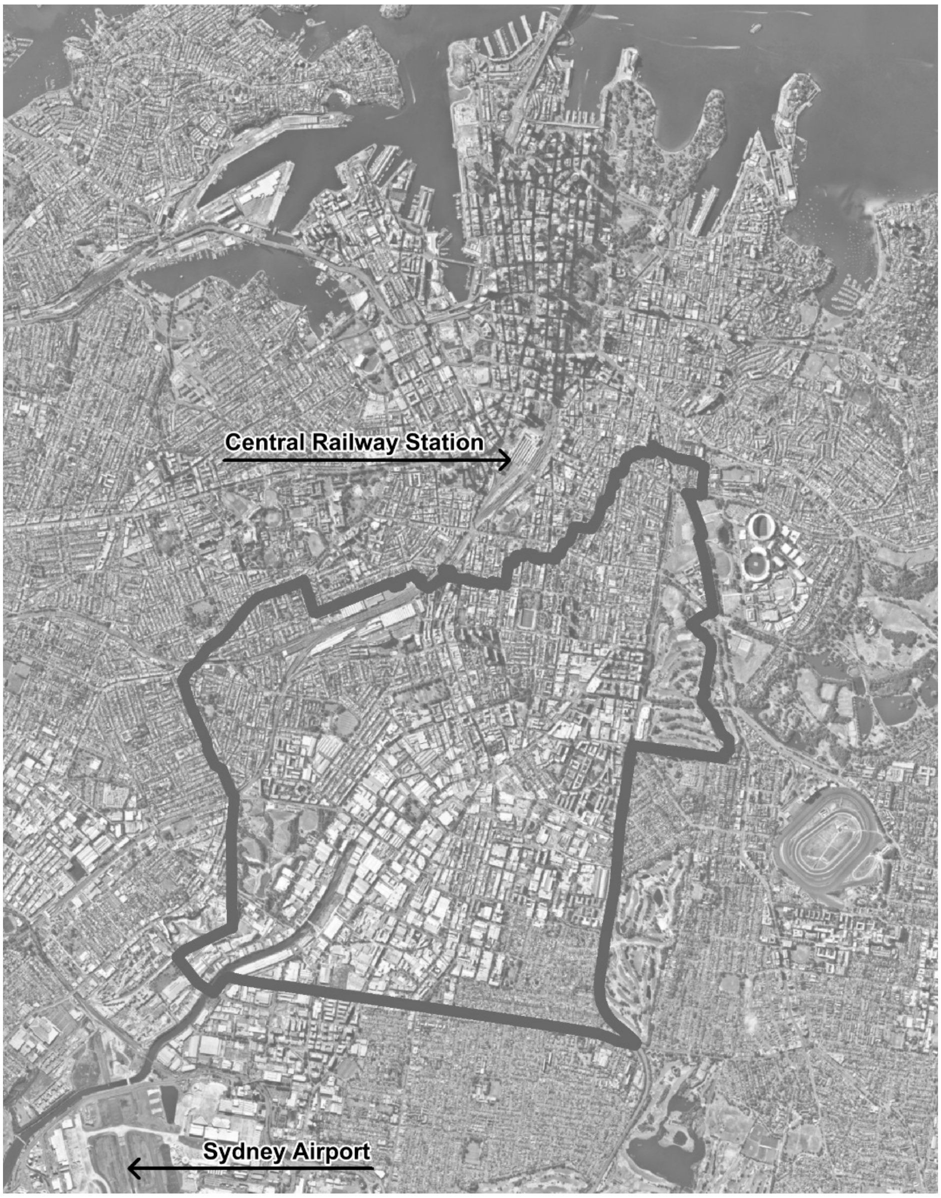

Figure 1. Alexandra Canal Catchment study area (aerial image source – Nearmap)

The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces including Moore Park playing fields, golf courses, Sydney Park, Redfern Park, Waterloo Park and Alexandria Park. Drainage systems consisting of open channels, covered channels, in-ground pipes, culverts and pits convey runoff from the catchment towards Alexandra Canal (in the south-west of the catchment) which discharges into the Cooks River. The majority of the trunk drainage system is owned by Sydney Water Corporation, with the feeding drainage systems primarily owned by Council.

The fully dynamic 1D/2D modelling package SOBEK was used to estimate flood behaviour in the catchment for the Flood Study. This SOBEK model was also used for the evaluation of flood mitigation options for the Floodplain Risk Management Study and proposed developments of sites within the catchment.

3 SOBEK MODEL

Previous flood assessments and modelling within parts of the catchment used a variety of hydrologic and hydraulic model packages. For the ACCFS, the rainfall-on-grid (direct rainfall) procedure in SOBEK was used whereby rainfall is applied directly on the 2D grid, such that the hydrology and the hydraulics is undertaken in the same modelling package.

A hydraulic model converts runoff into water levels and velocities throughout the major drainage or creek systems in the study area. The model simulates the hydraulic behaviour of the water within the study area by accounting for flow in the major stormwater pipes and channels as well as potential flow paths, which develop when the capacity of the stormwater pipes and channels is exceeded. It relies on boundary conditions, which include the runoff hydrographs produced by the hydrologic model and the downstream boundaries.

A 1D and 2D fully dynamic hydraulic model was established for the study area using SOBEK which is developed by WL|Delft Hydraulics of the Netherlands (2004). The system is used world-wide and has been shown to provide reliable, robust simulation of flood behaviour in urban and rural areas through a vast number of applications. The model allows addition of a 2 dimensional (2D) domain (representing the study area topography at a 4m by 4m grid cell resolution) to a one dimensional (1D) network (representing the channels, pits and pipes in the study area) with the two components dynamically coupled and solved simultaneously using the robust Delft Scheme.

An important feature of the model is the ability to model the hydraulic structures in the 1D component rather than in the 2D domain. The benefit of this approach is that structure hydraulics are modelled more precisely than the approximate representation possible in a 2D domain.

In the application of rainfall directly on the 2D grid ('Direct Rainfall' method), the hydrology and the hydraulic calculations are undertaken in the same modelling package. In the model, rainfall is applied directly to the 2D terrain, and the hydraulic model automatically routes the flow using the same computation process that controls the routing of all other flows through the model. This means that catchment outlets do not have to be predefined, and overland flowpaths are identified by the model, rather than being assumed using traditional hydrologic and hydraulic approaches.

There are a number of advantages of the modelling approach, particularly given the nature of the Alexandra Canal Catchment. In flat areas, overland flow paths are not always obvious. Furthermore, additional and unexpected 'cross-catchment' flows may activate in larger events. The rainfall on the grid approach overcomes these issues, as the model will automatically divert flood waters along different flowpaths (based on the terrain and the roughness) during high flow events.

When there are a large number of stormwater pits and pipes, such as in the Alexandra Canal catchment, it can be difficult to determine the catchment that applies to a particular pit in using a traditional hydrological modelling approach. With the Direct Rainfall method, flows are automatically routed to the actual pit reducing potential errors in the application of input flows.

This method was verified using the traditional hydrological model XP-RAFTS and calibrated using reported flood levels and reports from actual rainfall events.

4 ALEXANDRA CANAL CATCHMENT FLOOD BEHAVIOUR

Flooding throughout the catchment is a combination of overland flow and mainstream flooding. Mainstream flooding issues tend to occur around Alexandra Canal and the open channels in the study area. Elsewhere, flooding is primarily a result of overland flow influenced by the capacity of the stormwater network and overland flowpaths.

A feature of the catchment is the prevalence of 'trapped' low points. These areas, due to topographical, development / building constraints, and piped drainage capacity, result in significant ponding and flooding of properties and roads. Figure 2 shows locations of runoff ponded at depths greater than 0.5m which includes some main roads. In a number of these locations, the only way for water to escape is via the pit and pipe system.

An annual average damage of about $13 million was estimated for stormwater flooding of the catchment within the LGA based on the modelled SOBEK results and extensive building floor level survey.

5 MITIGATION OPTIONS

The FRMSP reviewed a series of flood mitigation options for the catchment including structural, planning, and emergency response measures. These were evaluated for potential implementation based on a multi-criteria analysis considering economic (eg capital and maintenance cost, potential reduction in flood damages, cost-benefit ratio), social (eg reduction in risk to life, community support), and environmental aspects (eg heritage, flora / fauna impact). Potential structural mitigation measures were modelled in SOBEK by incorporating the concept design in the model 1D layer and/or 2D grid.

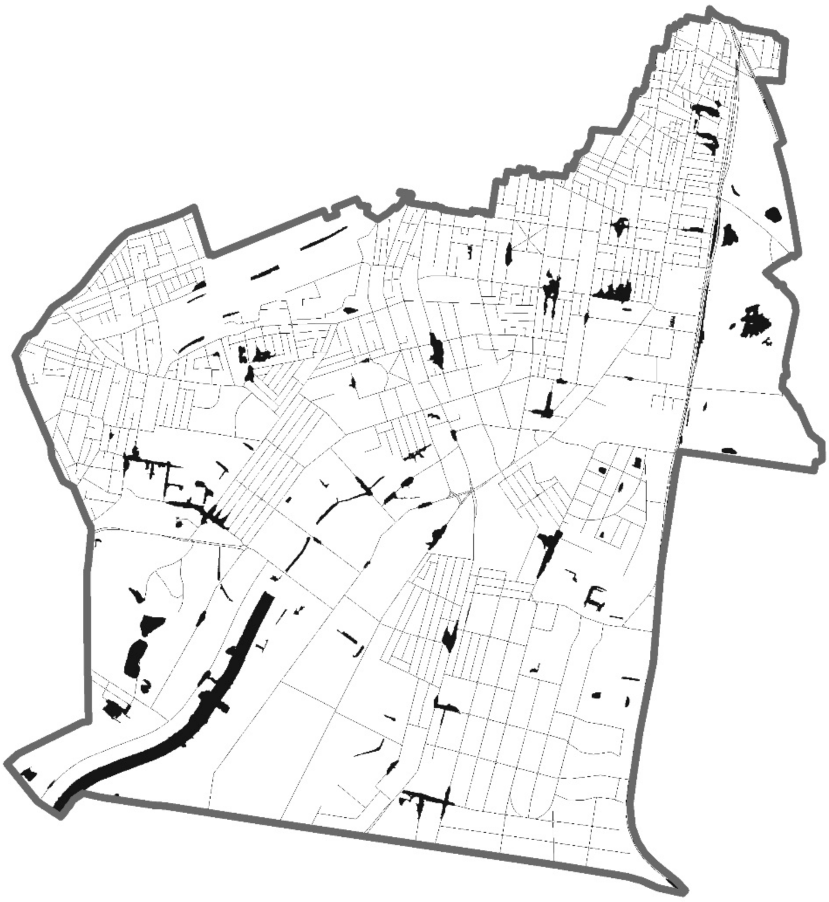

Figure 2. Areas of ponding (>0.5 m deep, >500 m^2) in 100 year event

5.1 Options Evaluation

A multi-criteria matrix assessment approach has been adopted for the comparative assessment of all measures identified using a similar approach to that recommended in the Floodplain Development Manual (2005). This approach uses a subjective scoring system to assess the merits of various measures. The principal merits of such a system are that it allows comparisons to be made between alternatives using a common index.

The scoring is based on a triple bottom line approach incorporating economic, social and environmental criterion. Each measure is given a score (positive or negative) according to how well the measure meets specific considerations. The economic category is given more weight than either the environment or social categories. This is due to the economic category being the most direct measure of both the effectiveness of the measure on flooding as well as its affordability. Measures that rank highly on environmental or social categories do not necessarily provide significant flooding benefits.

Criteria for the economic category are:

- Benefit Cost Ratio.
- Reduction in Risk to Property.
- Essential Infrastructure.
- Future Development.
- Capital Cost.
- Operating Costs.
- Constructability.
- Implementation Timeframe.

Criteria for the social category are:

- Reduction in Risk to Life.
- Reduction in Social Disruption.
- Compatibility with Council Policies & Plans.
- Community & Stakeholder Support.
- Urban Design.
- Governance.

Criteria for the environment category are:

- Compatibility with Water Quality Objectives.
- Groundwater.
- Heritage.
- Compatibility with Water Reuse Schemes.
- Fauna/Flora Impact - including street trees.
- Contaminated Land & Acid Sulfate Soils.

5.2 Options Short-term and Long-term

Flooding problems within the catchment occur predominantly as a series of trapped lowpoints distributed across the catchment. Creation of overland flowpaths as potential mitigation measures is limited in this highly urbanised catchment, thus the options evaluated were primarily use of existing parks as detention basins and / or upgrade of existing underground piped drainage.

Park sites are distributed across the catchment with some located near to problem areas. However, potential application of these sites for creation of detention basins was limited due to:

- Location (sited away from the main flood area);
- Topography (ground elevation above main flood area);
- Complex underground drainage pipe requirements; and
- Social issues (heritage or high use parklands not suitable for detention basins).

Some locations were modelled in SOBEK showing potentially viable sites for detention basins to reduce the extent of flood inundation. The available size of detention basins generally resulted in mitigation of flooding in the local area, but each basin did not have a significant impact for other flooded sites across the catchment.

A long term strategy for upgrading the underground drainage was developed for the catchment in order to achieve the following outcomes:

- A 20 year Average Recurrence Interval (ARI) design capacity of the drainage system; and
- Parity across the floodplain with regards to delivery of infrastructure and floodplain management.

The potential of this measure is to provide a long term strategy and guidance for the Council in upgrading their stormwater infrastructure. The key objective of the system was to achieve flood inundation of no more than 170mm of water on the road (or roughly the top of kerb).

The analysis was undertaken in a number of steps:

1. Establish an additional stormwater network throughout the study area in the model;
2. Size the “new” stormwater network in the model to accommodate the 20 year ARI flows, being the additional flows not already conveyed by the existing stormwater system. This is an iterative process, as the downstream pipes are dependent on the upstream pipe solutions;
3. The results of Step 2 above provide guidance on indicative flows and pipe sizes required to achieve a 20 year ARI design capacity. However, they do not take into account constraints to construction like buildings, roads etc. Therefore, they provide a useful benchmark by which to undertake a design of suitable infrastructure;
4. Using the results of Step 2, determine an indicative pipe layout taking into considering constraints based on available information. This concept level strategy generally followed the following principles:
    a. Avoid pipes through residential properties, where easements would be difficult to achieve due to densities of developments and impacts on houses; and

b. Generally assume a parallel stormwater system is developed, in addition to the existing stormwater system. It is noted that in some cases these two could be combined, with a replacement of the existing stormwater drain with a larger capacity system.

5. Step 4 provides one potential alternative, but it is not the only stormwater layout that is possible. There are likely to be multiple solutions in the different parts of the study area.
6. Undertake costings of this proposed layout, to provide Council with an indication of the overall cost. This costing was also broken down into sub-areas, as the works are likely to be staged over a period of time. The next phase of the project will look at optimising these works based on their effectiveness.

The long term flood modification strategy involves multiple drainage components across the whole study area (shown in Figure 3) to enable additional drainage for the widely distributed problem areas to the outlet at Alexandra Canal. As the works would be undertaken over a long time period, the future system was divided into a series of subcatchments and reaches. A strategy for implementation was determined to achieve the best outcomes both in the short term and the long term, whereby works should be undertaken at the downstream end of the catchment working towards the upstream end of the catchment where possible. There are numerous potential alternatives that could also be achieved, through different alignment of pipes or different configurations which could be reviewed at a future stage.

6 DEVELOPMENT IN THE CATCHMENT

A significant amount of redevelopment is occurring within the catchment, including:

- Single allotment residential extensions and rebuilds;
- Existing commercial and warehouse site reconstruction as residential apartment buildings;
- Precinct-scale redevelopment as residential apartments over several street blocks (eg Ashmore Street Precinct and Lachlan Street Precinct); and
- Redevelopment of a large part of a whole suburb (eg Green Square) with retail, commercial, and residential buildings as well as open space and facilities (such as a library and aquatic centre).

The SOBEK flood model has been used extensively for assessment of these redevelopments for estimation of habitable floor and basement entry levels, potential impacts to neighbouring properties, and evaluating potential options to manage flows through the sites (both as overland and piped flows).

Generally, the process has been similar for many of the development flood assessments:

- Review flood affectation and behaviour for the site from the ACCFS modelled results;
- Identify peak flood levels, required floor levels, and potential constraints to the development;
- Adapt ACCFS SOBEK flood model for a detailed flood assessment –
    - Create a higher resolution grid (ie child grid of smaller grid cell size) in the vicinity of the site;
    - Refine the model for pre-development scenario with detailed ground survey and other hydraulic controls identified on site;
    - Establish a model for the post-development scenario with the proposed layout;
    - Assess modelled flood behaviour for compliance with Council’s Interim Floodplain Management Policy and impact to neighbouring sites; and
    - Modelling of potential flood mitigation options to manage flood issues.
- For some developments, the modelling of the post-development scenario shows negligible impacts whereas others may be significantly affected by overland flowpaths or inundation from flows along the roads. For the Green Square redevelopment project, extensive flood modelling using SOBEK was completed to manage flows upstream, downstream and through the site examining a multitude of piped and overland flow options.
- In some cases, modelling of proposed realignment of the existing trunk drainage through the site has been analysed using other 1D drainage models (DRAINS, XP-SWMM). Flows from the SOBEK catchment model are integrated to the 1D model which has a shorter runtime as only pipe flows near the site are analysed (not overland flows across the whole catchment).

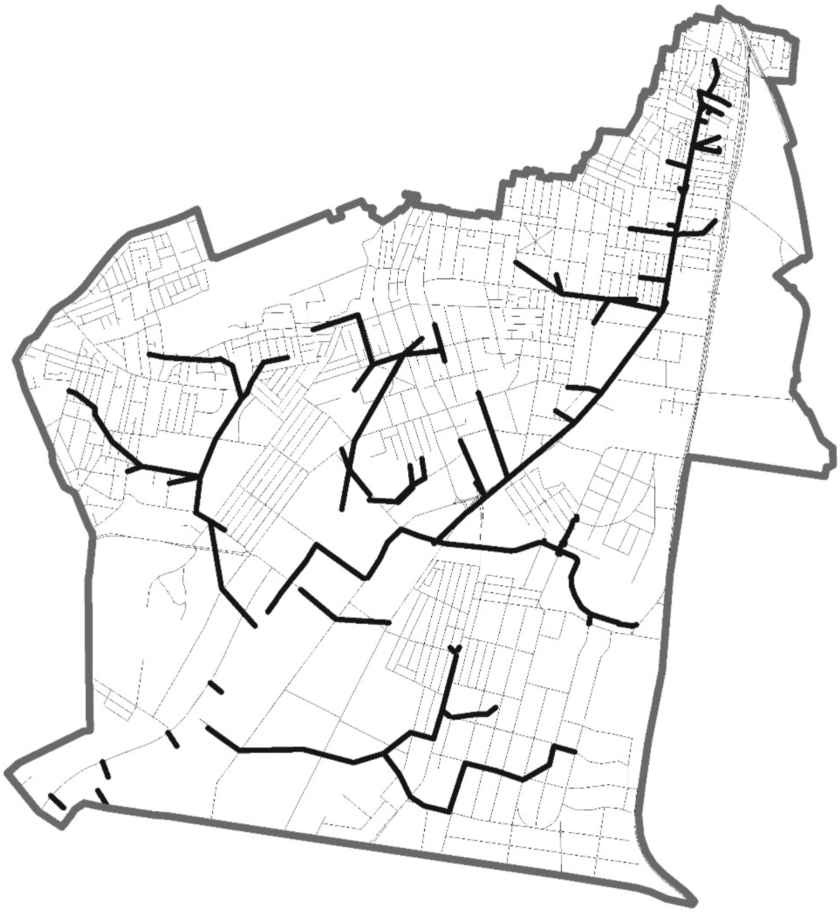

Figure 3. Long-term flood modification strategy

7 SUMMARY

A SOBEK combined 1D/2D flood model was established for the Alexandra Canal Catchment for the preparation of a formal Flood Study and Floodplain Risk Management Study and Plan. The model estimated flood behaviour across the catchment identifying a series of distributed trapped lowpoints. It was used to assess the effectiveness of flood mitigation measures from which a series of potentially feasible options were determined. Currently one of these measures, comprising an extensive trunk drainage augmentation, is being constructed. The SOBEK model has also been applied to numerous sites for evaluation of post-development flood behaviour.

REFERENCES

[1] Cardno (NSW/ACT) Pty Ltd, "*Alexandra Canal Catchment Flood Study*", (2014).

[2] Cardno (NSW/ACT) Pty Ltd, "*Floodplain Risk Management Study - Alexandra Canal Catchment Floodplain Risk Management Study and Plan*", (2014).