LARGE SCALE MODELLING OF MELBOURNE WATER CATCHMENTS – LESSONS LEARNT

Mark Groves, Louise Algeo & Liam Foster - Opus International Consultants; Andy Chan – Melbourne Water

Abstract

This paper discusses the technical challenges of carrying out a rain on grid assessment covering Melbourne Water's area of responsibility in Victoria Australia, a combined catchment of approximately 12,500km2, equivalent to approximately 10% of the North Islands land mass or 12 times the urban area of Auckland.

A key requirement of the project was to test and determine confidence in the modelling approaches compared with current flood modelling approaches and then utilise this to deliver for the first time catchment scale flood modelling assessments for areas that have been unmapped in the past.

Melbourne Water's goal was to develop a better understanding of broad scale drainage and flood modelling and move towards developing integrated urban drainage models. This Model Pilot Project helped Melbourne Water to determine how best it could develop a whole of catchment modelling approach, deliver an integrated urban drainage model and work collaboratively within the company to deliver multiple objectives to best meet customer's expectations.

The paper presents the organisational and technical challenges associated with delivering a project of this scale, concentrating on developing a robust technical approach, with a short project timescale.

Technical challenges included the long times of concentration (in the range of days) associated with large catchment modelling (which would be of interest to those involved in catchment modelling across New Zealand). The paper also discusses how the project team determined and overcame the limitations of the Australian Rainfall Runoff approach when applied on this scale. Additionally, the paper shares some key lessons associated with delivering large models (with long simulation times), as well as how the team worked through the validation stages to approach the sensitivity to depression storage / mesh resolution.

Finally, the paper will share an appropriate methodology for presenting the modelling results so that all stakeholders can best understand the uncertainties associated with such large scale coarse assessments, yet still understand the response required to help protect communities at risk of flooding. This approach would help overcome some of the reservations with releasing broad scale flood modelling to the communities involved.

Introduction

Melbourne's water industry has provided safe and reliable water services for over 125 years. The Melbourne water industry (which incorporates Melbourne Water (responsible for bulk water and wastewater services) and several Water Retailers (responsible for the smaller reticulation network)) recognised the need for a more integrated approach to delivering water services, in order to create more sustainable and liveable communities. Planners are facing up to the need to adopt a different way of thinking in responding to the opportunities and challenges associated with delivering water and wastewater services. These include:

- population growth
- climate change
- heightened community expectations in relation to service, liveability and affordability
- improving technology and science

The development of a three year modelling development programme enabled the opportunity to identify the best approaches to serve customers and their operating environment. As such, the concepts of developing whole of catchment integrated drainage models is one such method that Melbourne Water is investigating to help deliver healthy, sustainable and prosperous communities to maintain Melbourne current status as a leading liveable city.

In Melbourne, over 100,000 properties are at risk of being flooded by overflows from rivers, creeks and Melbourne Water's regional drainage system during heavy rain or storms, and it has been estimated that the annual average damage caused by flooding in the region is c. $245 million,[i] placing a huge burden on the social, economic and environmental structure of communities across the region.

Melbourne Water works with local partners and stakeholders, has developed the Port Phillip and Westernport Region Flood Management and Drainage Strategy to set the framework for addressing current and future issues across Melbourne Water's operational area. A key focus of this strategy is the need to continue to develop local flood management plans and use appropriate tools to help:

- minimise risks through improved planning, land use control and appropriate structure works, BEFORE THE EVENT;
- determine appropriate ***response*** activities, DURING THE EVENT (including warnings, monitoring and emergency activities), and;
- set the framework for ***recovery*** activities, AFTER THE EVENT (including financial assistance, community response, counselling, restoration and rebuilding).

Melbourne's water industry uses a variety of modelling approaches to model aspects of the water cycle including river basin flows and loads, flows through the water and sewerage system and stormwater run-off. These modelling tools play a critical part in planning and addressing specific requirements such as assessing compliance, system performance and planning for growth and renewals.

Melbourne Water realises that a lack of integration of the sewer and drainage modelling tools has prevented longer-term strategic planning for integrated water cycle management and forecasting the impacts of climate change. As such, Melbourne Water has developed its strategy to undertake this hydraulic planning work in an integrated platform using Infoworks ICM. Melbourne Water sees that the benefits for the Water Services Planning team of using this software are:

- An ability to develop regional or local scale innovative solutions for a separate collection system in one single modelling platform
- To consider sewer hydraulic performance and flood planning holistically
- To facilitate learning and innovation and the application of best practice - To utilise existing models and software appropriately - Melbourne Water currently uses InfoWorks CS to model its sewer network system. The model can readily be import to Infoworks ICM (Compatibility with existing modelling platform) and was seen as a key driver to start to include existing land topography to determine the impact of the levels of service through better understanding of the current and future consequences.

Melbourne Water's Objectives and Approach

The purpose of this Model Pilot Project was to develop a better understanding of waterways and stormwater networks flood modelling using available data and to determine the next steps in developing a fully integrated catchment model to support key performance drivers for Melbourne Water.

This project was conceived to help Melbourne Water develop appropriate modelling strategies for their operational waterway catchments, covering approximately 12,500 km².
Melbourne Water invited Opus to assist in developing a pilot multi catchment large scale model consisting of two main parts:

- A multi-whole of catchment 2D Rain on Grid model, covering the five major catchments (shown below), contributing to Port Phillip Bay, that constitute the Operational Waterways area.
- The development of a 1d/2d urban drainage model for the Greater Melbourne Urban Area, covering a population in excess of approximately 4 million as shown in the image below.

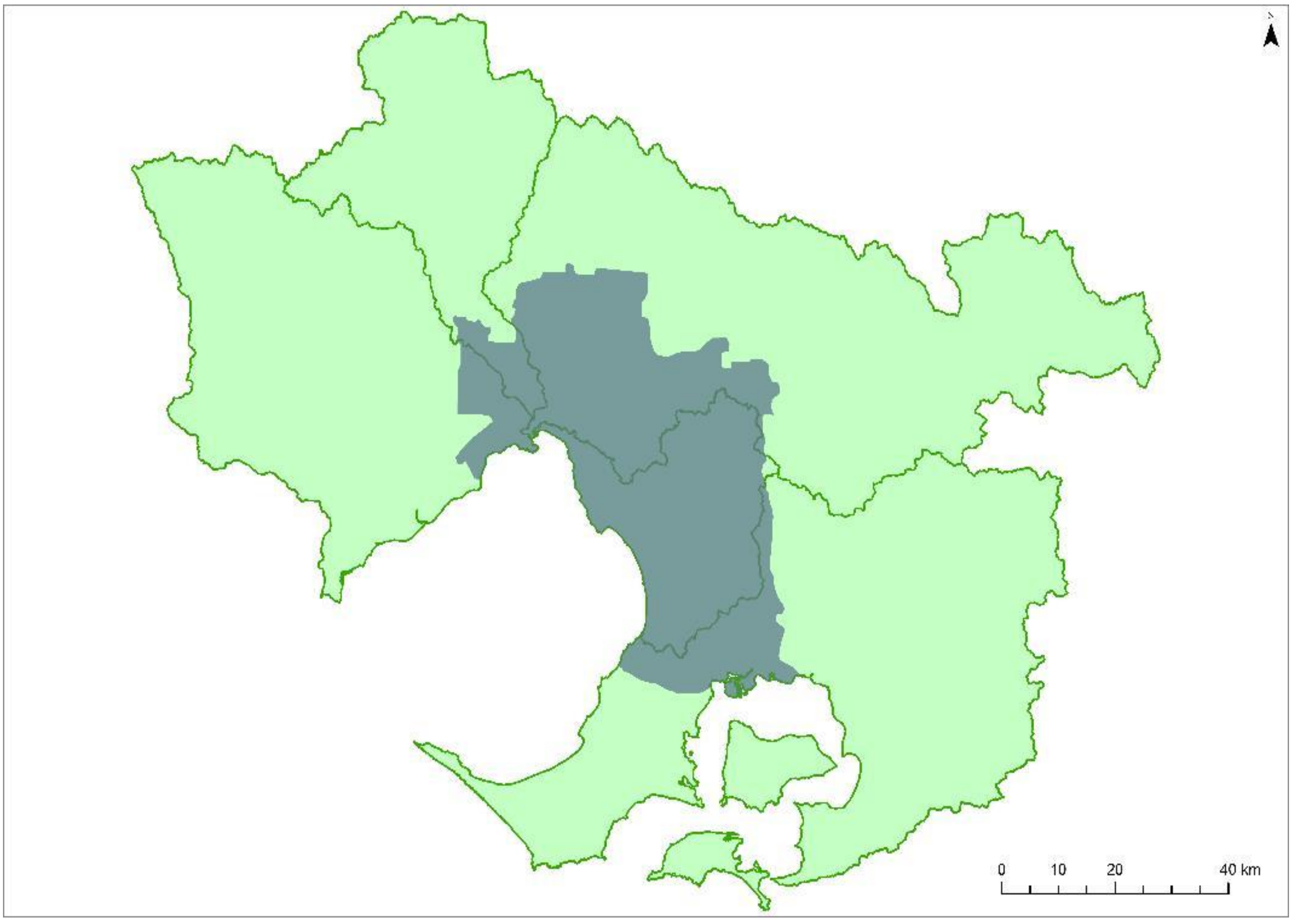

Figure 1 – Map of the five major catchments representing the operational area of Melbourne Water (shown in light green) with the Greater Melbourne Urban model area (dark hatching).

A further key requirement for the Pilot Project, was to identify the next steps for Melbourne Water to continue the development of the integrated urban drainage modelling tools to achieve a suitable integrated tool which will allow Melbourne Water's customers to be better served.

This paper seeks to share the lessons that have been learnt across the Project Team and include the organisational lessons, which are equally as important and fundamental to the success of the project as the specific modelling lessons presented.

Organisational Lessons Learnt

The process of devising a modelling strategy to cover both drainage and waterways in itself identified several elements that have been beneficial to Melbourne Water and can be summarised into the following key lessons:

1. *Start Small but Think Big:*

Stormwater and flood risk modelling had never been undertaken across the whole operational area before and as such the scale of the catchments being investigated were a barrier to commencing these studies in the past, due to the availability and capability of the relevant software and hardware to efficiently undertake models of this size.

On a journey towards developing an integrated vision for waterways and drainage management through the operational area, Melbourne Water deliberately looked to commence the work on a small scale trial basis covering the area to test the tool's capabilities, functionalities and use the outputs to then determine how best to proceed.

The key focus of developing the approach was to undertake a short trial programme with an expected outcome and budget. Over six months, Melbourne Water invested in understanding the software, discussing and becoming aware of the model build process, determining the knowledge gaps and then focussed on delivering outputs in the form of two pilot models, identified above, that would help to showcase and demonstrate how the tool could help the overall business.

Concurrently, the key element that helps to demonstrate the success of this project was that the degree of realism and common sense approach to the model development that included the decision to model key assets only, and hence not receive vast quantities of asset information. This enabled the pilot project team to achieve the tight timescales of delivering the two modelling outputs within six weeks of project award.

The trial was also set into the context of being part of a three year model development programme that was instigated to test better methods for developing catchment models to best serve their needs. Melbourne Water also realised the limitations of the timescales place on the Pilot model programme and that the modelling development over the next few years would seek to sequentially add further information/detail into areas of concern, such that the benefits could then start to flow through to how Melbourne Water impacts on the environment and their customers.

2. *Right People at the Right Time*

A key element of developing this project within the organisation was the realisation that the corporate or institutional knowledge of integrated drainage modelling and the software tool was limited. To achieve the overall objectives, a key decision was made to involve the right team to develop the pilot modelling approach and to test the long term strategy at the commencement of their activities.

In this case, a mix of hydraulic modelling specialists, water planners, flood risk experts and three water strategists was perfect to ensure that the project aspirations could be met through the developing pilot models and equally signpost the direction of travel around the organisation to deliver best value for customers and the environment.

A further key success for the project was the decision internally within Melbourne Water to involve the IT team early. The standard available IT infrastructure present across the support teams at the water company (largely low specification machines with insufficient RAM) would not perform optimally to help achieve the project ambitions in suitable timescales. Equally, improving certain assets (hardware) then could enable internal staff to develop skills with the provided tools/models to help improve project ownership and development.

3. *Collaboration, Engagement & Communication*

From the beginning of the project it was clear that the modelling had the potential to assist several areas of Melbourne Water's key business from land drainage, waterways and wastewater networks teams, operational teams as well as the business planning and infrastructure strategy teams. It is clear that across these teams there was a vast array of:

- levels of ownership and understanding over the waterways issues;
- differential business needs and drivers across sections but common values and goals;
- awareness of the stormwater/sewer network dependencies;
- Individual staff skills and attitudes, with some staff focussed keenly on the process who had a strong understanding of hydraulics/hydrological modelling and others in the team that had other roles and focusses, and;
- Out of this the project team had to face challenges over the need to invest in integrated modelling, with some people very much concerned on what this would mean for their work area, whereas others could see synergies and value to their work and hence could be future advocates for the project.

In summary, the project team found that there is no right time or best time to engage people around the business nor how far and wide you should engage. It was evident that being clear on the current level of model accuracy and the improvement plans helped to satisfy the majority of stakeholders.

A further key finding of undertaking the Pilot project and developing the methodology was the ability for different departments to discuss and investigate opportunities collaboratively. Through this it is expected that through the deliberate involvement of other internal sections, the model will begin to show greater value and help them achieve their individual requirements/expectations, which include but are not limited to flood risk management, land use planning, network system improvements and long term infrastructure planning to future growth.

Reporting the successes, failures and next steps for the project delivered great value in helping to communicate the works to wider audience and to start to show how the modelling could help improve customer experience for the organisation. This was achieved through holding multiple workshops across the various teams internally and sharing the message wider through the production of promotional project flyers internally.

Melbourne Water is very clear that this developed model is not a solution to everything and that there is a structured programme of work to help to address current (and expected future) gaps, but that the journey of change is upon them and that the customers and the environment would ultimately benefit from this approach.

Model Development

The Melbourne region has a combined catchment area of just over 12,500km2. Modelling an area of this size has various conceptual, technical and technological challenges.

Options for the region were considered and a 2-dimensional 'Rain on Grid' model was proposed and developed. Due to technological limitations this was split into the 5 major river catchments. The basis of the model was a coarse scale 25x25m (625m2 area) gridded Digital Terrain Model (DTM) based on photogrammetry.

Due to the coarse nature of the DTM, a 2D hydraulics mesh was created with large triangle sizes of 250-1000m² for the flatter urban areas and 500-2000m² for rural areas with well-defined topography. This resulted in up to approximately 7 million triangles per river catchment. This appeared to be the limit of what could be run with the maximum amount of RAM available (32 gig). Whilst the 2D grid is a fairly coarse scale, at the catchment level, this provided a technically viable means to identify areas of further more detailed assessment and fill knowledge gaps within a short timescale and cost effectively relative to the large area involved.

Roughness values were estimated for each land use type and applied to regional land zone GIS mapping to account for spatial roughness variation through the catchments. Run-off co-efficients were estimated empirically for each catchment based on available flood flow estimates for the major river catchments and Australian Rainfall and Run-off design rainfall depths. Within each catchment, the derived run-off co-efficient was then spatially weighted by land use zone type with hydrological parameters applied directly to the 2D surface mesh (along with rainfall).

This approach was validated and found to generate valid flow hydrographs that matched well with prior estimates and records within an acceptable margin of error. However, derivation of the run-off coefficients yielded low values. This indicated significant retardation of the commonly used design event was occurring (failure for all catchment flows to converge within the storm duration). This was later confirmed through running the model and is a significant lesson for modelling studies of this nature to address in the future.

The commonly used storm event consisted of a 24 hour duration 1 in 100 year ARI rainfall event with a modified project specific storm profile. Applying a rainfall event to catchment areas of this size also presented a challenge in terms of conceptualising the spatial variation of the rainfall event. In this study the catchment was split into 18 Theissen polygons based on Australian Rainfall Runoff maps for rainfall variation across the region. Total rainfall obtained from Intensity-Frequency-Duration curves from the Australian Rainfall Runoff data was then applied for each polygon. The Theissan polygons were generated to allow for variation in rainfall depths and topography across the catchment.

In this high level study, the coarse Rain on Grid approach was found to be very stable and computationally efficient. This was due to omission of any one-dimensional elements, large mesh triangle size, and the direct Rain on Grid approach with no 1D or point inflows to the two-dimensional surface. A further key finding for large scale catchment modellings, was the finding that the models had to be run for <u>at least</u> 5 days duration to allow sufficient time for flow in the upper catchments to reach the coast and exit the 2D surface.

Model Results and Outputs

Simulation results were validated by comparing flood extent outputs from the model to prior modelling investigations by Melbourne Water and historic flood extents (where mapped). Further to this, the model derived flows for key rivers matched well with prior statistical assessments of flood frequency or estimated values using ARR confirming the approach was fit for purpose.

Sensitivity analysis was also carried out through a range of scenarios to assess the impact of the various assumptions made. This included mesh detail (artificial depression and flood plain storage), roughness (flow retardance), antecedent rainfall ('pre-wetting' the surface) and run-off coefficient for example. Given the coarse scale of the assessment, this was considered a critical action and allowed us to develop flood mapping that spatially presented sensitivity and avoided the use of a 'definitive' flood line.

Instead of providing deterministic flood outlines, a range of potential flood extents were presented as a probabilistic Flood Confidence Map, which ranged from high probability through to low probability, with areas flooded during all scenarios considered, for example, to be categorised as high probability.

This allows decision makers and planners to visually conceptualise uncertainty and the spatial variation in model sensitivity. The outputs are shown in four main confidence zones High (where more than 5 scenarios show flooding over 100mm depth in the grid cell), Medium (3-4 of the scenarios show flooding greater than 100mm), low (1-2 of the scenarios) or None (no scenarios have flooding greater than 100mm).

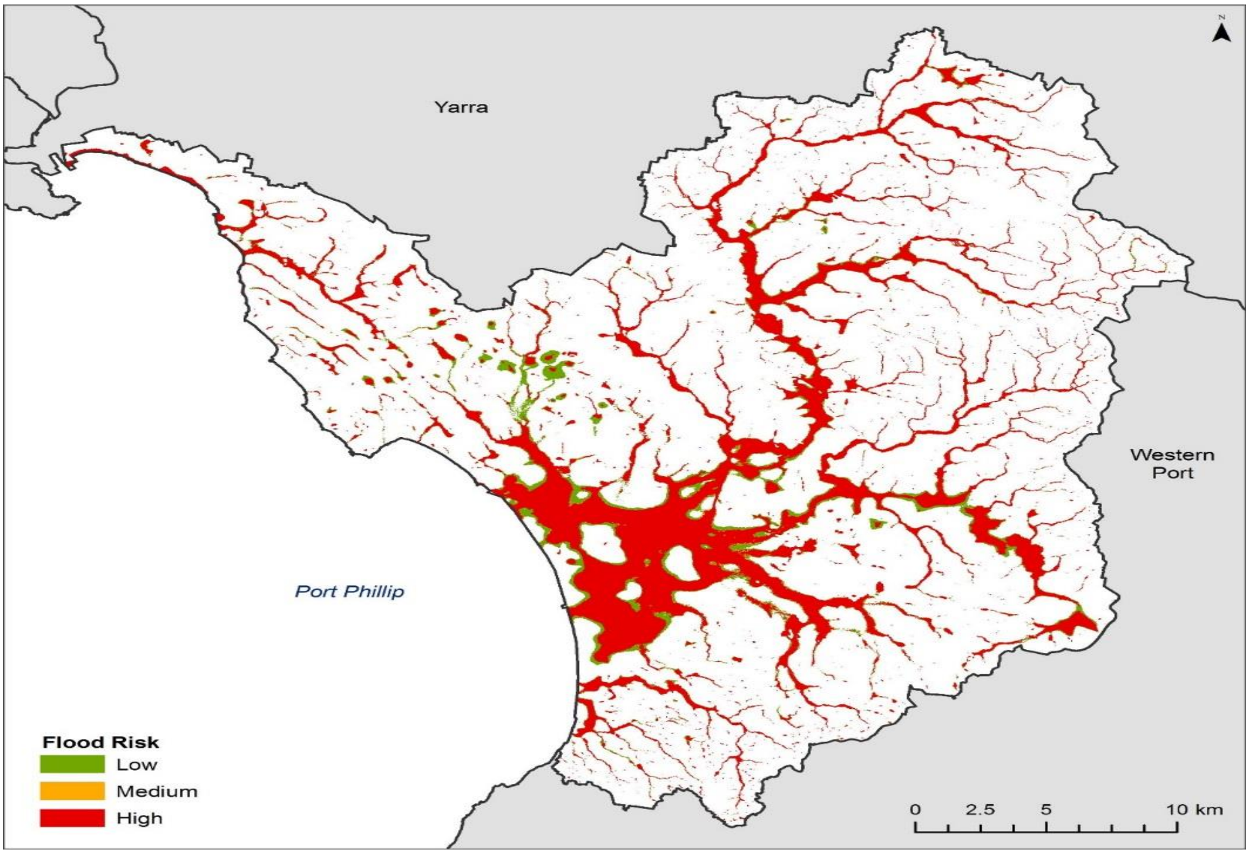

Figure 2 - Large scale catchment Probabilistic Flood Mapping for the Dandenong Catchment (one of the five major catchments)

Key Outcomes

It is feasible to assess potential flood extents for very large areas at a coarse scale within a short time frame and at a reasonably low cost. This approach is consistent with large scale coarse assessments undertaken overseas for planning purposes; for example by the Environment Agency across England. This approach provides valuable data for decision makers quickly: where it doesn't flood; where it may flood, the sensitivity of results; and; where further analysis is required.

This approach also provided identification of major flow paths across the entire region, as well as initial estimates of flow for any point in the catchment, which is a step change in understanding of the hazards facing communities for residents and planners alike, informing land use planning to help avoid areas at risk, identifying existing and potential future problem areas, enabling targeted maintenance where drainage network failure could have the highest consequence, and in some cases providing information suitable for informing catchment management plan or stormwater discharge consents.

Use of probabilistic mapping avoided the use of 'definitive' flood extents and highlights the inherent uncertainty as well as the spatial variation in model sensitivity; all of which are key for planning future more detailed assessment.

It was found that a PC with 32 gig of RAM was capable of running approximately 7 million triangles (InfoWorks ICM) within a reasonable period of time due to the computational simplicity of Rain on Grid without any 1D linkages. As a result, it took approximately 2 days to run the six scenarios (each simulating at least 5 days of time) for each of the 5 catchments. The models were stable and ran without issue due to the approach adopted and required minimal man hours for development.

Use of CUDA hardware acceleration via the GPU was critical in significantly accelerating 2D run times, thus making the project manageable. The development of CUDA technology has made projects of this scale far more viable and is, in our view, a major technological advancement in the field of 2D modelling.

By modelling the entire catchment, useful information was gleaned in terms of flow travel times and catchment critical duration. It was found that the larger catchments took at least 5 days for all flow to converge and reach the coast. This identified that the ARR 24hr duration storm commonly being used are not appropriate for catchments of this scale and that flood flows are likely to be highly sensitive to spatial distribution and antecedent rainfall as a result.

Sensitivity assessment showed that artificial storage created by the coarse DTM and 2D mesh could significantly affect peak flow and that pre-wetting was essential in order to replicate ARR flow estimates. In our view, sensitivity to mesh scale should be considered in sensitivity analysis. Too much detail can create false surface storage due to LiDAR 'noise' or vegetation capture in photogrammetry, and too large can create artificial dams where rivers become narrow and incised (without use of break-lines).

Empirical derivation of run-off coefficients combined with use of 2D 'RoG' hydrology is capable of providing reasonably accurate estimates of flood flow, or in this case, an appropriate range of flows allowing for parameter sensitivity. This is in-line with a recent Opus hydrology assessment for GWRC, which determined an empirically derived run-off co-efficient can appropriately be applied at the catchment scale over a range of rainfall return periods.

Conclusions

Several key lessons have been learnt through the development of this Pilot Project:

1. Embarking on integrated urban drainage modelling has allowed Melbourne Water to start towards delivering better outcomes for the customers and the environment and understanding the consequences of failures better.

2. Engaging other departments in the project enabled a greater understanding of the potential synergies of delivering an integrated urban drainage model.

3. Rain on Grid modelling should be undertaken with care, particularly across large catchment areas as there are a wide range of assumptions and modelling decisions that can affect the overall model performance. Unpicking these, requires involvement of skilled practitioners at the right time.

4. Gaming (in this instance, CUDA) technology is making large scale catchment modelling more accessible through faster processing times and the ability to cover larger areas.

5. Representation of modelling uncertainty through Probabilistic mapping can help provide better understanding of current risks and where greater accuracy and effort would be required.

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[i] Melbourne Water (2007) Flood Management and Drainage Strategy (Port Phillip and Westernport Region) http://www.melbournewater.com.au/aboutus/reportsandpublications/key-strategies/Documents/Flood_Management_and_Drainage_Strategy_complete.pdf