GREEN SQUARE: ENABLING URBAN RENEWAL THROUGH EFFECTIVE FLOOD RISK MANAGEMENT

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ABSTRACT

The Green Square urban renewal area in Sydney, New South Wales is Australia's largest urban renewal project delivering significant economic benefits, including 31,000 residential dwellings housing 60,000 new residents and catering for a permanent workforce of 21,000. Total development costs are forecast to exceed $16 billion.

The Green Square Town Centre is located at the heart of this urban renewal area. Prior to European settlement, this area was part of a series of ponds, swamps and creeks that drained through to Botany Bay. Urbanisation changed the hydraulic character of the area, from a natural water reservoir and waterway corridor to an area of hazardous flash flooding. As old industrial land gives way to modern high-density development, existing flood hazards needed to be resolved to protect a growing community.

The preferred solution involved the installation of 2.5km of new conduits specifically to reduce high hazard flooding to low hazard in the 1% AEP. The project presented many technical, logistical and community related challenges from solving complex hydraulic issues to installing large conduits in heavily built-up areas with extensive existing services clashes and potential major traffic disruption. The trunk drain, now substantially complete, interacts with the local sub-surface drainage system and the ground surface therefore requiring extensive 1D and 2D hydraulic modelling as well as Computational Fluid Dynamics (CFD) and physical modelling of local drainage inflow structures, to ensure the finished system would meet the project objectives. To meet the construction challenges, minimise the social impact and minimise cost, the Drying Green Alliance (consisting of City of Sydney, Sydney Water, WSP, UGL, Seymour Whyte and RPS) adopted a design and construction method that used tunnel boring machines to install 1800mm diameter pipes in long runs (known as micro-tunnelling) well below street level.

This is a complex project that is critical in eliminating the high-hazard flooding from the area to deliver a liveable urban renewal of this inner-city area. It is being delivered through the cooperation of local and state government, construction contractors and designers through an alliance framework. The most beneficial and cost-effective infrastructure is being built because of the thorough planning process and rigorous hydraulic modelling that has been undertaken, both as part of developing the reference design and by the alliance designers in optimising the final design. Innovative construction methods and a collaborative approach will help to nurture the thriving communities and reap further economic benefits.

Highlights of the project include:

- Effective outcomes under complex asset ownership arrangements requires close collaboration and strategic alignment

- Micro-tunnelling provides substantial community and financial benefits compared with open trenching, with significant reductions in disturbance and disruption
- Complex hydraulics solved with a combination of modelling techniques
- Alliancing provides additional benefits over other delivery options given the risks faced by the project

KEYWORDS

Flood hazard, alliance, hydraulics, microtunnelling

PRESENTER PROFILE

Nick has 32 years' experience in all areas of civil engineering from feasibility, planning, concept and detailed design, construction phase services and commissioning. His expertise includes water, wastewater and storm water planning and design, airport and road infrastructure, flood and traffic studies and subdivisions and industrial, environmental and remote community engineering works. Nick has recently been technical lead on a number of water, wastewater and storm water projects and programs involving multi-disciplinary coordination.

1 INTRODUCTION

Located about 3.5 km south of the Sydney CBD, the Green Square urban renewal area is Australia's largest urban renewal project, delivering significant economic benefits, including 31,000 residential dwellings housing 60,000 new residents and catering for a permanent workforce of 21,000 by 2030. The population density in Green Square will be 50% higher than Pyrmont/Ultimo in inner Sydney, which has the highest current population density in Australia. Total urban renewal development costs are forecast to exceed $16 billion and the "total realisation value" will be around $25 billion.

The Green Square Town Centre (GSTC) is located at the heart of this urban renewal area. Prior to development, this area was part of a series of ponds, swamps and creeks that drained through to Botany Bay via the Botany Aquifer and the Cooks River. Urbanisation changed the hydraulic character of the area, from a natural water reservoir and waterway corridor to an area of hazardous, flash flooding.

Under existing catchment conditions, DRAINS and TUFLOW numerical modelling predict peak flood depths in excess of two metres at the Joynton Ave boundary of the GSTC, and up to one metre at the main transport interchange on Botany Road, for the 1% AEP (annual exceedance probability) event. These models also predict flooding of the underground Green Square Railway Station.

As old industrial land gives way to modern high-density development, these existing flood hazards needed to be resolved to protect a growing community.

Sydney Water and City of Sydney share stormwater management responsibilities in the Green Square area under a complex ownership arrangement. Sydney Water is the owner and manager of the "trunk" drainage system, while City of Sydney owns and manages the "local" drainage system.

Effective flood risk management required close collaboration and strategic alignment to arrive at a trunk drainage solution that meets the key project objectives of ensuring community safety during floods and enabling urban renewal. The preferred solution involved the installation of 2.5 km of new conduits with the specific aim of reducing high hazard flooding to low hazard in the 1% AEP flood.

In addition to reducing flood risk, the project assists in realising broader benefits by incorporating stormwater treatment measures, facilitating the GSTC non-potable water recycling scheme, and implementing critical sections of the City's regional cycleway for southern Sydney.

With flow capacity of almost 30 cumecs and a capital value of $100 million, the GSSD is the largest brown-field urban drainage project in Sydney for 30 years. The City of Sydney, Sydney Water and NSW and Australian Governments are jointly funding the project.

The project presented many technical, logistical and community related challenges from solving complex hydraulic issues to installing large conduits in heavily built-up areas with extensive services clashes and potential major traffic disruption. The proposed trunk drain interacts with the local sub-surface drainage system and the ground surface so therefore required extensive 1D and 2D modelling as well as Computational Fluid Dynamics (CFD) and physical modelling of local drainage inflow structures, to ensure the finished system will meet the project objectives. To meet the construction challenge, minimise the social impact and minimise cost the Drying Green Alliance (consisting of City of Sydney, Sydney Water, WSP Parsons Brinckerhoff, Seymour Whyte, UGL and RPS Manidis Roberts) adopted a design and construction method that uses tunnel boring machines to install 1800mm diameter pipes in long runs (known as "micro-tunnelling") well below street level.

Design and construction of the GSSD was awarded to the Drying Green Alliance following a competitive alliance process. Two alliance consortia were short-listed, on their respective concept designs and total out-turn costs based on the provided reference design and hydraulic models prepared. The Drying Green team developed an alternative design that used micro-tunnelling of twin and triple reinforced concrete jacking class pipes in parallel instead of open trenched box culverts.

Figure 1: Overall plan of GSSD

2 FLOOD RISK PLANNING

Flood risk planning for Green Square was jointly undertaken by City of Sydney and Sydney Water through a committee of State and local agencies, community members, elected representatives and specialist consultants, and guided by the NSW Governments Floodplain Development Manual. The planning process culminated in a recommendation to upgrade the existing trunk drainage system with new twin box culverts to remove high hazard flooding in and around the new Green Square Town Centre.

This recommendation followed extensive optioneering, and was based on a combination of hydraulic modelling and other supporting investigations. The alignment of the new trunk drain was mostly contained in existing or future roads or land owned by City of Sydney and Sydney Water.

3 DESIGN

3.1 OVERVIEW

The hydraulics of the proposed system differed significantly from the reference design, which assumed box culverts running not more than 80% full. The adopted system transitions from part-full to full and pressurised depending on the flow and tail-water conditions. Areas that required special attention were:

- structures with large lateral and plunging local drain inflow
- the two to three pipe transition structure
- air transport and blow-back potential as the system transitions from part to full flow
- interaction between the trunk drain hydraulics and the local surface drains and flooding
- the confluence of the new trunk drain with the existing main open channel
- the existing twin culverts crossing Huntley Street
- the twin gross pollutant traps on the new trunk drain
- potential mobilisation of sediments in Alexandra canal where the GSSD discharges

The alliance method of delivery allowed a wider project team to be involved in identifying and evaluating options to ensure the infrastructure delivered the greatest benefit and value for the community.

The trunk drain design relied on computer simulation of the catchment hydraulic behaviour above and below ground. As the pipe system was pressurised in the 1% AEP event, a hydraulic grade line analysis was used to assess different pipe and structure configurations during design development and confirmed through surface catchment modelling that the flood hazard reductions could be achieved.

3.2 HYDRAULIC MODELLING

The whole catchment is modelled using TUFLOW with 2D surface modelling linked to a network of 1D sub-surface conduits. The model is very large and takes many hours for each run (between 6 and 24 depending on the time step chosen). The long run time made testing concepts time consuming, so just the new GSSD was modelled in 1D using XPSWMM. For the concept design, the 1D unsteady flow model of the trunk drain was developed using parameters from published standard formulae. There are over 20 structures which add head loss to the system, being inflow/junction structures, access structures and mitred bends. The large number of structures had the potential to add significantly to the headloss in the system, raising the hydraulic grade line (HGL) to the point where it would start to choke the inflow and increase surface flooding. Therefore, accurate determination of structure losses was essential.

Critical structures were modelled using 3D computational fluid dynamics (CFD). This allowed the head loss and flow split between parallel conduits to be accurately determined. In all, seven structures were modelled, some because they were unique designs and some because they were representative of a number of structures within the system. If the standard loss factors were inaccurate, the cumulative effect had the potential to be significant. However, it was found that the initial calculations were generally confirmed by the CFD modelling. CFD modelling did not inform the air transport behaviour and as this was considered to be a significant risk to drain capacity, physical modelling was carried out.

Physical modelling was undertaken on three of the most critical or representative structures to confirm that the CFD was providing realistic results and to assess air transport in the part-full to full flow transition. This allow us to further refine the hydraulic loss factors used in the hydraulic grade line analysis and provide insights into air and water movement at different headwater, tailwater and flow conditions.

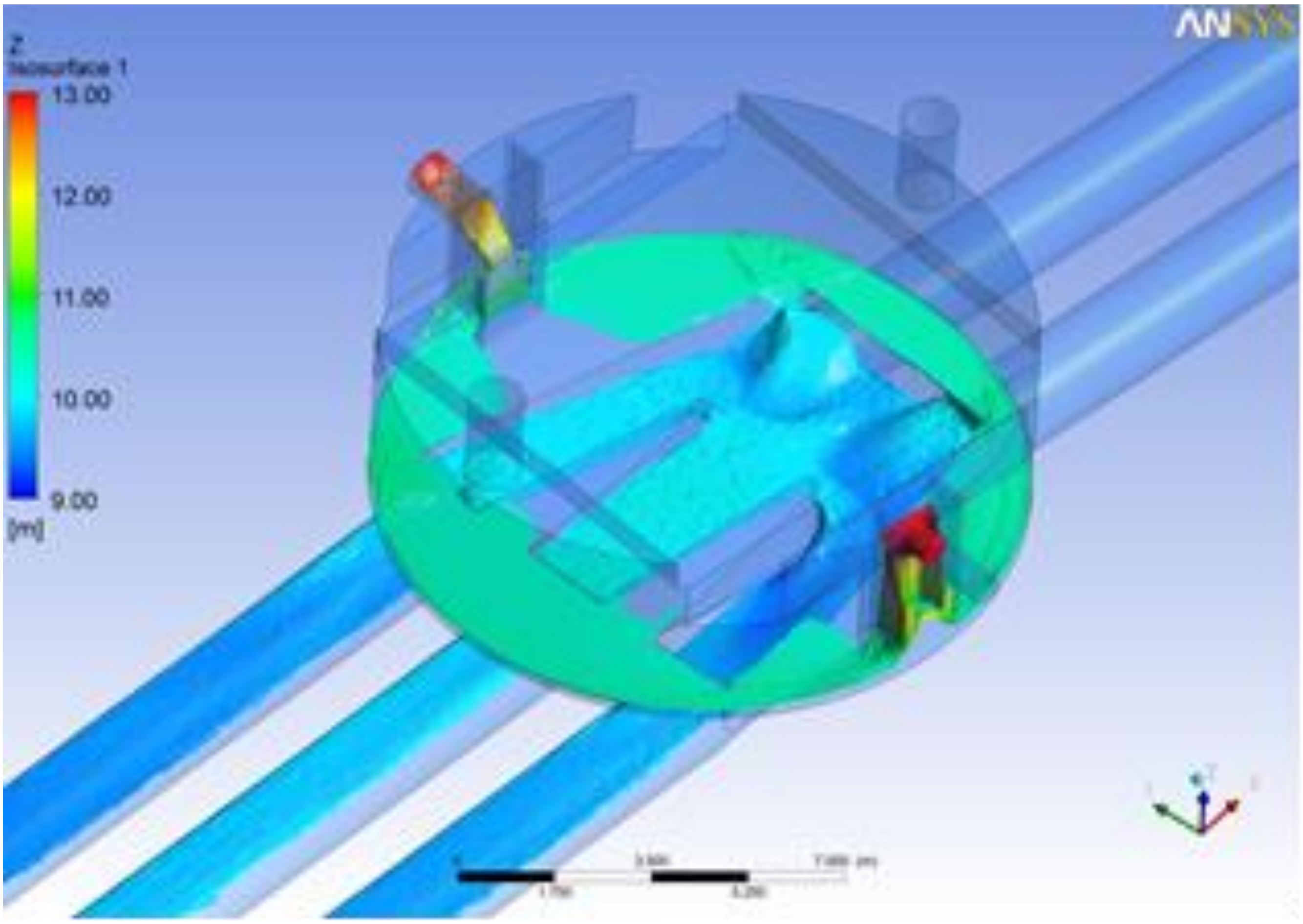


Figure 2: *CFD model - three-pipe to two-pipe transition, water surface*

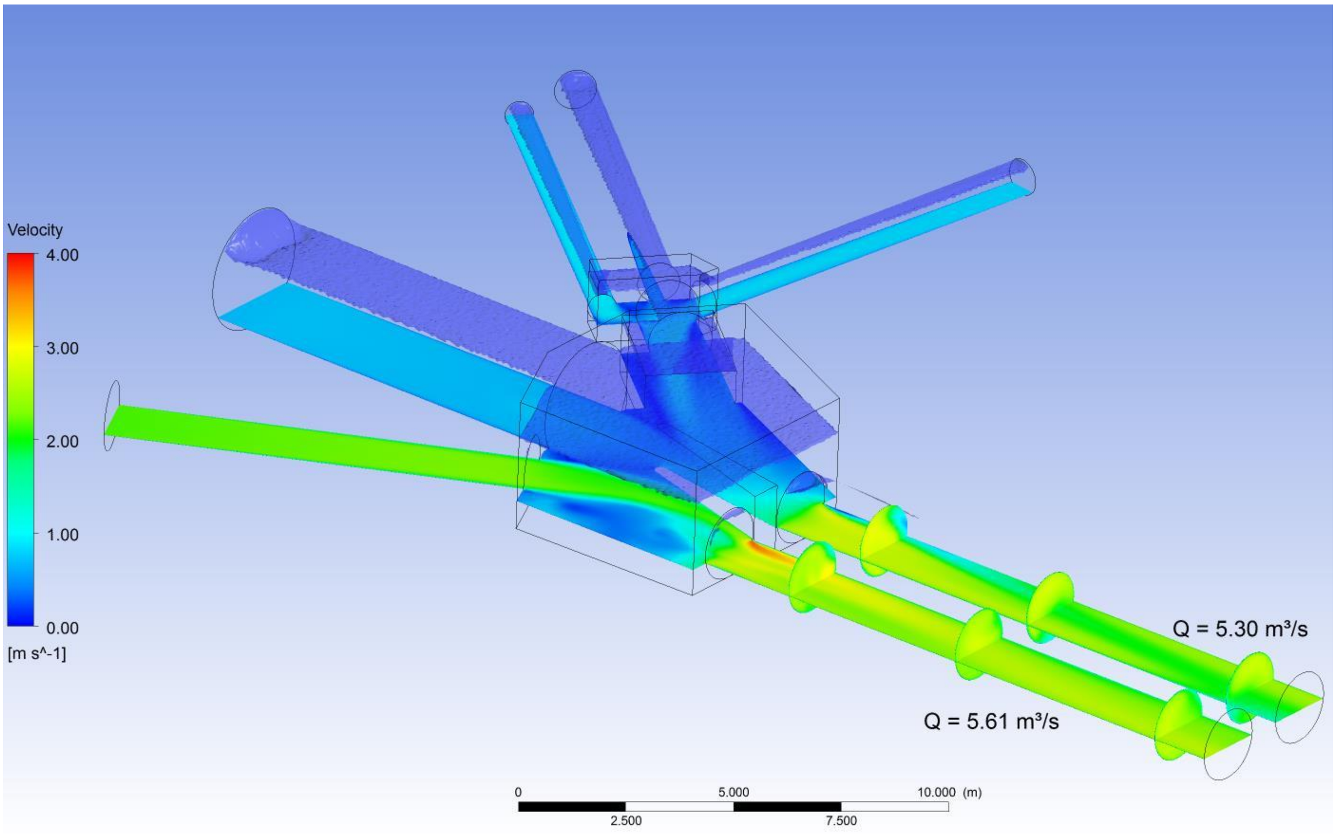


Figure 3: CFD model: upstream connection structure – velocity

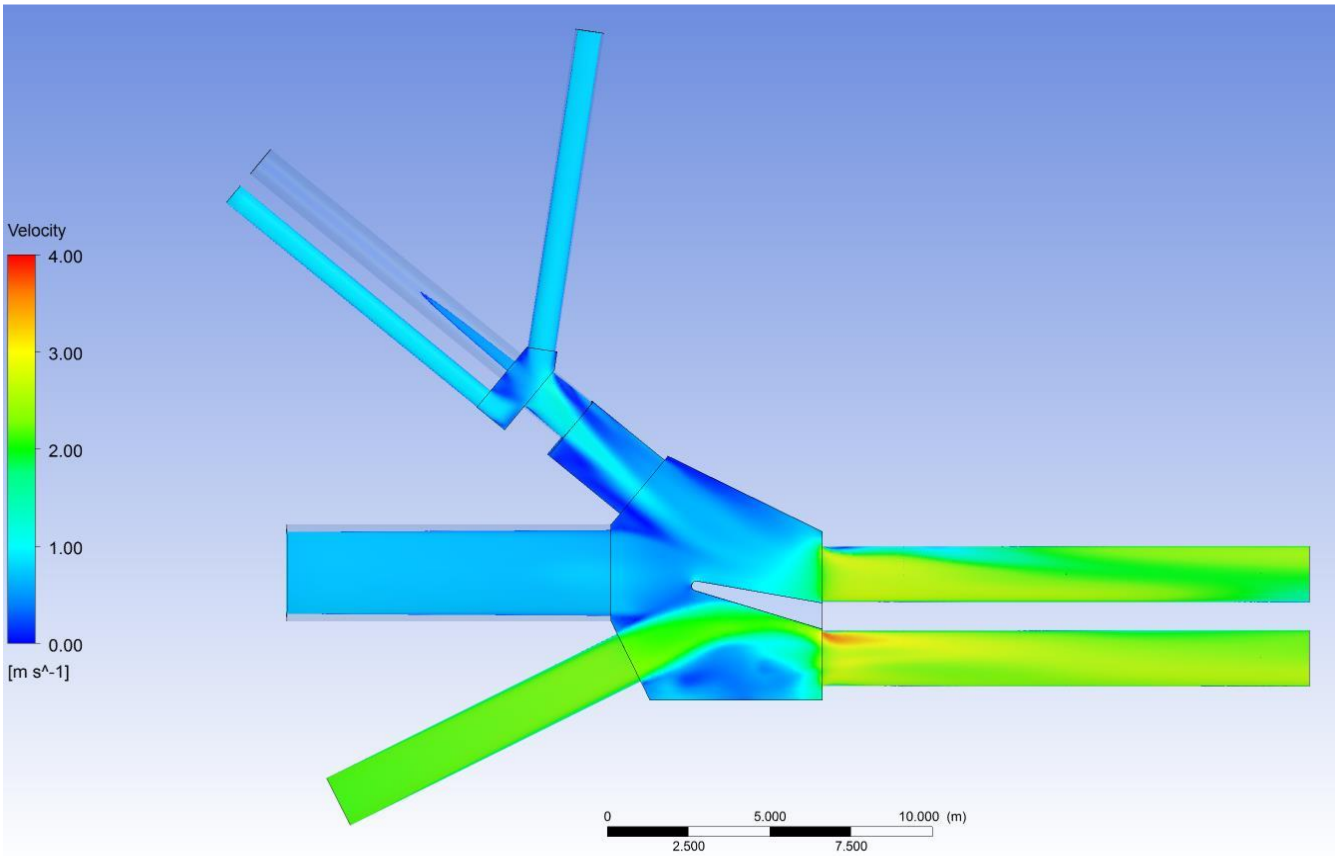
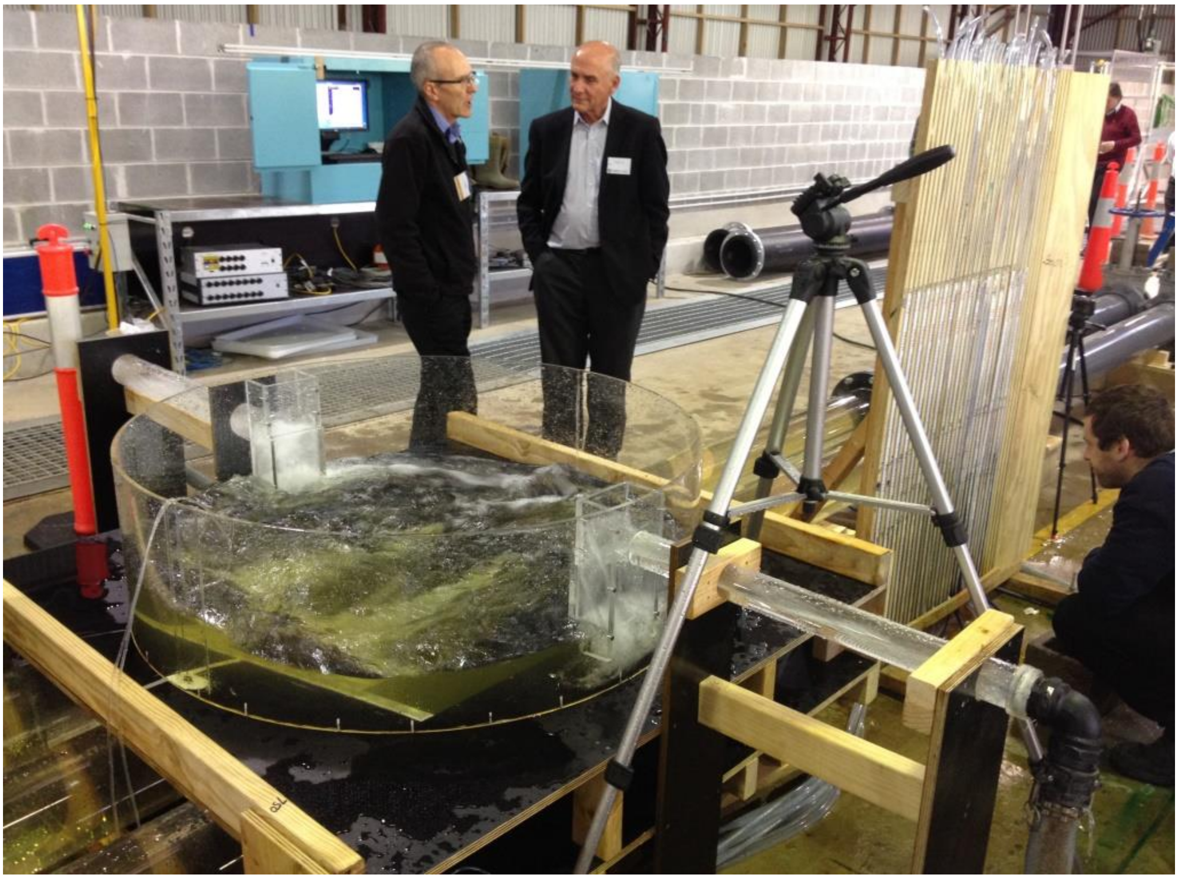
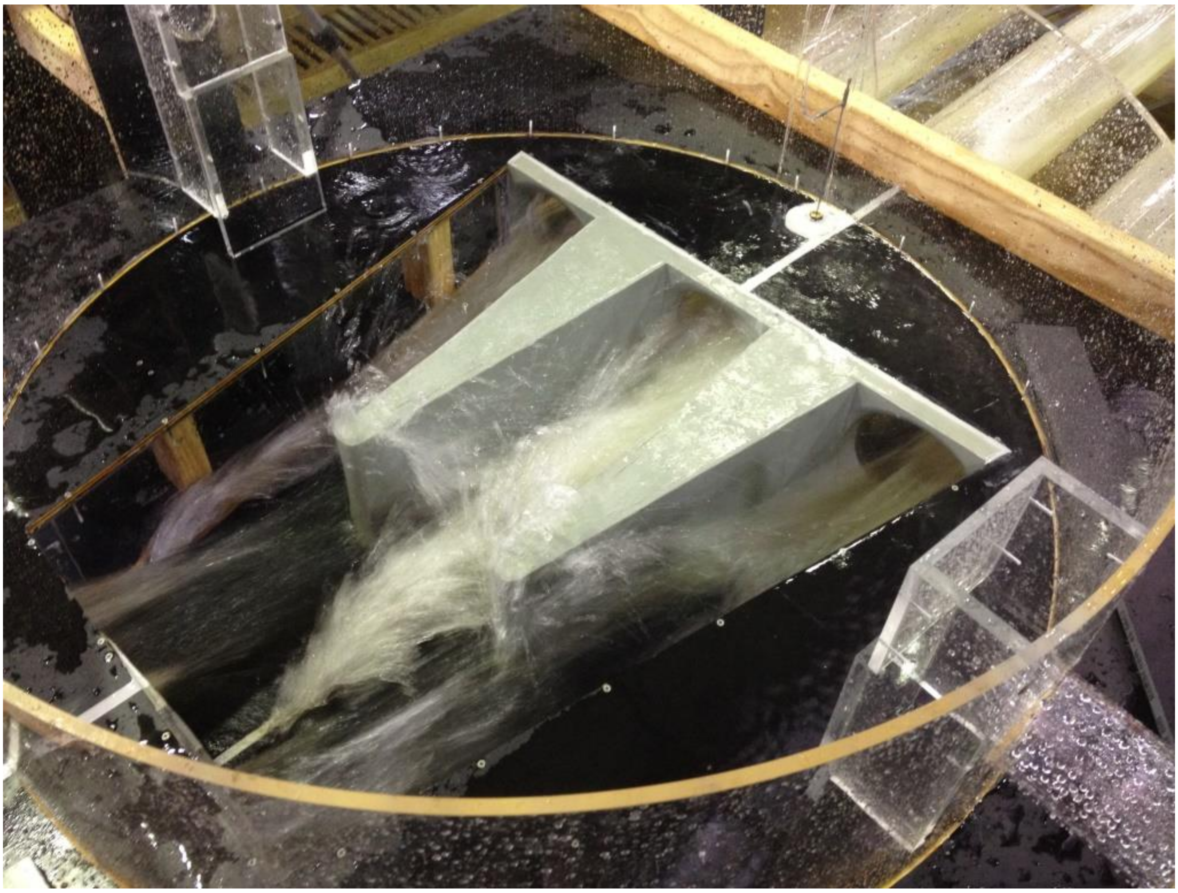


Figure 4: CFD model: upstream connection structure - velocity



Photograph 1: Physical model, three-pipe to two pipe transition



Photograph 2: Physical model - three-pipe to two pipe transition – low tailwater

The CFD and physical models also allowed optimisation of the final designs of a number of structures. For example, the alignment of guide walls was adjusted based on modelling to yield even flow splits between conduits for optimum hydraulic performance of the system.

The CFD and physical model results provided cross checking and verification of theoretical structure losses, providing certainty in the overall modelling and confidence that the system would operate as intended.

3.3 SURFACE FLOOD MODEL

The interaction between the hydraulic grade line (HGL) in the trunk drain and the surface flood water was modelled in TUFLOW. The model allowed assessments of the impact on surface flooding, of different flows and physical configurations of the GSSD.

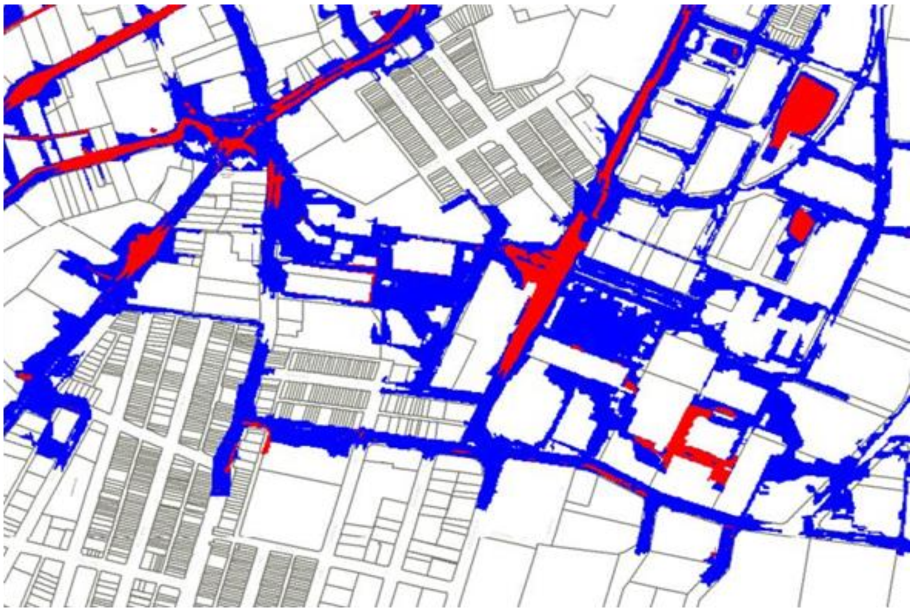


Figure 5: Flood hazard before GSSD

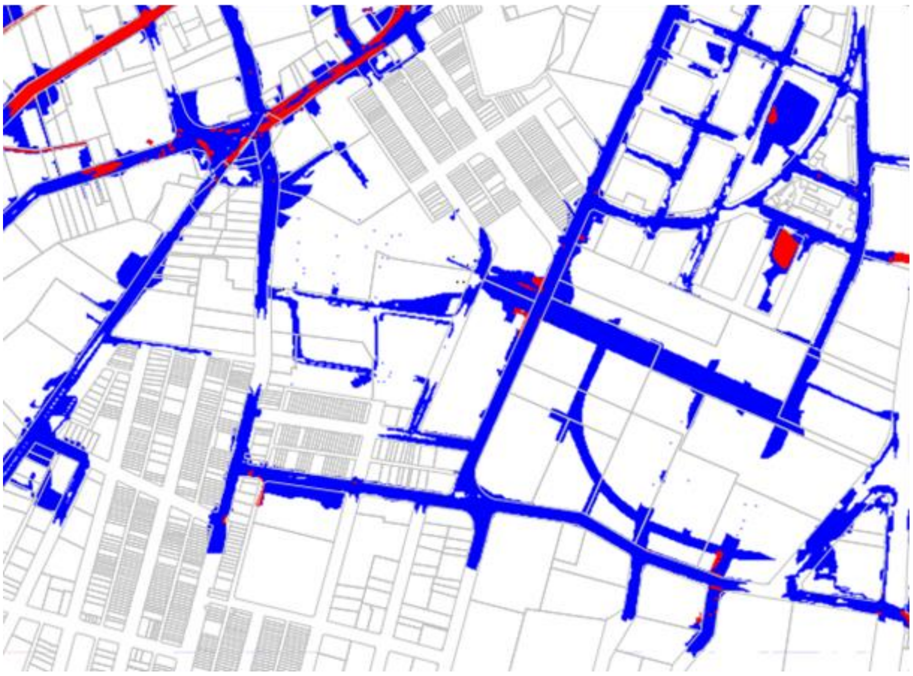


Figure 6: Flood hazard after GSSD

3.4 CHALLENGES

The hydraulic modelling was a challenge due to the large catchment and complex interaction of 1D and 2D elements. For example, there are over 1,500 pipes and pits in the overall catchment model. This resulted in very long run times of the 2D catchment model, which necessitated decoupling of the 1D trunk model so it could be modified and re-run more readily. This 1D trunk hydraulic model needed to be updated continuously during the design phase to account for the developing design and progressive results from the CFD and physical modelling. The site investigations, modelling, design and construction were run concurrently due to overall project time constraints, meaning that the model had to be repeatedly updated and re-run as designs developed and construction difficulties were encountered and overcome.

The trunk drain operates under pressure in the design 100 year storm event and the hydraulic grade line (HGL) analysis was critical to confirm flooding compliance. Where the HGL came close to the ground surface, the inlet capacity began to be impacted, resulting in an increase in surface flood levels. To address this, the trunk drain size in the upstream reaches was increased to provide additional conveyance and some additional temporary storage. This reduced the peak flow rate somewhat, due to the nature of the storm events in this catchment, which produce relatively short duration, peaky flow hydrographs.

The upstream reaches presented hydraulic challenges as the GSSD incorporates two (one per pipe) in-line gross pollutant traps (GPTs), each treating 3-month flows of 2.0 m3/s. Substantial design development in consultation with the GPT supplier resulted in a design for a streamlined diversion structure, which minimised the headloss at 1% AEP design flow. The diversion structure also has a 1.2 m drop in the floor to provide driving head for the vortex separator without compromising the streamlining of the through conduit.

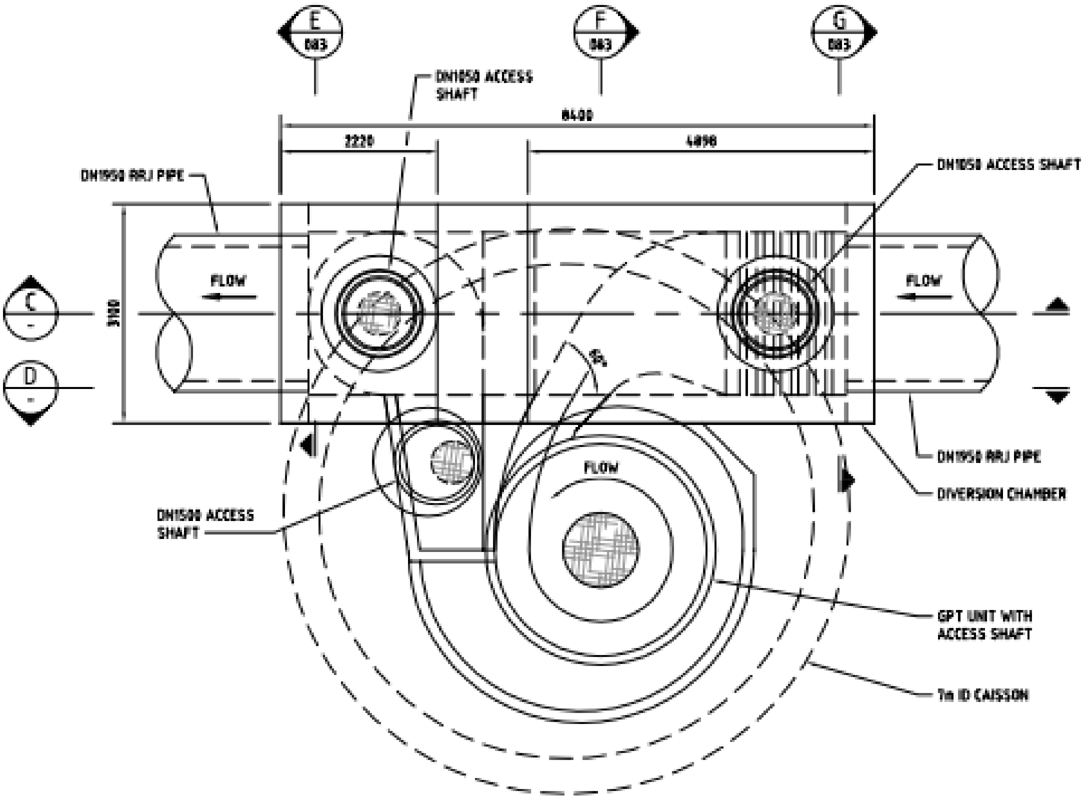


Figure 7: GPT plan

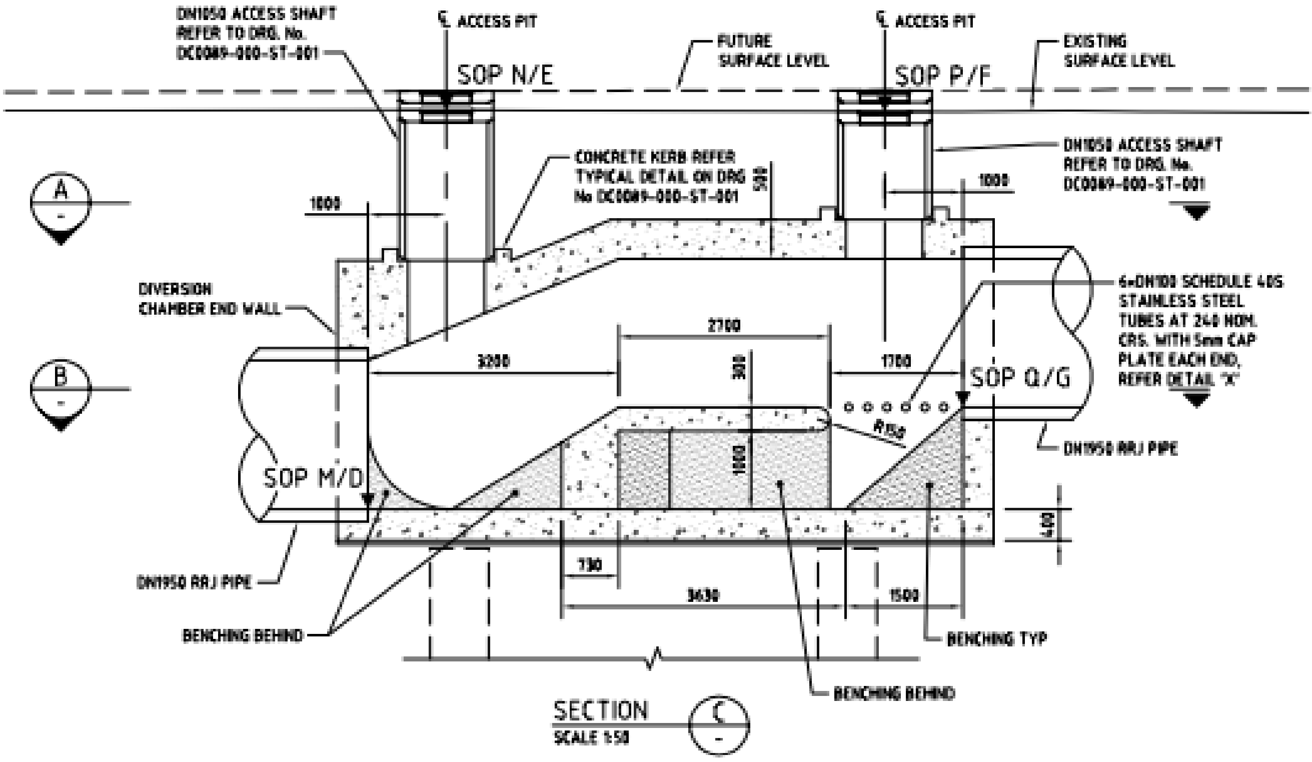


Figure 8: GPT diversion chamber section

The GSSD passes under Sydney's Main Southern Sewer at O'Riordan Street, requiring a significant longitudinal grade change and the potential for a hydraulic jump to form and entrain air into the flow. Hydraulic calculations showed that the flow velocity would transport air downstream and out the provided vent shafts, rather than trying to rise upstream or "blow-back", a potentially dangerous situation that can blow off access shaft covers. In the transition from part to full flow the resulting air movements were catered for by providing fully vented access shafts at the structures immediately upstream and downstream of the grade change, allowing free movement of air along the pipes.

Further downstream, the GSSD merges with the existing open channel trunk drain near Maddox Street. The confluence of flows (30 m3/s and 80 m3/s respectively) at this location was complex, with unpredictable hydraulic interaction. Different models yielded differing results, so the uncertainty was addressed by adopting the higher of the modelled water levels.

4 IMPLEMENTATION

4.1 MICROTUNNELLING

The deep drains were installed by microtunnelling using earth pressure balance tunnel boring. This suited the geotechnical conditions of low strength clays and silts and high groundwater tables. Microtunnelling was also often in uncontrolled fill that is contaminated with building waste, requiring careful monitoring and control of pump pressures to minimise the risk of settlement.

One section of the project, a diversion of the existing trunk drain required microtunnelling under an existing 100 year old DN840 steel lead-jointed water main with 200mm clearance. In consultation with Sydney Water operators, the water main joints were strengthened as insurance against damage and the microtunnel was successfully completed with no impact to the strategically important water main.

Microtunnelling construction benefits include:

- minimum impact on the more than 120 underground utilities that cross the GSSD alignment
- minimum impact on existing roads and developments (no open cut)
- minimum environmental impact (spoil and dewatering)
- minimum community impact (no open cut)
- cost effective hydraulic solution

Photograph 3: Microtunnel installation DN1800 pipe

4.2 HUNTLEY ST BRIDGE – WIN-WIN

The GSSD design was originally intended to transition from 3 x 1800 mm diameter pipes into a single large box culvert for the final 300m from Maddox St to Alexandra Canal. The box culvert was to be constructed into the bank of the existing open channel. This channel passes under Huntley Street via twin box culverts where there are more than 15 services up to 750mm in diameter. Some of the services pass through the walls of the twin box culverts (refer Figure 10), reducing the waterway area, resulting in afflux and exacerbating local flooding.

A constructability assessment for the installation of the box culvert within the narrow corridor between the existing open channel and adjacent buildings indicated that open trench box culvert construction would not be cost effective. An innovative solution was identified by the alliance, where the existing channel was widened and a new bridge constructed at Huntley Street, replacing the existing under-capacity box culverts. The hydraulic conveyance required by the GSSD was maintained via the widend channel, whilst the congested utilities at Huntley Street were rationalised and better managed with the bridge. An added benefit is that the local flooding will be reduced due to lower afflux at Huntley Street.
A landscape architect designed shared path for cyclists and pedestrians was also incorporated into the overall design, providing a transport linkage and future community benefits.

This win-win solution was made possible by the on-going consultation with the Project Owner, that an alliance of this type provides.

Photograph 4: Existing Huntley St culverts showing the many intruding services

5 CONCLUSIONS

The GSSD is a complex project that is essential to eliminate the high-hazard flooding from the area to deliver a liveable urban renewal of this inner-city area. It is being delivered through the cooperation of local and state government, construction contractors and designers in an alliance framework. This most beneficial and cost effective infrastructure is being built because of the thorough planning process and rigorous hydraulic modelling that has been undertaken, both as part of developing the reference design and by the alliance designers in optimising the final design. This work, together with the willingness of all to adopt innovative construction methods, will result in wide ranging community and economic benefits.

Photograph 5: Channel widening near Alexandra Canal outfall (artist's impression)

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