

Virginia Airport Emergency Stormwater Upgrade

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ABSTRACT

The Virginia Airport is located at the bottom of a large urban catchment in Durban North, Durban. Sections of the catchment are characterised by steep slopes and high runoff coefficients due to the large percentage of impervious pavements.

Subsequently, the resulting stormwater runoff during flooding events produces volumes that exceed the current stormwater infrastructure capacity, which is designed for a one in ten year storm return interval. This results in excess stormwater runoff becoming overland flow as it cannot enter the stormwater network. The overland flow accumulates at a critical point, where three sub catchments combine, at Virginia Airport. The overland flow floods the adjoining road infrastructure and enters the Virginia Airport premises, and flows into the airport buildings.

The stormwater network infrastructure capacity is further hampered by the constriction of the culvert outlet, which provides the exit point for the stormwater runoff into the ocean. The culvert exit point is constricted by the ingress of marine sediment during tidal cycles. The marine sediment accumulates in the culvert, preventing the culvert from operating optimally. Although periodic flushing occurs during smaller rainfall events, the initial choking effect compounds large flooding events.

This project involved detailed 1D and Quasi-2D modelling of the catchment that assisted the design process to alter the storm discharge characteristics in order to mitigate flood inundation at the Virginia Airport. The project required a multi-lateral approach of solutions in order to mitigate future flooding events.

INTRODUCTION

Anthropogenic impacts on stormwater runoff are generally well understood to result in increased runoff and changes in flow characteristics. With ever increasing development resulting in higher runoff volumes and less natural depression storage in catchment the need to manage existing stormwater infrastructure and improve current design techniques is often challenging for most municipalities.

Whereas new developments are faced with the question of 'climate change' effect on the precipitation characterisation and consequential runoff, current infrastructure is often limited by acceptable mitigation options. These options are generally constrained due to the budget required to work in existing developed areas, or the implications on current users of the area to be disrupted. Although some may argue the cause of climate change, scientists generally agree that there will be an increase in the frequency of high intensity storms.

In order to provide managers with mitigation outcome options, the use of models are generally utilised. These provide insight into how old infrastructure can function with new design options, and thus help reduce unforeseeable engineering 'mishaps'. Such events often occur when dealing with stormwater runoff due to rapid changes in flow and high velocities that may occur.

PROJECT BACKGROUND

The Virginia Airport is located at the bottom of a large urban catchment. Sections of the catchment are characterised by steep slopes and high runoff coefficients due to the large percentage of impervious pavements (see Figure 1).

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The stormwater network infrastructure capacity is further hampered by the constriction of the culvert outlet, which provides the exit point for the stormwater runoff into the ocean. The culvert exit point is constricted by the ingress of marine sediment during tidal cycles. The marine sediment accumulates in the culvert, preventing the culvert from operating optimally (see Figure 2). Although periodic flushing occurs during smaller rainfall events, the initial choking effect compounds large flooding events.

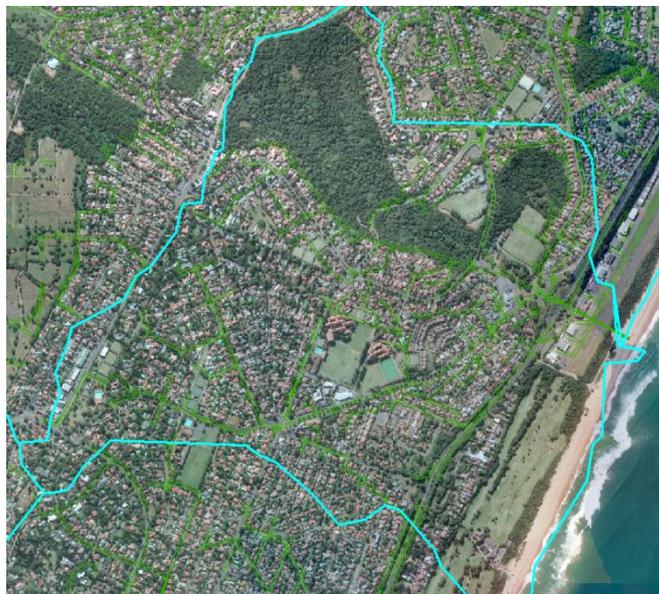


Figure 1: Virginia airport catchment



Figure 2: Stormwater culvert blocked by the ingress of marine sediment

The stormwater system functions satisfactory for most precipitation events with continual maintenance to clear out the marine sediment. However, when a large storm event occurs preceded by light rains to saturate the catchment depression storage, and the culvert is marginally blocked, causing flood damage to the lower catchment. Figure 3 illustrates recent storm flood inundation at the airport.



Figure 3: Flood inundation in the parking lot, and flood water flowing through the airport building.

METHODOLOGY

Site investigations

Preliminary site investigations focussed on gathering field data, liaison with the community and affected businesses within the airport region, compiling rainfall statistics and a flood event history timeline. This provided the basic analysis to better understand catchment development, increased flooding occurrence and problems areas to be focus on.

The site investigations indicated that flooding patterns varied, which underlined a better understanding of how the system function and responded to flood events. This entailed an extensive Geographic Information System(GIS) investigation and setting up a Storm Water Management Model(SWMM) 5 1D model. Validation of GIS data can prove time consuming. Two surveys were commissioned in addition to a desktop study approach that was used to fill in missing data.

Catchment modeling

Field data highlighted two main flooding patterns. One governed by the ingress of marine sediment, and the second by overland flow. In order to understand whether the blocked outfall caused the overland flow, or whether the infrastructure capacity was exceeded first, a model was set up.

The Environmental Protection Agency's(EPA) SWMM5 model was selected and setup for the entire catchment. Sub-catchments of approximately ten houses per group were identified. GIS tools were used to generate Rasta layers from 2m contour data and then to infer zonal statistics for sub-catchment properties required for the model. A multitude of dual drainage systems were created in order to replicate field observation data obtained for flooding events from the community. This allowed for all surcharging manhole water volumes to be accounted for and improve accuracy of the model outputs.

Calibration and validation of the model was done with the use of a water level and rainfall data. An acoustic doppler water surface height measuring instrument was installed early on in the project in a manhole located at the airport. Measurements of 5 to 15 minute intervals provided a large data set with which to calibrate the model using rainfall data from a gauge within the catchment. Validation was done in a similar manner routing subsequent rainfall data and comparing simulated runoff against measured stormwater runoff values. Validation was also done by comparing model simulation estimated overland flood volumes to water level depth reported in and around the airport building. Here, actual hind cast rainfall data for large storm events were simulated.



Figure 4: Stormwater network in the lower lying section of the flooding section in SWMM5

Modeling results

The modeling results indicated that a two pronged approach to mitigate flooding was required: (1) the extension of the culvert to prevent marine ingress blockages occurring and (2) the altering of runoff flow time characteristics. Initially it was thought that just extending the culvert would prevent flooding. The analysis showed however that the change in grade from steep to flat in the lower lying section of the catchment induced a hydraulic jump essentially in the three main 1200mm stormwater pipes before the airport. This change in grade resulted in a backup of water in the system that surcharged several manholes in the lower lying areas (see Figure 5). Even with an unblocked outfall, the system would flood the lower catchment. In a specific storm event the box culvert roof slab was lifted up by the pressure build up in the system, resulting in two strips of approximately 30m in length before and after the runway being lifted. This was purely due to a blocked outfall and did not significantly flood the lower catchment.

The use of a quasi 2D inundation model was also used to check the overland flow results from the 1D model. Figure 6 illustrates the overland flow flooding event model. The models setup was based on a digital elevation model that incorporated 2m contour data and surveyed spot heights.

DESIGN APPROACH

Multi-lateral approach

The convergence of three 1200mm stormwater pipes draining the south, central and northern regions was primarily responsible for surcharging the system. The three converge into a manhole just landward of the

airport, and just seaward of the Virginia turning circle. The initial design approach was to re-route all three stormwater pipes into a large dry detention pond in the circle. The hydraulic modeling indicated that the pond size possible, limited by the circumference of the road network and the very high ground water table in the region, would not reduce the flooding potential. A second design approach used the hydraulic model to investigate mitigation scenario permutations to find an optimum flow pattern incorporating new stormwater sections and various attenuation options. Figure 7 presents the multi-lateral design approach adopted to mitigate the flood of the lower section of the catchment.

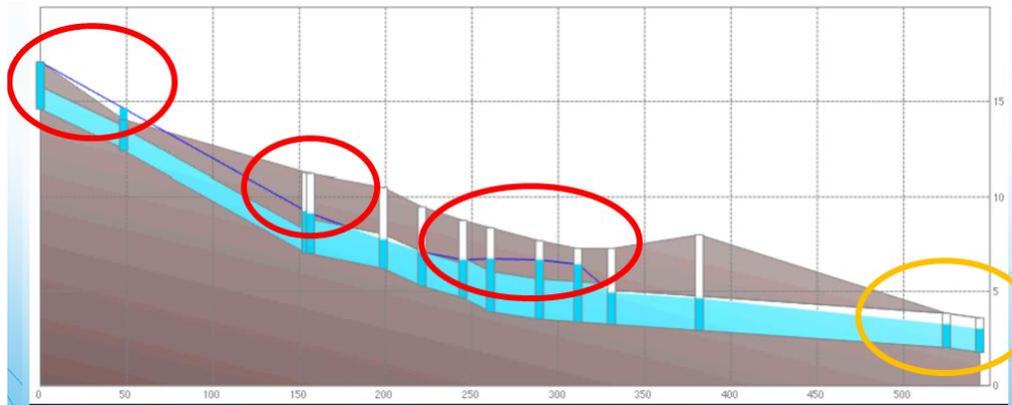


Figure 5: Flooding at several nodes due to gradient changes and not marine sand ingress

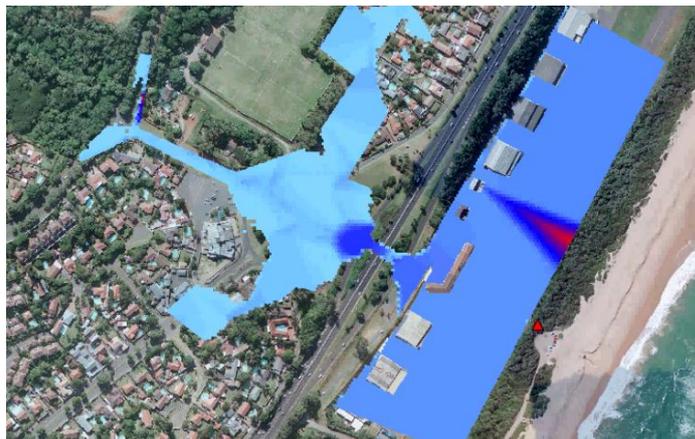


Figure 6: Flooding simulation results from a quasi 2D model



Figure 7: Multi-lateral approach to mitigate flooding

Part (a & b) involved the lowering of the ground level by approximately 1.5 to 2.5m and constructing 10 000 m³ and 2 000 m³ dry detention ponds. Limited by a high ground water table in depth, bank slopes were increased and a multi-cell embankment stabilised with grass used. An active sewer system was diverted around the new pond edge (e). Part (c) required some ingenuity as the pond was to remain dry and only function during high rainfall events. The new stormwater 1200mm stormwater pipe system placed in (d) flowed into a dual manhole chamber. During low flows, the stormwater would be re-directed in the chamber via a constriction point into the old existing stormwater system. The constriction was designed so that when flow rates exceeded a threshold, the excess flow would be diverted into the pond.

Alterations were also made to the overland flow (f) so as to divert the surface flow on the street to a small stormwater system that fed into (b). A new development of a shopping centre (g) required restrictions in the stormwater run-off and onsite storage to reduce additional stress on the system.

The combination of all these parts provided the optimum flood mitigation for the lower catchment. However, the key finding was that if the timing of the flows of the three main stormwater pipes could be changed, the surcharging manholes would be significantly reduced. In other words, the main objective of the detention pond is to retain the central stormwater pipe discharge in the detention pond, whilst the northern and southern runoff volumes pass through. The stored volume then enters the existing system after their peaks have passed through.

The design of the culvert extension highlighted the success of an extensive monitoring program implemented by the local authorities. Figure 8 presents surveys measured of the beach profile over several years. If one only had a snap shot of the beach width and profile in 2012, a culvert extension of approximately 20m seawards would appear satisfactory. Fortunately, profiles for several years back were recorded that indicated the necessity of a 48m extension to exceed the 90th percentile of maintaining an open culvert. If the beach profile survey had been done after the project had commenced, the culvert would have been designed too short, and once the beach profiles returned to normal, the culvert would have been blocked again.

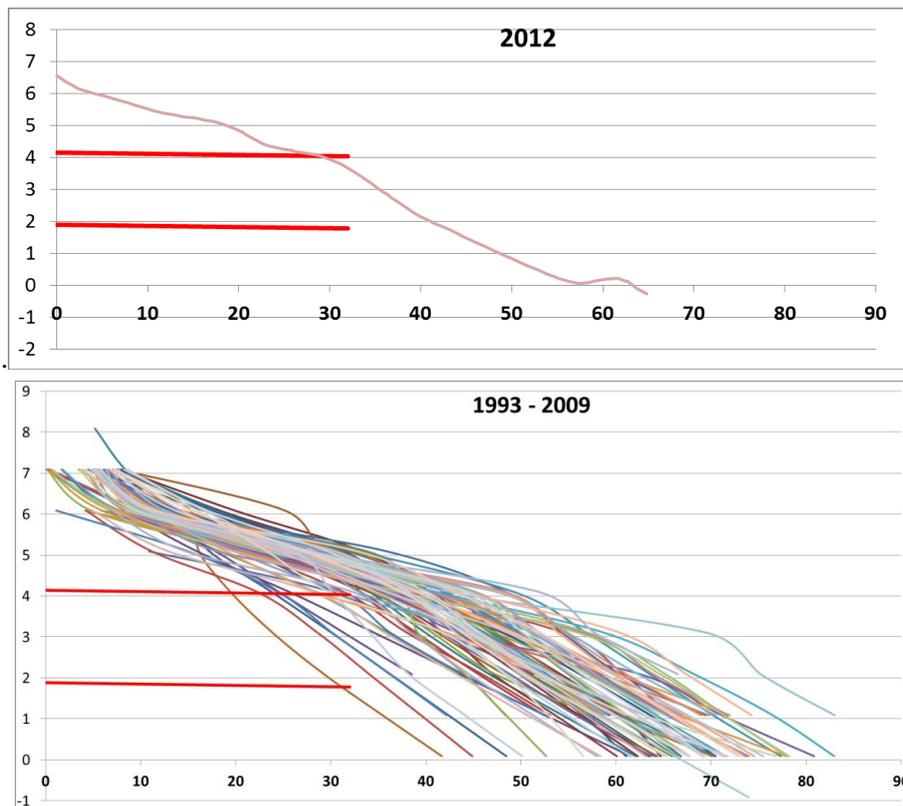


Figure 8: Culvert extension length determination – looking at a snap shot in 2012 and then looking at a combination of data sets collated from 1993 to 2009.

CONSTRUCTION PHASE

Detention Pond

The construction phase of the detention pond and surrounding upgrades was awarded with a six month contract. The bulk of the costing involved the excavation and removal of the soil to spoil. The sediment characterisation indicated the sediment to be of good quality, and it was eventually utilised in the lining and subsoil layers of the landfill site. This was deemed a success in terms of bi-lateral usage of the material removed from site.

Due to the limitations of sizing the pond, between the road circle and high water table, berms were created on the lower end of the pond. The ground level has a natural slope towards the east, and so a semi-circle berm was built on the lower end top embankment to increase the capacity of the pond. Figure 8 illustrates the use of a multi cell that was planted with grass to increase side slopes for an increased capacity, while maintaining a natural appearance as oppose to the use of retaining blocks. The berms were however limited in height so as to allow the public to see into the pond, whether in a vehicle or walking past. This was a safety concern that was incorporated into the design.

The community also played a large role in the construction approach of the detention pond. Initially the design incorporated an open air theatre that could accommodate small events such as Christmas Carols. This was turned down by the community, but a request was made to save some of the old fig trees and maintain a green park appearance. In order to achieve this, the design team worked with the contractor and horticulturist to ‘save’ the fig trees. By lifting the trees up with an excavator and lowering the ground level below them, before replanting, the fig trees were kept in place, at 3m below original level. The trees took several weeks to respond, but have successfully grown again (see Figure 9 to see the 2 largest ones in the middle of the construction site).



Figure 9: Construction around several old fig trees resulted in the successful replanting of them to the communities delight.



Figure 10: The use of multi-cell planted with grass allowed steeper gradients to increase capacity and the natural appearance of the pond. The multi-cell was also used with concrete to build open channels, linking low flows through the pond from adjacent stormwater manholes to the outlet of the pond.

Control Point

The construction of the control point for the detention pond required the construction of a large chamber to incorporate the control constriction opening and link into the existing stormwater system. The high ground was tabled, and higher than average rainfall during made construction troublesome. The chamber needed to withstand large flows and high velocities impacting on the wall. Normal dry flows were redirected through the constriction opening, but once flow exceeded a threshold value of approximately $1\text{m}^3/\text{s}$, the chamber is forced to surcharge out an opening to the detention pond. Due to the high velocities exiting the chamber into the detention pond, an extensive break down system was built (see Figure 9).



Figure 11: Construction of the control point diverting flows above $1\text{m}^3/\text{s}$ threshold from the chamber into the detention pond.

In order for the detention pond project to be aesthetically pleasing to the community and enhance the 'green zone' of the area, the contract included planting of grass and approximately 20 new fig trees along the streets. Figure 10 presents the project just after completion with the control chamber in action.



Figure 12: Post construction of the Virginia dry detention pond and the control chamber in action.

CONCLUSIONS

The project, although simple from a construction point of view, required an in-depth modeling program to understand how the system was functioning and what mitigation options would actually work. In many projects the modeling only assists in the design phase, but this one certainly highlighted the need for a modeling approach pre-design. Some suggestions of just expanding or extending the culvert under the airport may well have helped, but in all probability would not have prevented future flooding.

The project highlighted the importance of on-going collection of data. Be it survey, rainfall, flow or beach slope measurements, the collection and generation of historical datasets is often overlooked in municipal budgets, until the importance of this data is realised in hindsight. Had the project only extended the

culvert by 20 to 30m as indicated in a limited data set, and the sand levels returned to that of a year ago, the money spend would have been wasted to the rates payers.

The control chamber has functioned well, although we are still waiting for a very large storm event to fully test the dry detention pond. The velocities and flow rates due to the steep catchment have created problems entering the pond, but with minor augmentations post construction, the scouring of the grass is now expected to be insignificant. It highlights that at the end of the day, the modelling has assisted greatly, but we will need to continually monitor and record observations as storms occur to see if improvements are required.