Estimating the Treatment Performance and OSD Characteristics of Both Proprietary and Non-proprietary WSUD Systems at Castle Hill in Sydney

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Abstract

In Water Sensitive Urban Design (WSUD) there is often a focus on water quality control. In practice however, there is normally a need to provide extensive flood control, often through some form of on-site stormwater detention (OSD). Techniques such as stormwater infiltration and stormwater reuse allow opportunities for on-site retention, with little or no downstream stormwater discharge. However in heavy clay soils this is not always achievable and a hybrid WSUD/OSD system is often desirable.

The first part of this paper examines the conceptual development of such a hybrid system that was able to achieve good WSUD objectives while still satisfying the local government authority's OSD requirements, which is one of the most stringent in Sydney. The issues arising from the realisation of that concept design through the detailed design and construction phases are also described.

The second part of the paper explores various techniques for modelling such hybrid systems using the MUSIC program. There are several Water Sensitive Urban Design (WSUD) models available in Australia, including MUSIC, ERWIN and Switch2. However, while such software can readily model standard WSUD components such as bioretention systems, it can be difficult to use the models for non-standard hybrid systems and proprietary products such as the Rocla ecoRAIN and the HydroCon Stormwater System. The examples used to illustrate the techniques are all taken from an actual development at Castle Hill, involving a 64-lot residential subdivision in north-western Sydney that incorporates an integrated WSUD system. The modelling of both water quality treatment and the provision of on-site stormwater detention (OSD) are examined and detailed guidelines for adapting off-the-shelf software are provided.

Comparisons with simpler analysis procedures, such as regression equations and the NSW EPA Level One Type Assessment are also made, and the limitations of such approaches are explained.

1. INTRODUCTION

1.1. The Development Project

The 4.98ha site is located at the corner of Old Castle Hill Road and Heritage Park Drive, Castle Hill. The site is situated on cleared land and is currently under consideration for 64-lot residential subdivision. The site is owned and being developed by Mirvac Homes Pty Ltd. See Figures 1 and 2.

Water Sensitive Urban Design (WSUD) features were initially included within the proposed development to satisfy the requirements of Council's DCP. Upon further investigation it was decided that numerous best management practices (BMP) would be incorporated into the development to achieve an environmentally sensitive project. The WSUD BMPs were seen as a distinct marketing advantage by the developer to maximise lot returns.

Downstream of the site is the Heritage Mews development. A staged development, this integrated site includes several WSUD methods including rainwater tanks, infiltration trenches and UniSATanks within the road carriageway. The current development proposal by Mirvac Homes aims to complement and expand on the existing downstream WSUD measures.

For the project described in this paper, the architect is HPA Pty Ltd while UmbaCo Landscape Architects Pty Ltd has prepared landscaping plans.

1.2. The Development Site

The site is situated on a relatively steep grade. The soil stratum consists of approximately 300-400mm of topsoil overlying silty-clay. Shale is encountered at relatively shallow depths generally between 1.1 and 2m.

Limitations of the site were considerable and included:

- Steep site gradients (generally greater than 15%)
- Shallow rock depths (1.1m to 2m)
- Substrata of silty-clay representing limited infiltration opportunities
- Existing creek line and variable width riparian zone required by DIPNR
- Restricted Development Area (RDA) of some 0.95ha for passive recreation purposes

Numerous WSUD BMPs have been proposed for the site. These include:

- 3.9kL rainwater reuse tanks for each of the proposed 64 residential lots. Tanks are to be connected to external taps for garden use and internally to the downstairs toilet.
- Hybridised HydroCon Stormwater Systems along the main creek line to treat road and lot runoff prior to controlled discharge into the creek system.
- HydroCon Stormwater Systems in the rear of yards, again discharging to an ephemeral creek.
- Bag inserts in all street pits to trap gross pollutants at the source and maximize the longevity of the downstream BMPs.

Numerous options were investigated in order to meet Council's OSD requirements. Such options included underground tanks within the road carriageway and larger rainwater tanks incorporating dedicated OSD storage.

Ultimately, 3.9kL rainwater tanks overflowing into an extensive HydroCon Stormwater System were adopted for detailed concept modelling.

Several models have been developed to simulate the behaviour of the proposed WSUD system. The modelling work includes water balance, conceptual treatment measures, water quality modelling and on-site detention volume calculations.

2. CONCEPT DESIGN

2.1. Design Principles

The development at Castle Hill proposes to integrate water sensitive urban design (WSUD) principles into the treatment of on-site stormwater runoff. The source controls at the site consists of:

1. *On-Site Detention (OSD)*
   This utilises on-site rainwater tanks to collect, store and reuse roof runoff for household toilet flushing and associated outdoor use. Further OSD storage volume is contained in a confined WSUD hybrid system that includes the HydroCon porous pipe technology.
2. *Stormwater Runoff Treatment*
   This is effected primarily using HydroCon systems to treat on-site road and lot runoff as well as any rainwater tank overflows.

The final concept design included dimensions and site locations for the proposed system components, as shown in Figure 3.

Figure 1 Pre-development Site at Castle Hill (looking southeast towards Old Castle Hill Road) Note eucalypts and weeds along one of the ephemeral creek lines.

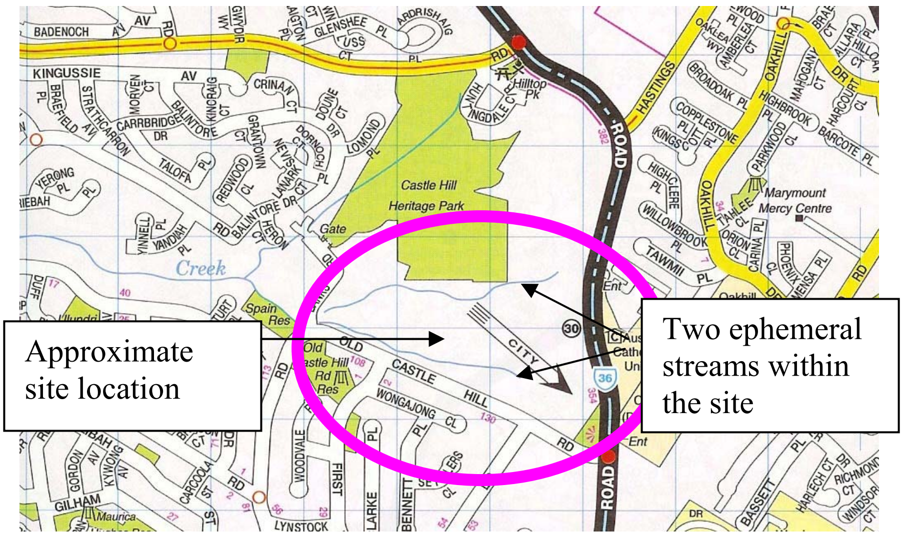

Figure 2 Site Location.

2.2. On-Site Detention

As well as providing enhanced water quality control, the HydroCon Stormwater System also afforded the additional benefit of providing large storage volumes for on-site detention of stormwater. By controlling the outflow, it was possible to achieve 575 m^3 of storage across the site. Together with a proportion of the volume of the above ground rainwater tanks, this allows matching of the pre- and post-development peak discharges.

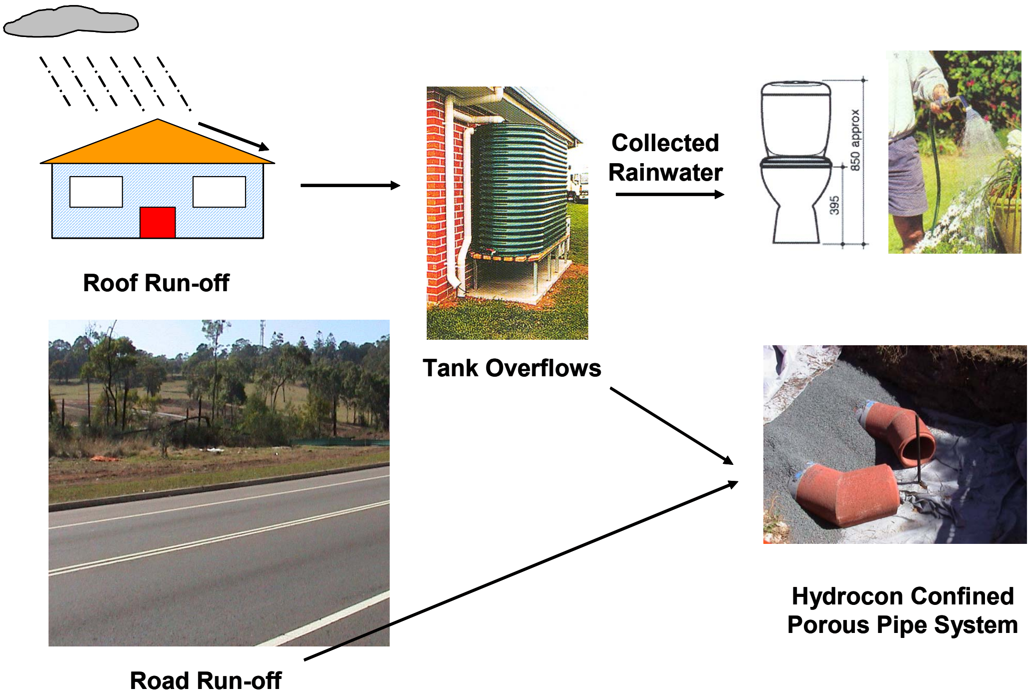

Figure 3 Concept WSUD System.

2.3. Water Quality Treatment

The HydroCon Stormwater Treatment and Management System to be used at Castle Hill represents an innovative water sensitive stormwater management technique. The system provides a cost effective and sustainable alternative to traditional drainage systems, enabling treated stormwater to be retained for re-use, infiltrated into the ground or discharged into waterways in a controlled manner (Dierkes et al. 2002a, 2002b).

The Castle Hill development proposes to use 600 metres of HydroCon porous concrete pipe and 12 HydroCon pre-filtering chambers or pits. The system will be located underground embedded in 1 metre wide gravel filled trenches, partially lined with geotextile to allow filtration direct to ephemeral streams.

The system is able to treat stormwater on-site through a multiple stage treatment process. A unique aspect of the system is its ability to remove pollutants such as heavy metals, hydrocarbons and nutrients both in particulate and dissolved forms.

Particles are removed by sedimentation, adsorption and filtration, while oxides added during the manufacture of porous concrete components trigger ion exchange or chemical precipitation of soluble heavy metals and phosphorus. Precipitation is assisted by interaction between the porous concrete and the stormwater, which is typically acidic.

The majority of sediment and associated pollutant particles are trapped in the pre-filtering chamber. Although not required for the Castle Hill development, treatment is enhanced when a single or multilayered porous concrete filter is fitted within the chamber.

Stormwater is forced upwards within the pre-filtering chamber (through the filter if fitted) before flowing horizontally into the HydroCon pipes. The relatively large pipe diameter (500 mm) reduces turbulence and promotes sedimentation. The bottom of the pipes is sealed, allowing any sediment not retained in the pre-filtering chamber to settle on the bottom. Filtration and chemical precipitation occur as water moves through the walls of the pipes.

Final treatment takes place in the gravel media surrounding the pipes and in biofilms formed in the pipes themselves. The media assists with biological reduction, breaking down remaining organic substances and nutrients, particularly nitrates.

Tests in Germany have shown a removal efficiency of over 98% in the case of lead and copper, and over 95% for zinc and cadmium. Removal rates for phosphorus range between 90–98%. Removal rates for nitrates depend on the system residence time.

The system is easy to maintain. A maintenance regime can be established by monitoring sediment accumulation in the pits and pipes during the first twelve months following installation. Sediment in the pipes can be flushed into the pits, where it can be removed either manually or mechanically. Filters, where fitted, are self-cleansing, long lasting and relatively inexpensive to replace.

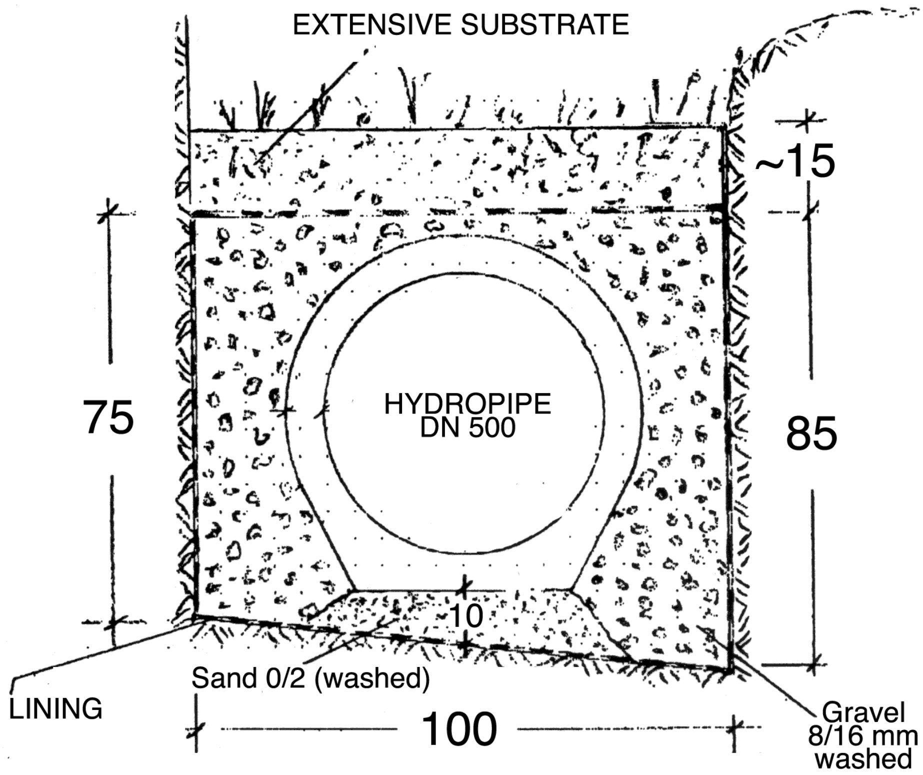

Figure 4 Final Design of Confined HydroCon Stormwater System.

3. WATER QUALITY MODELLING

3.1. MUSIC

Modelling was carried out to determine the extent of the pollutant removal of each of the proposed systems. One model used was the Model for Urban Stormwater Improvement Conceptualisation (MUSIC, v1). The site was broken into nine sub-models in MUSIC as shown in Figure 5.

MUSIC has been developed by the Cooperative Research Centre for Catchment Hydrology (CRCCH) as an aid for decision making as it predicts the performance of stormwater quality management systems. It is intended to help organisations plan and design (at a conceptual level) appropriate stormwater management systems for their catchments (CRCCH, 2001).

MUSIC, like most off-the-shelf water quality modelling programs, does not contain pre-designed modules for simulating proprietary products such as the HydroCon Stormwater System. It is therefore necessary to adapt MUSIC standard elements to achieve satisfactory results. It was decided that the most suitable standard MUSIC element to adapt was the bioretention system, since it contained similar system components such as overlying vegetative filters, soil surround media (filter soil) and subsurface porous pipes. MUSIC simulates the removal of pollutants in a bioretention system by modelling both the treatment in the storage over the soil filter and the treatment in the soil filter itself.

3.2. Treatment in the Storage Over the Soil Filter (Ponding Area)

MUSIC uses a combination of two principles to create a model that is suited to treating stormwater runoff entering into the ponding area of a bioretention system. This model is known as the Universal Stormwater Treatment Model (USTM). The principles are:

1. The First Order Kinetic (k-C*) Model

   The basis of this model is the idea that as water containing pollutants enters into an area, such as the ponding area of a bioretention system, the concentration of the pollutants move by an exponential decay process towards the background concentration or equilibrium value (CRC, 2002).

   The process can be described mathematically as:

$$\frac{\left(C_{out} - C^*\right)}{\left(C_{in} - C^*\right)} = e^{\frac{-k}{q}} \qquad 1$$

   where C* = background concentration or equilibrium value
   C_{in} = input concentration
   C_{out} = output concentration
   k = exponential rate constant
   q = hydraulic loading (flow rate per surface area)

2. Continuously Stirred Tank Reactors (CSTRs)

   The reason for the development of the concept of CSTRs is the idea that as water containing pollutants enters an area, such as the ponding area of a bioretention system, the water is likely to disperse because of turbulence. This can be modelled as a set of well-mixed waterbodies positioned within the ponding area of the bioretention system (CRC, 2002). These waterbodies are represented as CSTRs.

   The number of CSTRs used has a great impact on the modelled behaviour. Typically 3 CSTR cells are used to model a bioretention system.

3.3. Treatment in the Soil Filter

The treatment that takes place in the soil filter of the bioretention system is largely dependent on the detention time and the diameter of the particles in the soil filter.

The detention time is calculated from the hydraulic conductivity and the depth of the filter medium. There is a strong analogy in this situation with the k-C* model. In version 1 of MUSIC however, fixed equations or transfer functions are used to model the behaviour of the filter. These are (CRC, 2002):

Log SS Output% = 1.00 – 0.27 log (Detention Time / Particle Size) *2*
Log TP Output% = 1.64 – 0.10 log (Detention Time / Particle Size) *3*
Log TN Output% = 1.80 – 0.06 log (Detention Time / Particle Size) *4*

Where, Detention time is in days and Particle Size and Particle Diameter are in mm. SS, TP and TN refer to suspended solids, total phosphorus and total nitrogen respectively.

With its Continuously Stirred Tank Reactor model to account for hydrodynamic behaviour, the USTM is a key component of MUSIC. However, the current USTM model has a number of limitations, not the least being the assumption that a first-order decay model adequately describes the treatment processes (Kadlec, 2000). Ongoing research at the CRCCH is aimed at refining the USTM model to improve the performance of the MUSIC model.

3.4. Model Calibration

An experimental investigation is currently underway at the University of Technology Sydney (UTS) to collect field and laboratory data to calibrate the HydroCon modelling in MUSIC. Funded by the Australian Research Council (ARC), field data from three HydroCon Systems installed at three sites in NSW are being collected. The treatment processes are being investigated through batch and column studies. Working with the CRCCH, it is intended that these investigations will lead to the development of a Technical Note to be issued with future versions of MUSIC to enable modellers to model HydroCon Systems directly with the software.

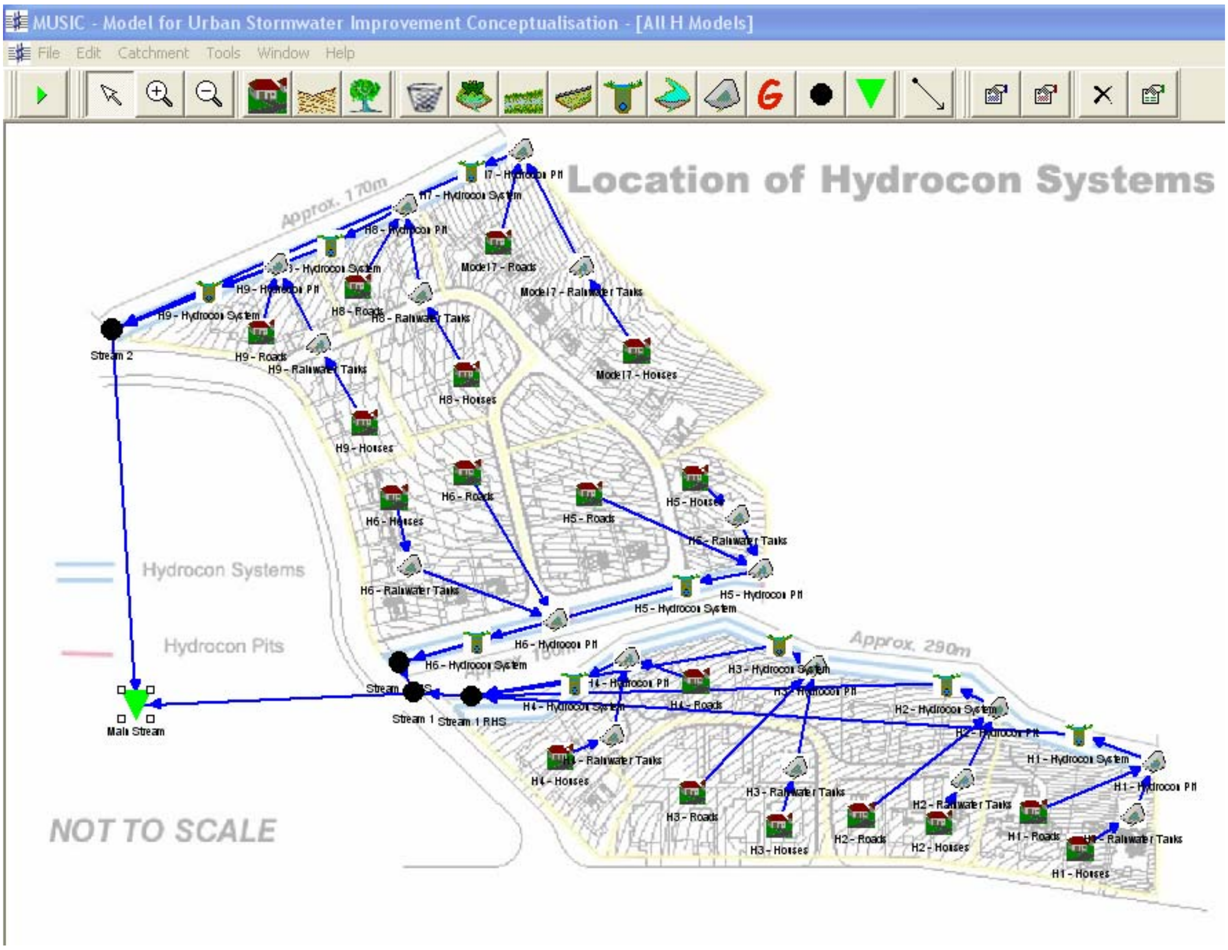

Figure 5 Sub-Model Layout.

3.5. Modelling Results

To compare the performance of the hybridised HydroCon Stormwater System with a conventional bioretention system, both configurations were modelled in MUSIC. Table 1 shows the median and 90th percentile values for the key pollutant types for both systems. While the table indicates that the bioretention system performance is slightly better than the HydroCon, this is simply due to the way the HydroCon Systems had to be modelled in MUSIC. Since the HydroCon Systems have larger pipe diameters and reduced filter media volumes, the routines in MUSIC predict a slightly lower treatment performance. MUSIC is currently not able to simulate the enhanced treatment afforded by the HydroCon system, as described in Section 2.3. Consequently the water quality improvement achieved by the HydroCon System in practice is likely to be better than the MUSIC modelling predicts. Following the calibration work described in Section 3.4, it should be possible to accurately model HydroCon Systems in MUSIC.

The other advantage of the hybridised HydroCon System is that the OSD storage volumes are far higher than could be achieved with rainwater tanks and bioretention systems alone.

Water Quality Parameter	Biofiltration Systems		Hydrocon Systems	
	Median	90th Percentile	Median	90th Percentile
TSS (mg/L)	5.37	34.8	7.1	17
TP (mg/L)	0.038	0.153	0.045	0.083
TN (mg/L)	0.38	1.71	0.428	1.03

Table 1 MUSIC Results for Bioretention Systems and HydroCon Systems

Comparisons were also made with simpler modelling procedures, including regression equations and the NSW EPA Level One Type Assessment. However, these generally over-predicted the treatment capabilities of the systems. In particular, with annual export models, such as the EPA method, it is not possible to accurately represent the different pollutant loads carried by different size events.

4. CONCLUSIONS

A hybridised WSUD system has been developed that meets the requirements of Council, DIPNR and other regulatory bodies while maximising lot returns. Both water quality and OSD objectives were fully achieved on the site through an environmentally sensitive development that maintains existing flow conditions to integrate with existing downstream WSUD measures.

It has been shown how to adapt water quality modelling software such as MUSIC to model proprietary WSUD systems such as HydroCon, although further refinement of this technique is currently underway, supported by Federal Government funding. A technical note will be developed for MUSIC to assist modellers and designers to allow accurate modelling of such systems. However, water quality models still require calibration and data collection for this is also underway.

5. ACKNOWLEDGMENTS

The authors would like to thank Paul Hogan of Mirvac Homes for his assistance and permission to publish this paper.

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