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Integrated Water Cycle Management at the Heritage Mews Development in Western Sydney

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Abstract:

The "Heritage Mews" development applies a regime-in-balance stormwater management strategy which requires runoff volume from a developed site to be equal to the discharge from the site prior to development in the adopted critical design storm. Retention/infiltration technology, the first option of choice, was impractical at "Heritage Mews" because of the impermeable nature of its surface geology. Instead, the objectives of 'before-and-after' runoff volume equality and peak discharge less than permissible site discharge (PSD) were achieved using rainwater tanks, gravel trenches and 'slow-drainage'. Continuous simulation using the PURRS model and distributed modelling using the WUFS model was used to prove that the configuration of retention components planned for the development delivered the flow quantity objectives set by Council and, also, that the 3.0 kL rainwater tanks would provide 22% of domestic water use. The development incorporated four "UniSAtanks" which provide a high standard of quality control to 95% of average annual flow. The water sensitive urban design (WSUD) approach resulted in infrastructure savings of $2,500 per allotment and land savings of $51,000 per allotment.

Keywords: rainwater tanks, infiltration, continuous simulation, stormwater quality, flood control

1. INTRODUCTION

Heritage Mews is a residential development with 62 allotments located at Castle Hill in the north western region of Sydney in New South Wales, Australia. The development site includes a ridge that falls with gradients of 8%, 11% and 5% in the west, south and north directions respectively to ephemeral creek systems (Figure 1). A silty clay soil with depths ranging from 1 m on the ridge to 2.5 m adjacent to the creek systems overlay highly weathered sandstone at the site. Ground water was found at depths of 1.5 m to 2 m adjacent to the creeks.

The development is located within the Hawkesbury River Catchment and the Local Government area of Baulkham Hills. Baulkham Hills Shire Council requires that stormwater runoff from the site must comply with the permissible site discharge (PSD) and site storage (SSR) rules of the former Hawkesbury River Catchment Trust. Additionally it was required that stormwater runoff from the development did not adversely impact on the receiving environment by limiting post development peak and volumetric discharges to pre development levels.

Baulkham Hills Shire Council's stormwater management policy requires the provision of 362 m^3 of on-site detention storage and allows a permissible site discharge of 104 L/s for each hectare of development. Heritage Mews has a total developed area of 3.04 Ha. Thus a 1,100 m^3 volume of on-site detention storage was required with a permissible site discharge of less than 316 L/s for design storms with an average recurrence interval (ARI) of 10 years.

A conventional design using detention basins discharging to the surrounding creek systems via discharge control facilities and water quality improvement devices was expected to consume 8% (0.25 Ha) of the available site area representing a loss of 7 housing allotments. This would result in a reduction in revenue from the development of about $3.15 million.

Whilst the on-site detention policy is simple to implement, it was perceived to have another distinct disadvantage. The likely scenario of a succession of similar subdivisions arranged in series along the same waterway may generate peak discharges downstream that are similar to, or larger than, traditional uncontrolled stormwater discharge practice [Debo and Reece, 1995].

An alternative approach to stormwater management at the Heritage Mews development was proposed to Council. This approach would limit post development stormwater runoff volumes to less than predevelopment runoff volumes whilst also meeting the PSD requirement. It was agreed that the adoption of water sensitive urban design (WSUD) philosophy would met these objectives as well as providing stormwater quality improvement and water conservation.

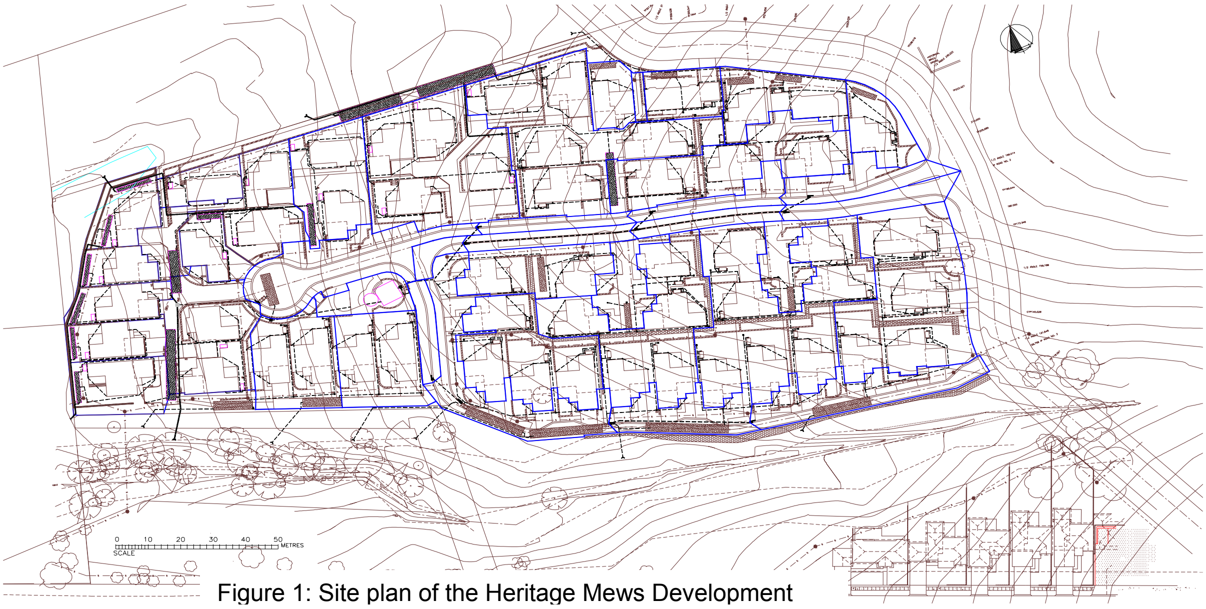

Figure 1: Site plan of the Heritage Mews Development

The WSUD elements proposed for the development included rainwater tanks and gravel infiltration trenches. Baulkham Hills Shire Council was persuaded to allow the development to proceed as a special case study from which the Council, developers and consultants could obtain additional knowledge about alternative design practices. This paper presents the WSUD design approach used in the development, describes the methodology used to implement the design and highlights experiences from the design and construction process.

2. DESIGN SPECIFICATION

The Council specification for the design of Heritage Mews included a requirement to manage major flooding generated by 100 year ARI storm events by routing stormwater runoff through road reserves or overland flow paths without flood waters reaching residential floors.

Also, stormwater runoff volumes generated during a 10 year ARI design storm with duration of two hours from the site in a developed state should be equal to or less than the volume of stormwater runoff from the site in a natural state. The surface runoff from the undeveloped site was estimated to be 759 m^3 for this storm. The peak stormwater discharge from the design storm was required to be less than 316 L/s.

In addition, the development was required to demonstrate an adequate level of stormwater quality control. All stormwater runoff from roofs, cleared of sediment by first flush devices, is directed to rainwater tanks and stormwater runoff from non-roof surfaces within allotments is passed through underground gravel trenches via small silt traps. Thus the allotments within Heritage Mews will not contribute significantly to the development's pollutant load.

Stormwater runoff from the road reserves and some of the surfaces within allotments was expected to contribute significant pollutant loads to the street drainage system. The developer guaranteed a high standard of treatment for at least 95% of annual stormwater volumes. This can be achieved by cleansing all discharges from the road reserve catchments up to and including the storm event containing the 3 month ARI peak discharge [Wong et al., 2000].

3. THE DESIGN ENVIRONMENT

The design constraints affecting the project were assessed by a design team that included the developer, consulting engineers, an architect, landscape architects, a real estate agent and various technical specialists.

The site was found to be generally too steep for the use of grassed swales adjacent to road carriageways for stormwater quality improvement. Also the density of the development and the location of services imposed limitations on the size and location of rainwater tanks and limited opportunities for placement of stormwater retention devices within road reserves or allotments. Relocation of roads was not possible because the subdivision planning and lot layouts were completed prior to the commissioning of infrastructure design professionals.

The silty-clay soils and sandstone sub-structure on the site were relatively impermeable thereby the use of infiltration as a method of stormwater management was considered to be unacceptable. The presence of shallow sandstone also indicated that the depth of gravel trenches had to be minimised.

A lack of previous experience with these problems presented difficulties for Council officers who, normally, dealt with development applications that were considerably less complex. This situation was exasperated by a lack of "best practice" design guidelines or plans for WSUD approaches. The use of innovative solutions, new technologies and new mathematical models in the design of the development also provided challenges to approval authorities and designers.

The project was also subject to a critical timeline and could not afford to endure a significant delay in approval because it was delivering a WSUD solution. It was also required that the cost of the WSUD solution be comparable to the cost of a conventional solution.

4. RAINWATER TANKS

The primary objective of the integrated water management philosophy for Heritage Mews was the use of rainwater tanks for control of stormwater quantity and quality, and for water conservation. This decision was the subject of considerable debate throughout the conceptual planning and design phases of the project. For example the determination of rainwater tank size was not only a question of balancing stormwater retention versus water conservation objectives. The design also needed to consider the type and location of the rainwater tank, architectural, sales and marketing perceptions.

It was also considered essential to limit the impact of the tanks on the small yard areas. The architects concern about the size and visual impact of the tanks was overcome by site visits to houses with a variety of tanks installed. Following these site inspections, the architect specified the preferred colours and shapes of rainwater tanks located in "dead spaces" identified within each house yard. Typically each housing allotment will have about 5% to 10% unusable yard area known as "dead space". It was decided that the rainwater tanks should have a capacity of 3 kL.

The ultimate choice of tank type also impacted on the proposed mains water top up arrangement. The option of installing underground rainwater tanks was explored during the process but this raised policy issues with Sydney Water Corporation (SWC) which could not be resolved within a reasonable timeframe. Considerable delays also resulted from Sydney Water Corporation's reluctance to accept the use of rainwater for any household purpose including outdoor and toilet uses. It was claimed that the NSW Department of Health (DoH) did not allow use of rainwater in urban areas. The DoH confirmed that the use of rainwater for any purpose was not prohibited. With assistance from the Ministry of Energy and Utilities it was finally agreed that rainwater would be used to supply toilet and outdoor uses.

4.1 Designing the Rainwater Tank

Modelling of the performance of the rainwater tanks was undertaken using the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) water balance model [Coombes and Kuczera, 2000; Coombes, 2002]. Rainfall input at 5 minute intervals to the PURRS model was provided by the DRIP synthetic rainfall model by Heneker et al. [2001] that was based on the North Ryde rainfall gage [see Coombes et al., 2002].

Roof water from each dwelling (average roof area: 200 m^2, average allotment area: 380 m^2 and average non-roof impervious area: 50 m^2) is directed via leaf guards, a first flush device and a sealed charged downpipe system to 3 kL modular rainwater tanks. The size of the rainwater tanks was chosen on architectural grounds rather than consideration of water conservation or stormwater management objectives therefore it was necessary to provide a trickle outlet with a diameter of 20 mm located 500 mm below the top of the tank to ensure that a maximum retention storage was available prior to storm events for stormwater management. This ensured that a retention volume of at least 1.2 m^3 was available in the tank prior to each storm event (Figure 2).

The water level in the rainwater tank will be constantly drawn down below the trickle overflow by the toilet flushing and outdoor water demand. When the water level in the rainwater tank is drawn down below 300 mm from the base of the tank, a float switch opens a solenoid valve allowing top up of the tank with SWC mains water to a maximum level of 300 mm. This dual water supply strategy satisfies SWC's current backflow prevention requirements by providing a visible air gap between the mains water outlet and the top of the tank. Note that this requirement is excessive in comparison to the configuration required by Australian Standard ASNZ3500.1.2. Stored rainwater is reticulated into each dwelling for toilet flushing and for outdoor water use via a small pump. The rainwater tanks overflow to gravel trenches with slow drainage outlets.

4.2 Water Balance Results

The water balance at typical allotment scale was simulated at 5 minute time steps for a period of 1000 years. Each dwelling was assumed to have three residents.

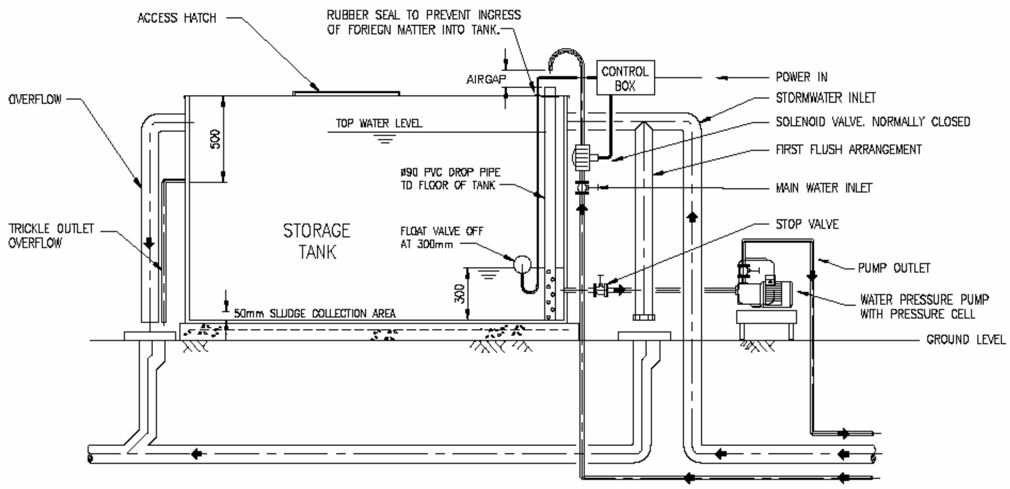

Figure 2: Schematic of the 3 kL modular rainwater tank

The monthly average daily indoor and outdoor water demand of the dwellings in the Castle Hill area (Table 1) was estimated using the socio-economic climatic water demand relationships developed by Coombes et al. [2002]. A diurnal pattern of domestic water use allows the determination of water demand at 5 minute intervals.

Table 1: Monthly average daily water demand

Month	Indoor (L/day)	Outdoor (L/day)
January	602	246
February	600	253
March	605	246
April	593	210
May	598	169
June	590	130
July	592	131
August	593	181
September	596	213
October	596	251
November	596	283
December	597	321

The continuous simulation of water balances revealed that the use of rainwater tanks will reduce mains water demand by an average of 65 kL per annum. This equates to an average reduction in mains water use of 4.03 ML per annum reducing the impacts of the development on water treatment plants and regional water storages. The dual water supply strategy will also reduce the one year ARI annual maximum (peak) and instantaneous water demands by 26% and 34% respectively, reducing the impact of the development on mains water distribution infrastructure including water mains and pressure reservoirs.

4.3 Determination of the Retention Storage Available in the Rainwater Tanks Prior to Storm Events

The street drainage system at Heritage Mews was required to cope with design storm events up to and including the 10 year ARI by the Council. Similarly it was required that the stormwater quality improvement facilities were designed to treated all discharges up to and including the 3 month ARI storm event. The subdivision scale impact of the provision of rainwater tanks on stormwater infrastructure is dependant on the storage volume available in the tank immediately prior to a storm event of a given ARI.

It has often been argued that rainwater tanks will not reduce the requirement for stormwater infrastructure because the tanks will not have any retention storage available prior to the design storm event. Coombes et al. [2002a] showed this assumption to be incorrect for the Western Sydney region. However it is important to determine the magnitude of the available storage volumes prior to storm events with various ARIs for use in a subdivision scale stormwater model for the design of stormwater management measures.

Coombes [2002] developed a method using continuous simulation and on-site storage volumes that can determine the probable initial airspace storage available (PIAS) in a rainwater tank prior to a storm event with a given ARI. The on-site detention storage volume required to mitigate stormwater runoff for a storm event with a given ARI is determined for the allotment with and without the rainwater tank. The difference between the on-site detention storage volumes of the storm event with the same ARI will be the retention storage volume available in the rainwater tank prior to the storm event with a given ARI. The ARI at which a particular detention storage spills ARI_{OSD} can be estimated by:

$$ARI_{OSD} = \frac{Years}{Spills} \quad (1)$$

where Years is the length of the simulation period and Spills is the number of times the detention storage is overwhelmed during the simulation period.

The volume of the retention storage in a rainwater tank prior to a storm event is a function of the detention storage required on the allotment with no rainwater tank OSD_{NOTANK} and the detention storage required on the allotment with a rainwater tank OSD_{TANK} for a given ARI equal to n years.

$$PIAS_n = (OSD_{NOTANK} - OSD_{TANK})_n \quad (2)$$

The storage volumes available in the 3 kL modular rainwater tank prior to storm events with various ARIs were determined using the PURRS model and the procedure described above and are shown in Figure 3.

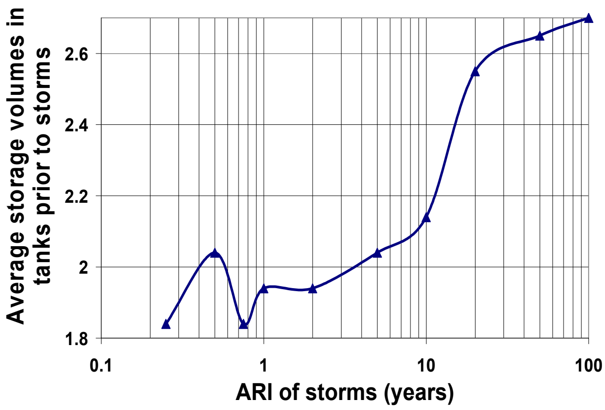

Figure 3: Storage volumes available in the rainwater tanks prior to storm events

Figure 3 shows that the available storage volumes in the rainwater tank ranges from 1.85 m^3 for a storm event with an ARI of 3 months to 2.7 m^3 for a storm event with an ARI of 100 years. This finding is of interest. The smaller available storage volumes in the rainwater tanks prior to storm events with low ARIs result from frequent storm events filling the tank more often during winter periods with minimal outdoor water use. Conversely the increased storage volumes available in the rainwater tank prior to storm events with larger ARIs are because larger storm events occur during summer months. During summer months the dry periods between storms are longer and volumes of outdoor water use are larger, drawing down water levels in the rainwater tank more rapidly.

5. GRAVEL FILLED TRENCHES AND ALLOTMENT DRAINAGE

The gravel trenches at Heritage Mews collect, filter and store all overflows from the rainwater tanks together with runoff from yards and driveways that is passed through silt arrestors fitted with "Enviropod" filters to trap gross pollutants and fine sediments.

It was apparent from geotechnical investigations that stormwater disposal into the silty-clay soil and underlying sandstone at the site by infiltration would be a secondary process. An alternative method was required to ensure that the gravel trenches emptied between storm events. A low flow pipe with a diameter of 15 mm that discharged at an average rate of 0.36 L/s over a 24 hour period was installed in each gravel trench to ensure the trenches had sufficient retention volumes prior to the storm events.

A typical slow drainage gravel trench (Figure 4) at Heritage Mews includes a trench filled with single, graded, clean, hard, angular gravel wrapped in a non-woven geofabric, an inlet that connects directly with a slotted diffuser pipe wrapped in a geofabric sock at the top of the trench to evenly distribute the inflow, a slotted distribution pipe wrapped in geofabric at the base of the trench to prevent stored stormwater collecting at a single point, and in the event of blockage or a major storm event, the trench is provided with an overflow pipe which allows any surcharge to be controlled and directed to the outlet.

5.1 Sizing of Gravel Trenches

The gravel trenches at Heritage Mews were sized using volume based regime in balance approach described by Argue [2001]. The volume of stormwater runoff from the developed site for the 10 year ARI storm event with a duration of 2 hours was calculated to be 1,338 m^3 using the rational method. The volume of stormwater runoff from the site prior to development was estimated to be 759 m^3 and the volume of stormwater retained in the rainwater tanks was conservatively estimated to be 124 m^3 for the same storm event. Thus the volume of storage required in the gravel trenches is estimated to be 455 m^3 or 0.025 m^3 per square metre of impervious surface.

6. THE "UNISATANK"

Treatment of stormwater runoff from road reserves at Heritage Mews takes place in 4 "UniSAtanks". Runoff from the road reserve sub-catchments enters kerb inlet pits fitted with trash screens designed to collect large items of urban litter including leaves, cartons and cans: this is called Chamber I. Stormwater passes from Chamber I to Chamber II where sediment particles larger than 300 µm are deposited.

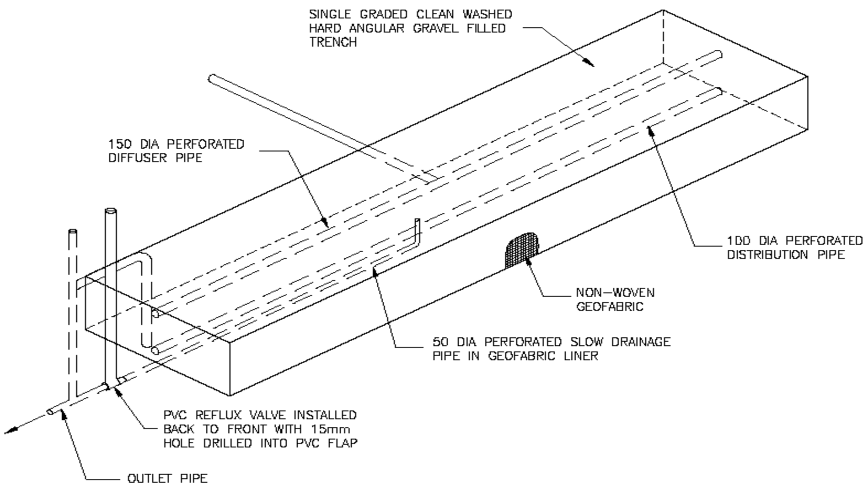

Figure 4: Schematic of the gravel trench

The third stage of treatment, Chamber III is where the bulk of sediments smaller than 300 µm are retained. Chamber I is simple trash screen pit that will require cleaning after each major storm event. Chamber II is a sediment tank with a floor baffle to reduce the energy of incoming stormwater flow and a hanging baffle to minimise short circuiting. In a typical urban residential setting Chamber II will require cleaning on an annual basis.

Chamber III is where fine particulate matter with sizes ranging from 300 µm to 20 µm is retained for the life of the installation, expected to be at least 25 years [Jacobs, 2001]. The chamber consists of a wide gravel filled trench with a central trapezoidal shaped filter comprising upper (woven) and lower (unwoven) layers of geotextile separated by a 75 mm thickness of 5 mm gravel (see Figure 5). The filter is effective in filtering sediment particles larger than the pore size of the lower geotextile fabric, typically 20 µm. Even smaller particulates may be retained in the system as it ages. Its trapezoidal shape ensures that many years of sediment can be retained.

Full scale laboratory studies of the performance of the three chamber installation revealed an 87% reduction in total suspended solids from input at a constant rate of 195 mg/L. A fuller description of the UniSAtank is presented by Espinosa et al. [2001] and Jacobs [2001].

7. HYDROLOGICAL PERFORMANCE OF HERITAGE MEWS

Current stormwater management practice in Australia [IEAust, 1987] using design storm based procedures is intrinsically incapable of satisfactorily assessing the hydrological performance of a development such as “Heritage Mews”. This is because the ‘design storm’ approach cannot account of the state of rainwater tanks, retention storages or soil moisture at the commencement of precipitation. It is now widely recognised that a design storm typically represents a burst of extreme rainfall embedded in a longer storm event and that pre-burst rainfall may significantly affect the performance of on-site elements such as rainwater tanks. Also, currently accepted stormwater models with discharge and lumped catchment philosophies cannot provide reliable assessment of the impact of stormwater management strategies that include distributed storages.

For these reasons, the performance of the stormwater management solution for the “Heritage Mews” subdivision was analysed using the WUFS (Water Urban Flow Simulator) rainfall/runoff program by Kuczera et al. (2000). This program determines stormwater discharges using design storms and is capable of assessing WSUD measures distributed at their actual spatial locations within catchments. Initial condition of elements in the stormwater treatment train and soil moisture prior to storm events were determined using the PURRS continuous simulation model. The average storage volumes available in rainwater tanks prior to storm events with given ARIs shown in Figure 3 were used in the WUFS model to determine the impact of rainwater tanks.

7.1 Results from Stormwater Modelling

The WUFS rainfall/runoff model was used to determine the combined impact of rainwater tanks, infiltration trenches and conventional stormwater infrastructure on stormwater runoff from the entire development. A detailed model of the “Heritage Mews” development was constructed in WUFS including all surface and underground components.

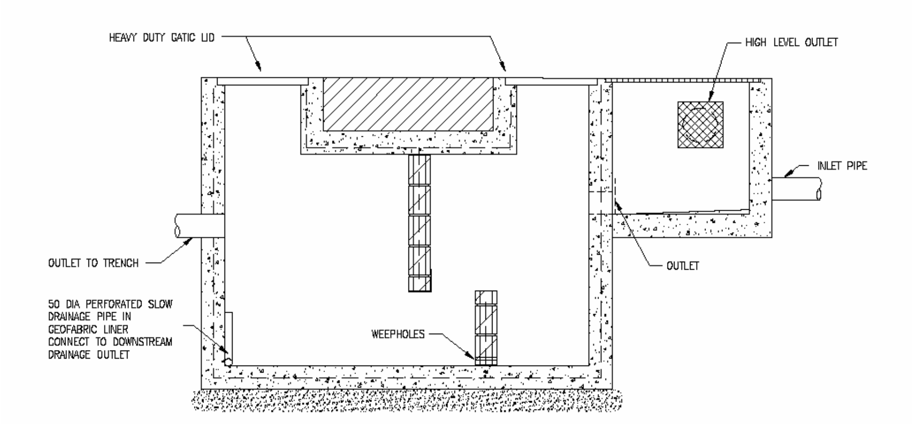

Figure 5: Chambers II and III of the UniSAtank

The model was used first to check peak outflow from the site from the distributed retention components sized according to the requirements of the volume based regime-in-balance strategy. This gave a 10 year ARI peak flow significantly less than the PSD of 316 L/s, thereby satisfying the peak discharge criterion.

The WUFS rainfall/runoff and PURRS models were then used to refine the volume-based design, as follows. The initial conditions for the rainwater tanks prior to storms of a given ARI derived using continuous simulation (Figure 3) were used together with the assumption that landscaping measures will provide 1 m^3 of retention storage on each allotment. PURRS was also used to determine the storage available in all of the infiltration trenches prior to design storms of given ARIs.

The WUFS model was employed to obtain a modified configuration of WSUD elements including rainwater tanks, landscaping, infiltration trenches and pipe systems which produced a peak discharge of 316 L/s for design storm events with an ARI of 10 years. The total storage required in the subdivision to match this discharge was 62 m^3 (landscaping) + 134 m^3 (rainwater tank retention storage) + 339 m^3 (infiltration trenches) = 535 m^3.

The detailed distributed modelling using WUFS indicated that the required storage volume in the development was 7.5% less than the on-site storage determined using the volume-based (regime-in-balance) calculation method (579 m^3). Note that the required storage volumes determined using the volume-based method and the detailed modelling were, both, significantly less than the volume of storage required by the council (1,100 m^3), and the volume of detention storage determined using an alternative, lumped catchment-based rainfall/runoff approach (1,048 m^3).

The peak discharges from the subdivision for each ARI are compared to estimates of peak discharges from the natural catchment in Table 2. It is shown in Table 2 that the distributed storage approach (rainwater tanks and infiltration trenches of the modified configuration) has reduced peak stormwater discharges from the development to significantly less than the estimated pre-development peak stormwater discharges. This indicates that the strategy will mitigate the impacts of the urban development on the downstream environment.

Table 2: Peak Discharges from the natural and developed catchments (modified configuration)

ARI	PEAK DISCHARGES (m^3/s)	
	NATURAL	DEVELOPED
10 years	0.584	0.316
5 years	0.444	0.256
2 years	0.271	0.12
1 year	0.138	0.026
9 months	0.1	0.014
6 months	0.073	0.012
3 months	0	0.01

8. COSTS AND BENEFITS

The costs to install the rainwater tanks were \$3000 per allotment, slow drainage trenches was \$280 per cubic metre and UniSAtanks were \$5800 per facility. The choice of modular rainwater tanks and the excessive requirements of SWC significantly increased to installation costs of the tanks.

The installation costs of the WSUD solution totalled \$13,500 per allotment whilst the expected cost of the traditional approach to stormwater management was \$17,000 per allotment. This represents an infrastructure cost saving of \$2,500 per allotment. Additionally the use of WUSD measures increased the allotment yield of the subdivision by 7 allotments resulting in an additional benefit of \$3.15 million or \$51,000 per allotment.

9 CONCLUSIONS

A novel integrated water management system has been designed for "Heritage Mews", a new residential sub-division in the western suburbs of Sydney, NSW. The project includes roofwater harvesting using 3.0 kL rainwater tanks providing 22% of total water demand. These tanks also assist in achieving the flood control criteria set by Council. Above-ground and in-ground retention storages including rainwater tanks and gravel-filled trenches were sized to ensure that post-development stormwater discharge from a storm event with an ARI of 10 years is equal to the runoff (volume) estimated for the predevelopment site in the same design storm. The regime-in-balance strategy was employed to produce this outcome.

Slow-drainage gravel trenches and pipelines designed to ensure emptying of all in-ground components in 24 hours, in combination with the rainwater tanks, guarantee that the peak discharge from the site in the design storm is significantly less than the permissible site discharge (PSD). A stormwater quality improvement system is provided that will treat 95% of annual average runoff volume to reduce sediment concentrations to 20 mg/L with a maximum particle size, 20μm. The flood control design process was extended using the WUFS distributed stormwater model and the PURRS continuous simulation model to refine the design to achieve peak discharges equal to PSD. This configuration showed a reduction of 7.5% in the on-site retention storage volume requirement compared with that produced by the regime-in-balance procedure.

This project demonstrates, using continuous simulation and distributed modelling, that small rainwater tanks, plumbed to supply over 20% of household demand, can contribute significantly to achieving catchment-wide flood control and stormwater quality improvement objectives. Importantly this paper describes a methodology to determine the impact of rainwater tanks on stormwater discharges and the consequent provision of stormwater management infrastructure. It is noteworthy that very significant stormwater management objectives were met on this difficult site using distributed retention/infiltration measures.

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