Innovative Water Cycle Design/Management at a Difficult Site : "Heritage Mews" in Western Sydney, Australia

John R Argue[1], Danny Boubli[2] and Peter J Coombes[3]

[1] Adjunct Professor of Water Engineering, Urban Water Resources Centre,
School of GMC, University of South Australia, Mawson Lakes Campus,
Mawson Lakes, South Australia 5095.
[2] Director, Cardno BLH, Castle Hill, NSW.
[3] ARC Post-Doctoral Fellow, School of Engineering, University of Newcastle, NSW.

ABSTRACT :

The "Heritage Mews" development applies the **regime-in-balance** stormwater management strategy which requires runoff *volume* from a developed site to be equal to its 'greenfields' discharge 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 Q_{peak} less than permissible site discharge (PSD), were achieved using rainwater tanks, in-ground trenches and 'slow-drainage'. Continuous simulation (the WUFS and PURRS models) 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 some 22% of domestic water use. The development incorporated four "UniSAtanks" which provide a high standard of quality control to 95% of average annual flow.

1. INTRODUCTION

In a Keynote paper presented to the 1st National Conference on Sustainable Urban Drainage Systems, Argue (2001) showed that the European/UK domain of stormwater 'source control' practice represented by SUDS is broader than its Australian counterpart. But that SUDS is, itself, embraced by the scope of **total water cycle management** currently being sought in Australia where it is referred to as Water Sensitive Urban Design or WSUD.

Much urban drainage practice over the past 30 years has focussed on making **peak flow** from a site or sub-catchment *after* development equal to the value estimated for its "greenfields" or pre-developed state. The hydrological basis for such equality is the storm of critical duration. Terms such as "permissible site discharge" (PSD) interpreted as a set value in litres per second per (developed) hectare are used in this connection, along with detention technology - basins and on-site detention tanks – to achieve the required peak outflow equality through temporary ponding.

The 2001 Keynote paper addressed this issue and showed that this focus on peak outflow equality alone was far less effective in reducing flood peaks in multi-sub-catchment urban streams, than design based on equality of 'before-and-after' runoff **volumes,** determined, also, for the storm of critical duration. The consequences of this change of focus are numerous and include: control of downstream flooding to acceptable levels despite continued development; conservation of natural stream environments including their benthic communities; support for linear parks and stream-associated urban forests; and improved amenity, generally, for inhabitants of the urban landscape which results from these qualities. The technical basis for this change of emphasis is described in recommended Australian practice as the **regime-in-balance** strategy (Argue, 2003).

The task of executing a **regime-in-balance** design is remarkably simple, as the following case study will show – its complexities, however, requiring considerable ingenuity and creativity on occasions, are focussed on :

- the means by which stormwater is retained on site and, effectively, excluded from further involvement in the flood wave; and,

- ensuring that any on-site storage device or installation has sufficient available capacity following a storm to adequately accommodate runoff generated in the succeeding storm(s).

Devices and installations which may be used to achieve the **former** include rainwater tanks, stormwater retention trenches, “soakaways”, “dry ponds”, etc., as well as percolation to unconfined aquifers or bores transferring cleansed runoff to confined aquifers. The **latter**, above, issue requires that speedy emptying of retention devices takes place so that the central feature of the **regime-in-balance** strategy – equality of ‘before-and-after’ surface runoff *volumes* – is not compromised. The “Heritage Mews” project illustrates all of these aspects in what might be regarded as an extreme setting.

2. SOME PRELIMINARY CONSIDERATIONS

2.1 Policy Concession/Agreement by Council

“Heritage Mews” is a new ‘greenfields’ residential sub-division located in Castle Hill, a north-western suburb of Sydney, NSW. The development falls within the jurisdiction of Baulkam Hills Shire Council whose stormwater control policy requires 362 m^3 of on-site detention storage to be installed for every hectare of development undertaken in its area; the PSD is 104 L/s per (developed) hectare. In the case of “Heritage Mews”, these requirements amounted to 1,100 m^3 for the 3.04 ha site containing 56, two-storey townhouses, and PSD of 316 L/s. A conventional design meeting Council requirements would therefore see about 0.25 ha (8%) of the site (including associated earthworks) devoted to a temporary-detention holding basin or basins discharging directly through controlled outlets into the bordering stream(s).

While this solution for an isolated development has the benefits of simplicity and easy provision of peak outflow or PSD in the design storm, it suffers from two disadvantages :

- the ‘land take’ required by the basin represents a loss of some 5 - 7 allotments; and,

- the likely scenario of a succession of similar sub-divisions arranged in series along the same waterway, could generate (design storm) flow peaks downstream little different from or even higher than those of traditional, uncontrolled practice (see Debo and Reece, 1995).

An alternative approach was proposed to Council based on equality of ‘before-and-after’ **runoff volumes**, as outlined above, *as well as* meeting the PSD requirement. These discussions with Council also involved two other aspects of WSUD, those of stormwater quality control and stormwater harvesting : the Developer’s consultant undertook to incorporate a high level of sediment control into the development as well as significant water conservation through the use of rainwater tanks.

Council was persuaded to allow the development to proceed along these lines as a special case study project from which much could be learned by all parties – the developer, consultants, and Council.

2.2 Basic Design Specification

The Council specification for the design of "Heritage Mews", therefore involved :

1. Management of major flooding in the average recurrence interval (ARI), Y = 100-years storm on the (developed) catchment : the resulting flow must be conveyed by way of roadway reserve and overland flood paths without stormwater reaching residential floors (0.30 m "freeboard" required under the Institution of Engineers, Australia design criterion).

2a. Control of stormwater generated within the development in the ARI, Y = 10-years, 2-hours storm (intensity, $i_{10} = 32$ mm/h) : the total volume of storm runoff from the developed site must be the same as from the 'greenfields' site. In this connection, the runoff coefficient for a 'greenfields' site in Castle Hill is $C_{10} = 0.39$. Surface runoff from the 3.04 ha undeveloped site in the design storm :

$$\text{Volume} = 0.39 \times 30{,}400 \text{ m}^2 \times (0.032 \times 2) = \mathbf{759\ m^3} \qquad \textbf{(1)}$$

2b. Peak flow rate from the developed site in the design storm, **less than** PSD = 316 L/s.

3. Stormwater quality control : All allotment roof runoff, cleared of sediment, passes into rainwater tanks at "Heritage Mews" and some allotment surface runoff will pass into underground gravel-filled trenches after being cleansed of silt : none of these elements will therefore contribute to the development's pollution load. All roadway reserve runoff plus some allotment paved and pervious areas will contribute runoff containing sediment to the street drainage system. A high standard of treatment was guaranteed by the Developer for at least 95% of the stormwater (total annual flow). This can be achieved by cleansing all flows from roadway catchments up to and including Q_{peak} for the ARI, Y = 0.25-years critical storm event (Wootton et al. 1999). This corresponds, approximately, to use of the 90 percentile peak flow of UK practice.

2.3 The Site

The 3.04 ha "Heritage Mews" site straddles a ridge which has an average longitudinal fall to the west of approximately 8% and transverse falls of approximately 11% and 5% to the south and north respectively. The site is bounded by a new public road in the east and watercourses to the south and north which converge past the western end of the site as shown in Figure 1.

Soils on the site consist of silty clays overlying weathered sandstone at about 1.0 m depth along the ridge increasing to over 2.5 m towards the watercourses and the western end of the site. The ground water depth varies similarly, but is, generally, fully contained within the sandstone sub-structure.

2.4 The Design Environment and Team Organisation

The constraints of the project and the site were assessed by a design team or committee which included the Consulting Engineer, the client/developer, Council and the technical specialists brought in for the project. The following aspects of the task were recognised :

- The site was generally too steep to consider the use of swales adjacent to carriageways for stormwater quality improvement.
- Density of development and location of services meant limitations on the size and location of rainwater tanks and limited opportunities for placement of stormwater retention devices within road reserves and/or allotments.

- Planning and lot layouts had already been completed so there was no opportunity to re-align or relocate roads.
- The silty clay soils and rock sub-structure were relatively impermeable which made it unacceptable for percolation into these systems to be the primary mechanism for (on-site) disposal of retained stormwater.
- Because of shallow rock in places, depths of gravel-filled trenches (where these were used) had to be minimal.
- Lack of previous experience with these problems raised difficulties with Council officers who, normally, deal with much less complex development applications.
- Lack of a readily available suite of "good practice" plans from previous projects made the preparation of detailed construction drawings a very time consuming activity.
- Use of innovative solutions, new technologies, new (mathematical) models as well as the level and intricacy of the detail involved resulted in a 'pressured' design process.
- The project time-line was, as with any commercial project, critical. The developer had made a commitment to the project but also had to face commercial realities. The project could not afford to get 'bogged down' because it was delivering a WSUD solution.
- Capital costs of the WSUD solution had to be comparable to a conventional solution.

It was originally intended that the required reduction in runoff volume from the site would be achieved through retention practices of various types including rainwater tanks and on-site "soakaways", soil moisture increase, evaporation/evapotranspiration, etc. This aspect of the design and the complex nature posed by the site, as outlined above, coupled with those of pollution control and stormwater harvesting, led to separation of the design tasks into two distinct domains :

- **above-ground** components, in particular, rainwater tanks; and,
- **below-ground** components including "soakaways", pollution control installations, etc.

A further reason for this separation was the locations of the various participants in the design process residing in Adelaide, South Australia, and Sydney and Newcastle in NSW, a distance overall of nearly 2,000 km.

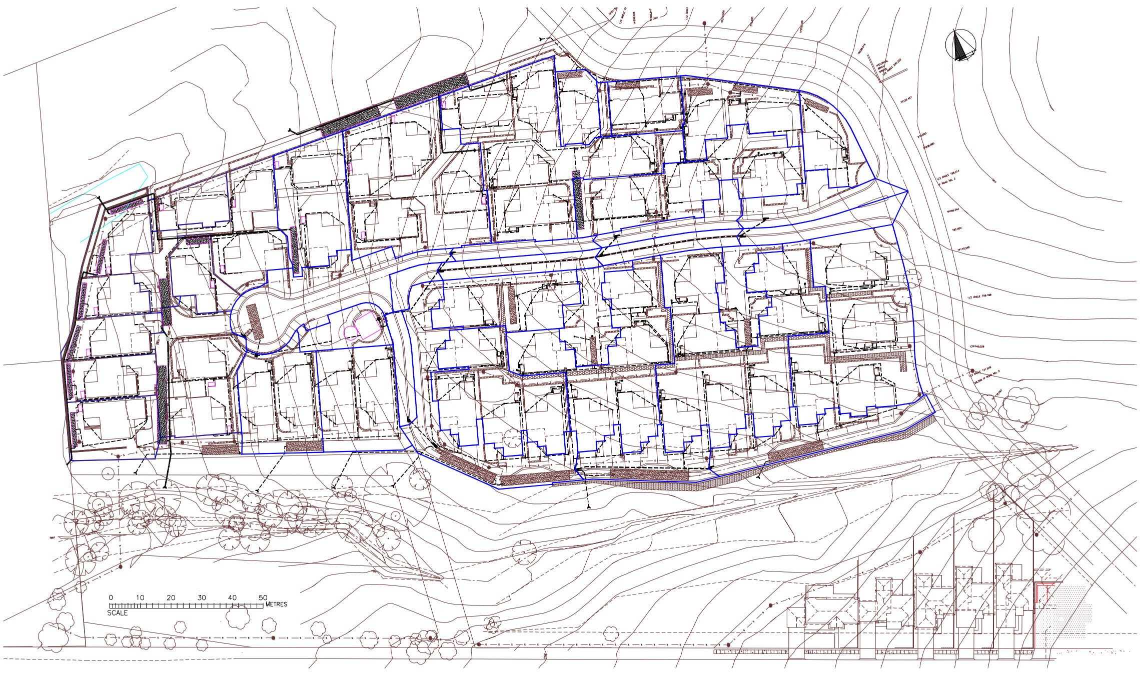

FIGURE 1 : Site plan of "Heritage Mews"

3. ABOVE-GROUND COMPONENTS

3.1 Rainwater Tanks

A basic aim of water cycle management at “Heritage Mews” was to include rainwater tanks. However, between the concept and final design there was much debate. For example the question of rainwater tank size became not only a question of stormwater benefit versus water conservation benefits but, together with the question of type and location of tank, an architectural, sales and marketing issue. It was considered essential to minimise the impact on the small yard areas. The ultimate choice of tank type also impacted on the proposed mains top up arrangement. The option of undergrounding the rainwater tanks was explored during the design process but this raised policy issues with Sydney Water which were unable to be resolved in the available time frame, so underground rainwater tanks were not considered, irrespective of cost.

Modelling of the rainwater tanks and their potential contribution to flood mitigation was undertaken using the PURRS (Probalistic Urban Rainwater and Wastewater Reuse Simulator) water balance model (Coombes and Kuczera, 2001; Coombes 2002). The roof-water of each dwelling is passed over leaf guards in the eaves gutters and directed through a sealed, charged system via first flush arrangement to a 3.0 kL modular, above-ground rainwater tank. Each tank is provided with a ‘trickle overflow’ set 500 mm below the top, ensuring that an air-gap of at least 1.2 m^3 is available to temporarily detain roof storm runoff (see Figure 2). Continuous simulation (using PURRS) of the performance of this system, including in-house and outdoor use of tank water, showed available detention storage of 2.14 m^3 prior to storm events of ARI = 10 years.

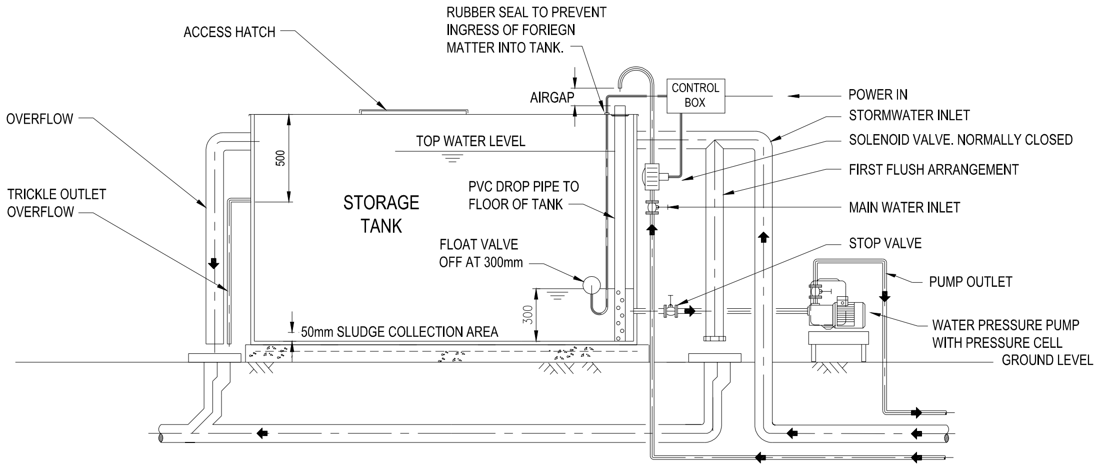

FIGURE 2 : Schematic layout of 3 kL modular rainwater tank.

The level of water stored within the tank is constantly being drawn down below the air-gap by toilet flushing and outdoor usage. When the level of rainwater within the tank gets to 300 mm above the base of the tank, as determined by a float switch, a solenoid valve engages the Sydney Water mains top-up.

The rainwater tank satisfies Sydney Water’s cross connection requirements by providing a visible air-gap between the outlet of the mains top-up and the top of the tank. This arrangement is in excess of the requirements of the National Plumbing and Drainage code AS3500 but represents the current requirements of Sydney Water.

Stored rainwater is reticulated back into the dwelling via a small pump, fitted with a pressure cell, which will typically provide two half flushes to the toilet. There are also external, outlets provided for outdoor and garden uses. The rainwater tanks overflow to the slow-drainage, gravel-filled trenches located close to the residential allotments.

3.2 Water Balance Results

The water balance at each allotment was calculated at 5 minute time steps using the PURRS model. Each dwelling was assumed to have four residents. The modelling used the long term monthly average daily indoor and outdoor water uses shown in Table 1. These values for monthly average daily outdoor water use are employed in PURRS in a probabilistic behavioural outdoor water use framework developed by Coombes et al. (2000) to estimate outdoor water use on any day in accordance with climatic variables. A diurnal pattern of domestic water use allows the determination of water use at 5 minute intervals.

TABLE 1
Monthly Average Water Use

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

Water supply from the rainwater tank is directed to the household for toilet flushing and to outdoor taps via a small pump. Toilet flushing was considered to be 20% of indoor water demand.

When tank water levels are low, such as during hot, dry periods, the tank is topped up with mains water via a trickle system. The trickle top up system will reduce the daily peak demand on the mains water distribution network. In the event of pump or power failure the rainwater tank can be bypassed.

The continuous simulation of water balances at each allotment using a rainfall series with a length of 1,000 years revealed that the use of the rainwater tanks will reduce annual average mains water demand by 65 kL. This equates to annual average mains water savings of 4.03 ML for the entire development. This will reduce impacts on water treatment plants and improve the security of regional water storages. The use of the rainwater tanks will reduce the one year ARI annual maximum daily (peak) water demand by 26% and the instantaneous demand by 34%.

4. IN-GROUND COMPONENTS

4.1 Gravel-filled Trenches and Allotment Drainage

It was apparent from the initial geotechnical investigation that stormwater disposal into the site soil/rock by way of infiltration or percolation would be a secondary process – if at all; an alternative mechanism therefore had to be found which would achieve the goal of speedy in-ground device emptying (between successive storms), required for successful retention practice. The obvious solution was incorporating into the design some form of (hydraulic) system for emptying each gravel-filled trench using a pipe set at a low level, and draining it by gravity to the nearest waterway.

While this mechanism can, undoubtedly, achieve the goal of swift emptying at a site as steep as "Heritage Mews", its easy adoption using typical 'engineering' components such as *unthrottled* 90 mm pipelines is likely to cause an outflow magnitude comparable to – or even greater than – that associated with detention practice. In these circumstances, the benefits of 'source control' of stormwater by retention are completely lost.

The key guiding principle to be adopted here is, therefore, emptying in "not more than 24 hours, but, also, **not much less**". This is the essence of the 'slow-drainage' principle and called for inclusion of the reversed, non-return valve illustrated with a gravel-filled trench in Figure 3. This device enables outflow rates to be controlled to a fraction of a litre per second as required by 'slow-drainage'; the arrangement also provides easy access for inspection of the outflow and maintenance/cleaning of the outlet.

The slow-drainage gravel trenches collect and store all overflows from rainwater tanks together with runoff from yards and driveways after passing through silt arrester pits fitted with "Enviropod" filters to trap gross pollutants and fine sediment. A typical slow-drainage trench comprises :

- A trench filled with a single, graded, clean, washed, hard, angular gravel wrapped in a non-woven geofabric.
- An inlet which connects directly to a slotted diffuser pipe wrapped in a geofabric sock at the top of the trench to evenly spread the inflow.
- A slotted distribution pipe wrapped in geofabric at the base of the trench to prevent stored flows from collecting at one point.
- In the event of a 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.

4.2 'Sizing' of Trench Components

The essence of the **regime-in-balance** approach to fixing the sizes of trenches is equality of 'before-and-after' surface runoff volume from the entire site in the design storm event, defined as ARI = 10-years and duration 2-hours (rainfall intensity, i_{10} = 32 mm/h). The 'before' runoff volume [see Eqn (1)] was calculated as **759 m^3**.

'After' runoff volume :

- paved areas (total, 17,750 m^2) = 17,750 × (0.9 × 0.032 × 2) ie volume = 1,022 m^3
- pervious areas (total, 12,650) = 12,650 × (0.39 × 0.032 × 2) ie volume = 316 m^3

hence, TOTAL runoff volume = **1,338 m^3** **(2)**

Hence, **'after' – 'before'** = (1,338 – 759) m^3 = **579 m^3** **(3)**

This on-site storage (retention) during the design storm of 2-hours duration can be provided by :

- rainwater tank available storage, say 1.0 m^3 per tank = 56 m^3
- This leaves (579 – 56) m^3 = 523 m^3 which must be provided withingravel-filled trenches, etc., receiving runoff from roofs and all other paved surfaces, at the rate of :

$$(523/17{,}750) = \mathbf{0.030\ m^3\ per\ square\ metre\ of\ paving} \qquad \mathbf{(4)}$$

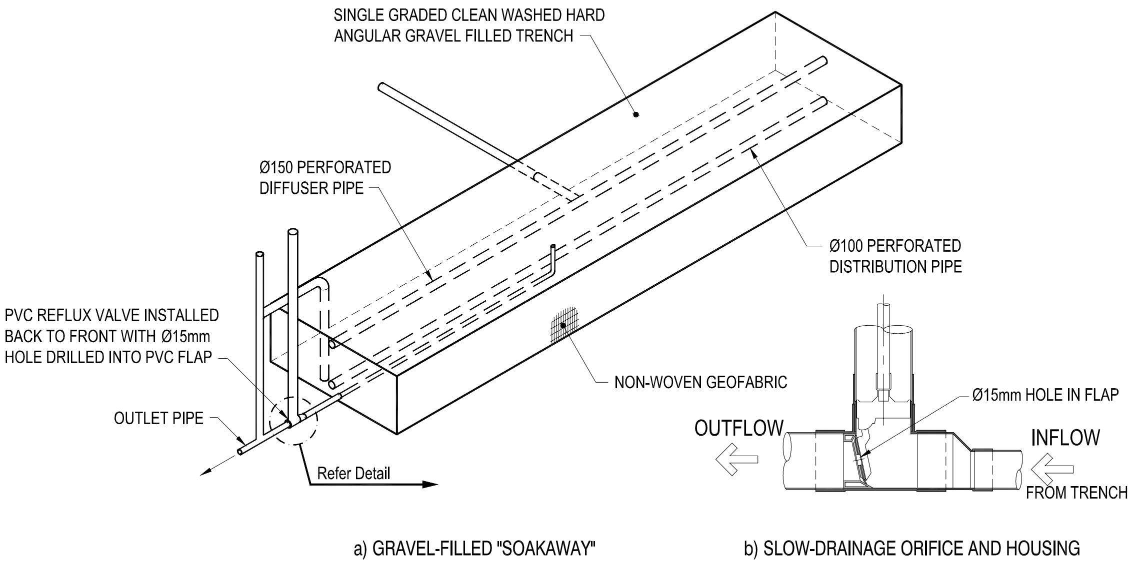

FIGURE 3 : Gravel-filled trench, pipework and detail of reversed, non-return flap with 15 mm diameter orifice

Application of this requirement is illustrated for the group of allotments draining to **Trench 15** (there are 28 trenches in “Heritage Mews”) :

• 4 residences @ 209 m^2 roof area	=	836 m^2	
• driveway/paving	=	345 m^2	
hence, TOTAL area	=	**1,181 m^2**	**(5)**

Required (retention) storage : 1,181 m^2 @ 0.030 m^3 per square metre	=	35.37 m^3	
less allowance of 1.0 m^3 per residence for rainwater tanks	=	– 4.00 m^3	
hence, TOTAL required retention volume	=	**31.37 m^3**	**(6)**

Trench 15 :

L = 17.1 m; w = 3.9 m; depth = 1.55 m, hence, total (gravel) volume = 103.4 m^3

void space ratio, e_S = 0.32, hence retention volume = **33.1 m^3**, therefore OK.

Now, total (design storm) surface runoff from the multi-lot catchment draining to Trench 15 will be :

$$1{,}181\ m^2 \times (0.9 \times 0.032 \times 2)\ m \quad = \quad \mathbf{68.0\ m^3} \qquad \mathbf{(7)}$$

In this event, there will be an overflow of (68.0 – 33.1) m^3 = 34.9 m^3 which is, approximately, the (design storm) surface runoff volume estimated for the same area considered as a “greenfields” site. It is desirable but not critical that equality of ‘before-and-after’ (development) storm runoff volume be preserved on a site-by-site basis, only that this (equality) be achieved overall, across the entire site. However, given this latitude in matching surface runoff volume to retention capacity, designers must be careful to ensure that available storage capacity *does not exceed* the runoff volume generated at a particular component in the critical design storm. Any excess storage of this type will be "wasted space".

It was found that limitations of space within the allotment and swale areas of the development made it impossible to provide all of the required on-site storage in gravel-filled trenches only, and that "Atlantis" cells – heavy duty plastic containers similar in appearance to milk crates – were needed. The particular advantage of these devices is 95% open storage space per unit of gross cell volume, compared with 35% for gravel-filled trenches. These cells were incorporated into the Chamber III segments of the four UniSAtank installations constructed, mainly, in roadway reserves (see Figure 5).

4.3 'Slow-Drainage' Provision

Given the nature of the "Heritage Mews" site, as reviewed in earlier sections, and its inability to dispose of stored storm runoff in an acceptably short time, it was essential that 'slow-drainage' of gravel-filled trenches by pipeline be provided (see Section 4.1). The (design) time-scale for emptying was set, arbitrarily, at 24 hours. In the case of Trench 15, above, this translates to outflow at the average rate of 0.36 L/s.

Given that the average water depth above the slow-drainage outlet in the trench during emptying is $H_{ave} = 0.20$ m, it can be shown by simple hydraulic calculations that an orifice of diameter 15 mm can provide the required average flow of 0.36 L/s (see Figure 3).

4.4 Three-Stage Treatment Train : the "UniSAtank"

Treatment of roadway runoff at "Heritage Mews" takes place in four "UniSAtanks". Runoff from the roadway reserve catchment up to a set Q_{peak} matched to the contributing paved area in each case, enters a kerb inlet pit fitted with trash screens designed to collect large items of urban litter, leaves, cartons, cans, etc. : this is called "Chamber I". Flow passes from Chamber I to Chamber II where sediment particles larger than 300 μm are deposited. The third stage of treatment, Chamber III, is where the bulk of sediment particulate matter finer than 300 μm is retained.

Chamber I is a simple, trash screen pit : cleaning is necessary following each major storm. Chamber II is a fairly conventional sedimentation tank with a floor baffle to destroy the energy of incoming flow, and a hanging baffle to prevent 'short-circuiting'. In typical urban residential situations, cleaning out of Chamber II should be an annual or even biennial operation only.

Chamber III is where fine particulate matter, typically in the range 20 μm to 300 μm, is retained for the 'lifespan' 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 "nappy" comprising upper (woven) and lower (non-woven) layers of geotextile separated by a 75 mm thickness of 5 mm gravel (see Figure 4). The "nappy" is effective in filtering sediment particles larger than the pore-size of the **lower** geotextile fabric, typically 20 μm; even smaller sized particulate matter may be retained by the system as it 'ages'. Its trapezoidal shape enables many years of sediment contribution to be stored.

Laboratory studies (full-size) of the performance of the three-chamber installation show TSS reduction of 87% from input at the constant rate of 195 mg/L; Chamber II accounted for 72% of this retention. The "UniSAtank" is described more fully in Espinosa et al. (2001) and Jacobs (2001).

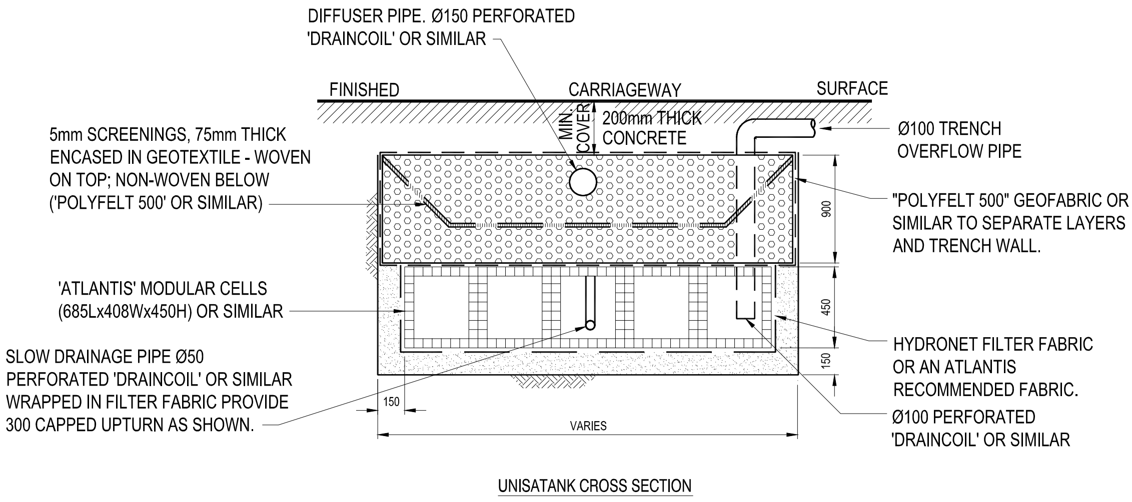

FIGURE 4 : Details of the central "nappy" filter, Chamber III of the 'UniSAtank'. Note, also, "Atlantis" cells beneath the gravel-filled section.

5. HYDROLOGICAL PERFORMANCE OF "HERITAGE MEWS"

5.1 'Design Storm' Approach and Rainfall/Runoff Simulation

Current 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 takes no 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, etc.

For these reasons, the performance of the **regime-in-balance** stormwater management solution for the "Heritage Mews" subdivision, described above, was analysed using the WUFS (Water Urban Flow Simulator) rainfall/runoff program of Kuczera et al. (2000). This program determines stormwater discharges, and is capable of assessing WSUD measures distributed at their actual spatial locations within catchments. The PURRS model (see Section 3, above) was also used to provide continuous simulation of the water balance using synthetic pluviograph rainfall records generated by the DRIP (Disaggregated Rectangular Intensity Pulse) point rainfall model of Heneker et al (2001). PURRS was also used to determine the impact of allotment-based measures and to define initial conditions impacting on the performance of management measures prior to storm events.

5.2 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. The model was used first to check peak outflow from the site for the distribution of retention components - rainwater tanks etc. - designed according to the requirements of the **regime-in-balance** strategy. This gave a 10-year ARI peak flow significantly less than the PSD of 316 L/s, thereby satisfying Design Specification 2b (see Section 2.2).

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

The WUFS program was employed to obtain a **modified** configuration of surface runoff components – rainwater tanks, landscaping, infiltration trenches, etc – which gave Q_{peak} = 316 L/s (corresponding to the PSD) for ARI, Y = 10 years. The total storage required in the subdivision to match this discharge was 62 m^3 (landscaping) + 124 m^3 (rainwater tank retention storage) + 349 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 stormwater peak discharges from the development to significantly less than (estimated) pre-development stormwater peak 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

6. CONCLUSION

An innovative water cycling system has been designed for "Heritage Mews", a new residential sub-division in the western suburbs of Sydney, NSW. Its main features include –

1. Stormwater harvesting using 3.0 kL rainwater tanks providing, annually, some 22% of in-house and outdoor demand. The tanks also assist in achieving the flood control criteria set by Council;

2. Above-ground and in-ground retention storages (rainwater tanks, gravel-filled trenches, etc) sized to ensure that post-development stormwater discharge in the critical design event

(2-hours duration, ARI, Y = 10 years) is equal to the runoff (volume) estimated for the "greenfields" site in the same design storm. The **regime-in-balance** strategy was employed to produce this outcome;

3. An infrastructure of 'slow-drainage' orifices and pipelines designed to ensure emptying of all in-ground components in 24 hours;

4. Items 3 and 4, above, taken together, guarantee Q_{peak} from the site in the design storm is significantly less than the permissible site discharge, PSD;

5. Provision for treating 95% of annual average runoff (volume) to a standard of TSS less than 20 mg/L and maximum particle size, 20µm.

The flood control design process was extended using the WUFS and PURRS continuous simulation models to refine the design to achieve Q_{peak} 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.

While the goal of 'before-and-after' runoff volume equality is achievable in the great majority of urban catchment cases using retention/infiltration technology, its application to "Heritage Mews" is noteworthy. This follows from the nature of the site - very low permeability clays over rock – making disposal of temporarily retained storm runoff by infiltration, impractical as the primary disposal mechanism for in-ground stored runoff.

The project also demonstrates, using continuous simulation modelling, that small rainwater tanks, plumbed to supply over 20% of household demand, can contribute significantly to achieving catchment-wide (minor) flood control objectives.

REFERENCES

Argue, J.R. (2001). Recent developments in Australian 'source control' technology and practice. Proc 1st National Conf on SUDS, Coventry, June.

Argue, J.R. (2002). A new stormwater 'source control' handbook for Australian practice : an outline. Proc 9th International Conf on Urban Storm Drainage, Portland, Oregon, US, September.

Coombes, P.J. (2002). Rainwater tanks revisited : new opportunities for urban water cycle management. PhD. Thesis. University of Newcastle. Australia.

Coombes, P.J., Argue, J.R. and Kuczera, G. (2000). Figtree Place : a case study in water sensitive urban development. Urban Water. 1(4). 335 – 343.

Coombes, P.J., Frost, A., Kuczera, G., O'Loughlin, G. and Lees, S. (2002a). Rainwater tank options for stormwater management in the upper Parramatta River Catchment. Proceedings of the 27th Hydrology and Water Resources Conference. Melbourne, Australia.

Coombes, P.J., Kuczera,G. and Kalma, J.D. (2002). Economic, water quantity and quality results from a house with a rainwater tank in the inner city. Proceedings of the 27th Hydrology and Water Resources Conference. Melbourne, Australia.

Coombes, P.J. and Kuczera, G. (2001). Rainwater tank design for water supply and stormwater management. Stormwater Industry Association 2001 Regional Conference. Port Stephens, NSW.

Debo, T.N. and Reece, A. J. (1992). Determining downstream analysis limits for detention facilities. Proc Novatech Innovative Technologies in the Domain of Urban Stormwater Drainage, Graie, Lyon, France.

Espinosa, R., Al-Fayyaz, T., Argue, J., Johnston, L. and Pezzaniti, D. (2001). High performance sediment-retaining device for urban catchments : introducing the UniSAtank. Proc Novatech Innovative Technologies in the domain of Urban Stormwater Drainage, Graie, Lyon, France.

Heneker, T.M., Lambert, M.F. and Kuczera, G. (2001). A point rainfall model for risk based design. J. Hydrology. Vol. 247. 54 – 71.

IEAust. (1987). Australian rainfall and runoff : a guide to flood estimation. Vol. 1. The Institution of Engineers, Australia.

Jacobs, R.R. (2001). Development and evaluation of an improved infiltration device technology. Report, Urban Water Resources Centre, University of South Australia, Adelaide, June.

Kuczera, G., Williams, B., Binning, P. and Lambert, M. (2000). An education web site for free water engineering software. 3rd International Hydrology and Water Resources Symposium. Institution of Engineers Australia. Perth. Western Australia. 1048 – 1053.

Wong, T., Wootton, R., Argue, J. and Pezzaniti, D. (2000). Bringing order to the pollution control industry : issues in assessing the performance of gross pollution traps. Trans Australian Civil Engineering, I E Aust., Vol CE42, pp 57 – 62.