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Managing Urban Regrowth with an 'at capacity' Stormwater Infrastructure

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Abstract: *The stormwater infrastructure of the City of Gosnells, WA, is 'at capacity' (ARI, Y = 5 years). The cost of conventional upgrade ahead of further urbanisation has been estimated as $ 120 million. An alternative, cost-effective approach has been adopted based on WSUD 'source control' principles. There are two, basic, soil domains: sand and sandy-clay, and, medium to heavy clay. The adopted criterion for stormwater control is set at ARI, Y = 100-years, determined for the* ***site*** *worst case resulting from application of storm durations 6 mins to 72 hours. Three design scenarios result: (1) large lots in sand or sandy-clay soil which require full retention/disposal on site with no outflow to street drainage;(2) Small lots (A < 350 m^2) in sand or sandy-clay which require retention/disposal on site with permissible outflow equivalent to pre-development ARI, Y = 5-years; and (3) All lots in medium to heavy clay soil which require full detention on site with permissible outflow equivalent to pre-development ARI, Y = 5-years. A design spreadsheet has been prepared: this provides details of 'soakwell' and detention installations and provision for outflow, orifice details, etc.*

Keywords: *'at capacity', detention, extended detention, 'soakwells', source control, stormwater*

1. INTRODUCTION

The City of Gosnells, Western Australia, is a municipality serving a population of around 100,000 people located 15 km south-east of Perth CBD encompassing an area of 127 km^2 on the edge of the Perth Plain and extending into the foothills of the Darling Ranges. The City was established in 1907 as one of the earliest population areas away from Perth and Fremantle. Unlike most of the other municipalities making up the Greater Perth Region, soils in the Gosnells area range from deep sands through peaty sands and sandy clays to gravelly sandy clay, granite and laterite – the latter soil/geological conditions being encountered in the foothills region of the City.

This range of soils is in sharp contrast to the fairly uniform 'deep sands' which characterise soil conditions of the bulk of other Perth municipalities along the seaboard and on the sandy plain. Common practice in the Perth region is for roof runoff to be diverted to "soakwells" which pass the stored flow, by percolation, into the local sands and, ultimately, the unconfined aquifers (water table). The prime focus of residential street drainage infrastructure – in such circumstances - is therefore to cater, almost entirely, for runoff generated within road carriageways and connected paved areas (eg allotment driveways), only. The soil/geological situation in Gosnells support this common practice, but only in about half of the area within the municipality.

The City has attracted increased business and industrial activity in recent years and, associated with it, increased population. The resulting needs – greater commercial and industrial precincts and estates as well as new residential sub-divisions featuring medium density allotments (see Figure 1) – has put considerable stress on the existing street drainage network causing ‘overload’ to occur in many areas.

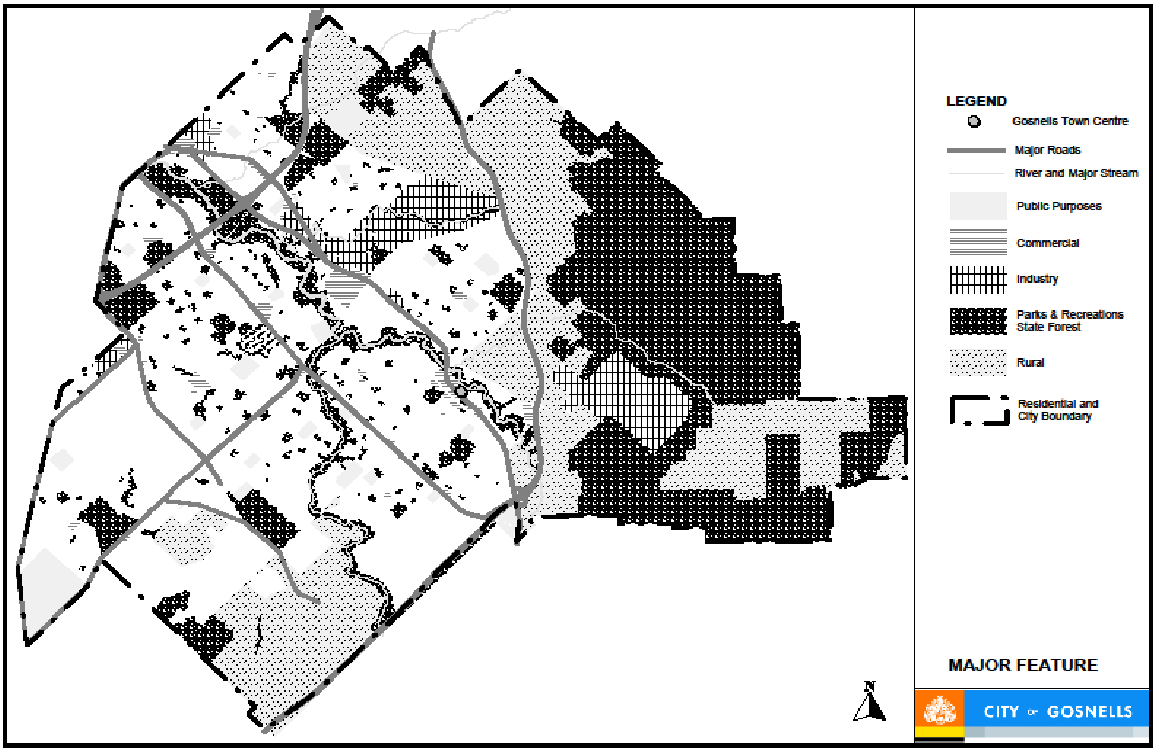

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Figure 1: Major features of the City of Gosnells, Western Australia.

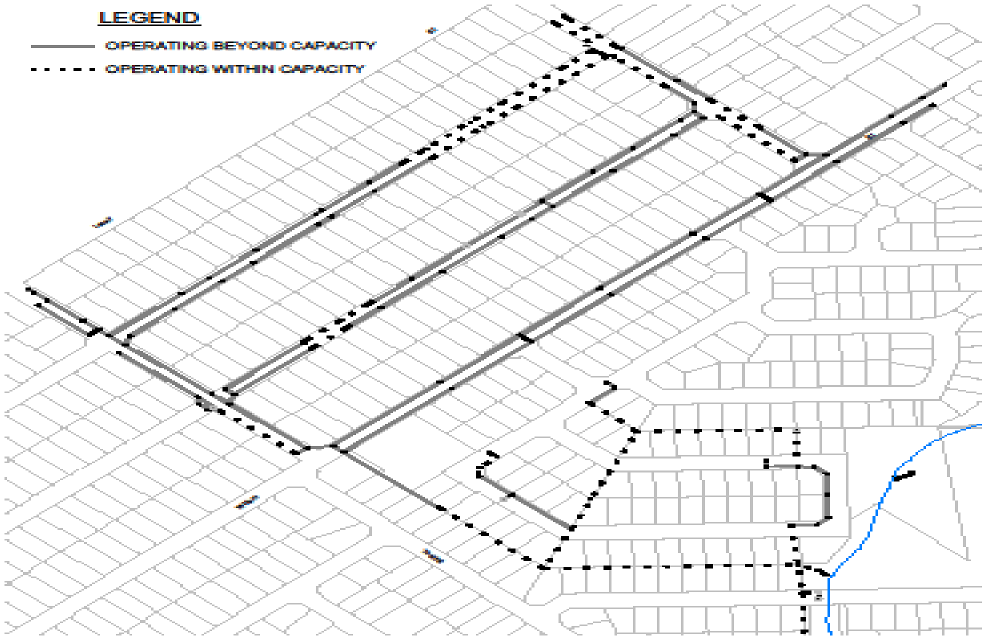

Figure 2: City of Gosnells sub-catchment B13/Beckenham showing pipelines operating ‘beyond capacity’ and ‘within capacity’.

As a first step towards solving the problem of overload of (street) stormwater pipelines in design storm events (ARI, up to Y = 5 years), the City instituted a survey and assessment of its networks and produced a file of plans separating those (pipelines) operating 'beyond capacity' and those operating 'within capacity'. An example of one of these plans is presented in Figure 2.

The next step in the task was to seek advice on re-development of the entire network to match the expected additional flows. This was done and an estimate of $ 120 million was determined as the anticipated cost of the augmentation. Faced with this, City of Gosnells decided to explore an alternative stormwater management strategy involving (on-site) **retention practices (or stormwater 'source control')** whereby flow rates of stormwater delivered to the network would be reduced to match the flows that could be carried by it without augmentation. The paper describes this process and the Spreadsheet developed by the City to simplify the design process involved and to ensure that acceptable development applications were presented to the City for approval.

2. SOME PRELIMINARY DECISIONS

The new strategy for stormwater management in Gosnells was based on the following decisions/practices -

1. (a) Street drainage networks, generally, are near or beyond 'capacity'; additional development on allotments **greater than 350 m^2** must therefore be designed – generally - to **fully retain** "100-years" (ARI) storms with no outflow to (fronting) street drainage systems, *if at all possible.* [The retained storm runoff will be stored temporarily in *soakwells* (common practice in Perth sandy soils).

   (b) This requirement is relaxed, however, in certain areas of the City, in particular, those areas characterised by clay and silty soils which have low percolation capability. In these cases a small outflow is permitted equivalent to a maximum permissible *pre-development* flow from the lot area calculated using **5-years** ARI and storm duration given by the allotment 'time of concentration', typically 20 minutes. The runoff coefficient adopted for calculating this flow is C = 0.143. [Concrete, circular pipes (in-ground, axis vertical) are to be used for temporary retention of storm runoff in these cases.]
2. All properties **smaller than 350 m^2** are allowed to **discharge a small outflow** to the (fronting) street drainage system. This outflow is set at equivalent to a maximum permissible *pre-development* flow from the lot area with **5-years** ARI and storm duration given by the allotment 'time of concentration', typically 15 minutes. The runoff coefficient adopted for calculating this flow is C = 0.143;

3. Additional assumptions/practices –

   - All roof areas and connected paved areas are connected to in-ground soakwells;
   - Pervious and unconnected paved areas do not contribute stormwater to soakwells;
   - "Design runoff volume" (ARI, Y = 100 years) is determined using rainfall intensities drawn from the full range of storm durations – 6 mins to 72 hours. This produces the greatest runoff volume which must be (temporarily) stored and, therefore, the greatest number of in-ground retention devices; the optimum storm duration given by this process is called "critical storm duration".

This interpretation of 'critical storm duration' based on the *"...full range of storm durations..."* instead of on values derived from *catchment-wide analyses* (normal best practice), is justified by the particular circumstances presented by Gosnells, namely, 'at capacity' drainage networks and the acceptance of a small flow from each site (maximum permissible pre-development, 5-years ARI) into the formal drainage path. It also enables standardisation of the design procedure to be incorporated into the Spreadsheet.

3. IMPLEMENTATION – SITE COMPONENTS

The City of Gosnells provides a Typical Residential Layout for developers to be used with the Spreadsheet in preparing a development application. This is illustrated in Figure 3.

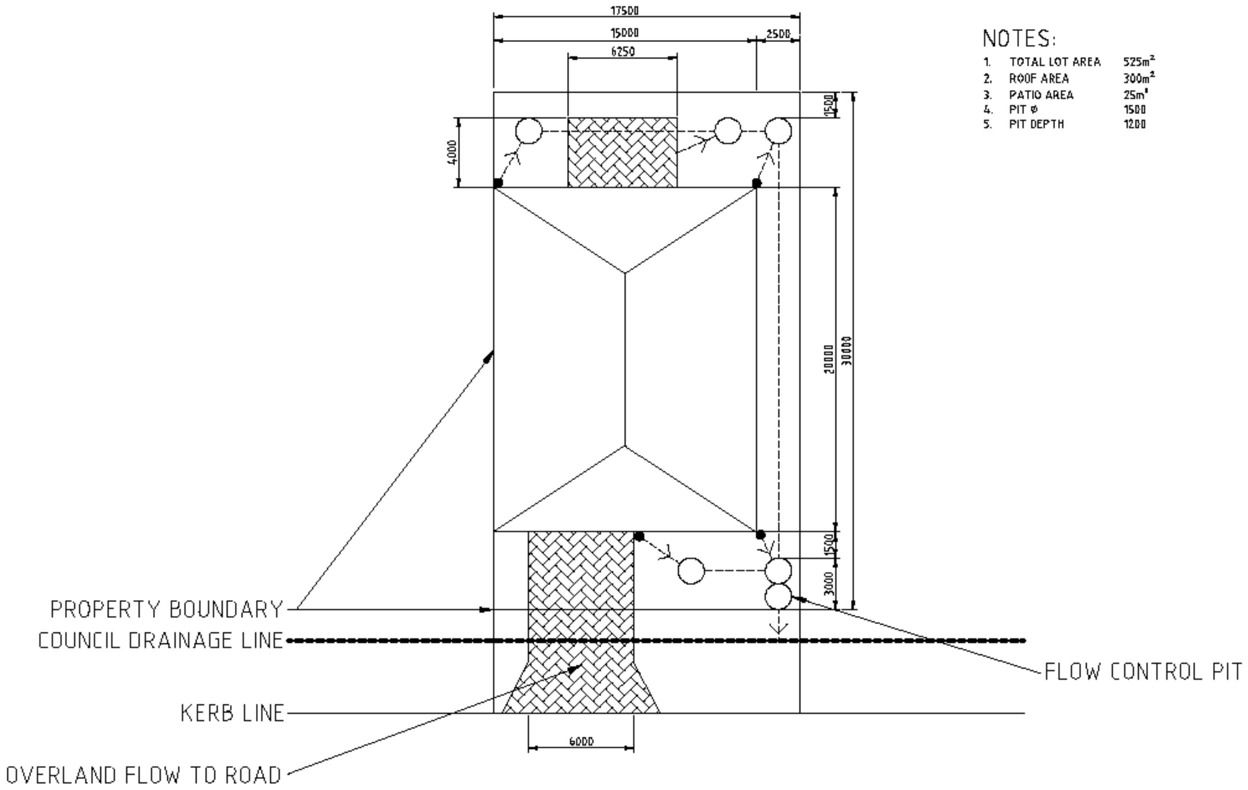

Figure 3: Typical residential layout showing arrangement of *soakwells* and other features. (model for development application)

Also provided to developers are standard drawings showing construction details of *soakwells* and *concrete (in-ground) tanks* as required by the City for inclusion in development applications. These drawings remove any uncertainty or misunderstanding about the City's intentions and requirements for stormwater management on new developments. The details are illustrated in Figures 4 and 5.

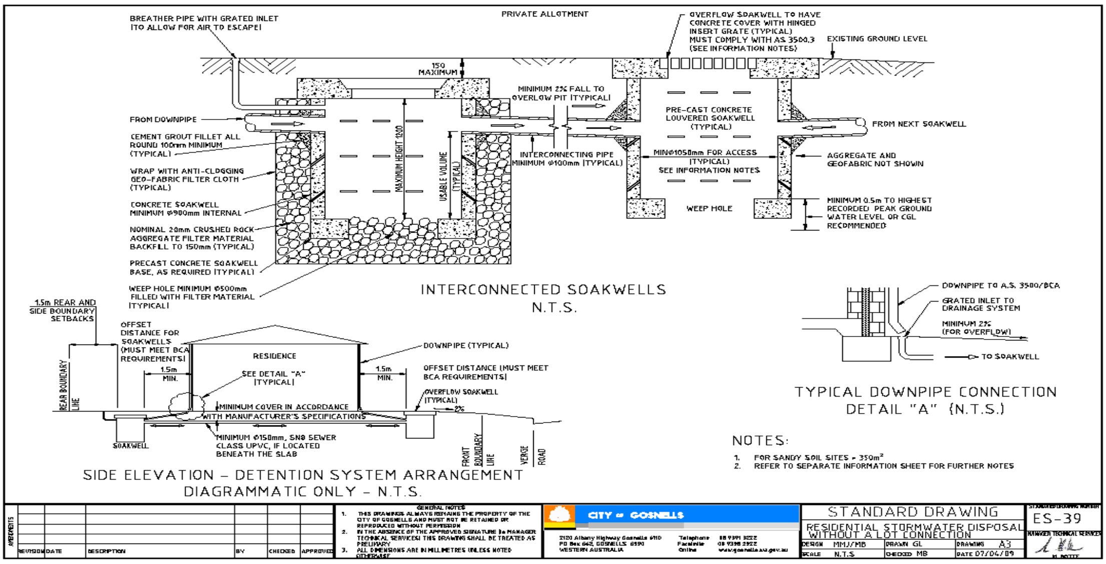

Figure 4: Details of inter-connected soakwells and house/soakwells arrangement: high soil permeability sites

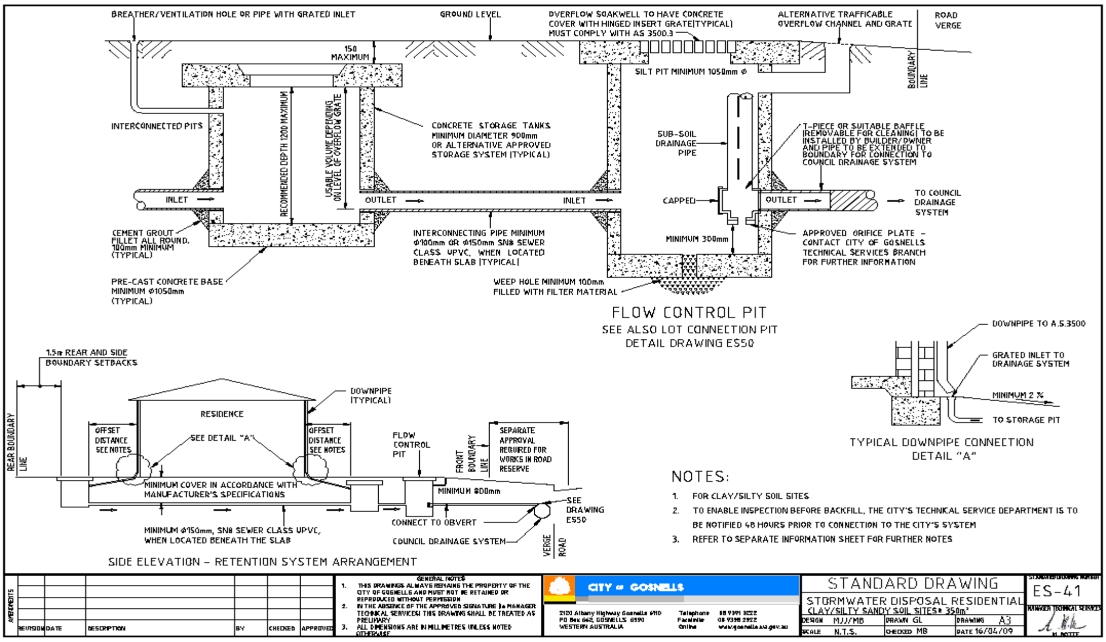

Figure 5: Details of inter-connected circular concrete tanks and flow control pit: low-permeability sites

4. SPREADSHEET: BASIC THEORY

4.1 Soakwells

The theory upon which the Spreadsheet calculations are based for specifying *soakwells* at a given site is set out as –

> "**Procedure 2A:** 'Leaky' well with cleansed water inflow typically from a roof"
> in *"WSUD: basic procedures for 'source control' of stormwater – a Handbook for Australian practice"* (Argue, 2004/2009). The derivation leads to the formulation –

$$D = \sqrt{\frac{\forall}{\frac{\pi}{4}\left(H+120k_h\,.\tau.U\right)}} \qquad \text{(m)} \qquad \textbf{(1)}$$

[This formula includes the assumption, D ≈ H]

where $\forall$ = volume of (roof) runoff in storm of critical duration (m^3)

D = diameter of soakwell (m)

H = height of soakwell (m)

k_h = soil hydraulic conductivity (m/s)
τ = time base of the design storm runoff hydrograph (mins)
U = Moderation Factor : 0.5 (sand); 1.0 (sandy clay); 2.0 (clay).

[Moderation Factor, U, is a multiplier which reflects the **difference** between permeability results obtained in borehole (site) field tests and the observed permeability associated with installed retention devices such as *soakwells*, *gravel-filled trenches*, etc.]

Application of this formula leads, typically, to devices of great and impractical size (diameter) in the first instance. It is therefore necessary to 'compartmentalise' the roof – dividing it into a number of equally-contributing sections. This process is carried out in the software supporting the Spreadsheet: the in-ground devices have minimum diameter of 900 mm and maximum depth, 1.80 m.

Another important factor required in design is that of *emptying time*. In situations where stored runoff must be passed in its entirety [Case 1(a), above] into the parent soil of the residential site, then it is important to ensure that the device is empty at the time of arrival of a succeeding significant storm. This issue involves two information sub-sets: first, the means (formula) to calculate how long it takes for the device to empty, and, second, a practice criterion (relating storm successions and ARI) against which to compare the time of emptying.

- Emptying time, T in seconds (Argue, 2004/2009):

$$\text{soakwells :} \qquad T = -\frac{4.6D}{4k_h}\log_{10}\left[\frac{\frac{D}{4}}{H+\frac{D}{4}}\right], \; s \qquad \textbf{(2)}$$

- Criterion relating emptying time, T, and ARI:

TABLE 1 (Argue, 2004/2009)

INTERIM RELATIONSHIP BETWEEN ARI AND 'EMPTYING TIME'

Ave Recurr. Interval (ARI), Y-years	1-year or less	2-years	5-years	10-years	20-years	50-years	100-years
Emptying time, **T** in days	0.5	1.0	1.5	2.0	2.5	3.0	3.5

4.2 Concrete tanks (circular) and flow control pit

This infrastructure, recommended for allotments in clay and silty sand sites, operates entirely as a (roof) runoff temporary detention system with discharge to the street drainage network via a *submerged* orifice (see detail, Figure 5). This provision ensures that outflow to the street will only take place when 'head' (pressure) in the receiving system falls *below* that of the water stored on site, and, even then, at a quite small flow rate initially. In time, as the peak of flow in the street drainage network passes and capacity for conveyance in that system increases, flows through the (submerged) orifice plates of individual allotments will increase leading, ultimately, to complete emptying.

The Spreadsheet provides a calculated "allotment outflow rate" determined (maximum) as the 5-years ARI flow from the site in its pre-development state (see Section 2, above). However, this rate will only occur with the orifice operating under "free fall" conditions encountered in the latter stages of a storm event. The orifice formula used in the Spreadsheet is (Eqn 3) –

$$A_o = \frac{Q_{des}}{B \cdot C_d \cdot \sqrt{2 \cdot g \cdot h}}$$

C_d = orifice discharge coefficient (0.6)
B = blockage factor (0.5)
h = depth of water above the centroid of the orifice (m)
A_o = orifice area (m^2)
Q_{des} = design discharge (m^3/s)

Given the manner in which the on-site (roof) runoff storage system operates and its inter-relationship with the particular circumstances occurring in the street drainage network during a flood – as explained above - it is not possible to assign a *time of emptying* to any individual site or group of allotments in the network. However, it is predicted that the slope of natural surface within the *developed* region of the municipality – ranging from 3.0% down to a minimum of 0.1% - is sufficient to guarantee that all stormwater temporarily retained during a 'design' storm event (100-years ARI) will be completely cleared from allotment sites within the 3.5 days specified in Table 1. This matter is, of course, complicated by 'tailwater' considerations in receiving pipelines conveying stormwater down-slope from the City of Gosnells.[A monitoring programme involving water level, etc recoding instruments will be mounted by the City to check the performance of the system under 'real world' operating conditions.]

5. USING THE SPREADSHEET

The Spreadsheet is set up for easy and speedy use by developers and their consultants, ensuring a competent outcome acceptable to the City. It involves three steps –

STEP 1: insert roof area and total area of paving draining to on-site soakwells and concrete tanks;

STEP 2: select size (diameter and height) of proposed soakwells or tanks from drop down menu;

STEP 3: select soil type (sand or sandy clay or clay) from drop down menu;

Three *default* values of Moderation Factor, U (see Section 4.1), are incorporated into the calculations for soils nominated as "sand" or "sandy clay" or "clay". However, these values can be over-ridden and a value for U inserted from a regression relationship (U *versus* Hydraulic Conductivity) where information on field soil permeability measured at a site is known.

STEP 4: select 'yes' or 'no' to the question: "permission to connect to council drainage ?"

The intent of this step is to prevent allotments of (relatively) large size discharging storm runoff into the street drainage system. Special consideration – derived from the answer to the STEP 4 question - is given to sites where this requirement causes distress, for example, at a site slightly larger than 350 m^2 located in heavy clay.

The Spreadsheet produces three Outcomes –

OUTCOME 1: Number of soakwells or concrete tanks needed on the property;

Care needs to be exercised in locating the soakwells on the site layout to ensure that sufficient *clearance distance* between soakwells is provided, and between soakwells and footings/boundaries.

OUTCOME 2: Volume required to be retained/detained within the soakwells or tanks;

OUTCOME 3: Diameter of orifice of the outlet pipe to council drainage (with concrete tanks - see Figure 5).

The Spreadsheet designed for use in the Gosnells region can be viewed at:

http://www.gosnells.wa.gov.au/scripts/viewurllist.asp?NID=21183

6. DISCUSSION-CONCLUSION

A spreadsheet has been developed for use by developers and consultants active in the process of 'growth' development within the City of Gosnells as well as re-developing presently occupied sites through initiatives such as the Local Housing Strategy which will result in increased densities in activity nodes. The intention of the spreadsheet is twofold –

- First, to provide a clear and cost-effective practice enabling the City to achieve its development and re-development goals despite the presence of a largely 'at capacity' stormwater infrastructure. Intelligent use of the infiltration capabilities of the municipality's sandy soils makes this possible in a large part of the City; the concepts of *retention* and *extended detention,* intelligently applied, account for the remaining areas of less permeable soils; and,

- Second, it provides a tool for use (and submission) in the approval process, ensuring that practices acceptable to the City are followed with minimum design effort on the part of proponents of development/re-development projects, and minimum staff 'time' required to carry out checking procedures;

The initiative taken by the City of Gosnells in developing its cost-effective stormwater management strategy in the circumstances of a substantially 'at capacity' infrastructure and faced with demand for urban growth, is likely to attract the attention of other municipal agencies, not only on Perth but, also, across the nation.

In the case of Perth itself, urban development has extended along the coastline north to Yanchep and south to Rockingham, a distance of nearly 100 km, while penetration of the city *eastwards* towards the Darling Range has been minimal. There are two reasons for this: residents of Perth are particularly attracted to a coastal life-style. But there is, also, a hesitation for development to extend eastwards beyond the limits of the sandy plain, driven by some uncertainty about building practices required in the less permeable soils encountered towards the foothills, and the presence of an elevated water table. Indeed, it is common for residential sub-divisions and industrial estates in the eastern suburbs of Perth to introduce a layer of sand – up to one metre thick – as a base for new development to overcome these joint problems. A shortage of sand required for this practice to continue is causing serious concern in Perth, and alternative approaches, such as that offered by the City of Gosnells' is likely to attract some interest.

Further afield – across the nation – the problem of 'at capacity' stormwater infrastructure within a context of anticipated further urban growth, is a not uncommon scenario. The City of Gosnells' approach using the benefits to be gained by on-site *retention* of ARI, "100-years" storm runoff followed by 'slow-release' (*extended detention*) of the temporarily stored stormwater over a period of around 3.5 days could provide a solution for cash-strapped municipalities unable to fund expensive infrastructure upgrades and located in regions of clay or high water tables.

REFERENCES

Argue, J R (Ed, 2004/2009). *WSUD: basic procedures for 'source control' of stormwater – a Handbook for Australian practice.* Urban Water Resources Centre, Univ of South Australia, Adelaide. Student Edition of the Handbook in 6 Parts can be downloaded from – www.unisa.edu.au/water/UWRG/publication/ follow the prompts