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Report for Potential Use of Stormwater in the Perth Region Quantity and Storage Assessment

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Prepared for the Department of Water



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Executive Summary

The Department of Water (DoW) is investigating the potential for stormwater harvesting of the drainage network within the Perth metropolitan and Peel regions as a source of potable or non-potable water. The purpose of this study was to estimate the quantity of available stormwater, to identify harvesting options and to present a preliminary indication of geographical locations within the metropolitan region that may be suitable for surface or groundwater storage of stormwater. Discharge estimates were based on a combination of data and catchment modelling.

The median annual discharge of stormwater from the Perth and Peel Metropolitan regions was estimated as 120 GL with approximately 67% from the Swan-Canning catchment (exclusive of Avon and Helena rivers; and Ellen, Jane and Susanah brooks), 16% from the coastal Main Drains (Carine, Herdsman and Subiaco) and 17% from the Peel's Main Drains. This stormwater volume is equivalent to approximately 2 Mundaring Weirs at full storage capacity (63.6 GL) or 2.5 desalination plants (45 GL). This is also greater than the potential volume from rainwater harvesting of the region's residential roofs.

Strategies for harvesting and storage of this potential drainage resource are dependent on the hydrology of the study area. In two Main Drains (Bayswater and Yule Brook) approximately 40-50% of the winter discharge is generally comprised of baseflow, and the remaining 50-60% is stormwater runoff. Harvesting of stormwater events requires an opportunistic approach such as filling basins (i.e. underground voids, storage basins). In contrast, stormwater harvesting and storage of winter and spring baseflows can be achieved through relatively constant pumping of these waters into the aquifer.

Alternative strategies such as stormwater aspects of Water Sensitive Urban Design (WSUD) and modification of the Main Drain invert (or bottom) levels aim to increase the fraction of the stormwater runoff volume transferred and maintained in the groundwater. For example, greater infiltration and a decrease in the direct loss of stormwater via the drainage network occur via the implementation WSUD principle of 'infiltrating at source'. Further, the WSUD principle of detaining flood volumes near the source also extends the duration from which stormwater can be extracted from the drainage network. Another approach is to increase invert levels at appropriate locations in the drainage network to decrease groundwater exfiltration into the Main Drains. A concomitant increase in the channel width along these reaches is required to maintain hydraulic capacity for conveyance of floods. Both of these strategies aim to maintain water in the superficial aquifer rather than losses via the drainage network. Potential locations for drainage water storage options (lined and unlined basins, below ground basins, groundwater) are summarised on the basis of spatial constraints (i.e. depth to groundwater, distance from Main Drain, soil type, acid sulphate soils, wetlands and Public Drinking Water Source Areas).

An integrated approach is suggested to realise the potential for stormwater harvesting of the drainage waters that includes:

- » Continue implementation of the WSUD principle of 'infiltrate at source';
- » Identification of suitable reaches along the Main (and Local) Drain network to raise invert levels and widen the channel;
- » Extraction of winter and spring baseflows with injection (or infiltration) into the superficial aquifer; and
- » Storage of stormwater events in detention basins with possible injection or infiltration into the superficial aquifer.



1. Introduction

Urbanisation of catchments can generate substantial stormwater runoff. In the Perth metropolitan region an extensive drainage network collects and conveys stormwater runoff that is subsequently discharged to the Swan-Canning Estuary or ocean outlets. Similarly, the drainage network of the Peel region within the Metropolitan Region Scheme collects and conveys stormwater runoff that is then discharged into the Serpentine River and ultimately to the Peel-Harvey Estuary.

The Department of Water (DoW) is investigating the potential for stormwater harvesting from the drainage network within the Perth metropolitan and Peel regions as a source of potable or non-potable water. Understanding the potential use of this resource is important because of the uncertainty in future water sources and supply. Additionally, there is growing environmental awareness within the community and a changing view of stormwater from a waste product to a valuable resource (Department of Environment 2004).

The objective of this study is to estimate stormwater quantity in the Perth and Peel regions, to identify harvesting strategies and to provide a preliminary indication of geographical locations that may be suitable for surface or groundwater storage of this potential resource.

1.1 Study Area

The study area is shown in Figure 1. There are approximately 830 km of Main Drains in the Perth Metropolitan region with more than 3000 km of Local Drains. The study area primarily focuses on regions serviced by Water Corporation Main Drains for several reasons, namely:

- » Data availability: Long-term discharge data is available from the Main Drains but not the Local Drains;
- » Numerical modelling: Discharge from the Main Drains into the Swan-Canning Estuary have been simulated over the period of 1965-2000 with a catchment hydrology model; and
- » Greater Water Harvesting Potential: Greater discharge in the Main Drains results from the aggregation of stormwater runoff from the Local Drains.

Several areas in the study region not included in this analysis including:

- » Northern coastal suburbs: Rainfall does not generate substantial stormwater runoff, rather much of the water infiltrates rapidly into the superficial aquifer;
- » Rockingham Main Drains: Data was not available to estimate stormwater discharge of the Rockingham Main Drains; and
- » Upper Swan River: The upper Swan River (Avon, Ellen Brook, Helena, Susanah Brook, Jane Brook) catchments were not assessed. However, the stormwater harvesting principles developed here are valid for these waterways as well.

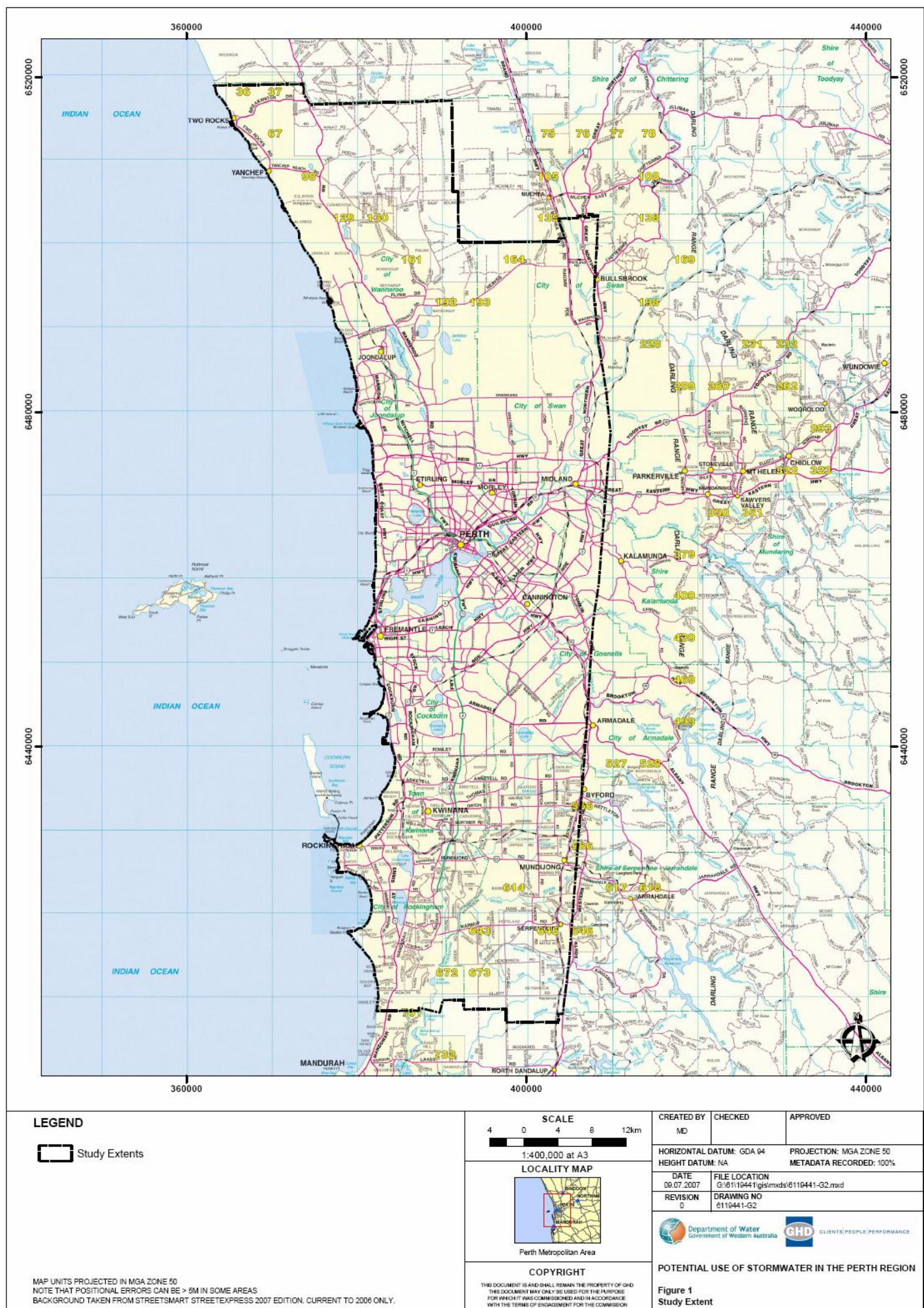


Figure 1 Study area

2. Literature Review

In this section a summary of relevant findings from several past investigations of the regional surface water resources across the Perth metropolitan and Peel regions is provided.

2.1 Perth Urban Water Balance Study

The objectives of the Perth Urban Water Balance Study (Water Corporation 1987) were to:

- » Identify areas where unconfined groundwater resources may be at risk;
- » Investigate the areas greatest at risk; and
- » Identify groundwater management options for risk areas.

A representative water balance model for the Perth urban area was developed. The water balance was developed by equating changes in groundwater storage from inputs and outputs. Inputs included rainfall, groundwater inflow and artificially imported water. Outputs included evapotranspiration, groundwater outflow, wastewater disposal and surface drainage.

This study identified that the drainage network can be either an input into groundwater via infiltration basins or an output via drainage networks. Stormwater runoff was estimated as rainfall over the percentage of impermeable areas that drain to the receiving environments. The potential for additional stormwater runoff to recharge groundwater through infiltration basins was suggested.

2.2 Drainage Management Swan-Canning Catchment, Bulletin 1131

The Environmental Protection Authority (EPA) published Bulletin 1131 (EPA 2004) in response to a request for advice on statutory mechanisms to control the quality and quantity of drainage into the Swan and Canning rivers. Bulletin 1131 reviewed the outcomes and recommendations from a number of previous drainage management studies and the Drainage Management Forum of late 2003 to early 2004. Key recommendations from Bulletin 1131 include:

- » Effective management of urban drainage was identified as a high priority to reduce nutrients to the Swan and Canning Rivers;
- » Total water cycle management was outlined as a requirement in urban drainage management in order to improve water use efficiency through increasing the capture, storage and reuse of water close to the source;
- » The review identified drainage management responsibilities within the metropolitan region. There are 29 local governments managing approximately 80% of the drainage network (the local drains), while the Water Corporation manages the remaining 20% (the Main Drains); and
- » Stormwater drainage estimates in the Bulletin are over 200 GL of stormwater is conveyed to the rivers and ocean. However, the source or method of this volume estimate is not outlined.

3. Methodology

To reiterate the objective of this investigation is to estimate the quantity of stormwater runoff and to identify suitable storage options of harvested stormwater for re-use. The approach was as follows:

- » Estimation of the discharge volume through the drainage network and the seasonal pattern of the flows¹;
- » Review and development of suitable stormwater 'harvesting' options; and
- » Identification of geographical areas to implement stormwater harvesting techniques.

Multiple sources of information were used to estimate stormwater runoff in the Perth and Peel regions. These included:

- » Discharge data from gauging stations at several key locations were used to:
 - Characterise seasonal baseflow patterns in the Main Drains;
 - Validate numerical simulations of the Main Drain catchments that discharge into the Swan-Canning Estuary; and
 - Develop linear regression relations between several Main Drains in the Peel region to synthesise a long term record for one of the drains;
- » Prior simulations with LASCAM (LArge SCAle CAatchment Model) served to estimate the stormwater volume of the Main Drains into the Swan-Canning Estuary; and
- » Approximate annual estimates of three coastal Main Drains from the Water Corporation.

Options for stormwater storage were then developed. This included the identification of opportunities and constraints in the siting of these storage techniques. Spatial mapping was then used to identify suitable locations and their areal extent to implement storage options for stormwater harvesting.

Specifically, the study's methodology included:

- Review of available discharge data from drainage monitoring stations;
- Comparison of selected Swan-Canning Main Drain data with LASCAM simulations;
- Estimation of total annual runoff of the Swan-Canning region Main Drains with LASCAM simulations;
- Estimation of total annual runoff of several of the Peel region Main Drains with available discharge data and statistical correlations;
- Forecast the impact of inter-annual climate variability on stormwater quantity;
- Examination of seasonal patterns of baseflow in the Main Drains;
- Review of stormwater harvesting options and implementation considerations;
- Spatial opportunities analysis of stormwater harvesting options; and
- Examination of potential locations and areal extents for each harvesting option.

¹ This latter point is important in the selection of appropriate harvesting and storage options.

4. Data Analysis

In this investigation annual discharge was estimated for the Main Drains of the Swan-Canning Estuary and several within the Peel region. It was assumed that stormwater harvesting from Main Drains generally provides a more consistent source to design stormwater harvesting and storage infrastructure than the Local Drains.

This study did not consider flood discharge from the upper Swan River inclusive of the Avon River, Ellen Brook, Jane Brook and Susanah Brook. Annual discharge estimates are provided for these waterways, but the focus here was on the Main Drains of the Swan-Canning catchment and the Peel region.

Additionally, estimates of stormwater quantity for the northern urban corridor were not included in the analysis. Firstly, there is a lack of drainage discharge data for this region. Secondly, much of this region has natural high rates of infiltration negating the need for Main Drains to convey stormwater runoff or to manage water levels of the superficial aquifer.

Though stormwater quantity was estimated for several 'focus' regions, namely the Swan-Canning and Peel Main Drains, the subsequent spatial analyses to identify suitable stormwater storage options considered the entire area of the Metropolitan Region Scheme.

4.1 Gauging Station Data

Several of the waterways in the study area had discharge data of sufficient duration from either the Water Corporation or DoW to allow estimation of discharge (Table 1 and Figure 2). These gauged Main Drains were representative of different regions within the study area.

Table 1 Gauging station information

DoW Station Number	Station Name	Easting	Northing	Start of record	End of record	Yearly	Monthly	Daily	Data Exceeds 10 yrs
616084	Bennet Brook MD ²	404589	6472648	Jan-88	Dec-06	Yes	Yes	No	Yes
614005	Dirk Brook Kentish Farm MD	406240	6412129	Apr-71	May-01	Yes	Yes	No	Yes
616087	South Belmont MD Abernethy Road	397864	6464787	Jan-88	Dec-06	Yes	Yes	No	Yes
616042	Yule Brook MD	402472	6456289	Jan-85	Dec-06	Yes	Yes	Yes	Yes
614096	Peel MD Folly Rd	389725	6422690	Jun-94	Jan-98	Yes	Yes	Yes	No
616082	Bayswater MD Slade St	398086	6467454	Jan-98	Dec-06	Yes	Yes	Yes	No

² MD = Main Drain

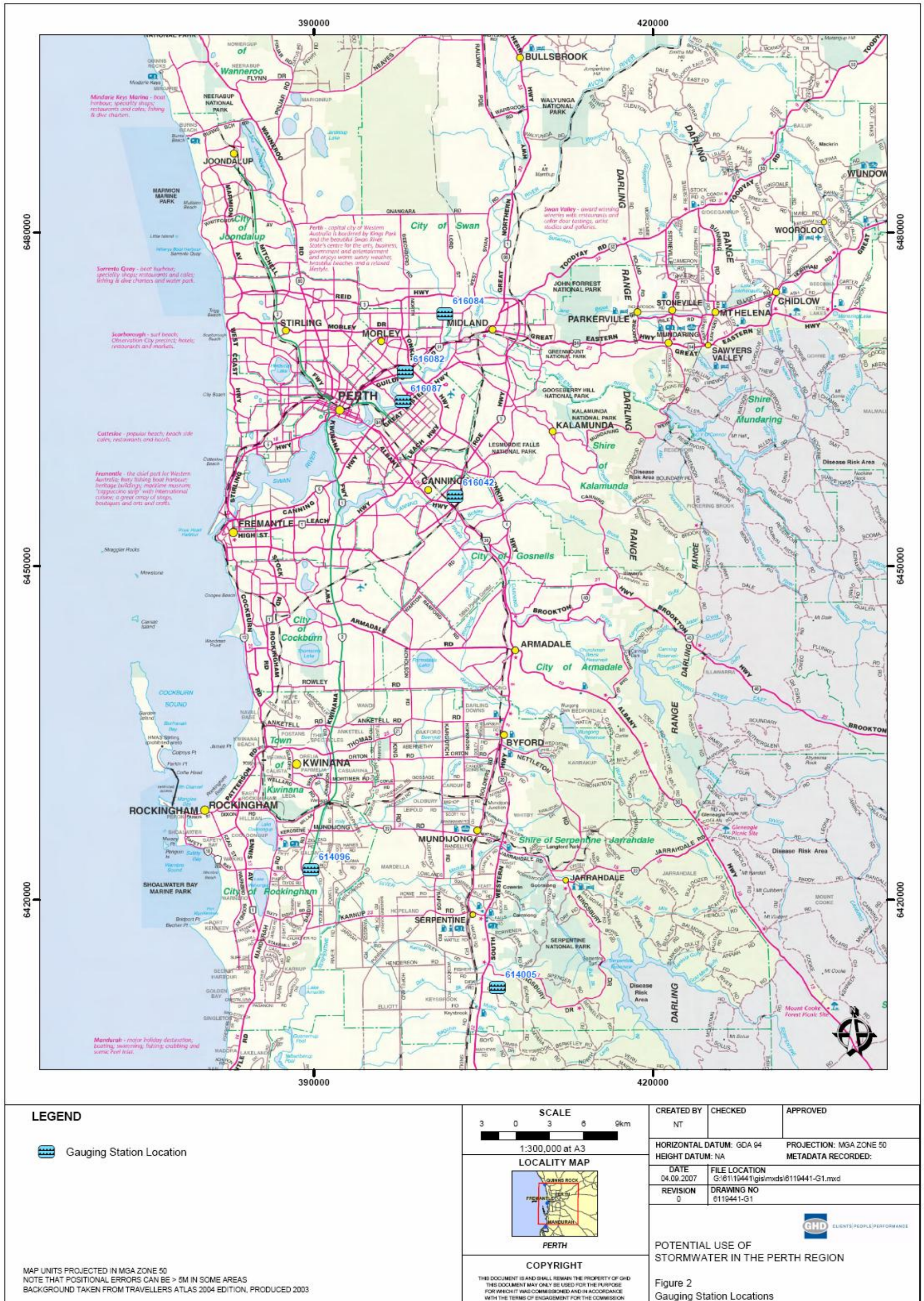


Figure 2 Locations of gauging stations.

4.2 Simulated Discharge of Swan-Canning Estuary Main Drains

A LASCAM (LArge SCale CAtchment Model) simulation was used to estimate the quantity of stormwater discharge from Main Drains of the Swan-Canning Estuary. LASCAM simulates sub-catchment scale hydrological processes that were aggregated to generate the hydrology of the Main Drain catchments over a 35 year period from 1965-2000 (Zammit et al. 2002). As most of the Main Drains are not gauged, LASCAM simulations provided discharge estimates for these waterways. The 35 year simulation period also provided an opportunity to consider climatic variability on stormwater quantity. For validation purposes the simulated annual total discharge was compared to the few Swan-Canning Estuary Main Drains with gauged discharge data.

A comparison of the annual total discharge between model output and gauged data for the Bayswater and South Belmont Main Drains indicate reasonable correlations (Figure 3) with approximately 39% and 54% of the variance explained by a linear relation, respectively. Further, the slopes of the linear relations were near 1 (y-intercept of zero assumed).

Given the lack of long-term discharge data records and the paucity of measurement locations, this simulation currently provides the best available method to estimate flows in the Swan-Canning Main Drains. Improvements to these initial estimates can be derived from DoW's derivative of the LASCAM catchment model (SQUARE). A comparison between LASCAM (this study) and SQUARE estimates of annual discharge is recommended.

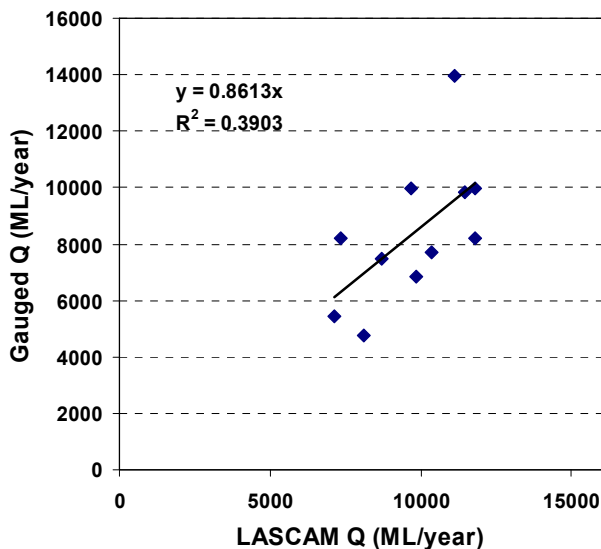


Figure 3 Comparison of LASCAM and gauged annual discharge for the Bayswater Main Drain

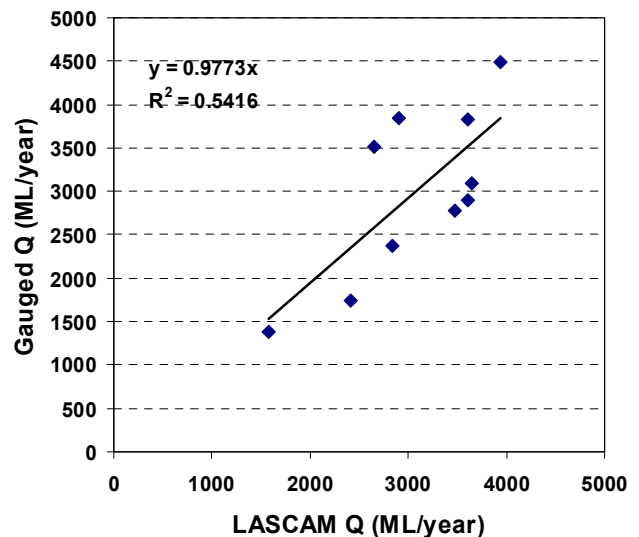


Figure 4 Comparison of LASCAM and gauged annual discharge for the South Belmont Main Drain

4.3 Correlation between Peel and Dirk Brook Main Drains

In the Peel region of the Metropolitan Region Scheme the Peel and Dirk Brook Main Drains convey most of the stormwater. Unfortunately, the record of measurements at the Peel Main Drain gauging station at Folly Road (Station #: 614096) spanned only from 1994-1997, whereas the Dirk Brook Kentish Farm Main Drain (Station #: 614005) extends over 30 years (see Table 1). The Folly Road station is the southernmost gauging station on the Peel Main Drain, and therefore is a suitable location to estimate the annual discharge for this catchment. Hence, a linear regression was developed between the periods of simultaneous measurements at these 2 stations to extend the Peel Main Drain discharge record.

Over the 4 years of simultaneous measurements (1994-1997) the linear regression accounted for 90% of the variability between the 2 data sets (Figure 5). Hence, this linear relation was used to estimate a long-term monthly data record for the Peel Main Drain at Folly Road.

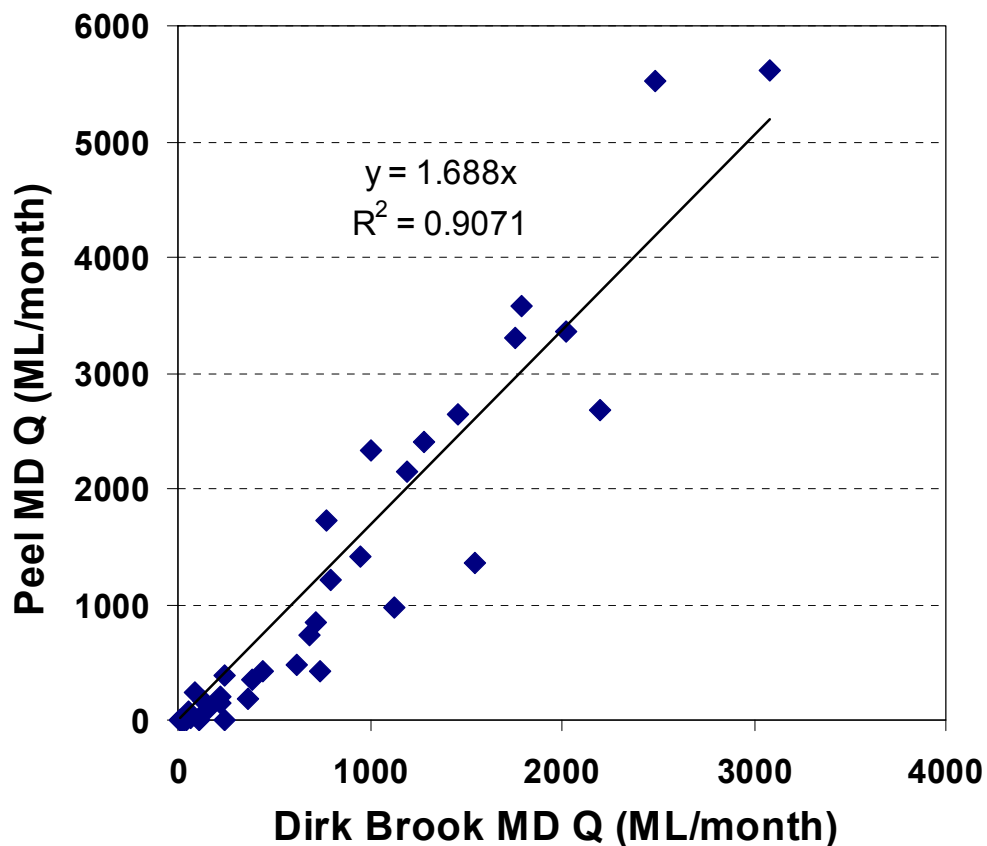


Figure 5 Comparison of monthly discharge data between Dirk Brook and Peel Main Drains from 1994-1997



4.4 Annual Runoff Estimates

Annual discharge totals from the Main Drain catchments in the Swan-Canning Estuary were derived from LASCAM simulation output from 1975-2000. The initial 10 years of the LASCAM simulation (1965-1974) was not utilised to allow sufficient time for the model to equilibrate (or 'spin up') its groundwater stores. The area was approximately 280 km² and included 75 drainage catchments in a size range of 0.2 to 27.8 km². The median annual discharge was 80.7 GL/year.

Bulletin 1131 states the generation of 200 GL/year of stormwater runoff from the Perth Metropolitan region, however the source of this estimate is not provided. Zammit et al (2002) estimated that the average total discharge from all catchments excluding the Avon River above the Millendon gauging station was approximately 150 GL/year (350 GL/year from the Avon River). Approximately 70 GL/year is from the upper Swan catchments of Ellen Brook (36.5 GL/year), Susanah Brook (7.5 GL/year), Jane Brook (16.5 GL/year) and Helena River (9 GL/year). The remaining 80 GL/year are the focus of this assessment.

Estimates of the three major coastal Main Drains in the Perth metropolitan area, namely Carine, Herdsman and Subiaco have been estimated by the Water Corporation to account for 7, 8 and 3 GL per year. Hence, the coastal Main Drains account for approximately an additional 18 GL per year.

For the two Peel Main Drains the median annual discharge from 1971-2001 was estimated as 8 GL and 12.6 GL for the Dirk Brook Main Drain at Kentish farm and the Peel Main Drain at Folly Road, respectively. This yields a regional median total of approximately 20.6 GL per year.

The combined mean annual runoff for the Swan-Canning Estuary, Coastal and Peel Main Drains is about 120 GL per year, which is approximately equivalent to 2 Mundaring Weirs at full storage capacity (63.6 GL) or 2.5 Desalination Plants (45 GL). This estimate also is greater than the volume of water that would be collected in rainwater tanks with 100% harvesting from urban roofs assuming an average annual rainfall of 800 mm/year. These discharge volumes are summarised in Figure 6.

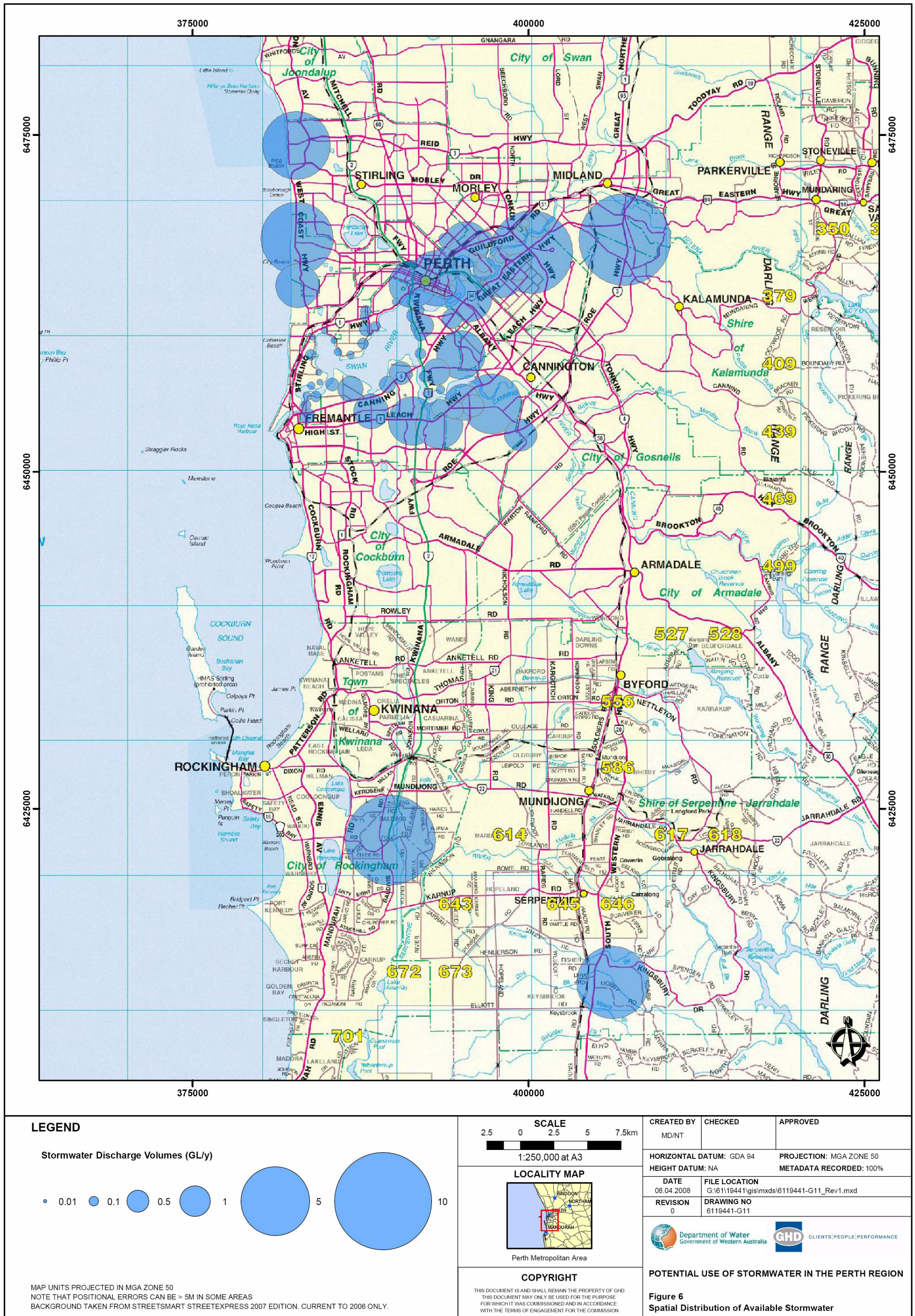


Figure 6 Median annual discharge volumes in the study area

4.5 Interannual Variability of Annual Runoff

A trend in declining rainfall has been experienced across southwestern Australia over the past 25 years that largely coincides with the period of data and simulations considered in this investigation. In this section the interannual variability of annual runoff from the Swan-Canning Estuary and Peel Main Drains are evaluated, but not the coastal Main Drains due to unavailability of data.

The range of annual runoff from the Swan-Canning and Peel Main Drains was from 78-129 GL/year for the 10th and 90th percentiles, respectively (Figure 7). For the Swan-Canning catchments annual total runoff range from 63 and 98 GL/year for the 10th and 90th percentiles, respectively, with a median of approximately 80 GL/year. For the Peel Main Drains the annual runoff was from 14.3 and 31.6 GL/year for the 10th and 90th percentiles, respectively, with a median of approximately 18.6 GL/year. In short, these simple statistical measures indicate that relative to the median discharge (i.e. 50th percentile), extremely dry years (i.e. 10th percentile) will have 21% less annual runoff and very wet years (i.e. 90th percentile) will have 32% greater annual runoff.

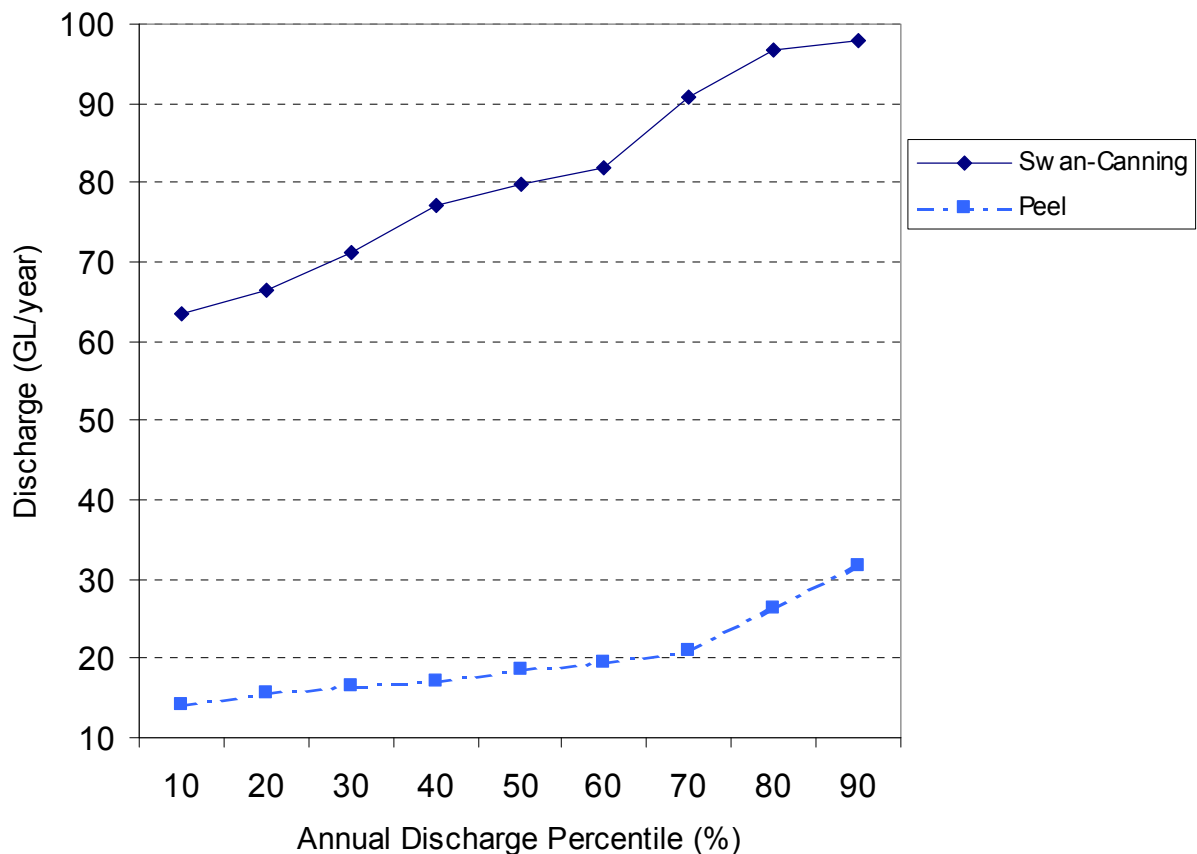


Figure 7 Variation in annual discharge from drainage catchments due to climatic variability

4.6 Patterns of Seasonal Baseflow

The temporal distribution of stormwater discharge in the Main Drains is an important determinant that guides the appropriate approach to the potential harvesting of this resource. For example, if most of the stormwater is conveyed in a short period of time (e.g. days), then basins are needed to capture the stormwater volume. Alternatively, if a large portion of the stormwater-derived discharge is conveyed over longer time scales because of time lags caused by infiltration into the groundwater with subsequent release to the Local and Main Drains, alternative strategies such as Managed Aquifer Recharge could be considered.

The availability of stormwater in the drainage network within the Perth metropolitan region was investigated through inspection of daily discharge data for several Main Drains, namely the Bayswater Main Drain of the Swan River and Yule Brook Main Drain of the Lower Canning River. A graphical representation of typical discharge patterns over several years indicates a very strong seasonal baseflow pattern with substantially higher winter flow rates (Figure 8 and Figure 9).

Surprisingly, approximately 50% of the total winter discharge (inclusive of stormwater events) is comprised of the baseflow component of the seasonal hydrograph for Bayswater Main Drain, while short episodic stormwater events of 1 to several days duration comprise the other 50% (Figure 8). Clearly, the high winter baseflows in this catchment results from elevated superficial groundwater levels through infiltration of winter rainfall that causes a substantial increase in the groundwater discharge directly into the Main Drain. The Bayswater Main Drain maintains these elevated baseflow discharge levels from July to November regularly, which could be readily extracted via pumping and injected into the superficial aquifer an appropriate distance from any Local or Main Drains.

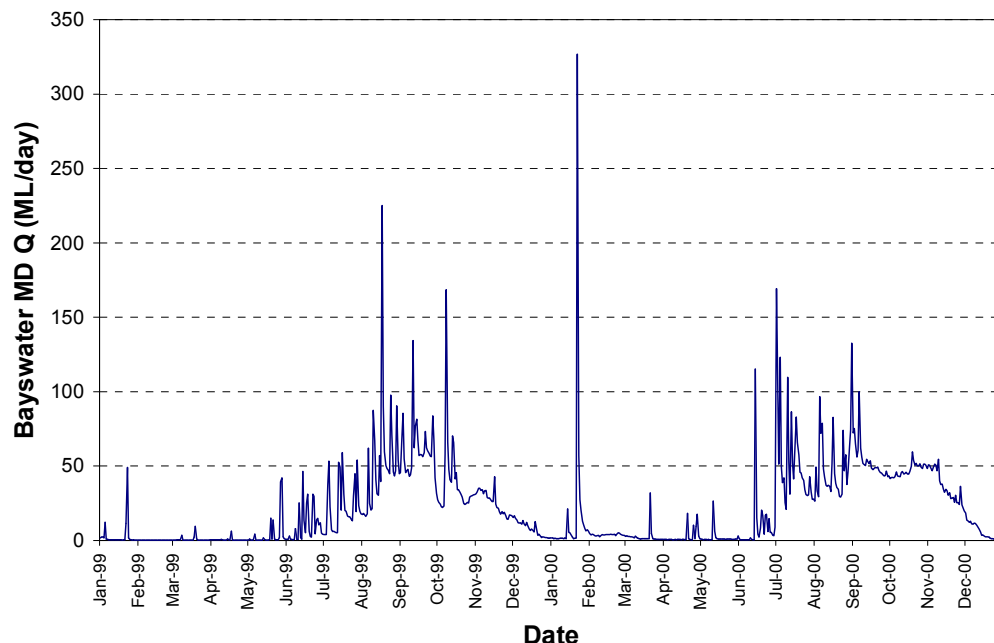


Figure 8 Daily DoW gauging station flow data for Bayswater Main Drain

Similarly, Yule Brook Main Drain also maintains elevated baseflow discharge during the winter and spring months (Figure 9) in a similar manner as the Bayswater Main Drain. However, the duration of this elevated baseflow is a month shorter, presumably because of the differences in catchment geology.

In summary, daily data from 2 of the Swan-Canning Estuary Main Drains highlight that two different approaches can be employed to capture elevated winter flows in the Main Drains. To capture the episodic high flow rates, either basins or underground voids would be required to harvest these types of events. In contrast, both Main Drains also have a substantial component of the winter and spring discharge as baseflow, which could be extracted via pumping.

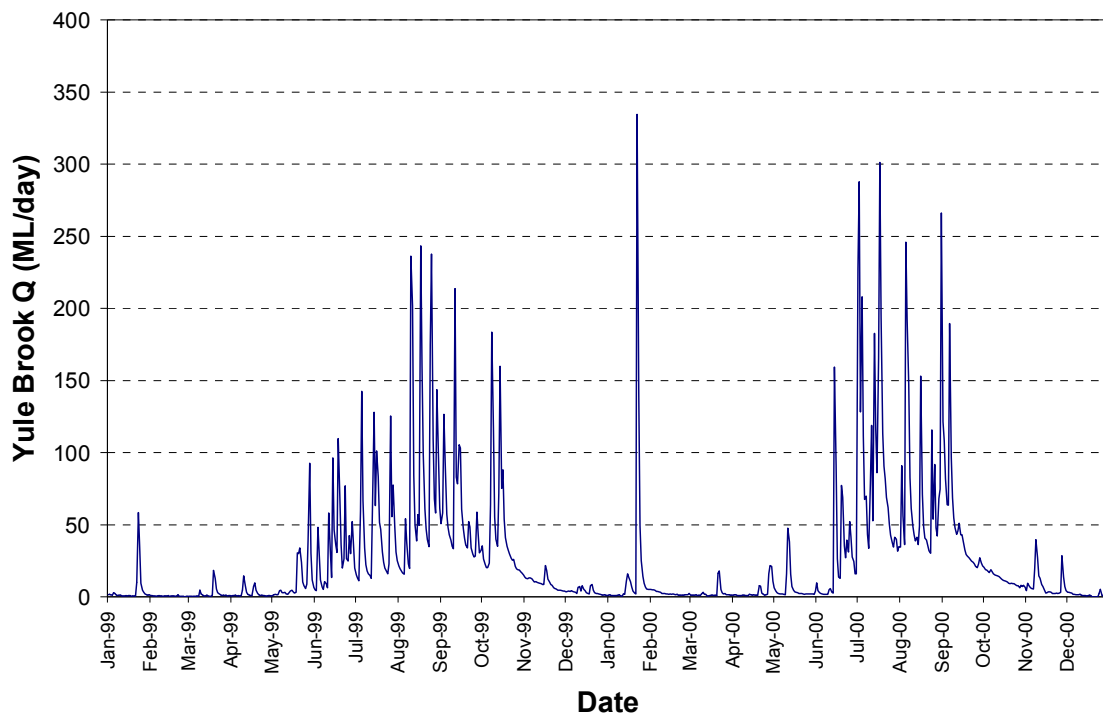


Figure 9 As Figure 8 for Yule Brook Main Drain

5. Options for Stormwater Harvesting

This section considers major options for storage of runoff from the Swan-Canning and Peel Main Drains. The stormwater harvesting options are also applicable to Local Drains. The *Stormwater Management Manual for Western Australia* (Department of Environment 2004) states that the aging drainage systems within established urban areas provide an opportunity for retrofitting to increase stormwater infiltration and reuse.

Here a number of retrofitting options are considered to increase reuse of stormwater within urban areas inclusive of:

- » Water Sensitive Urban Design (WSUD);
- » Managed Aquifer Recharge (MAR), which in this report is narrowly defined as extraction of water from the Main Drains (via pumping) and recharging the superficial aquifer a sufficient distance from any Main or Local Drains;
- » Underground Storage Systems to store Main Drain runoff either from winter/spring baseflow or from episodic stormwater events;
- » Above Ground Storage Systems to be used in a similar manner as the Underground Storage Systems; and
- » Drainage Channel Modification whereby the invert levels (i.e. base levels) of the Main Drains are elevated to drain less of the local groundwater stores and widened to maintain hydraulic capacity.

Next, further brief descriptions are given for each of the harvesting options along with identification of opportunities and constraints in their application.

5.1 Stormwater Aspects of Water Sensitive Urban Design (WSUD)

Among other objectives water sensitive urban design (WSUD) aims when possible to infiltrate locally generated stormwater 'at source'. Examples of WSUD methods include infiltration basins and swales, as well as lot scale infiltration via soakwells, are all now widely encouraged and used within urban areas. These methods follow the WSUD principles outlined in the *Stormwater Management Manual for Western Australia* (Department of Environment 2004).

Another objective of WSUD is to attenuate stormwater peaks in the drainage network. In Perth new urban developments must be able to store the 1 annual recurrence interval (ARI) discharge on site. In effect this attenuates stormwater peaks over a longer period of time.

5.1.1 Opportunities and Constraints

Clearly both of these WSUD objectives (stormwater infiltration at source and flood attenuation) provide opportunities for greater stormwater reuse. The first objective of stormwater infiltration at source is a direct manner to decrease the loss of this resource via the drainage network and to the estuary or ocean. The second objective of attenuating the flood peak in the drainage network provides two opportunities:

- » Decreases the magnitude of floods thereby decreasing the size of infrastructure to harvest the resource; and



- » Through storage of the 1 year ARI flood on site with release over approximately a 36-72 hours, the time to harvest the 'peak episodic events' of this resource is extended relative to the current case. re is greater duration to period.

Implementation of WSUD principles clearly is limited by geology and underlying soils. In sandy environments high infiltration rates provide a favourable setting for rapid dispersion of stormwater runoff into the groundwater stores. On the other hand, clay soils do not. Rather in these environment the second aim of WSUD considered for the purposes of this investigation (flood attenuation via storage of 1 year ARI flood on site) allows more stormwater to be harvested on site or downstream through extending the detention period.

5.2 Groundwater Storage

The groundwater storage option is a reuse strategy whereby stormwater is extracted and injected (via wells or infiltration basins) into suitable aquifers (likely the superficial) for later use in times of peak demand. In this approach the aquifer is treated as a storage facility similar to surface water storages such as basins. Stormwater recovery would include single or multiple recharge well to the superficial aquifer within the metropolitan area. In this investigation the groundwater storage option is limited to a non-potable water supply because recharge to the confined aquifers (i.e. Leederville) as treatment would likely be required beforehand.

5.2.1 Opportunities and Constraints

The stormwater quality is a primary constraint. Although biogeochemical processes within the soil or groundwater may improve water quality, contaminants may not be removed (or immobilised) sufficiently thereby yielding unacceptable risks to aquifer contamination (Department of Environment 2004). First autumn flush events have been identified as a major stormwater pollutant source. However, elevated nutrient and metal concentrations also occur during subsequent stormwater events after the first flush and therefore pre-treatment of runoff may be required throughout the year (Department of Water 2007). Pre-treatment of stormwater may also be required prior to injection or infiltration into the groundwater stores to prevent clogging of the substrate.

Spatially the stormwater must be conveyed sufficient distance from Main (and deep Local) Drains so that the injected stormwater is not rapidly discharged via the groundwater pathway back to the drainage network. Technically this spatial constraint will require pipes to transport water from the Main Drains to the injection location.

Further, input into groundwater stores via large infiltration basins requires substantial land to be effective. In cases where these facilities need to be retrofitted within established urban areas, land reclamation may be required. While surface storage facilities typically comprise only a small part (2-3%) of the contribution catchment (Department of Environment 2004), land is typically scarce or prohibitively expensive in many parts of the metropolitan region. Where land constraints disallow large scale infiltration basins, groundwater storage may be achieved through storage and pre-treatment of water within surface or below ground storage facilities, which is then followed by injection into the superficial aquifer.

Suitable attributes of the superficial aquifer to implement this groundwater storage option within the metropolitan region include soil type and permeability, and sufficient depth to groundwater table. Typically infiltration or injection of water into the superficial aquifer will require a soil with moderate to



high permeability. In addition soils that feature an aquitard or bedrock at shallow depth will be unsuitable. Acid sulphate soils (ASS) are also a consideration as this groundwater storage option may lead to large variation in groundwater level and the generation of acidity.

5.3 Underground Storage Systems

Underground Storage Systems capture and store runoff in large pipes and/or other subsurface structures. This stored water may be released to the environment through an outlet pipe or allowed to infiltrate to recharge groundwater. Subsurface storage systems may be constructed from concrete, rigid plastic (HDPE), steel or aluminium. Benefits associated with underground stormwater retention/detention have been identified as including:

- » Attenuation of peak stormwater flows;
- » Potential for extended storage and slow controlled release of collected stormwater runoff;
- » Prefabricated modular systems that can be rapidly installed and require limited land, therefore suitable for high density or expensive urban areas;
- » Materials are durable and have extended life spans (50+ years); and
- » Underground storage improves public safety and may be more aesthetically pleasing than some surface storage options.

5.3.1 Opportunities and Constraints

Similar to MAR the major constraints to underground storage is stormwater quality as inadequate pre-treatment may lead to contamination of superficial groundwater. If harvested stormwater is to be infiltrated into groundwater then pre-treatment of runoff should incorporate Best Management Practices in-line with the storage system (i.e. a treatment train approach). Alternatively, the harvested stormwater could be simply stored for later non-potable reuse.

Underground storage systems are typically not constrained by available land though extensive excavation during the installation phase may be required. Though soil types do not constrain the location of underground storage facilities, during construction prevention of exposure or mobilisation of ASS needs to be implemented to avoid further water quality issues.

The largest constraint to underground storage systems is cost. A 'rule of thumb' cost for underground storage in large diameter pipes is \$1,000 per cubic metre.

5.4 Above Ground Storage

In this investigation Above Ground Storage of stormwater is storage within an above ground facility that enables abstraction at a later date. A number of storage options are included within this category such as stormwater re-use ponds, detention basins and constructed wetlands. Wetlands as mapped under the *Geomorphic Data Atlas* are not incorporated within this category as abstraction of water from these wetlands is prohibited. Further, permanently inundated basins of open water formed by simple dam walls or by excavation below ground level must comply with DoW's July 2007 'Interim Position Statement: Constructed Lakes'.



5.4.1 Opportunities and Constraints

Each of these Above Ground Storage systems can store urban drainage runoff and generally improve water quality. Stormwater reuse ponds and detention basins generally are deeper than constructed wetlands, and if are lined then do not have any soil constraints in their siting. Constructed wetlands are generally unlined with connections to the groundwater table that also provide habitat for flora and fauna.

Above ground storage can be problematic because of high evaporative and seepage losses for unlined basins during summer months. Land requirements for off-stream (or off-drain) above ground storages may also be prohibitively expensive and spatially unavailable. In-stream (or in-drain) above ground storages need to be carefully designed to maintain hydraulic capacity for flood events.

5.5 Modification of Main Drain Channel Morphology

Historically, the Main Drains (and Local Drains) were designed for two primarily two purposes:

- » Stormwater drainage systems to alleviate flooding; and
- » Lowering superficial aquifer levels through interception, collection and conveyance for a number of historical reasons (i.e. improve agriculture, lower levels for septic tanks).

These historical drivers either no longer exist (i.e. centralised wastewater treatment) or are being managed with new approaches (management of stormwater via WSUD).

Hence, one manner to increase stormwater reuse³ is to modify the morphology of the Main (and Local) Drains to reduce winter groundwater losses and yet maintain the flood hydraulic capacity. This can be achieved by elevating the inverts of the Main Drains so that less of the upper superficial groundwater level is intersected thereby decreasing losses from the subsurface stores. Concomitantly the channel width would be increased to accommodate the required (or design) flood discharge conveyance. In short, through modification of the Main (and Local) Drain channel morphology from a deep incised channel to a wide shallow channel, much less groundwater will be lost across the Swan-Canning and Peel regions (particularly in the sandy geological regions).

5.5.1 Opportunities and Constraints

Most of the opportunities and constraints with this approach revolve around spatial considerations. Implementation of this approach would only be able to occur in regions where there is sufficiently wide reserve to widen the Drain sufficiently to meet stormwater hydraulic capacity needs as required given the amount the invert level is raised. There also needs to be sufficient room to allow access for maintenance activities of the Main Drain. In light of these spatial considerations, it is likely that there are some reaches where channel modification to the morphology could be implemented in the short term.

³ Better stated as a manner to reduce losses of groundwater derived from stormwater infiltration.



6. Spatial Analysis

As outlined in Section 5 the stormwater harvesting options evaluated within this report have a number of environmental attributes that determine the viability of each option. Spatial data sets that represent these environmental attributes were collated for the study area and are briefly described below. For the groundwater storage options it has been assumed that later abstraction of injected, infiltrated or stored groundwater from over allocated Ground Water Source Areas (GWSAs) will not be an issue.

6.1 Overview of Spatial Attributes

6.1.1 Geology

The Environmental and Urban Geology Map Series 1:50,000 for the Perth Metropolitan Region (Geological Survey of Western Australia) was used to represent the soil types for the study area (Figure 10). Using the broader geological units, the soil types were simplified and ranked according to their suitability for the different stormwater storage methods that were evaluated.

6.1.2 Depth to Groundwater and Water Corporation Drainage

While there is extensive data for groundwater table depth in m AHD for the Perth Metropolitan Region, there is no existing spatial dataset of depth to groundwater relative to the surface. Davidson (1995) included broad scale mapping of the depth to groundwater below ground level for the Swan Coastal Plain. The map by Davidson (1995) was generated from groundwater depths from September and October 1992. Some spatial inaccuracies are likely in Davidson's (1995) depth to groundwater image because of scale and density of bores from which the image was derived. Nonetheless, the map is useful as it represents a conservative estimate of groundwater levels for the study area during a wetter period with greater superficial groundwater stores than currently. The map was digitised to enable consideration in the spatial analysis of this investigation (Figure 11). The depth to groundwater is an important spatial consideration for nearly all of the stormwater reuse options considered here.

Further, on the same image the Water Corporation Main Drains are illustrated (Figure 11). This spatial data set is particularly important in determining appropriate regions in which to infiltrate or inject stormwater via MAR. This was implemented by creating spatial buffers around the Main Drains based on the distance from Main Drains in which harvested stormwater that is stored in the groundwater would not return to the drainage network for a reasonable duration (i.e. at least 1 year).

6.1.3 Acid Sulphate Soil Risk

The Western Australian Planning Commission (WAPC) Planning Bulletin No 64 outlines Acid Sulphate Soil (ASS) risk areas within the study area (Figure 12). The dataset was collated at the 1:50,000 scale for broad scale assessment of ASS risk associated with the stormwater reuse options.

6.1.4 Geomorphic Wetlands and Public Drinking Water Source Area

The DoW's Geomorphic Wetlands dataset (Department of Water) comprises wetlands of the Swan Coastal Plain that have been classified as either Conservation, Resource Enhancement or Multiple Use



category wetlands (Figure 13). The wetland category, based on a series of geomorphic characteristics, provides guidance on the level of wetland protection that wetlands are afforded.

Public Drinking Water Source Area's (PDWSA's) are defined areas in which restrictions are placed on activities that may pollute surface or groundwater sources. The DoW's PDWSA dataset shows that within the study area boundary three gazetted PDWSA occur (Figure 13). These correspond with the Gnangara and Jandakot water mounds, and the Dirk Brook Water Reserve corresponding with the proposed Karnup-Dandalup PDWSA.

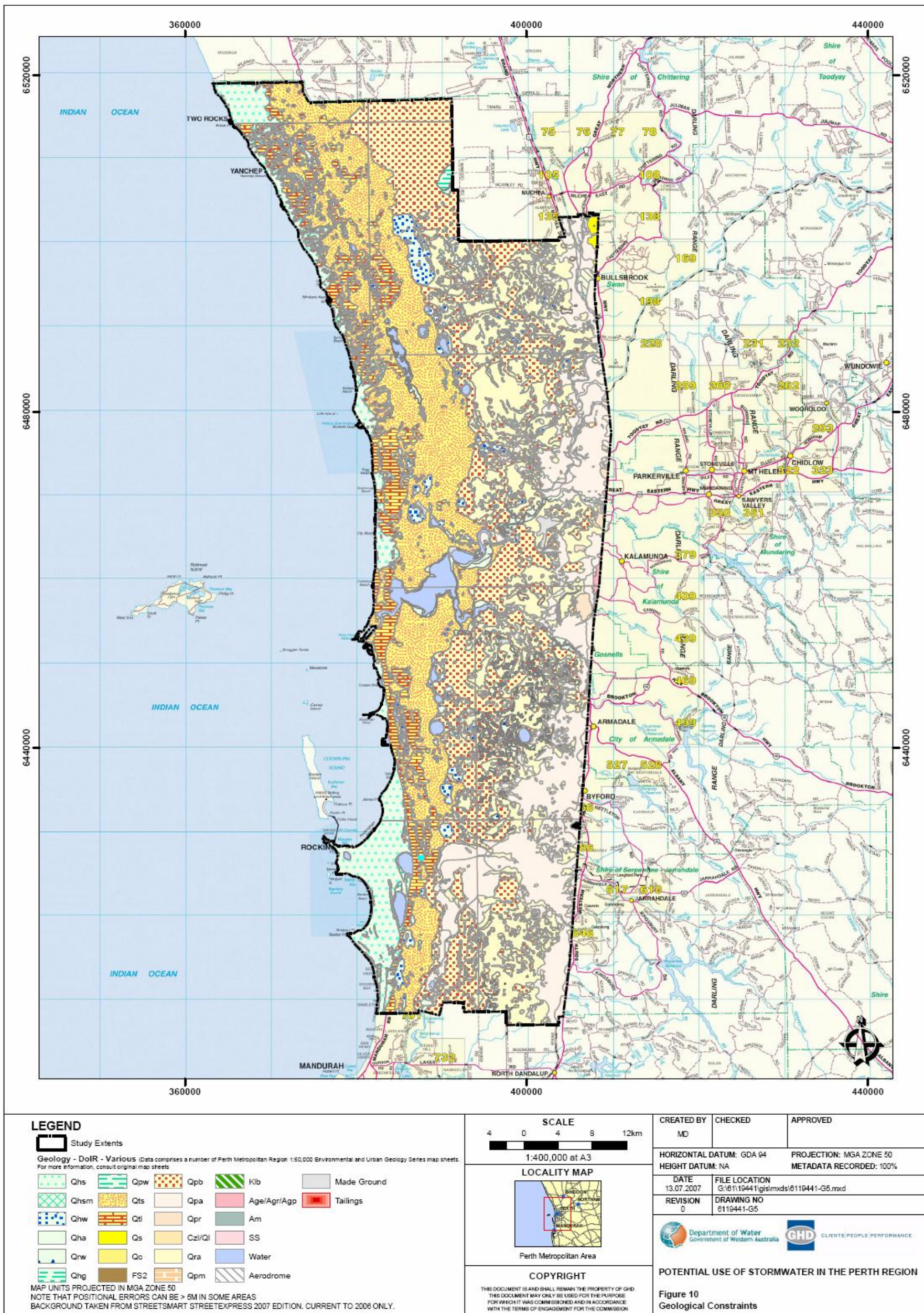


Figure 10 Geology of study area

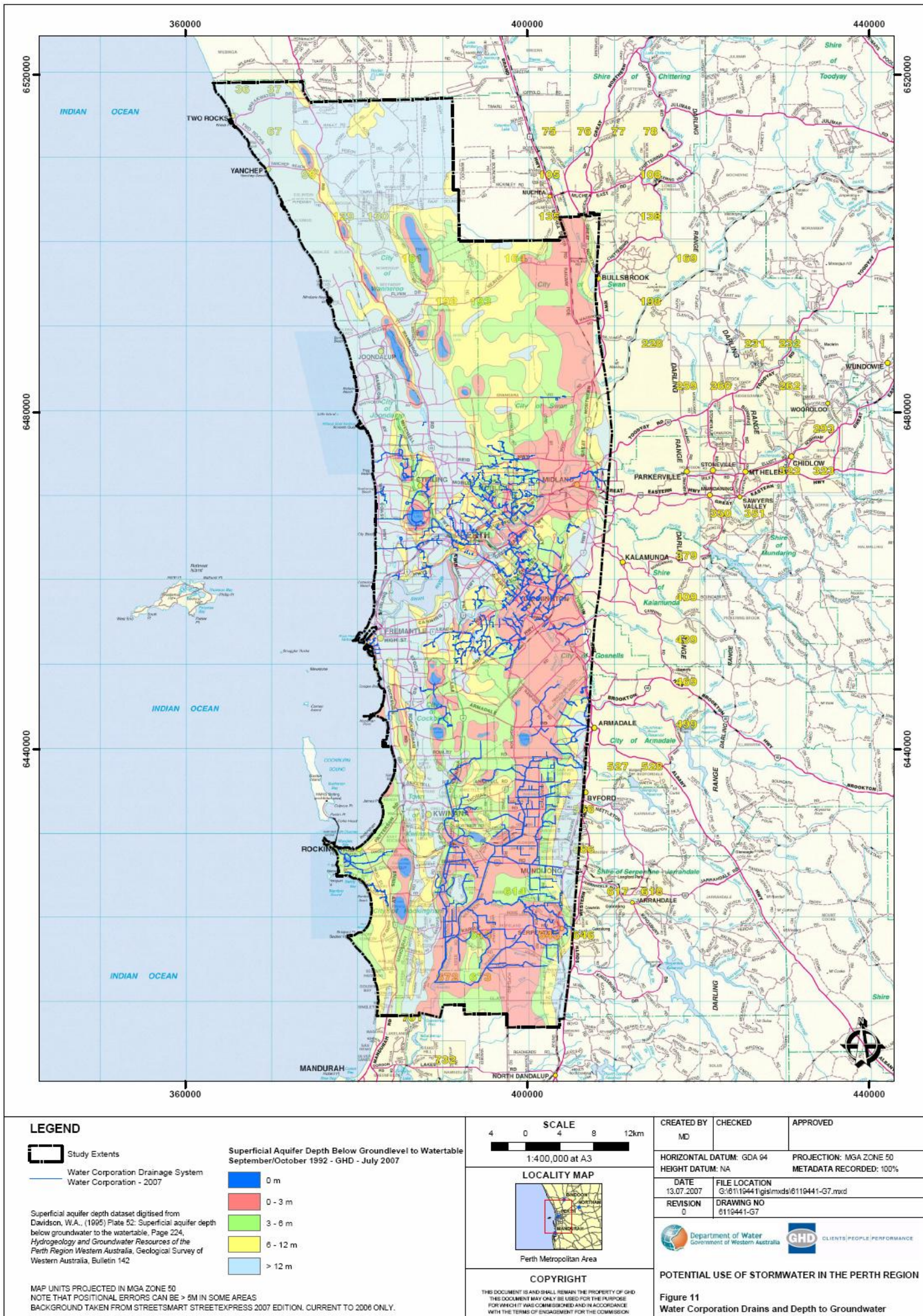


Figure 11 Depth to groundwater and Water Corporation Main Drains

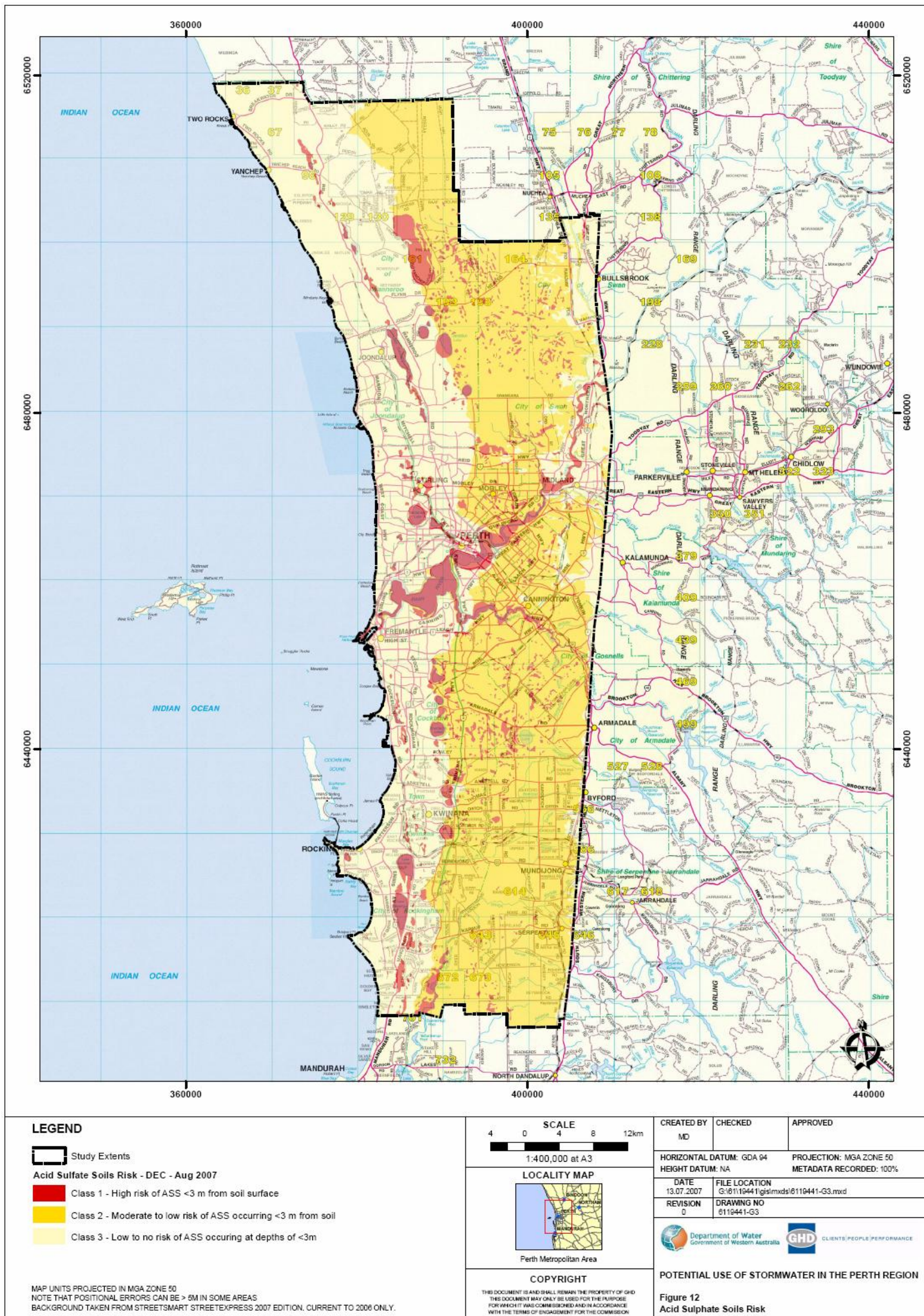


Figure 12 ASS risk of study area

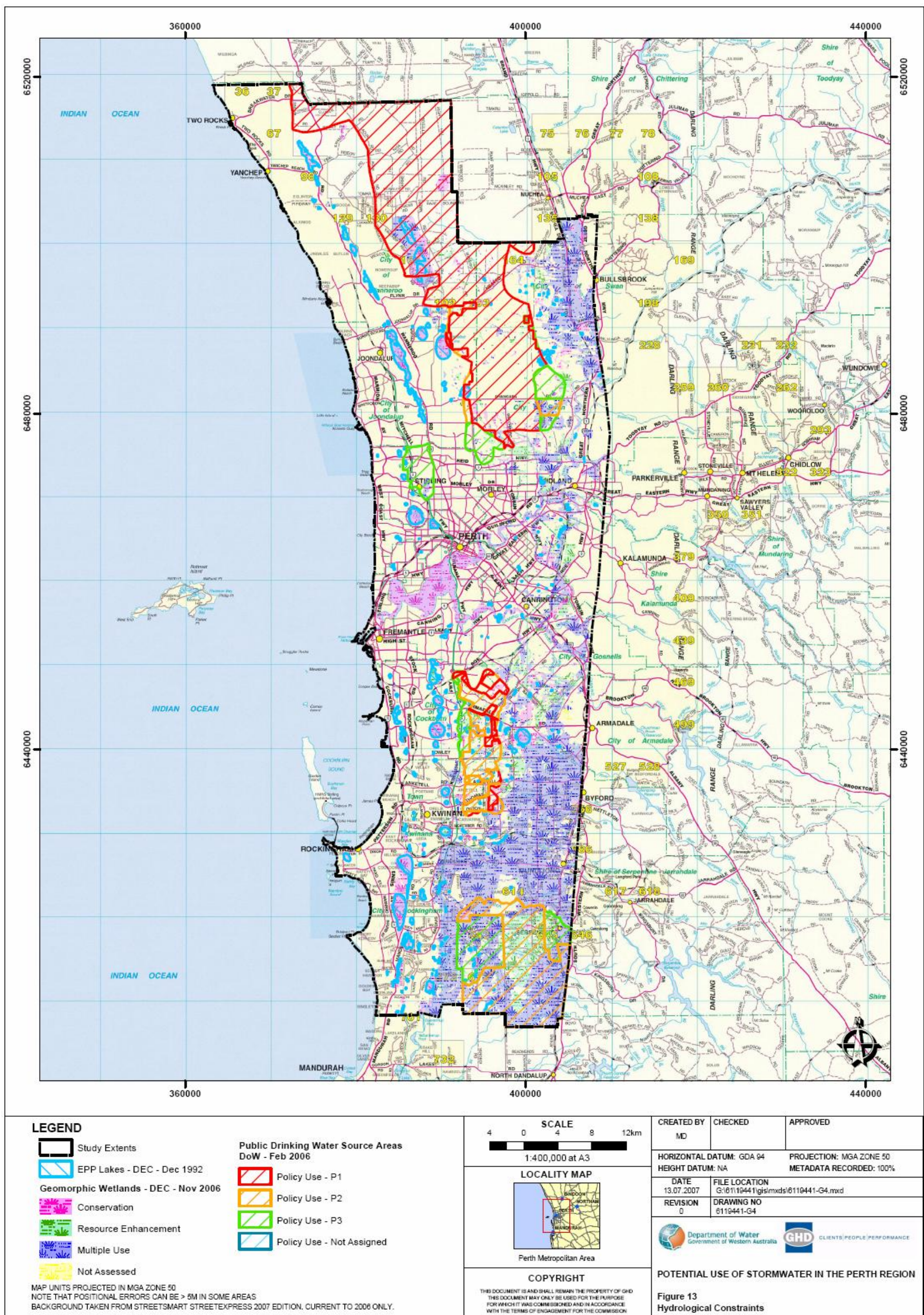


Figure 13 Geomorphic wetlands and PDWSA of study area

6.2 Definition of Spatial Opportunities for Stormwater Storage

Table 2 below presents the ideal input parameters, or opportunities, for three of the stormwater harvesting options, namely MAR, Above Ground Storage and Below Ground Storage. WSUD can be implemented throughout the catchment and modifications to the morphology of drainage channels are obviously spatially constrained to the locations of Main and Local Drains.

Shaded input parameters in Table 2 are mandatory constraints. Where input parameters are not shaded, the ideal input parameter is shown, but other parameter values or types may be viable.

During the formulation and definition of the appropriate criteria to delineate regions across the study area for the various stormwater harvesting options, it became evident that MAR substantially differed from both Above and Below Ground Storage options. In particular, MAR requires a underlying geology type that rapidly infiltrates to the superficial (sands and limestone) and regions that are a substantial distance from Main Drains (>500 m).

It became apparent that the spatial criteria for 'lined' and 'unlined' Above Ground Storage options were the same except for underlying geology. 'Unlined' Above Ground Storage could only occur in regions with clays, otherwise the water would be returned immediately again to the drain as these options would be placed close (<250 m) or within the drain. Further, the 'lined' Above Ground Storage option was the same as the Underground Storage Option (i.e. void) whereby these structure could be placed in any underlying geology within close proximity to the Main Drain (<250 m).

Table 2 Spatial opportunities matrix for stormwater storage options

Attribute	MAR	Above Ground Storage Unlined	Below Ground Storage and Above Ground Storage Lined
Geology	Sands and limestone	Clays	All
Depth to Groundwater	>3 m	>3 m	>3 m
Distance from existing drainage line	>500 m	<250 m	<250 m
Acid Sulphate Soil	Low (and Moderate)	Low (and Moderate)	Low (and Moderate)
Geomorphic Wetlands	>50 m from CC ⁴ >30 m from RE ⁵	>50 m from CC >30 m from RE	>50 m from CC >30 m from RE
PDWSA	No	No	No

⁴ Conservation category

⁵ Resource enhancement

6.3 Locations of Stormwater Storage Options

Next a series of locations over the study area that spatially represent suitable locations for three of the stormwater storage options (groundwater storage, Above Ground Storage, Below Ground Storage) are presented. The basis for the siting of the three stormwater options was based on the spatial opportunities defined in Table 2. Initially, only low ASS potential was evaluated as suitable sites for any of these options because of either enhanced groundwater level fluctuations and acid mobilisation via MAR, or alternatively construction impacts via the above or below ground storage options. However, because management and operational strategies are available to mitigate for these related issues in moderate risk soils for ASS, spatial representations are also illustrated in these regions.

6.3.1 Groundwater Storage Option

The most suitable sites for the implementation of groundwater as a stormwater storage option are mainly along the corridor of sandy soils within 5-10 km of the coast (Figure 14). The primary constraints along this area are regions of extensive wetlands. The total area available for the implementation of MAR is approximately 864 km² (Table 3).

6.3.2 Underground Voids and Lined Surface Basins

Because of the requirement that Below Ground Storage and Above Ground Storage options are in close proximity to the Main Drains, the areal extent was considerably less than the MAR option. An areal extent of approximately 275 km² would be suitable to place either underground voids or lined surface basins for the storage of stormwater (Table 3). These areas are concentrated in regions where the Main Drain network occurs around the perimeter of the Swan-Canning Estuary and the eastern Peel region (Figure 15). Clearly, some portion of the Local Drains would also be suitable for these types of storage options, but the focus of this initial investigation into the potential for stormwater reuse was on the Main Drains.

6.3.3 Unlined Surface Basins

For 'unlined' surface basins again the requirement that Above Ground Storage option is in close proximity to the Main Drains and in appropriate underlying geology (i.e. clay soils), the areal extent was considerably less than the underground void and lined surface basin options. An areal extent of approximately 70 km² would be suitable to place unlined surface basins for the storage of stormwater (Table 3). These areas are concentrated in the proximity of the Main Drain network of the eastern Peel region (Figure 16). Clearly, some portion of the Local Drains would also be suitable for these types of storage options, particularly in the eastern Peel region, but the focus of this initial investigation was the potential for stormwater reuse of the Main Drains.



Table 3 Areal extent of different stormwater harvesting options.

Option	Suitable	Possible
Groundwater Storage	758 km ²	106 km ²
Underground Voids and Clay-Lined Above Ground Storage Basins	268 km ²	9.5 km ²
Un-Lined Storage Basins	52 km ²	18 km ²

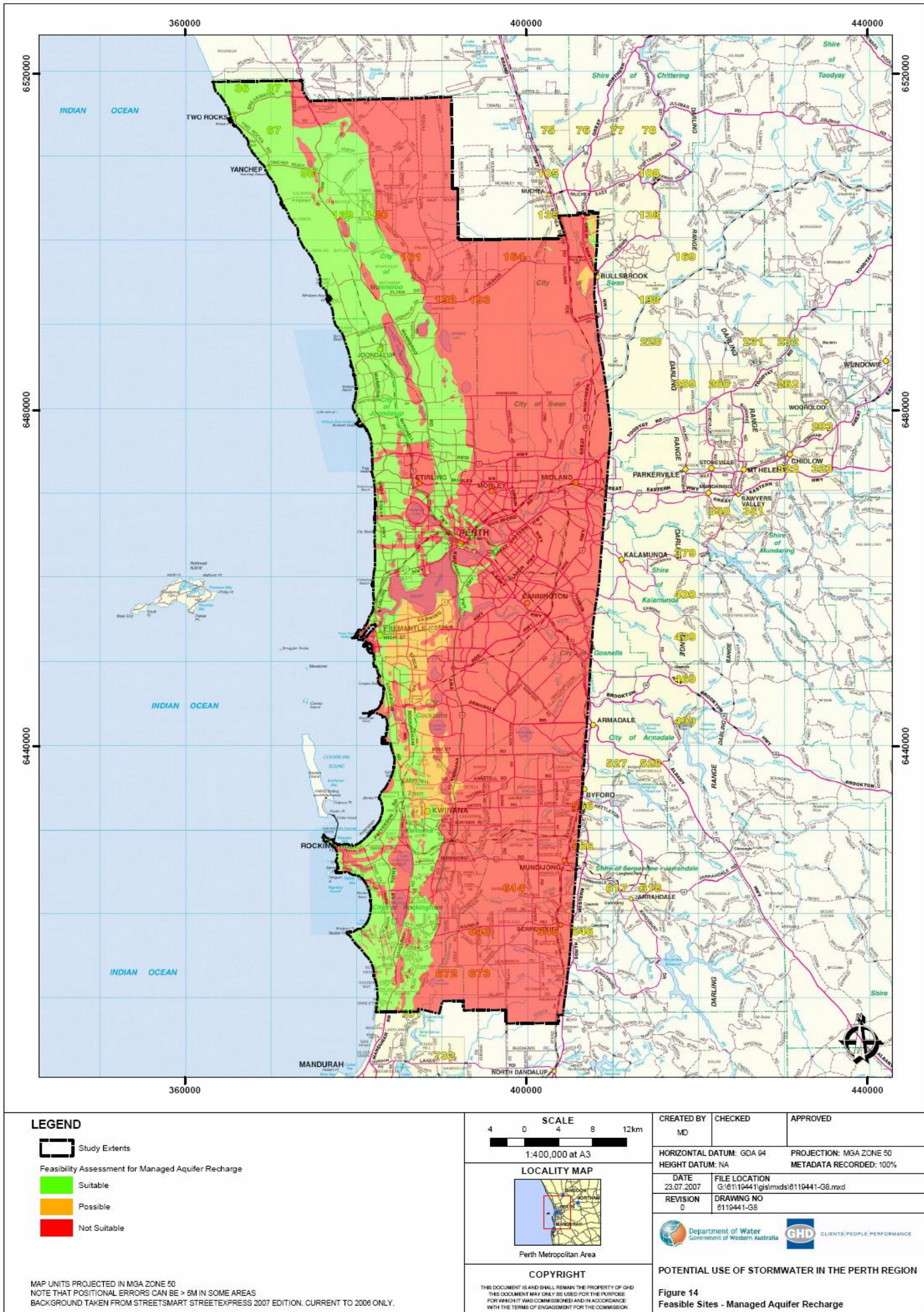


Figure 14 Locations to inject or infiltrate stormwater harvested via MAR

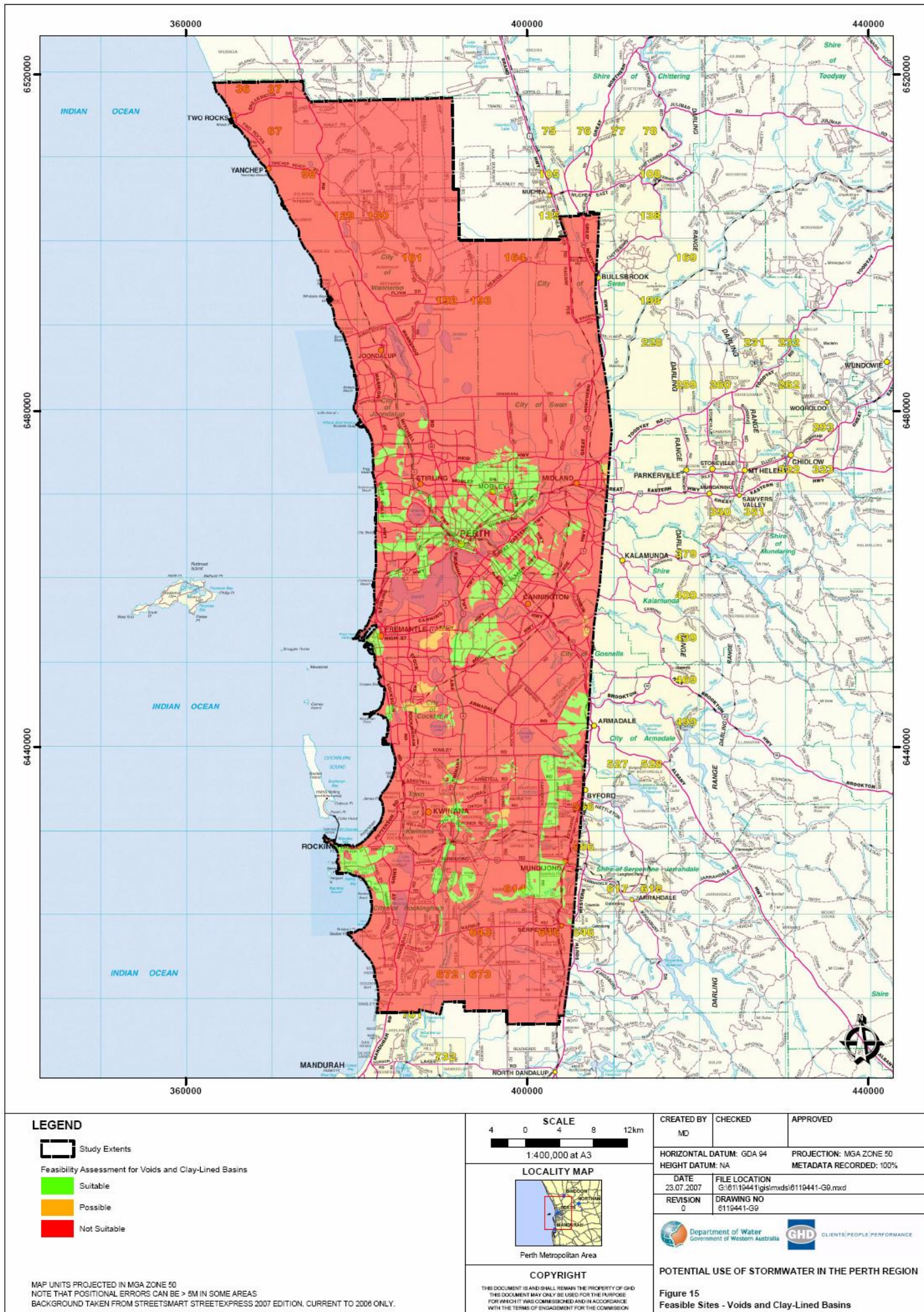


Figure 15 Locations to store stormwater in large underground voids or lined above ground storage basins

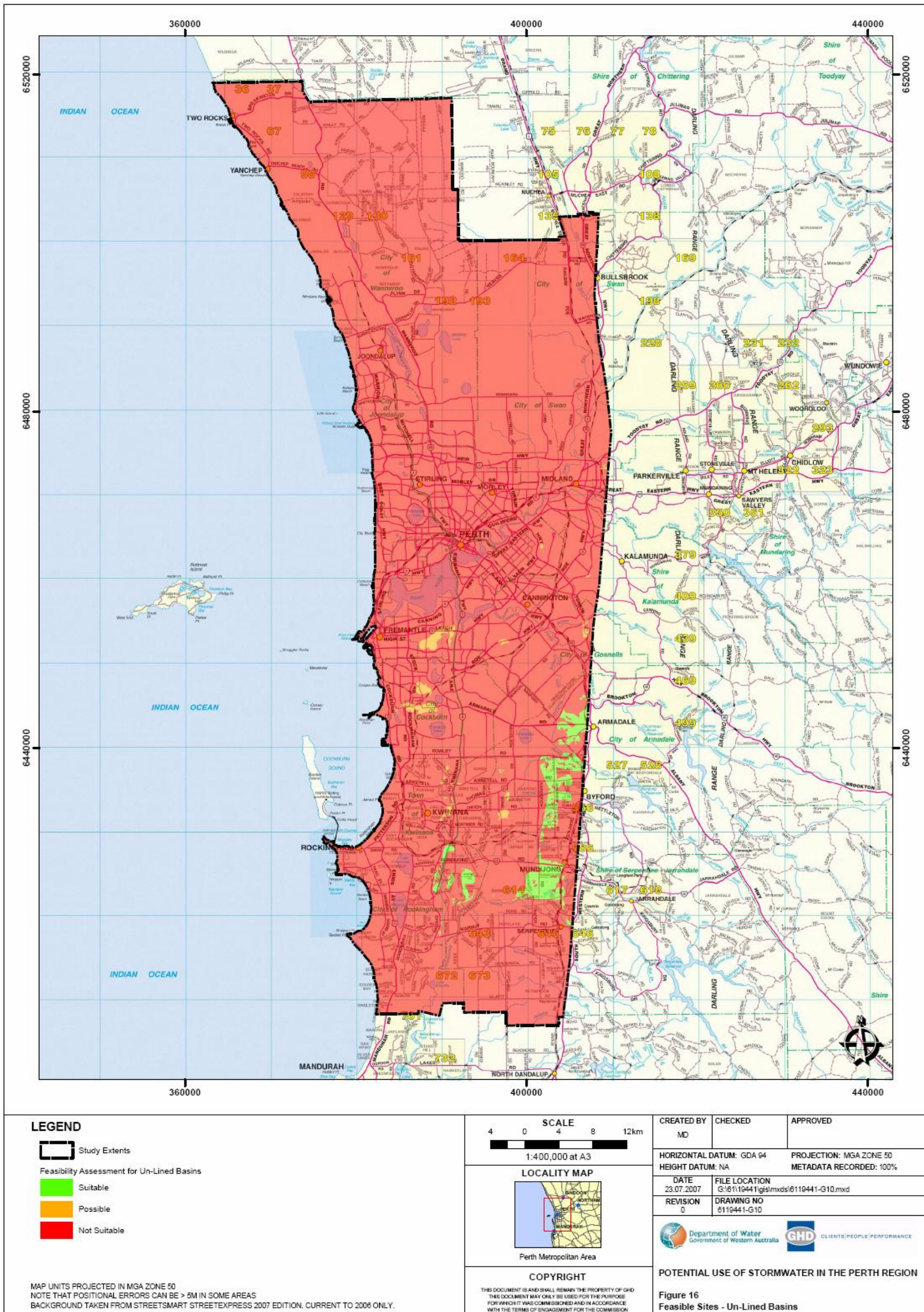


Figure 16 Locations to store stormwater in large above ground unlined storage basins

7. Synthesis and Recommendations

This evaluation indicates a significant volume of stormwater is generated in the Perth Metropolitan and Peel regions that can be harvested as a non-potable water supply. Patterns of baseflow two typical Main Drains (Bayswater and Yule Brook) illustrate that winter baseflow provides a constant source of stormwater runoff. This baseflow can be pumped directly from the Main Drain and infiltrated or injected into the superficial aquifer as a storage option. Stormwater harvesting into basins and voids is recommended to capture and to store runoff from episodic storm events. Temporary storage of episodic stormwater volumes in these above or below ground storage basins can also serve as a supply source for subsequent injection or infiltration into the aquifer.

Current recommended practices of 'stormwater infiltration at source' decreases stormwater 'losses' down the drainage network and storage in the aquifer. Further, if the surface geology is not appropriate for infiltration, then detention and 'slow release' of stormwater into the drainage network provides additional 'time' for the stormwater to be appropriately extracted from the Main Drain.

Lastly, opportunities throughout the network of Main and Local Drains to modify the cross-sectional morphology to decrease groundwater losses (increase invert level), but yet maintain flood conveyance capacity (widen the channel) need to be identified and assessed.

This analysis represents an initial broad scale assessment of the potential for stormwater harvesting via pumping into aquifers, and storage in basins and voids. Clearly, further work is required at the local scale to assess the viability of these three stormwater harvesting options at any particular site. Local studies should assess aquifer characteristics in order to determine storage requirements. At the more detailed site assessment stage further considerations include the impact of contaminated sites on siting of both above and below ground storage methods.

Nonetheless some general approaches have emerged as integrated strategies to harvest stormwater that include:

- » In suitable areas with laterally wide drainage reserve modify the Main (and Local) Drain morphology to drain less groundwater;
- » Target winter and spring seasonal base flows in the Main Drains for removal via pumping and injection into aquifers. This does not require large basins to hold or retain the water. Pumps can be placed in small off-drain basins or within the drains to extract water, which can then be transported a sufficient distance to recharge the superficial aquifer; and
- » Utilise Below or Above Ground Storage Basins to capture and retain stormwater events. Storage of this water is recommended throughout the winter and spring, but then can utilise the same groundwater pumps to inject into groundwater during the summer and autumn when the Main Drain baseflow is lower.

Lastly, this study only considered the quantity and not quality of stormwater discharge. It is recommended that an investigation to characterise the stormwater quality be undertaken. Further, consideration of this stormwater resource as a potable water supply will require investigations into treatment needed during and prior to distribution.



8. Acknowledgements

Many thanks to Christian Zammit of DoW for providing past LASCAM simulations.



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