ABSTRACT
The NSW Government has identified Green Square, located about 4km south of the Sydney CBD, as a major centre for urban renewal. The redevelopment of the Green Square Town Centre (GSTC) will feature high rise commercial/residential buildings and community facilities located near the Green Square Railway Station. Historically, significant overland flooding has occurred within the GSTC and adjoining areas and managing flood risk is a key consideration in the renewal of the area.

A SOBEK 1D/2D floodplain model was established and used to define flood behaviour both pre- and post-development in the area. Modelling identified high hazard areas associated with overland flows which compromised pedestrian safety in the 100 year ARI event for the post-development scenario with no mitigation measures. Potential structural flood mitigation options to manage these risks were modelled and evaluated for their relative benefit and cost. A Floodplain Management Plan was developed for the site, comprising structural measures, property measures and emergency response measures. This Plan was formulated in consultation with the City of Sydney Council, Landcom (Council’s development partner), and the NSW State Emergency Service (SES).

Very short warning times mean the evacuation of residents, workers and commuters from the GSTC area is not feasible for extreme events. Public safety will be managed by community awareness programs, flood signage and warnings, and shelter-in-place practices. The approach to determining the requirements for specific sites to provide for safe refuges for people in buildings above the Probable Maximum Flood level is described.

It is concluded that the urban renewal of the GSTC will attract a greater number of people into an area that historically has experienced significant overland flooding. This urban renewal has also provided an opportunity to improve the management of the existing flood risks and to improve public safety.

INTRODUCTION
In July 2008 the NSW Government released the Draft Subregional Strategy for Sydney City (NSW Government, 2008). The Subregional Strategy provides a framework for the future management and development of the City of Sydney which has as one of its key directions
planning for the sustainable development of urban renewal projects, with specific reference to Green Square. Green Square is identified to be a key site in terms of implementing the Strategy (NSW Government, 2008). Figure 1 shows the location of the GSTC.

Under the Sydney City Subregional Strategy (NSW Government, 2008), Green Square is targeted as a ‘Planned Major Centre’, that will incorporate shopping malls, specialist retailers, medical services, high rise office and residential buildings, Council offices and community facilities, which will also create approximately 8,000 jobs. The Green Square Railway Station (an underground station at the western edge of the Town Centre) will act as a major transport hub for the GSTC.

Flooding in the GSTC, although rare, poses a hazard to future retailers, employees, visitors and residents around Green Square that needs to be managed. This has prompted the City of Sydney and Landcom (as the City’s Development and Project Manager for the development) to prepare a comprehensive Floodplain Risk Management Plan for the GSTC (Cardno, 2009). The site is located within the Green Square / West Kensington Floodplain, and the wider Alexandra Canal Floodplain.

An extensive assessment of flood risk and its management through design and planning was conducted. This assessment is described in this paper in broad detail.
This paper focuses on the management of residual flood risk for the site through the creation of multi-purpose flood refuges.

THE GSTC – A SUMMARY OF THE PROPOSED DEVELOPMENT

The GSTC can be divided into a number of ‘Sites’, open areas and roads. These include:

- 19 ‘Sites’ (each site contains one or more buildings);
- Civic Plaza;
- Neighbourhood Plaza;
- Boulevard Park/Sheas Stream area; and
- Key existing and new roads (Botany Road, Portman Street, Joynton Avenue, New Cross Street, Town Square Street).

Figure 2 shows the general building features that form the ultimate development condition within the GSTC.
FLOOD BEHAVIOUR IN THE GSTC – EXISTING AND FUTURE CONDITIONS
Flooding in the GSTC is caused by a combination of the geographic features of the catchment and floodplain creating complex flow regimes and flooding mechanisms. The site is drained by an underground stormwater system (owned by Sydney Water Corporation) but this network has a limited capacity leading to surcharge and overland flows in major events (e.g. the 100 year ARI event).

The majority of the catchment that drains to Joynton Avenue, and subsequently to the Green Square Town Centre, lies to the north-east of the GSTC. The catchment is highly urbanised and has an extensive network of street drainage. There are a number of trapped depressions (e.g. low points in roads) that act as temporary storages during flood events and these features play a significant role in governing the flood behaviour of the area (Connell Wagner and Cardno, 2009).

Few records are available of historical flooding at the site itself whereas data does exist for surrounding areas. Anecdotal evidence is available for the October 1987 and November 2007 flood events for local road flooding in trapped depression areas (such as Joynton Avenue). This information suggests depths of floodwaters in these areas of the order of 0.5 – 0.6 m which is consistent with the flood modelling (Connell Wagner and Cardno, 2009).

The flood conditions for design were based on the ultimate development scenario (with indicative building layouts) for the GSTC which includes specific engineering works (flood modification works) to address flood impacts associated with the development. The Town Centre has been specifically designed to limit the intrusion of floodwaters from the urbanised catchment upstream of the site into key areas of the Town Centre. In particular, the plaza areas have been designed to not flood in the 100 year ARI event.

CLIMATE CHANGE AND THE GSTC
Climate change is expected to adversely affect rainfall intensities and global sea levels, which may consequently impact on flood behaviour. To assess the potential impact of climate change, flood modelling of the GSTC (under ultimate design conditions) was based on an increase in design rainfall intensities (Connell Wagner and Cardno, 2009).

In the case of Green Square, increased rainfall intensity (i.e. a larger volume of rainfall over a shorter time frame) was a more significant factor than sea level rise in terms of its influence on flood behaviour of GSTC. For this reason, a 10% increase of inflows was incorporated into the flood model for the GSTC, representing a reasonable estimate of the potential increase in rainfall intensity associated with climate change (Connell Wagner and Cardno, 2009). It is important to note that estimates of potential changes of rainfall intensity for rare and extreme events is still inexact and this assessment may require updating as more reliable estimates become available.

All design flood information for the 100 year ARI event incorporates this allowance for climate change which is embedded in the design floor levels adopted for all new buildings and facilities.

PLANNING AND DESIGN TO PROTECT FACILITIES
In addition to the engineering works for the development to manage flood risks described above, a range of planning and design controls have been prepared in order to manage the residual flood risk within the development as far as possible. These controls can be classified
into two categories, i.e. requirements for above-ground facilities and requirements for below-ground facilities. In particular, this paper discusses the provision of local flood refuges within the development, which overlaps with the emergency response measures described later in this paper.

**Above-ground Facilities**

The following building and development controls apply for all developments in the GSTC:

- Habitable floor levels to be set at the 100 year ARI +0.5 m (generally being the Flood Planning Level, FPL, but not for all circumstances).

- All buildings to provide a temporary refuge for persons escaping from the floodwaters in the surrounding street areas. The rapid rate of rise of floodwaters only allows a short period (ranging from approx. 10 – 45 mins) to walk to safety after the onset of rainfall. Any pedestrian within the GSTC area should be able to walk to the nearest building to seek temporary refuge once it becomes apparent that a major rainfall event is underway. It is expected that all buildings within the GSTC will be able to provide temporary refuge for the public as required. The temporary refuge could be an open space or foyer at the entrance of the building or a mezzanine level, open to the public, which needs to be at or above the PMF. Emergency lighting for the refuge is to be provided. Persons seeking refuge are expected to only need to take shelter for a short time (up to six hours). Therefore, for those buildings that are to provide refuge, consideration could be given to providing access to basic amenities such as a public telephone, seating, drinking water, toilet amenities etc.

- A Flood Emergency Response Plan is to be prepared for each development for submission with each development application. The plan should detail the measures that would need to be taken in case of a flood emergency. The plan should be similar to the fire plan for the development and would require a similar approach for implementation.

- Design of public space areas should be such that in case of flood emergency, pedestrians are directed towards PMF refuges at or in adjacent buildings.

**Below-ground Public Domain Areas**

A large below-ground public domain area under the Plaza area may form part of the GSTC. There is a flood risk associated with the ingress of waters down stairs or other similar entry points for flood events rarer than the 100 year ARI. In an extreme event, such as the PMF, the risk to life associated with the ingress of waters to underground areas would be extremely high and the potential consequences of the flooding of the below ground domain would be catastrophic.

In order to manage this risk to life, the access points to any below-ground public domain, retail or public parking areas are to be set at the PMF. In adopting this level, below-ground areas are unlikely to be inundated during any flood event. In addition, a secondary exit to a flood free area away from the point where flood flows would enter must also be provided.

**Railway Access**
The access to the existing Green Square Railway Station will be carefully planned to manage the increased risk to the public. As discussed above, all access points to below-ground public areas located within flood prone locations, including that to the Railway Station, are to be placed at the PMF level to prevent inundation during a flood event.

**Below-ground Car Parking**

The South Sydney Development Control Plan, 1997, indicates locations within the GSTC where vehicle entry to basement carparks is not permitted. Additional locations, including major flow paths, such as the flowpath along the East-West Boulevard, will preclude any access to basement carparks unless some form of non-mechanical barrier can be installed (e.g. a hump in the driveway) to prevent ingress of floodwaters up to the FPL (calculated for that specific basement parking area). A similar approach is required for the street level building entry points, i.e. they should be kept away from the major flow paths, where possible.

With respect to vehicular entry points for basement carparks, an appropriate FPL should be adopted with the minimum level being the 100 year ARI plus 0.5 m. Where the 100 year ARI plus 0.5 m is adopted, the proponent is required to calculate the water depth in the carpark (based on the rate of inflow and area) if the crest is overtopped for greater events to determine the level of risk within the carpark if overtopping occurs. Alternatively, the carpark entry could be set at the PMF. In addition, a well signposted secondary pedestrian exit to a flood free area away from the carpark vehicle entry is to be provided.

**FLOOD REFUGE AREAS –BACKGROUND**

The provision of flood refuges for people walking within public open space areas at the time of flash flooding is a concept that has been applied in other areas of urban renewal. Examples include:

- Honeysuckle Development (located in Newcastle, adjacent to the Hunter River, Cottage Creek and Throsby Creek) (constructed); and
- Golden Sheaf Hotel Residential/Commercial/Retail development (Double Bay, Sydney) (adjacent to a Sydney Water Corporation open channel in a sag point) (consent obtained, development has not proceeded as yet).

The Honeysuckle example, as it has been constructed, is explained further. Reference should also be made to the *Linwood Flood Management Plan* (Lawson & Treloar et al, 1998a) and the *Marina Precinct Flood Management Plan* (Lawson & Treloar et al, 1998b). Both of these sites are precincts within the Honeysuckle Development.

The *Linwood Flood Management Plan* (Lawson & Treloar et al, 1998a) identifies flood refuges in an area known as ‘The Lane’ and in all multi-unit residential buildings. In the area known as The Lane, people in the public domain areas can take refuge in times of flood in areas identified to be above the PMF, although the number of people likely to be in the area is undefined. The first preference for residents and their visitors is to take shelter at upper storeys within the building above the PMF (residential floor levels in the development are set at the PMF level – 0.8 m rather than a 100 year ARI level +0.5 m). In this regard, provision has been made within multi-unit buildings for a public refuge space which is to be sized to accommodate all ground floor residents for up to 8 hours. No details on the method of sizing of the public refuges are outlined in the plan.
The *Marina Precinct Flood Management Plan* (Lawson & Treloar et al, 1998b) identifies public flood refuges in raised portions of the entrance areas of multi-unit residential buildings. The first preference for residents and their visitors is to take shelter at upper storeys of their building above the PMF level. No details on the method of sizing of the public refuge are outlined in the plan.

The approach adopted in the *Marina Precinct Flood Management Plan* (Lawson & Treloar et al, 1998b) is the one that has been adopted for the GSTC due to the similarities in the nature of flooding of the two areas. However, the approach has been enhanced to include the sizing of the public refuge areas.

**FLOOD REFUGE AREAS – DESIGN PARAMETERS**

There are three main inputs to the sizing of flood refuge areas:

- The number of people to be evacuated from an area;
- The distance of the flood refuge area from the evacuation area; and
- The size of the flood refuge area.

**Number of People to be Evacuated from an Area**

The number of people to be evacuated from an area can depend on the time of day. Possible scenarios for an urban area near a transport hub might include:

- A PMF event occurring during a public event where there are large number of attendees/participants in the public domain areas, and
- A PMF event occurring during a typical peak hour coinciding with the arrival or departure of many workers.

The number of people to be evacuated will vary as in one scenario, a public event may include a large number of people seated or standing in a crowd in a specific area whereas people walking between areas in the peak hour period may move in a lesser density, but over a larger space.

A review of the literature indicated few sources of data on the density of people who could be expected to gather in for open air gatherings or for normal morning and evening peaks. The Building Code of Australia (2008) stipulates that an area of public assembly such as halls or theatres should have a maximum density of one person per 1 m$^2$ (BCA, 2008). However, this density is for a closed space and is potentially excessive for the purposes of open space situations.

The Building Code of Australia (2008) also gives maximum densities for transport terminals and shopping centres. For example, the maximum density for a transport terminal is one person per 2 m$^2$ and for a shopping centre foyer is one person per 5 m$^2$. These numbers appear to be more reflective of likely densities of people in open public spaces. For the purposes of the GSTC assessments it was assumed that at any point in time it could be expected that the density may be approximately one person per 5 m$^2$ within identified public open space areas. A density of one person per 2.5 m$^2$ was also considered for sensitivity testing.
To estimate the number of people transiting an area during a peak hour a time window can be utilised. A time window of transit, say, 15 minutes could be considered as people either move to or from a specific area.

It can be assumed that during a peak hour, the area around a transport hub could be congested with people as they move to and from buses and trains. In the case of the GSTC, a review of the current City Rail timetable for Green Square Station indicates that trains arrive and depart every approximately 5 – 10 minutes in peak hour. In addition to this it can be assumed that the nearby bus terminal will be operating buses in a similar fashion. Table 1 shows an estimation of the frequency of train and bus arrivals at the GSTC as well as approximate maximum passenger numbers.

**Table 1 Transport Frequency and Maximum Capacity**

<table>
<thead>
<tr>
<th>Transport Type</th>
<th>Frequency of Arrivals/Departures</th>
<th>Maximum Capacity (persons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>Every 5 -10 minutes</td>
<td>80</td>
</tr>
<tr>
<td>Train (8 Carriage)</td>
<td>Every 5 - 10 minutes</td>
<td>900</td>
</tr>
</tbody>
</table>

Based on a 15 minute window with a 50% ingress/egress rate of passengers to buses and trains, it can be estimated that a total of 980 people could potentially be present in open space transit areas for pedestrians (2 buses and 2 trains in 15 minutes with 50% ingress/egress rate depending morning or afternoon peak).

This number may also be ‘sanity’ checked by assuming say 8000 people will need to get to a place of work within the GSTC between, say, 7:00am and 9.00am or to travel home between 4:30pm and 6:30pm. If this number of people is divided into the number of 15 minute time slots in the 2 hour peak time (i.e. 8000/8) then approximately 1000 people will be present in each 15 minute window. This figure is consistent with the 980 people estimate via Table 1. This number does not include, in addition, the approximately 5500 residents that may reside in the Town Centre as it could be assumed they would make up a portion of the workforce, would have access to private transport and would have access to private refuge locations.

In the early stages of a summer afternoon summer rainstorm, a certain proportion of the 8,000 or so people working in the Town Centre may decide to leave early and head for the rail station. This is a very difficult figure to predict. However, with flood management systems in place it is expected that this behaviour may be able to be managed to minimize the number who may otherwise attempt to “beat the storm home”.

*Proximity of Flood Refuge Area*

If it is assumed that an average adult in a moderately packed crowd has a walking speed of 1 m/s (Fang et al, 2008) and the assembly location needs to be reached within, say, 180 seconds (three minutes) (a sufficient time to evacuate via foot when flood waters are rising in the area) then the flood refuge areas need to be at least within 180 metres of the area to be evacuated (e.g. an area where there is a public gathering).

*Size of Flood Refuge Area*
Once the number of people to be evacuated from an area has been calculated, the size of the refuge area can be calculated. Two primary sources of information were utilised when considering how to calculate the size of a temporary flood refuge:

- Building Code of Australia (2008); and the

As outlined above, the Building Code of Australia (2008) stipulates that an area of public assembly such as halls or theatres should have a maximum density of one person per 1 m² (BCA, 2008). FEMA (2000) recommends a minimum of 0.45 m² per person for tornado shelters. It is important to note that for the GSTC in the vicinity of Sites 1 – 19, the duration for flood waters above >0.1m, for a Probable Maximum Flood, is typically less than one hour. Under these circumstances, considering the space requirements above, a maximum density of 0.5 m² per person was adopted.

For example, if 1000 people required temporary flood refuge within the Green Square Town Centre area then approximately 500 m² of space will need to be publicly accessible for flood refuge areas.

**FLOOD REFUGE AREAS – ESTIMATES FOR THE GSTC**

Due to the distance requirements the flood refuge areas within buildings were allocated based on the expected density of people at each major public open space location (i.e. the Plaza and Park areas). For example, buildings within 180 metres of Boulevard Park will need to accommodate these people.

Two scenarios were considered for the evaluation of a suitable plan area for temporary flood refuges within the buildings of the GSTC:

- A PMF event occurring during a public event (Scenario A) given the large amount of public domain areas within the GSTC and
- A PMF event occurring during a typical peak hour (Scenario B) given the arrival or departure of workers from the GSTC via the main mode of transport, the Green Square Railway Station.

Further, three cases within each Scenario were considered for the allocation of space:

- Case 1, allocation of space to all buildings within 180 metres of public open space,
- Case 2, allocation of space to all non-exclusively residential buildings within 180 metres of public open space, and
- Case 3 where 50% of the people to be accommodated are allocated to proposed community buildings in two public areas (Civic Plaza and Boulevard Park).

If the worst case scenario is considered, where all locations have people at the same density, then the floor space allocations are cumulative. By considering the three public open space locations separately then adding the result a weighting is introduced such that sites that are within 180 metres of more than one location must have space for people from these locations. For example, some sites are accessible from two public open space areas and thus must contain space for both groups of people.
To distribute the floor space on an equitable basis, the building footprint area for each site was used as a weighting. That is, larger building sites were allocated proportionally more space.

A summary of the recommended floor space as an outcome of the investigations is presented in Table 2. These numbers represent the largest of the floor space requirement for each site for either Scenario A - Case 3 or Scenario B - Case 3. Note that Table 2 assumes that both community buildings will have floor space above the Probable Maximum Flood allocated and available to accommodate 50% of people present. One site within the GSTC is greater than 180 metres from a major public open space area and while it is mixed residential and commercial, it has not been earmarked to have any floor space allocation for temporary flood refuge.

As outlined above, space has been allocated to locations within 180 metres walking distance from an area of public gathering or transport hubs. It is important that refuges are freely accessible and should provide public shelter for time periods in the order of 1 – 2 hours. Ideally, community buildings (such as those proposed in Civic Plaza and Boulevard Park) should be focal points for temporary flood refuge due to their proximity to potential pedestrian movements.

Table 2 Recommended Refuge Flood Space Allocation

<table>
<thead>
<tr>
<th>Building Purpose</th>
<th>Approximate Site Building Footprint (m²)</th>
<th>Recommended Refuge Floor Space Requirement (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial and Retail</td>
<td>3200</td>
<td>27.2</td>
</tr>
<tr>
<td>Multi-Storey Commercial Tower</td>
<td>1000</td>
<td>8.5</td>
</tr>
<tr>
<td>Multi-Storey Commercial and Retail Tower</td>
<td>900</td>
<td>7.7</td>
</tr>
<tr>
<td>Multi-Storey Commercial Tower</td>
<td>800</td>
<td>6.8</td>
</tr>
<tr>
<td>Multi-Storey Commercial/Residential</td>
<td>3200</td>
<td>44.8</td>
</tr>
<tr>
<td>Multi-Storey Commercial/Residential</td>
<td>3236</td>
<td>45.3</td>
</tr>
<tr>
<td>Multi-Storey Commercial/Residential</td>
<td>2375</td>
<td>33.2</td>
</tr>
<tr>
<td>Multi-Storey Retail/Commercial/Residential</td>
<td>6115</td>
<td>85.6</td>
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<tr>
<td>Multi-Storey Commercial/Residential</td>
<td>3877</td>
<td>75.5</td>
</tr>
<tr>
<td>Multi-Storey Residential</td>
<td>4200</td>
<td>0.0</td>
</tr>
<tr>
<td>Multi-Storey Residential Only</td>
<td>5240</td>
<td>0.0</td>
</tr>
<tr>
<td>Multi-Storey Retail/Commercial/Residential</td>
<td>7600</td>
<td>41.7</td>
</tr>
<tr>
<td>Multi-Storey Residential/Commercial</td>
<td>3320</td>
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<td>Multi-Storey Residential</td>
<td>4172</td>
<td>0.0</td>
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<td>Multi-Storey Residential/Commercial</td>
<td>2400</td>
<td>46.8</td>
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<td>1668</td>
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<td>Multi-Storey Residential/Commercial/Retail</td>
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<td>Multi-Storey Residential/Commercial/Retail</td>
<td>3637</td>
<td>70.9</td>
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<tr>
<td>Community Building 1</td>
<td>500</td>
<td>245.0</td>
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<tr>
<td>Community Building 2</td>
<td>250</td>
<td>125.0</td>
</tr>
</tbody>
</table>

CONCLUSION
The assessments conducted for the GSTC can be used as a template for similar assessments in urban renewal areas that are subject to flash flooding. The methodology developed for calculating the size of flood refuge areas, based on information in literature and aggregating similar ideas and concepts from the Building Code of Australia and FEMA, is a starting point for future similar assessments for the management of residual flood risk.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge the inputs of Landcom (including Eric Brodie (Landcom Project Manager) and the City of Sydney Council (including Peter Donley, Council’s Floodplain/Drainage Engineer) for their contributions during the undertaking of the assessments for the flood refuge areas as well as the contribution of Dr Brett Phillips of Cardno as Project Director. Many others also contributed to the development of the ideas and concepts outlined in this paper.

REFERENCES