SUTHERLAND SHIRE COUNCIL

INITIAL SUBJECTIVE ASSESSMENT OF MAJOR FLOODING

FINAL DRAFT

March 2004

Bewsher Consulting Pty Ltd

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Reasons for the Study

Flooding across Sutherland Shire led to serious damages on 13 May 2003. Acknowledging the problems of local overland flooding, and in keeping with the *Floodplain Management Manual*'s requirement to address major drainage problems, Sutherland Shire Council commissioned Bewsher Consulting to prepare an initial, subjective assessment of major flooding in the Shire. The aim of this study was to strategically assess 82 major drainage systems (defined as those with a pipe diameter >= 900 mm) and 19 waterways, and to present a prioritised action plan to investigate and manage these risks. Mainstream flood risks along the Georges and Woronora Rivers were not assessed.

Methods

Three approaches were used.

(i) Council's Customer Response Management System (CRMS) database was interrogated to assess the distribution of flood complaints.

(ii) Preliminary hydrologic and hydraulic analyses were conducted. These analyses involved the preparation of 100 year and 'extreme flood' flows using the Urban Rational Method. Areas of inundation were estimated by application of the open channel flow equation to cross sections derived from Council's 2 metre contour GIS layer. The number of properties subject to flooding was estimated using Council's cadastre GIS layer. These results must be regarded as coarse and indicative rather than precise.

(iii) Mr Mike Rogers, drawing on his long experience as Council's previous Stormwater Manager, provided valuable insights into relative flood risk across the Shire.

Results

The primary outcome of this study is a prioritised action plan for future flood studies and floodplain management studies/plans (**Table 5**). The "top 10" priorities are listed below.

It is important to recognise that this assessment is *initial* and *subjective*. Nevertheless, the concurrence between the Consultant's preliminary analyses and Mike Rogers' views lends a measure of confidence to the ranking, particularly for these high priority areas. A number of sub-catchments have been grouped into the one recommended study, either because they belong in the one larger catchment, or to increase cost-effectiveness. Additional groupings would promote further efficiencies. Assuming combined flood studies and floodplain management studies/plans, studies of a large scale are estimated to cost in the order of $120,000, of a medium scale, in the order of $60,000, and of a small scale, in the order of $30,000. On top of this would be the cost of ground survey – Shire-wide airborne laser scanning is likely to cost in the order of

$200,000. For flood studies to proceed, up to seven Floodplain Management Committees would need to be established.

EXTRACT FROM TABLE 5: PRIORITISED ACTION PLAN FOR FUTURE FLOOD STUDIES AND FLOODPLAIN RISK MANAGEMENT STUDIES/PLANS

RANK	AREA	SUB-CATCHMENTS (SSC NUMBERS)	SCALE OF STUDY
1	Sylvania Waters and catchments (including Gwawley Creek and Parraweena Rd trunk drain)	#13, 51, 44, 45, 52, 61	large
2	Kurnell township	81/82	medium
3	Botany Bay catchments (including Taren Point, Caringbah, Woolooware and Cronulla)	62/63/64, 65/66, 67/68, 72/73	large
4	Bundeena Creek	80	medium
5	Oyster Creek	35/33/36	medium-large
6	Dents Creek (and lower Savilles Creek)	37/38/40, 39	medium-large
7	Ewey Creek	46	medium
8	Unnamed Woronora R. tributary (Sutherland/Woronora)	30	medium
9	Kareela Creek	#17/41/43, 42	medium
10	Carina Creek	6	medium

1. INTRODUCTION

1.1 FLOOD PROBLEMS

Heavy rain led to severe flooding across Sutherland Shire Council on the morning of Tuesday 13 May 2003. Newspaper reports and correspondence received by Council record heavy damages to factories, houses and motor vehicles (**Photo 1**). About 60 factories were estimated to have been flooded to depths of up to 0.9 m in Bay Rd, Taren Point. At Brian Lovelock's Garden Centre in Taren Point, losses amounted to $50,000 for stock and $30,000 for fixtures and fittings, including floor-coverings (**Photo 2**). Flooding of garages, laundries and rumpus rooms was reported for many locations. The NSW State Emergency Service received 342 requests for assistance.

Photo 1: Parraweena Rd, Taren Point, 13 May 2003
Source: Sutherland Leader, Thursday May 15, 2003, p.1

Photo 2: Brian Lovelock's Garden Centre, Parraweena Rd, Taren Point, 13 May 2003
Source: Sutherland Leader, Tuesday June 3, 2003, p.14

Estimated Average Recurrence Intervals (ARIs) for rainfall on 13 May 2003 are recorded in **Table 1**. The normal design frequency for street drainage is 5 years (Mr Mike Rogers, pers. comm.), which was exceeded at the Cronulla South gauge, though only at the Audley gauge did estimated ARIs exceed 10 years. Although 'high tides' were cited as a reason for the floods in the press, an analysis of the tidal charts shows that the flood corresponded to a falling tide, from a peak that was not particularly high (**Figure 1**). The moderate rainfall ARIs and modest tides imply that flooding could be much worse under more extreme conditions.

Another possible influence on urban flooding is blockage of drains. For the May 2003 event, it had been a long time since the previous significant rainfall, so that an accumulation of leaves and other debris in the drainage system may have occurred – leading to blockage and increased flooding.

Floods in various parts of the Shire are also known to have occurred on 5 February 1990, (Kurnell), 17 August 1998 (Caringbah, Kurnell) and 1 May 2003 (Taren Point).

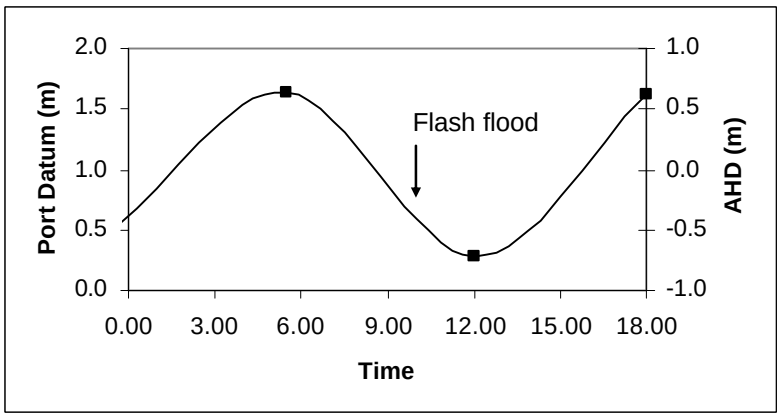
Photo 3: Flooding at Kurnell, 1990s
Source: Sutherland SES. Used with permission.

TABLE 1: RAINFALL INTENSITIES, 13 MAY 2003

Source: Sutherland Shire Council

Rainfall depth (mm)	Period	Ending at	Estimated ARI
Cronulla South Bowling Club			
7	5 mins	10:30	<1
8	6 mins	10:30	<1
12	10 mins	10:32	<1
17	20 mins	10:34	<1
20	30 mins	10:42	<1
27	1 hour	10:56	<1
46	2 hours	10:34	1-2
66	3 hours	11:09	2-5
104	6 hours	13:15	5-10
121	12 hours	15:11	2-5
Lucas Heights			
3	5 mins	9:56	<1
3	6 mins	9:56	<1
5	10 mins	9:57	<1
8	20 mins	9:59	<1
11	30 mins	9:59	<1
18	1 hour	10:06	<1
29	2 hours	10:29	<1
38	3 hours	11:37	<1
52	6 hours	13:26	<1
62	12 hours	15:51	<1
Audley, Royal National Park			
8	5 mins	9:59	1
9	6 mins	10:00	1
13	10 mins	9:12	1-2
22	20 mins	9:12	1-2
29	30 mins	9:13	2-5
53	1 hour	9:59	5-10
97	2 hours	10:41	20-50
108	3 hours	11:25	20-50
137	6 hours	13:15	10-20
154	12 hours	15:21	5-10

FIGURE 1: BOTANY BAY TIDES, 13 MAY 2003
Source: National Tidal Facility, Australia (http://www.ntf.flinders.edu.au/)



1.2 STUDY AIMS AND APPROACH

Acknowledging the problems of local overland flooding, and in keeping with the *Floodplain Management Manual*'s requirement to address major drainage problems, Sutherland Shire Council commissioned Bewsher Consulting to prepare an initial subjective assessment of major flooding in the Shire.

Council identified 82 major drainage systems (defined as those with a pipe diameter >= 900 mm) and 19 waterways where investigations may be warranted, though there is a good deal of overlap between the two. The aim of this study was to strategically assess these flood risk areas and present a prioritised action plan to investigate and manage these risks. Flooding of the Georges River and Woronora River (including Forbes Creek downstream of the Loftus Creek confluence) were excluded from this study, which did not assess mainstream flooding.

Three approaches have been used.

(i) Council provided a geo-referenced copy of its Customer Response Management System (CRMS) database, which contained 730 entries all relating to the storm of 13 May 2003. This database was interrogated to assess the distribution of flood complaints. A limitation of this data source is its reliance on only one event, with particular rainfall distribution.

(ii) Preliminary hydrologic and hydraulic analyses were conducted. These analyses involved the preparation of 100 year and 'extreme flood' flows using the Urban Rational Method in accordance with *Australian Rainfall and Runoff* (adapted for Sutherland Shire Council in the SSC Urban Drainage Design Manual). Areas of inundation were estimated by application of the open channel flow equation to cross sections derived from Council's 2 metre contour GIS layer. The number of properties subject to flooding was estimated using Council's cadastre GIS layer. **Appendix 1** details the procedure followed in these analyses, including assumptions, and **Appendix 2** records the flows derived from the Urban Rational Method. Given the reliance on 2 m contours (with an assumed accuracy of ± 1 m), and the scope of the study which limited the number of cross sections for any one sub-catchment – occasionally leading to spurious results – these results must be regarded as coarse and indicative rather than precise.

(iii) Another source of information resides in the experience of those with local knowledge of flood problems, who have worked in the industry for many years. Council's previous Stormwater Manager, Mr Mike Rogers, provided valuable insights into relative flood risk across the Shire. A previous SES Local Controller for Sutherland, Mr David Monk, also shared from his experience of responding to flood problems.

2. DAMAGE PROFILE FOR MAY 2003

A database containing 730 geo-referenced complaints was received from Council, and a further nine were added. These complaints were all associated with the storm of 13 May 2003. A first step in interrogating the database was to categorise the nature of the complaint. This was done by allocating complaints to one of six categories, as shown in **Table 2**.

TABLE 2: CATEGORISATION OF FLOOD COMPLAINTS

Damage category	Number of complaints	Description
-1	9	Repeated complaints
0	166	Not relevant: e.g. fallen trees; water leaks down light-fittings, through window frames; missing pit covers; pollution; potholes; trees clogging sewerage pipes
1	79	Marginal relevance: erosion or subsidence related
2	216	Flood-related: local significance, particularly blocked or broken drains or pipes
3	148	Flood-related: broader significance, including overland flow
4	121	Flood-related: inundation of garages, rooms, pools etc
Total	739	

A few complaints (probably under-counted) were repeated complaints from the same address (Category -1), a large number of complaints were not relevant to flooding (Category 0) and many others were about erosion (often from building sites) or subsidence (Category 1). Of the remaining complaints, 216 mentioned blocked or broken drains or pipes or some other local cause (Category 2), whereas 148 seemed to be of broader significance (Category 3). Admittedly, the distinction between Category 2 and 3 complaints is at times arbitrary, and depends on people's perceptions of the cause of flooding, which may be erroneous. Furthermore, it is unclear whether a report of a blocked drain says more about the cause of flooding or an effect of the flood. Category 4 complaints are probably the most telling, being those where actual building inundation occurred.

Figure 2 depicts the distribution of Category 4 and 3 complaints across the Shire. Four points may be noted:

(i) Complaints are dispersed across the whole of the Shire.

(ii) Complaints are not confined to larger catchments or to low-lying land.

(iii) A higher concentration of complaints occurs in the eastern area of the Shire relative to the western area.

(iv) Many complaints are proximate to the pipe network and pertain to overflowing easements and pipes.

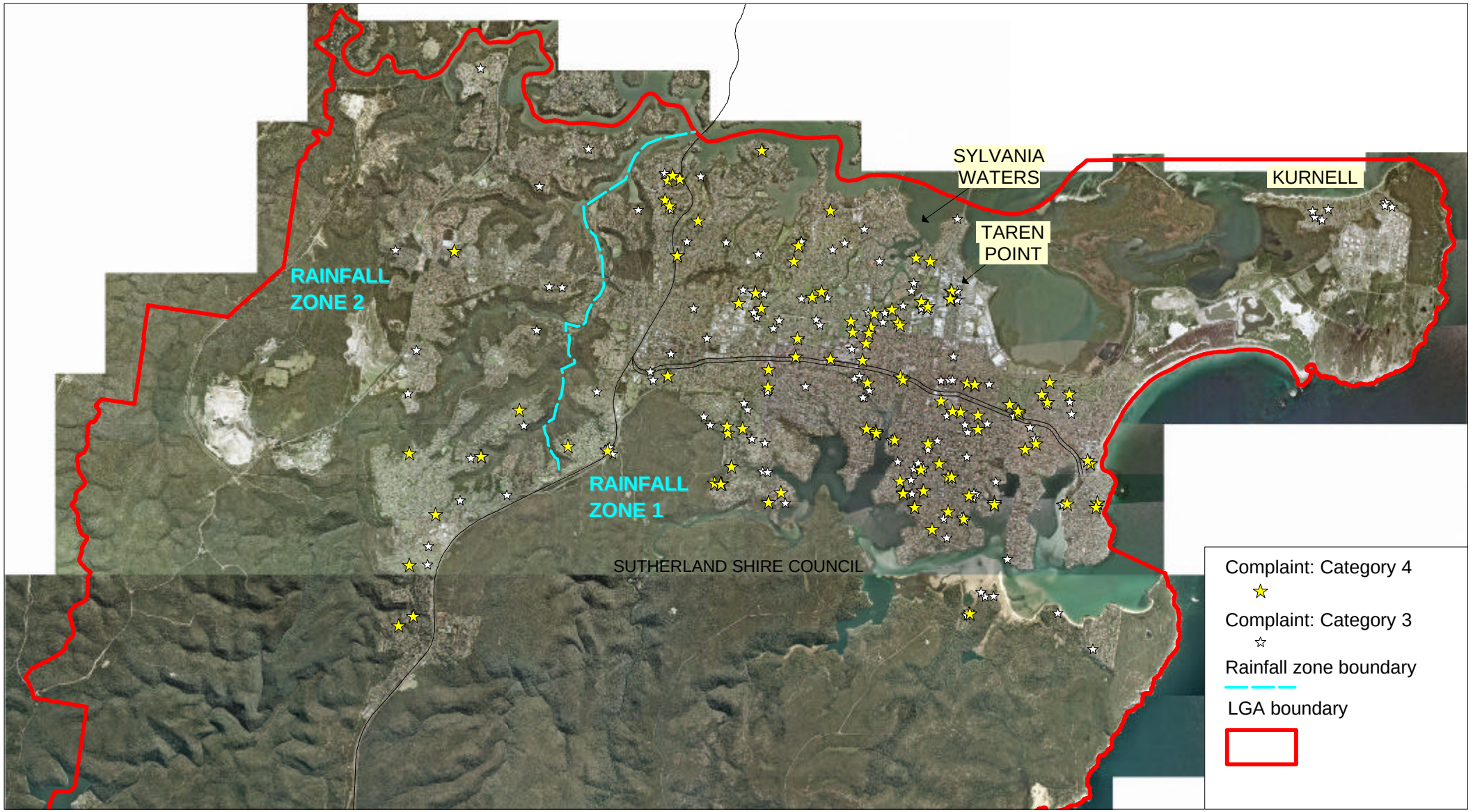
The dispersed nature of the complaints — including some on relatively high ground — points to the mechanisms of flooding at work during high-intensity rain events such as 13 May 2003: drains can be blocked, and overland flow can occur just about anywhere. The higher concentration of complaints in the eastern area may reflect the higher rain intensity experienced there (see **Table 1**). It may also reflect a tendency towards wider buffer zones in the western area.

Examples of complaints proximate to the pipe network, pertaining to overflowing easements and pipes, include the following:

CRMS object no.	Damage category	Address	Description
9	3	Crescent Rd, Caringbah	Open watercourse that runs alongside resident's property could not cope with the volume of water during yesterday's storm and it overflowed and flooded his property. There is a substantial loss of fencing and soil.
110	4	Woolooware Rd, Woolooware	Block of units – Council easement runs through this property – flooding of basement

Closer inspection does indicate some spatial concentrations. **Table 3** records the number of Category 4 complaints according to sub-catchments (with some grouping). A relatively high concentration of complaints occurred in sub-catchments flowing north into Botany Bay, including the Production Rd channel in Taren Point. This is consistent with newspaper reports that nominated Taren Point as one of the worst-affected areas. Another high concentration of complaints occurred in sub-catchment 52, which drains an area of Miranda flowing north into Sylvania Waters. Many properties were flooded in Kurnell, but there were no reports of building inundation, with the possible exception of Kurnell Public School. Kurnell residents cited a number of reasons for the flooding: a lack of kerb and guttering, new raised developments and an inadequate maintenance of drains.

FIGURE 2: DISTRIBUTION OF COMPLAINTS FOLLOWING STORM OF 13 MAY 2003



3. PRELIMINARY HYDROLOGIC AND HYDRAULIC MODELLING

Appendix 1 details the procedure followed in these analyses, including assumptions. Some assumptions tend to over-rate flood exposure (e.g., no account was taken of pipe capacities) and some assumptions tend to under-rate flood exposure (e.g., a property was only counted as flood-affected if its centroid was within the flood-affected area). As described in the introduction, the coarse resolution of the available contour mapping, plus the inability to construct a sufficient number of cross sections given the preliminary nature of this study, means that these results must be regarded as indicative rather than precise. This assessment estimated only the extent of flooding (not the depth of flooding) based on an open channel flow equation at two or more cross sections within each sub-catchment and a subjective interpolation between these sections.

Table 3 records the number of flood-affected properties for the modelled 100 year and extreme floods, for most of the 82 trunk drainage systems. Where flood patterns dictated, some of the systems have been combined. In aggregate, the Georges River sub-catchments contain the greatest exposure, followed by the Botany Bay sub-catchments. Significantly fewer properties are exposed to flooding in the Port Hacking and Woronora River sub-catchments.

The largest single exposures are from Sylvania Waters and Kurnell. There are significant uncertainties, however. It is possible that the number of properties for the 100 year flood is over-estimated. This is because – given the estimated 100 year flood level is 1.7 m AHD (from the Georges River FMS) – there are insufficient topographic data from the 2 m contour plans (with an assumed accuracy of ± 1 m) to properly define the inundated area. Actual top-of-kerb levels taken from Barcoo Island (1.45-1.7 m AHD) and Murray Island (0.6-1.2 m AHD) in Sylvania Waters suggest that it is reasonable to include this area in the 100 year flood zone (data from Survey Section of SSC). Of course, these exposures refer to ground levels, not floor levels. In Sylvania Waters, the minimum finished floor level is estimated at about 2.2 m AHD, and in Kurnell, the minimum finished floor level (for new developments only) is 1.9 m AHD (Mr Joga Jayanti, SSC). This suggests that, according to this criterion, the risk at Kurnell is higher than at Sylvania Waters.

Another large exposure is found within sub-catchments 65/66, draining an area of Caringbah flowing into Botany Bay. The number of exposed properties does seem rather high, which reflects the area's sensitivity to changes in flood extent. Sub-catchment 52 also recorded a large exposure. This is consistent with a high concentration of complaints.

There is only one large exposure (>50 properties) among the Woronora River sub-catchments (sub-catchment 30). This is because creeks such as Forbes Creek and Loftus Creek are incised and mostly surrounded by well-vegetated buffer zones (cf. **Figure 2**). Buildings tend to be more proximate to potentially flooded areas in the eastern area of the Shire, where buffer zones are not so common. Presumably, this development is older, probably pre-dating regulatory controls.

TABLE 3: NUMBER OF COMPLAINTS (CAT. 4) AND NUMBER OF PROPERTIES FLOODED FOR Q100 AND Q-EXTREME SCENARIOS BY SUB-CATCHMENT

Note: Arranged by major catchment, generally from upstream to downstream; # identifies one of designated waterways.

Catchment number (SSC)	Major catchment	Sub-catchment	Number of complaints (Cat 4)	Q100 number of properties	Q extreme number of properties	Notes
Woronora River catchments						
24	Woronora River	Bottle Creek	1	negligible	negligible	
25	Woronora River	Bottle Creek	1	8	8	
22	Woronora River		1	negligible	negligible	
23	Woronora River		0	1	1	
16	Woronora River		0	2	2	
21	Woronora River		0	negligible	negligible	
20	Woronora River	Forbes Creek	0	10	46	
17	Woronora River	Forbes Creek	0	2	3	
#8A	Woronora River	Forbes Creek	0	7	36	
15	Woronora River	Forbes Creek	0	negligible	negligible	
18	Woronora River	Loftus Creek	1	24	29	
19	Woronora River	Loftus Creek	0	6	10	
27	Woronora River	Loftus Creek	0	1	5	
28	Woronora River	Loftus Creek	0	negligible	negligible	
29	Woronora River	Loftus Creek	1	4	8	
14	Woronora River	Loftus Creek	1	negligible	negligible	
13	Woronora River	Crescent Creek	0	18	25	excludes Woronora flooding
10	Woronora River		0	14	27	excludes Woronora flooding
11	Woronora River		0	negligible	negligible	
12	Woronora River		0	8	34	excludes Woronora flooding
30	Woronora River		0	58	83	excludes Woronora flooding
9	Woronora River		0	9	11	
7	Woronora River	Still Creek	0	13	15	
8	Woronora River	Still Creek	0	2	5	
4	Woronora River		0	4	16	excludes Woronora flooding
SUBTOTAL			**3**	**191**	**364**	
Georges River catchments						
1	Georges River	Mill Creek	0	negligible	negligible	
2	Georges River		0	7	8	
3	Georges River		0	15	22	
5	Georges River		5	7	49	
6	Georges River	Carina Creek	3	49	68	
34/83	Georges River		0	61	68	
35/33/36	Georges River	Oyster Creek	0	86	124	

Catchment number (SSC)	Major catchment	Sub-catchment	Number of complaints (Cat 4)	Q100 number of properties	Q extreme number of properties	Notes
#17/41/43	Georges River	Kareela Creek	3	41	59	
42	Georges River		1	24	34	
54	Georges River		0	negligible	negligible	
55	Georges River		0	negligible	negligible	
51	Georges River		0	20	22	
44	Georges River	Sylvania Heights	1	72	83	
45	Georges River	Gwawley Creek	3	114	137	
#13	Georges River	Sylvania Waters	1	984	1042	Q100 assumed 2.01 m – over-estimate?
52	Georges River	(Near Goulburn Peninsula)	10	219	259	
61	Georges River	(Near Paroo Ave)	5	138	147	
SUBTOTAL			**32**	**1,837**	**2,122**	
Botany Bay catchments						
62/63/64	Botany Bay	Incl. Production Rd	6	60	81	
65/66	Botany Bay		5	451	480	spurious?
67/68	Botany Bay		8	98	141	
72/73	Botany Bay		2	23	38	
81/82	Botany Bay	Kurnell township	0	776	787	Q100 assumed 2.01 m – over-estimate?
SUBTOTAL			**21**	**1,408**	**1,527**	
Pacific Ocean catchments						
77	Pacific Ocean		0	negligible	negligible	
Port Hacking catchments						
26	Hacking River	Heathcote industrial area	0	negligible	negligible	
37/38/40	Port Hacking	Dents Creek	1	97	173	
31	Port Hacking	Upper Savilles Creek	0	6	18	
32	Port Hacking	Upper Savilles Creek	1	3	16	
39	Port Hacking	Lower Savilles Creek	2	3	5	
50	Port Hacking		4	3	8	
49	Port Hacking		0	3	4	
48	Port Hacking	Coonong Creek	0	4	6	
47	Port Hacking	Alcheringa Creek	1	53	80	
53	Port Hacking		1	8	17	
46	Port Hacking	Ewey Creek	3	54	88	
56	Port Hacking		0	negligible	7	
57	Port Hacking	“Camellia Gardens” Creek	3	31	82	

Catchment number (SSC)	Major catchment	Sub-catchment	Number of complaints (Cat 4)	Q100 number of properties	Q extreme number of properties	Notes
58	Port Hacking		0	12	25	
59	Port Hacking		3	12	29	
60	Port Hacking		0	negligible	negligible	
78	Port Hacking		1	negligible	negligible	
70	Port Hacking		4	10	20	
69	Port Hacking		0	2	10	
71	Port Hacking		0	7	15	
74	Port Hacking		1	8	19	
75	Port Hacking		0	19	35	
76	Port Hacking		0	negligible	negligible	
79	Port Hacking	Maianbar	0	negligible	negligible	
80	Port Hacking	Bundeena Creek	0	175	180	
SUBTOTAL			**25**	**510**	**837**	

4. EXPERT ADVICE

Mr Mike Rogers, Sutherland Shire Council's previous Stormwater Manager, provided a subjective assessment of the flood risk posed by each of the 82 identified major drainage systems. These judgements were based on memory of past flooding and potential for further flooding. Flood frequency and severity, the nature of development (residential given most weight), and the status of Council drainage works, were all influential factors. The sub-catchments were allocated a rating from 1 (high flood risk/high priority) to 5 (low flood risk/low priority). Flood risk rating and any comments are recorded in **Table 4**. Sub-catchments with a '1' rating were further categorised into 'extreme' and 'high' risks.

The highest rating was allocated to Sylvania Waters (#13) and the creeks flowing into Sylvania Waters, especially the one from Parraweena Rd (61) which has a notorious history of flooding (cf. **Photos 1 and 2**). Kurnell (81/82) and Bundeena (80) townships are both severely exposed to floods. Oyster Creek (35) poses the greatest problem among the Georges River sub-catchments, and Ewey Creek (46) among the Port Hacking sub-catchments. Other 'high' risks are a sub-catchment flowing from Sutherland into the Woronora River (30), a system flowing under Southgate Shopping Centre (44), Gwawley Creek (45), Production Rd Creek in Taren Point (62) and Dents Creek (38).

Mr David Monk, previous SES Local Controller for Sutherland, ranked Sylvania Waters as first priority and Kurnell as second priority for future flood investigations of Sutherland Shire's major drainage systems.

TABLE 4: MIKE ROGERS' ASSESSMENT OF FLOOD RISK BY SUB-CATCHMENT

Note: Arranged by major catchment, generally from upstream to downstream; # identifies one of designated waterways.

Catchment number (SSC)	Major catchment	Sub-catchment	Rating (1 = high, 5 = low)	Comments
Woronora River catchments				
24	Woronora River	Bottle Creek	4	Potential for flooding.
25	Woronora River	Bottle Creek	3	
22	Woronora River		3	Some history of flooding (Raymond Pl); possibly undersized pipes.
23	Woronora River		4	
16	Woronora River		5	
21	Woronora River		4-5	
20	Woronora River	Forbes Creek	3	
17	Woronora River	Forbes Creek	5	
#8A	Woronora River	Forbes Creek	3	
15	Woronora River	Forbes Creek	5	
18	Woronora River	Loftus Creek	4	
19	Woronora River	Loftus Creek	3	
27	Woronora River	Loftus Creek	4	
28	Woronora River	Loftus Creek	4	
29	Woronora River	Loftus Creek	4	
14	Woronora River	Loftus Creek	4-5	
13	Woronora River	Crescent Creek	3	
10	Woronora River		3	
11	Woronora River		5	
12	Woronora River		3	Steep catchment, rapid runoff.
30	Woronora River		1 high	Some history of flooding on higher land. Extensive flooding from the sub-catchment around Liffey Pl (near Woronora River). *S149 flood notations have been issued along Woronora River.*
9	Woronora River		3	Some history of flooding.
7	Woronora River	Still Creek	4	
8	Woronora River	Still Creek	4	
4	Woronora River		4-5	
Georges River catchments				
1	Georges River	Mill Creek	5	
2	Georges River		4	Some history of flooding.
3	Georges River		4	
5	Georges River		3	
6	Georges River	Carina Creek	2-3	
34/83	Georges River		3	
35	Georges River	Oyster Creek	1 extreme	Creek breaks banks in 2-5 year storm. Houses on western side Buderim Ave affected. Bates Dr bridge does affect flooding. Residents of Buderim Ave wanted bridge reconstructed. They rejected Council's proposal for 1.5 m levee. *S149 flood notations have been issued here.*

Catchment number (SSC)	Major catchment	Sub-catchment	Rating (1 = high, 5 = low)	Comments
33	Georges River	Oyster Creek	2	History of flooding. Council did major drainage upgrade at Glencoe St North. Flood study was done prior to extensions of nursing home, which were approved.
36	Georges River	Oyster Creek	3	Some problems years ago; piping done; potentially still problematic.
#17	Georges River	Kareela Creek		Not a significant exposure – golf course down to River.
41	Georges River	Kareela Creek	2	Extensive flooding years ago; drainage system upgraded; potentially still problematic.
43	Georges River	Kareela Creek	4	Golf course.
42	Georges River		2-3	History of flooding; court case; drainage problems.
54	Georges River		4	
55	Georges River		3-4	
51	Georges River		4	
44	Georges River	Sylvania Heights	1 high	1500 mm under Southgate Shopping Centre. Potential for serious flooding in 1% or PMF.
45	Georges River	Gwawley Creek	1 high	Some history of flooding near Sylvania Rd North. Some drainage upgrading Garnet Rd. Big potential for flooding. Major culvert on Port Hacking Rd will overtop.
#13	Georges River	Sylvania Waters	1 extreme	Subsidence problem at Murray Island resulting in current tidal inundation, mainly kept under control by a pump system.
52	Georges River	(Near Goulburn Peninsula)	1 extreme	Extensive history of flooding.
61	Georges River	(Near Paroo Ave)	1 extreme	'Huge' priority, but big budget. Flood study on Parraweena Rd (SSC). Drainage upgraded south of Parraweena Rd; requires upgrading north to Box Rd (where pipe goes under factory). Pipes very undersized. Open channel downstream of Box Rd – not much problem. Lovelock's Nursery may act as debris trap. *S149 flood notations have been issued near Parraweena Rd.*
Botany Bay catchments				
62	Botany Bay	Production Rd	1 high	Creek largely blocked by mangroves; requires cleaning and widening; easement needs widening. Extremely flat area with wide floodplain. Several flood studies done by developers. *S149 flood notations have been issued here.*
63	Botany Bay		4	
64	Botany Bay		4	
65	Botany Bay		3	History of flooding in Meta St. Low-lying, major culvert.
66	Botany Bay		3	Some flooding, major culvert, flat.
67	Botany Bay		3-4	Believed to have been flooding outside Toyota in May 2003.
68	Botany Bay		3	Some history of flooding. Golf course in lower reaches.

Catchment number (SSC)	Major catchment	Sub-catchment	Rating (1 = high, 5 = low)	Comments
72	Botany Bay		3-4	Previously, much flooding around golf course, sometimes inundated for days. Now addressed by major detention basins and major drainage upgrade down to Captain Cook Dr. Also significant upgrading south of Sturt Rd. Residual potential for flooding near blocks of units in upstream area.
73	Botany Bay		4	
81/82	Botany Bay	Kurnell township	1 extreme	Extensive, frequent (almost annual) but not severe flooding (mostly inundation of properties, not over-floor). Clearance of drains helps. Nevertheless, major flooding a few years ago. Illegal fill has caused problems by directing flow onto other properties. Old drainage scheme by Blair and Stuckey not adopted. *S149 flood notations have been issued here.*
Pacific Ocean catchments				
77	Pacific Ocean		5	
Port Hacking catchments				
26	Hacking River	Heathcote industrial area	4	
38	Port Hacking	Dents Creek	1 high	Flood study conducted from President Ave to Savilles Creek (SSC). *S149 flood notations have been issued here.*
40	Port Hacking	Dents Creek	2-3	History of backyard flooding. Major drainage works undertaken.
37	Port Hacking	Dents Creek	2	Some history of flooding.
31	Port Hacking	Savilles Creek	4	
32	Port Hacking	Savilles Creek	2	History of flooding.
39	Port Hacking	Savilles Creek	1 high	
50	Port Hacking		3	
49	Port Hacking		3-4	Flood problems years ago.
48	Port Hacking	Coonong Creek	3-4	Some flood history.
47	Port Hacking	Alcheringa Creek	3	Some flood history.
53	Port Hacking		3-4	Flooding a few years ago.
46	Port Hacking	Ewey Creek	1 extreme	Flood study conducted (SSC and consultant). *S149 flood notations have been issued here.* Extensive widening was recommended. Being implemented as medium-density development occurs.
56	Port Hacking		4	
57	Port Hacking	"Camellia Gardens" Creek	3	History of flooding.
58	Port Hacking		4	History of flooding, but major works done.
59	Port Hacking		3	History of flooding at lower end between buildings.
60	Port Hacking		5	
78	Port Hacking		4	
70	Port Hacking		3-4	Some history of flooding.
69	Port Hacking		3-4	Flooding upstream of parkland.

Catchment number (SSC)	Major catchment	Sub-catchment	Rating (1 = high, 5 = low)	Comments
71	Port Hacking		4	
74	Port Hacking		3-4	
75	Port Hacking		3	Flooding. Very old culvert. Very flat area.
76	Port Hacking		4	
79	Port Hacking	Maianbar	5	
80	Port Hacking	Bundeena Creek	1 extreme	Study conducted but without proper consultation process etc. NPWS agreed to put levee in National Park. Recommended major culvert upgrading and channel work in Scarborough St. Not implemented yet. *S149 flood notations have been issued here.*

5. CONCLUSIONS

The aim of this study was to assess the designated flood risk areas and present a prioritised action plan to investigate and manage these risks. The primary outcome of this study is **Table 5**, which ranks the major drainage areas in descending order of priority for future action (1 = first priority).

A number of sub-catchments were grouped, because they naturally form part of a larger sub-catchment (e.g., Oyster Creek), or in order to promote efficiencies (e.g., the "Botany Bay catchments"). Other sub-catchments could also be grouped to reduce costs (e.g., Ewey Creek and Alcheringa Creek; Dents Creek and Savilles Creek).

The estimated number of properties exposed to the 100 year and extreme floods was the first stage for prioritising future studies. This was then adjusted to incorporate Mike Rogers' assessment. For the purposes of ranking, no account was made of past flood studies or floodplain management studies. The impression gained from Mike Rogers is that previous flood studies may not have considered all floods up to the PMF, were of limited spatial extent (e.g. the Dents Creek Flood Study did not assess flood risks upstream from President Ave – **Table 4**), and were not followed by floodplain management studies (Bundeena Flood Management Study was an exception, though even there a process of community consultation was not followed). However, the activities undertaken for these previous studies are noted in the 'Progress' column in **Table 5**. The work already done for Bundeena Creek, Oyster Creek, Dents Creek and Ewey Creek may reduce the cost of future studies, though this has not been taken into account in the cost estimate.

Attached to each item of **Table 5** is an estimate of the scale of a combined flood study and floodplain management study/plan: a large study is estimated to cost in the order of $120,000, a medium study in the order of $60,000 and a small study in the order of $30,000. This costing excludes the cost of ground survey, which is an important prerequisite to detailed flood studies and floodplain management studies. In our opinion, it may well be prudent for Council to consider the preparation of Shire-wide ground level information by use of airborne laser scanning (ALS), as Bankstown and Fairfield Councils have recently done. The cost is likely to be in the order of $200,000, and the data could be used for a variety of purposes.

As emphasised by the title of this study, the ranking in **Table 5** must be regarded as *initial* and *subjective*. It is a *guide*, and is not intended to be definitive. However, the notable agreement between the Consultant's estimate of the number of properties exposed to the 100 year and extreme floods (**Table 3**) and Mike Rogers' rating of flood risks (**Table 4**), as well as Mike's concurrence with a draft version of **Table 5** (especially the "top 10"), lends a degree of confidence to this assessment.

A “Sylvania Waters and catchments” Flood Study and Floodplain Management Study/ Plan is regarded as the highest priority in Sutherland Shire. This incorporates the low-lying area of Sylvania Waters itself — which is likely to be seriously flood-affected even in a 1% event (based on tailwater levels and the limited survey data) — as well as the four catchments draining into Sylvania Waters (including Parraweena Rd trunk drain), which rated as high flood risks in their own right.

Kurnell is regarded as second highest priority, reflecting the extensive and frequent nature of flooding there. Third highest priority is a combined “Botany Bay catchments” area, incorporating areas of Taren Point severely flooded in May 2003, and stretching east through Caringbah, Woolooware and Cronulla. Fourth highest priority is Bundeena Creek. Most attention was given to ranking the more significant risks; the exposures towards the end of the list are regarded as minor and, in several cases, negligible.

TABLE 5: PRIORITISED ACTION PLAN FOR FUTURE FLOOD STUDIES AND FLOODPLAIN RISK MANAGEMENT STUDIES/PLANS

Rank	Area	Sub-catchments (SSC numbers)	Number of exposed properties		Scale of study *	Progress (SSC, March 2004)	Comments
			Q100	Q extreme			
1	Sylvania Waters and catchments (including Gwawley Creek and Parraweena Rd trunk drain)	#13, 51, 44, 45, 52, 61**	1547	1690	large	▶61: Some flood studies done by individual developers, with flood notations on S149 certificates ▶No formal flood study for whole catchment	Large area, large exposure.
2	Kurnell township	81/82	776	787	medium	▶No flood study ▶Flood notations attached to S149 certificates for all properties based on past experience	
3	Botany Bay catchments (including Taren Point, Caringbah, Woolooware and Cronulla)	62**/63/64, 65/66, 67/68, 72/73	632	740	large	▶62: Some flood studies done by individual developers, with flood notations on S149 certificates ▶No formal flood study for whole catchment ▶68: Flood notations attached to S149 certificates for properties along Sturt Rd	Modelling implies high exposure. Possibly over-rated.
4	Bundeena Creek	80	175	180	medium	▶Bundeena Ck Flood Management Study, Kinhill Engineers, 1993 ▶Considered 1%, 5% (not PMF) ▶217 properties identified as being likely affected by floods ▶Flood notations attached to S149 certificates and property owners notified	
5	Oyster Creek	35/33/36	86	124	medium-large	▶Oyster Ck FRMC formed ▶Flood Study conducted by Council in 2002/03 considered 1%, 5%, PMF, from Box Rd to 800m d/s Bates Dr culvert ▶51 properties identified under 1% + 500mm ▶19 properties identified under PMF ▶Flood notations attached to S149 certificates and property owners notified ▶Oyster Ck FRMS/FRMP ongoing (from 100m u/s Box Rd to 800m d/s Bates Dr culvert)	

Rank	Area	Sub-catchments (SSC numbers)	Number of exposed properties		Scale of study *	Progress (SSC, March 2004)	Comments
			Q100	Q extreme			
6	Dents Creek (and lower Savilles Ck)	37/38/40, 39	100	178	medium-large	▶Flood Study conducted by Council in 2002 considered 1%, 5%, PMF, from President Ave to confluence with Savilles Ck (including lowermost 300m of Savilles Ck) ▶92 properties identified under 1% + 500mm ▶17 properties identified under PMF ▶Flood notations attached to S149 certificates and property owners notified ▶Flood Study for section of Dents Ck from confluence with Savilles Ck to 1200m d/s (i.e. 800m from mouth of NW Arm) is ongoing (1%, 5%, PMF)	
7	Ewey Creek	46	54	88	medium	▶Flood Study conducted by Council in 2003/04 considered 1%, 5%, PMF, from Manchester Rd to confluence with Yowie Bay ▶100 properties identified under 1% + 500mm ▶90 properties identified under PMF ▶Flood notations attached to S149 certificates and property owners notified ▶Ewey Ck flood mitigation works being investigated	
8	Unnamed Woronora R. tributary (Sutherland/Woronora)	30	58	83	medium		
9	Kareela Creek	#17/41/43, 42	65	93	medium		
10	Carina Creek	6	49	68	medium	▶Land survey undertaken	
11	“Camellia Gardens” Creek	57	31	82	medium		
12	Alcheringa Creek	47	53	80	medium		
13	Unnamed Georges R. tributary (Oyster Bay)	34/83	61	68	small		
14	Unnamed Port Hacking tributaries (Cronulla)	74, 75, 76	27+	54+	medium		
15	Loftus Creek	18, 19, 27, 28, 29, 14	35+	52+	medium		
16	Forbes Creek	20, 17, #8A, 15	19+	85+	medium		

Rank	Area	Sub-catchments (SSC numbers)	Number of exposed properties		Scale of study *	Progress (SSC, March 2004)	Comments
			Q100	Q extreme			
17	Unnamed Georges R. tributary (Como)	5	7	49	small		High number of complaints.
18	Crescent Creek	13	18	25	small		
19	Unnamed Georges R. tributaries (Illawong)	2, 3	22	30	small		
20	Still Creek	7, 8	15	20	medium		
21	Upper Savilles Creek	31, 32	9	34	medium		
22	Unnamed Port Hacking tributaries (Caringbah)	58, 59	24	54	medium		
23	Unnamed Woronora R. tributaries (Bangor/Woronora)	10, 12	22	61	small		
24	Unnamed Port Hacking tributary (Grays Point)	50	3	8	small		
25	Unnamed Port Hacking tributaries (Caringbah/Dolans Bay)	70, 78	10+	20+	small		
26	Unnamed Port Hacking tributary (Yowie Bay)	53	8	17	small		
27	Unnamed Woronora R. tributary (Bangor)	9	9	11	small		
28	Bottle Creek	24, 25	8+	8+	small		
29	Unnamed Port Hacking tributaries (Caringbah/Woolooware)	69, 71	9	25	small-medium		
30	Coonong Creek and unnamed Port Hacking tributary (Gymea Bay)	48, 49	7	10	small-medium		
31	Unnamed Woronora R. tributaries (Engadine/Heathcote)	22, 23	1+	1+	small		
32	Unnamed Woronora R. tributary (Engadine)	16	2	2	small		

Rank	Area	Sub-catchments (SSC numbers)	Number of exposed properties		Scale of study *	Progress (SSC, March 2004)	Comments
			Q100	Q extreme			
33	Unnamed Georges R. tributaries (Sylvania)	54, 55	negligible	negligible	small		
34	Unnamed Port Hacking tributary (Miranda)	56	negligible	7	small		
35	Unnamed Woronora R. tributary (Bonnet Bay)	4	4	16	small		
36	Unnamed Woronora R. tributary (Barden Ridge)	21	negligible	negligible	small		
37	Unnamed Pacific Ocean tributary (Cronulla)	77	negligible	negligible	small		
38	Unnamed Port Hacking tributary (Lilli Pilli)	60	negligible	negligible	small		
39	Unnamed Georges R. tributary (Menai)	1	negligible	negligible	small		
40	Heathcote industrial area	26	negligible	negligible	small		
41	Maianbar	79	negligible	negligible	small		
42	Unnamed Woronora R. tributary (Sutherland/Woronora)	11	negligible	negligible	small		

* A large study may cost in the order of $120,000, a medium study in the order of $60,000, and a small study in the order of $30,000. The total estimated cost for combined flood studies and floodplain management studies/plans is in the order of $2 million.

** Note poorly defined catchment boundary between sub-catchments 61 and 62.

A number of Floodplain Management Committees would need to be established before flood studies began. The number of Committees across the Shire represents a trade-off between adequate representation of distinct communities and maximising efficiencies. One potential model recommends the establishment of up to seven Committees, as outlined in **Table 6**.

TABLE 6: POTENTIAL DISTRIBUTION OF SSC FLOODPLAIN MANAGEMENT COMMITTEES

FLOODPLAIN MANAGEMENT COMMITTEE	AREAS INCLUDED
Menai	Menai, Alfords Point, Illawong, Bangor
Loftus–Yarrawarrah–Engadine–Heathcote	Bottle Creek, Forbes Creek, Loftus Creek etc
Kareela Creek–Oyster Creek–Como–Woronora	All sub-catchments draining into Georges River, west of Sylvania Waters, as well as sub-catchments draining into lower Woronora
Sylvania Waters–Taren Point–Caringbah–Woolooware	All sub-catchments draining into Sylvania Waters and Botany Bay, except Kurnell
Kurnell	Kurnell
Port Hacking catchments	All Port Hacking sub-catchments
Bundeena	Bundeena, Maianbar

A second outcome of this study is a map showing the locations of the sub-catchments and areas subject to inundation from the estimated 100 year and extreme floods. The map is not included in this report, but has been given to Council as a GIS layer and as a hardcopy. As already discussed, the coarse contour data and interpolative methods used to construct this map limit its utility. It may be useful to give a broad picture, but the precision is not sufficient to notify potentially flood-affected residents via Section 149 Certificates. More detailed flood studies are necessary to provide the precision required for such purposes.

6. REFERENCES

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APPENDIX 1

METHOD FOR PRELIMINARY HYDROLOGIC AND HYDRAULIC ANALSIS

APPENDIX 1. METHOD FOR PRELIMINARY HYDROLOGIC AND HYDRAULIC ANALYSES

ESTIMATION OF DISCHARGES USING URBAN RATIONAL METHOD

- Digitise the 82 trunk drainage systems identified by SSC, as well as sub-catchments within these. Sub-catchments are defined by contours and pipe network GIS layers.
- Record catchment areas (A)
- Allocate each sub-catchment to one of Sutherland's two designated Rainfall Zones (see SSC Urban Drainage Design Manual [UDDM] p. 5.8).
- Estimate % catchment covered by different land uses.
- Estimate catchment areas impervious and pervious (UDDM p.5.25, assuming 55% impervious for the detached house land use).
- Apply runoff coefficient (C) values for Zones 1 and 2, for impervious/pervious, for seven ARIs (1, 2, 5, 10, 20, 50, 100) (UDDM p.5.23).
- Calculate CA.
- Calculate time of concentration (t_c)
  - If % impervious >= 0.70, then assume overland flow of 5 minutes, and add measure of channel/pipeflow time = distance measured/velocity (1.5m/s).
  - If % impervious 0.31-0.69, then assume overland flow of 10 minutes, and add measure of channel/pipeflow time = distance measured/velocity (1.5m/s).
  - If % impervious <= 0.30, then $t_c = 0.76A^{0.38}$, where A = area in km^2
- Calculate natural log t_c
- Calculate rainfall intensity (I) for Zones 1 and 2, for seven ARIs (UDDM p.5.19).
- Q = 0.278 CAI
- Extreme flood estimated as 4 times Q100
- No account was taken of pipe capacities

ESTIMATION OF FLOOD EXTENT FOR Q100 AND Q-EXTREME

- Create Digital Elevation Model for Sutherland Shire using 2 m contours and Vertical Mapper.
- Plot cross sections using Vertical Mapper.
- Estimate roughness across cross section using aerial photos (0.05 urban, 0.10 reserve).
- Estimate channel slope through cross section.
- Use open channel flow equation to calculate water levels at cross section for 100 year and extreme floods.
- Use Georges River Floodplain Management Study (Fig 4.5 and 4.6) and Woronora River Flood Study (Fig 11, Table 14 and Fig 6) to determine tailwater levels.
- Adopt 2.01 m AHD (not 1.7 m AHD as in Georges River FMS) as 1% tailwater level for Botany Bay and Georges River upstream to Illawong, since lowest contour in GIS is 2 m AHD, and to incorporate an estimate of local runoff; none of the sub-catchments situated upstream of Como Bridge were affected by this alteration, since there the estimated 1% tailwater levels exceed 2.0 m AHD.
- Adopt Botany Bay tailwater levels for Port Hacking i.e. 2.01 m AHD (1%) and 2.1 m AHD (extreme flood).
- Check water levels for sense and adjust where necessary.
- Add cross sections at top of sub-catchments, assuming water level just higher (~0.1 m) than ground surface.
- Convert cross sections (polylines) to points using Vertical Mapper.
- Use Vertical Mapper to generate Q100 and extreme flood surfaces (Create Grid > Interpolation), then subtract DEM from flood surface to yield flood extent/depth (Grid Manager > Analysis > Calculator), then allocate one colour (Grid Manager > Contour > Intervals).
- Check sense of results and modify flood extent where necessary.
- Use Query (SQL Select) to estimate number of cadastre within each catchment's flood extent – note that cadastre are counted only when centroid of cadastre included (for the "Contains" operator).

APPENDIX 2

RESULTS FOR URBAN RATIONAL METHOD

APPENDIX 2. RESULTS FOR URBAN RATIONAL METHOD

Note: Arranged numerically; # identifies one of designated waterways.

Sub-catchment number	Area (km^2)	Rainfall zone (SSC)	Discharge (cumecs) ARI 1	ARI 2	ARI 5	ARI 10	ARI 20	ARI 50	ARI 100	ARI extreme flood
01	0.1605	2	1.6	2.3	3.2	3.8	4.6	5.8	6.5	26
02A	0.2711	2	2.6	3.5	5.1	6.0	7.3	9.2	10	41
02B	0.5330	2	4.2	5.8	8.3	10	12	15	17	69
03	0.1902	2	1.7	2.3	3.3	3.9	4.8	6.0	6.8	27
04	0.0725	1	0.8	1.1	1.5	1.8	2.2	2.8	3.2	13
05	0.6672	1	5.4	7.5	11	13	16	20	23	92
06A	0.4883	1	4.3	5.9	8.6	10	13	16	18	72
06B	1.3260	1	9.3	13	19	23	28	35	40	160
07A	0.2181	2	1.9	2.7	3.8	4.6	5.5	6.9	7.8	31
07B	0.8466	2	6.0	8.3	12	14	17	22	25	99
08	0.3912	2	3.4	4.7	6.7	8.0	10	12	14	55
09	0.2603	2	2.3	3.2	4.6	5.5	6.7	8.4	9.5	38
10	0.0803	2	0.7	1.0	1.4	1.7	2.1	2.6	3.0	12
11	0.3179	1	1.9	2.6	3.8	4.6	5.6	7.2	8.3	33
12	0.1580	2	1.1	1.5	2.2	2.6	3.2	4.1	4.7	19
13	0.9126	2	4.5	6.2	9.1	11	13	17	19	78
14A	0.2476	2	2.2	3.0	4.3	5.1	6.2	7.8	8.8	35
14B	0.3705	2	2.7	3.7	5.3	6.3	7.7	10	11	44
15	0.0844	2	0.8	1.1	1.6	1.9	2.3	2.9	3.3	13
16	0.2682	2	2.5	3.5	5.0	6.0	7.3	9.1	10	41
17	0.2142	2	2.0	2.7	3.9	4.6	5.6	7.0	7.9	32
18	0.3123	2	2.6	3.6	5.2	6.2	7.6	9.5	11	43
19	0.3741	2	3.1	4.2	6.1	7.3	8.8	11	13	50
20A	0.2706	2	2.3	3.2	4.6	5.4	6.6	8.3	9.3	37
20B	0.6760	2	4.8	6.6	10	11	14	18	20	80
21	0.1401	2	1.3	1.8	2.6	3.1	3.7	4.7	5.3	21
22	0.1895	2	1.8	2.5	3.6	4.2	5.1	6.4	7.2	29
23	0.1441	2	1.3	1.8	2.6	3.1	3.8	4.7	5.4	21
24	0.2602	2	2.2	3.0	4.4	5.2	6.3	7.9	9.0	36
25A	0.5269	2	4.5	6.3	9.0	10.7	13	16	18	74
25B	0.7181	2	5.3	7.3	11	13	15	19	22	87
26	0.0620	2	1.0	1.3	1.9	2.2	2.7	3.3	3.7	15
27A	0.2739	2	2.5	3.5	5.0	5.9	7.2	9.0	10	41
27B	0.5954	2	4.2	5.9	8.5	10	12	16	18	71
28	0.1350	1	1.0	1.4	2.1	2.5	3.1	3.9	4.5	18
29A	0.7221	1	6.4	8.8	13	15	19	24	27	107
29B	1.0820	1	7.4	10	15	18	22	28	32	129
30A	0.4348	1	2.7	3.7	5.5	6.6	8.1	10	12	47
30B	0.3899	1	4.1	5.6	8.2	10	12	15	17	67
30C	1.0380	1	7.7	11	16	19	23	29	33	133
31	1.6800	1	7.6	11	16	19	23	30	34	137
32	0.4008	1	3.8	5.3	7.7	9.3	11	14	16	64
33A	0.4070	1	3.6	4.9	7.2	8.6	11	13	15	60
33B	1.0760	1	7.7	11	16	19	23	29	33	133
33&36	2.0170	1	15	20	30	36	44	56	63	251

Sub-catchment number	Area (km^2)	Rainfall zone (SSC)	Discharge (cumecs) ARI 1	ARI 2	ARI 5	ARI 10	ARI 20	ARI 50	ARI 100	ARI extreme flood
34	0.1195	1	1.2	1.7	2.4	2.9	3.5	4.4	5.0	20
35	2.6020	1	16	22	33	40	49	62	70	281
36Z	0.1409	1	1.9	2.6	3.8	4.4	5.4	6.7	7.5	30
36A	0.4966	1	5.3	7.3	11	13	15	19	22	86
36B	0.9401	1	6.9	10	14	17	21	26	30	119
37A	0.2365	1	2.2	3.0	4.4	5.3	6.4	8.1	9.2	37
37B	0.6210	1	4.8	6.6	10	12	14	18	20	81
38Z	0.1813	1	2.4	3.3	4.8	5.7	7.0	8.6	10	38
38A	0.4919	1	4.6	6.4	9.4	11	14	17	19	77
38B	1.1200	1	8.3	12	17	20	25	32	36	142
38C	2.3180	1	14	20	29	35	43	55	62	247
38D	8.5330	1	30	42	61	74	91	117	133	533
39	6.1540	1	20	28	41	50	61	79	91	364
40B	0.4622	1	4.2	5.9	8.6	10	13	16	18	71
40A	0.2379	1	3.0	4.2	6.0	7.1	8.7	11	12	48
41A	0.2748	1	3.8	5.3	7.6	9.1	11	14	15	61
41B	0.5522	1	6.4	8.8	13	15	19	23	26	104
42	0.2194	1	2.1	2.9	4.2	5.1	6.2	7.8	8.8	35
43A	0.1180	1	1.2	1.7	2.4	2.9	3.6	4.5	5.0	20
43B	0.7009	1	5.0	6.9	10	12	15	19	22	86
44A	0.2680	1	2.4	3.3	4.9	5.8	7.1	9.0	10	40
44B	0.4790	1	3.8	5.3	7.8	9.3	11	14	16	65
44C	0.7543	1	5.5	7.7	11	14	17	21	24	95
45A	0.9707	1	7.4	10	15	18	22	28	32	127
45B	2.3500	1	14	19	29	35	42	54	61	244
45Z	0.2399	1	2.3	3.1	4.5	5.4	6.6	8.3	9.4	38
46A	0.5519	1	6.2	8.6	13	15	18	23	25	101
46B	1.2850	1	10	13	20	24	29	37	42	166
46C	1.7800	1	12	17	24	29	36	46	52	206
47A	0.2544	1	2.5	3.4	4.9	5.9	7.2	9.0	10	41
47B	0.8026	1	6.3	8.8	13	15	19	24	27	108
48A	0.1436	1	1.6	2.2	3.1	3.7	4.5	5.7	6.4	26
48B	0.5117	1	4.4	6.0	8.8	11	13	16	18	74
49A	0.1568	1	1.6	2.2	3.3	3.9	4.7	5.9	6.7	27
49B	0.3673	1	3.5	4.8	6.9	8.3	10	13	14	58
50	0.5334	1	3.2	4.4	6.5	7.8	10	12	14	56
51	0.0963	1	1.0	1.3	1.9	2.3	2.8	3.6	4.0	16
52A	0.4124	1	3.2	4.5	6.5	7.9	10	12	14	55
52B	0.6845	1	6.3	8.6	13	15	18	23	26	105
52C	2.0470	1	13	18	27	32	40	51	57	230
53	0.2540	1	2.5	3.4	4.9	5.9	7.2	9.0	10	41
54	0.0135	1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	2.5
55	0.0400	1	0.4	0.6	0.9	1.0	1.3	1.6	1.8	7.2
56	0.1613	1	1.6	2.2	3.2	3.9	4.7	5.9	6.7	27
57Z	0.1979	1	2.7	3.7	5.3	6.3	7.7	10	11	43
57A	0.3493	1	3.8	5.2	7.5	9.0	11	14	15	61
57B	0.9443	1	7.7	11	16	19	23	29	32	130
58A	0.1247	1	1.2	1.7	2.5	3.0	3.6	4.5	5.1	20

Sub-catchment number	Area (km^2)	Rainfall zone (SSC)	Discharge (cumecs) ARI 1	ARI 2	ARI 5	ARI 10	ARI 20	ARI 50	ARI 100	ARI extreme flood
58B	0.4147	1	3.5	4.8	7.0	8.4	10	13	15	59
59A	0.3399	1	3.3	4.5	6.5	7.8	9.5	12	14	54
59B	0.8236	1	6.6	9.2	13	16	20	25	28	113
60	0.0758	1	0.8	1.1	1.5	1.8	2.2	2.8	3.2	13
61A	0.9214	1	7.1	10	14	17	21	27	30	121
61B	1.8300	1	12	17	25	30	37	47	54	214
62	0.4330	1	5.0	6.9	10	12	15	18	20	81
63	0.0118	1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	2.2
64	0.0541	1	0.9	1.2	1.7	2.0	2.4	3.0	3.3	13
65	0.3958	1	4.3	6.0	8.7	10	13	16	18	71
66A	0.4061	1	3.6	5.0	7.3	8.7	11	13	15	60
66B	0.3379	1	3.0	4.2	6.2	7.4	9.0	11	13	51
66C	1.1700	1	8.9	12	18	22	27	34	38	152
67	0.1435	1	1.3	1.8	2.5	3.0	3.7	4.7	5.3	21
68A	0.3727	1	3.6	5.0	7.2	8.6	11	13	15	60
68B	1.3620	1	10	14	21	25	30	38	43	173
68C	0.3747	1	3.6	4.9	7.1	8.5	10	13	15	59
68D	2.2880	1	14	20	30	36	44	56	63	252
69A	0.1357	1	1.4	1.9	2.7	3.3	4.0	5.0	5.6	23
69B	0.3759	1	3.2	4.4	6.4	7.7	9.4	12	14	54
70A	0.1425	1	1.5	2.1	3.0	3.6	4.3	5.5	6.2	25
70B	0.4646	1	4.3	5.9	8.6	10	13	16	18	71
71A	0.1242	1	1.4	1.9	2.7	3.3	4.0	5.0	5.6	22
71B	0.1851	1	1.9	2.6	3.7	4.4	5.4	6.8	7.7	31
72A	0.4479	1	4.7	6.5	10	11	14	17	19	78
72B	0.8823	1	6.2	8.6	13	15	19	24	27	107
73	0.3013	1	2.6	3.6	5.2	6.2	7.6	10	11	44
74A	0.0690	1	0.8	1.1	1.6	1.9	2.3	2.8	3.2	13
74B	0.2527	1	2.4	3.4	4.9	5.9	7.1	9.0	10	41
75A	0.1174	1	1.3	1.7	2.5	3.0	3.7	4.6	5.2	21
75B	0.5596	1	5.8	8.0	12	14	17	21	24	96
76	0.0386	1	0.6	0.9	1.2	1.5	1.8	2.2	2.4	10
77	0.2120	1	2.2	3.0	4.4	5.2	6.3	8.0	9.0	36
78	0.1194	1	1.2	1.7	2.5	2.9	3.6	4.5	5.1	20
79	0.0228	1	0.3	0.4	0.5	0.6	0.8	1.0	1.1	4.4
80A	0.8228	1	4.3	5.9	8.7	10.5	13	17	19	76
80B	2.6300	1	10	14	21	25	31	40	46	184
81	0.1657	1	1.3	1.7	2.5	3.0	3.7	4.7	5.4	21
82	0.6981	1	5.0	6.9	10	12	15	19	21	86
83 (near 34)	0.3056	1	2.8	3.9	5.6	6.7	8.2	10	12	47
85 (Mill Creek)	21.8200	2	46	64	93	112	137	176	206	823
#6A (Loftus Creek)	2.1350	2	11	16	23	27	34	42	49	194
#6B (Loftus Creek)	5.7530	1	26	36	53	64	79	101	115	461
#7 (Bottle Creek)	1.2180	2	7.7	11	16	19	23	29	32	130
#8A (Forbes Creek)	1.5130	2	8.7	12	18	21	26	32	37	147

Sub-catchment number	Area (km^2)	Rainfall zone (SSC)	Discharge (cumecs) ARI 1	ARI 2	ARI 5	ARI 10	ARI 20	ARI 50	ARI 100	ARI extreme flood
#8B (Forbes Creek)	3.1720	2	12	17	25	30	37	46	53	213
#8C (Forbes Creek)	9.9350	1	38	53	78	94	116	149	169	678
#11 (Still Creek)	5.1390	1	23	32	48	58	71	91	103	412
#13 (Sylvania Waters local area)	1.1860	1	10	14	21	25	31	39	44	176
#17 (Kareela Creek)	1.9500	1	13	18	26	32	39	49	56	224