Environment
Engineering
Software

SCOTLAND ISLAND WASTEWATER IMPACT STUDY:
Scotland Island, Sydney, NSW

Impact Assessment of Water and Wastewater on Environmental Quality and Public Health

STAGE 1: Report 96/019A

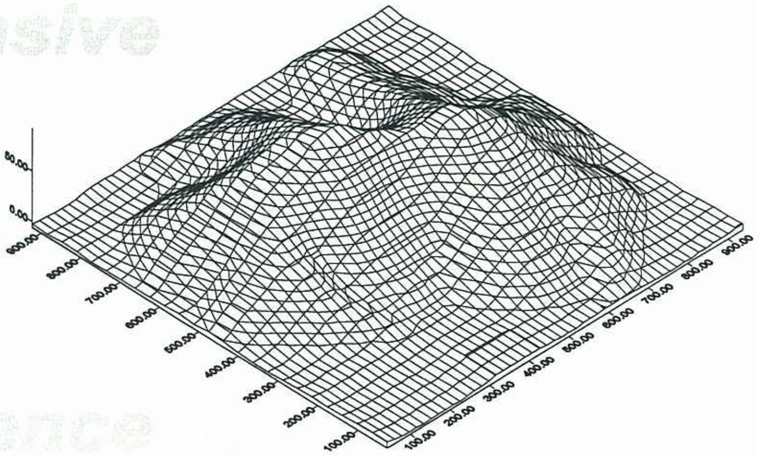

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Table 19: Summary data for Scotland Island soil CEC. Classification ratings are taken from Metson (1961).

Unit	A	Classification	B	Classification
CEC (cmol(+)/kg)				
Ridge	3.25	Very low	4.80	Very low
Slope	3.17	Very low	5.50	Very low
Swale (not 11)	4.91	Very low	4.01	Very low
Hawkesbury Group Average	3.00	Very low	3.35	Very low
Narrabeen Group Average	3.97	Very low	5.25	Very low
Average	3.69	Very low	4.77	Very low
Standard deviation	1.62	-	1.41	-

Exchangeable Calcium to exchangeable Magnesium ratios average 0.8 for A horizons and 0.1 for B horizons, indicating general Calcium deficiency (Eckert, 1987) and soils which (notably the B horizons) which are potentially dispersive (NSW Agriculture and Fisheries, 1989).

Geological influences on cation content are illustrated in Figure 11 which shows A and B horizon Magnesium content across the Island as interpolated with the GIS. The boundary of the Hawkesbury sandstone unit is clearly defined by lower Magnesium levels in soil B horizons.

Some non-geologic related spatial variations were also observed to occur on the Island. For example, Figure 12 showing Sodium levels in both A and B horizons [following GIS interpolation methods], indicates higher concentrations in A horizons in the NE corner, decreasing towards the SW. This is probably associated with salt laden northeasterly sea breezes providing sodium to the more exposed NE side of the Island. B horizon variations show the reverse, with the N-NE side of the Island having slightly lower Sodium concentration.

6.1.7 Sodicity

Sodicity is the level of exchangeable Sodium cations in the soil. It relates to likely dispersion on wetting and shrink/swell properties. Sodic soils can have the following problems:

1. very severe surface crusting;
2. very low infiltration and hydraulic conductivity;
3. very hard, dense subsoils;
4. high susceptibility to severe gully erosion; and
5. high susceptibility to tunnel erosion.

Sodicity is determined using the exchangeable sodium percentage (ESP%) which is the amount of exchangeable sodium as a percentage of the CEC (Equation 6).

$$ESP\% = \frac{Na(exchangeable)}{CEC} \times 100 \qquad \textbf{Eq.6}$$

where; *ESP%*= Exchangeable Sodium %
Na = Sodium (cmol(+)/kg)
CEC =Cation Exchange Capacity (cmol(+)/kg)

At most sites, ESP% measurements indicated non-sodic to marginally sodic A horizons with marginally sodic to highly sodic B horizons (Table 20). A horizon sodicity was somewhat higher in the Hawkesbury group but still only marginally sodic.

Table 20: Summary data for Scotland Island soil exchangeable sodium percentage (ESP%). Classification ratings for NSW are taken from Pope and Abbott (1989).

Unit	A	Classification	B	Classification
ESP %				
Ridge	6.1	marginally	9.5	marginally
Slope	8.5	marginally	11.2	Highly sodic
Swale (not 11)	5.2	marginally	17.0	Highly sodic
Hawkesbury Group Average	9.2	marginally	12.1	Highly sodic
Narrabeen Group Average	5.7	marginally	12.7	Highly sodic
Average	6.7	marginally	12.6	Highly sodic
Standard deviation	3.4	-	5.9	-

6.1.8 Nutrient Status

6.1.8.1 Nitrogen

Nitrogen occurs in soils in several forms. However, generally nitrogen has to be in a mineralised form, either nitrate (NO_3^-) or ammonium (NH_4^+), to be readily available to plants. Total nitrogen measures the total amount of nitrogen present in the soil, much of which is not immediately available to plants by may be mineralised to available forms. Both soil total nitrogen and nitrate (NO3-N) are given in Table 21 which indicates low nutrient status for the majority of sites.

The interpretation of nitrate (NO3-N) levels is determined by: antecedent soil moisture conditions; time of sampling; and depth over which the sample was taken. For these reasons, interpretation of soil NO3-N levels requires localised agronomic knowledge

(Hazelton and Murphy, 1992). However, at most sites, soil NO3-N was extremely low, ranging between 2.5 - 5.0 mg/kg, and indicating general deficiency and low nutrient status of the Island's native soils. Notably, site 8 (in Catherine Park), NO3-N concentration reached 13.5 mg/kg, suggesting the possibility of contamination with urban runoff. A horizons contained slightly higher levels, these being highest in the Narrabeen group.

Total nitrogen (as %) levels were also generally low to medium at most sites, ranging between 0.07 - 0.17 % and decreasing with depth. B horizons typically contained levels 50 % of the A.

Carbon to nitrogen ratios for most sites are medium and range between 10 - 15, indicating normal rates of decomposition.

Table 21: Summary data for Scotland Island soil nitrate (NO3-N) and total nitrogen content. Classification ratings are taken from Bruce and Rayment (1982).

Unit	A	Classification	B	Classification
NO3-N (mg/kg)				
Ridge	2.5	Deficient	2.5	Deficient
Slope	3.8	Deficient	2.5	Deficient
Swale	5.3	Deficient	2.5	Deficient
Hawkesbury Group Average	2.5	Deficient	2.5	Deficient
Narrabeen Group Average	4.3	Deficient	2.5	Deficient
Average	3.8	Deficient	2.5	Deficient
Standard deviation	3.0	-	0.0	-
TN (%)				
Ridge	0.17	Medium	0.08	Low
Slope	0.09	Low	0.08	Low
Swale	0.17	Medium	0.07	Low
Hawkesbury Group Average	0.12	Low	0.07	Low
Narrabeen Group Average	0.15	Low	0.07	Low
Average	0.14	Low	0.07	Low
Standard deviation	0.07	-	0.02	-

6.1.8.2 Phosphorus

Phosphorus is an essential plant macro nutrient. However, excessive amounts can lead to toxic levels, particularly for many Australian native species that have evolved in nutrient poor soils (Ozanne and Specht, 1981). Soil sampling indicated that the majority of the Islands soils maintain very low levels of Bray-phosphate in both A and B horizons (Table 22).

Table 22: Summary data for Scotland Island soil Bray-phosphate (Bray-P, mg/kg).

Unit	A	Classification	B	Classification
Bray-P (mg/kg)				
Ridge	6.6	Low	4.3	Very low
Slope	3.0	Very low	4.0	Very low
Swale (not 11)	3.0	Very low	3.0	Very low
Hawkesbury Group Average	3.5	Very low	4.3	Very low
Narrabeen Group Average	4.6	Very low	3.6	Very low
Average	4.3	Very low	3.8	Very low
Standard deviation	4.3	-	0.6	-

6.1.9 P-sorption Capacity

The P-sorption index provides a relative measure of the capacity of a soil to absorb phosphorus and is calculated by Equation 7. Phosphorus sorption (P-sorption) capacity of the Island's soils varies markedly between horizons (Table 23). Typically, A horizons have low to medium P-sorption ratings while B horizons vary between high and very high. However, the effectiveness of B horizon sorptive capacity is much reduced because of extremely low permeabilities.

$$P_I = \ln\left(\frac{Q-x}{x} \times \frac{v}{m}\right) \qquad \textbf{Eq. 7}$$

where P_I = P-sorption index
Q = initial concentration (mg/L)
x = final concentration (mg/L)
v = volume of liquid used for test (ml)
m = mass of soil used for test (g)

Equation 7 can be re-written to provide a crude estimate of the mass of phosphorus potentially sorbed per mass of soil (in mg/kg). This is not a definitive value but serves only to provide a conservative indication of the amount of phosphorus sorption per unit weight of soil (Tables 23 and 24). Calculations indicate that the Narrabeen group can potentially adsorb marginally higher amounts of phosphorus than the Hawkesbury group.

Table 23: P-sorption soil survey results. Ratings from Hazelton & Murphy, (1992).

Site	A Horizon			B Horizon		
	Units	Rating	Mass (mg/kg)	Units	Rating	Mass (mg/kg)
1	1.35	Very low	40.1	-	-	-
2	4.10	Medium	186.3	4.34	Medium	196.7
3	6.38	High	239.9	7.18	Very high	244.3
4	3.66	Low	163.7	7.41	Very high	245.0
5	-	-	-	-	-	-
6	6.12	High	237.6	-	-	-
7	3.37	Low	146.9	6.38	Very high	239.9
8	5.92	High	235.4	7.00	Very high	243.6
9	3.75	Medium	168.7	6.12	Very high	237.6
10	4.29	Medium	194.6	7.18	Very high	244.3
11	2.58	Very low	98.6	5.64	High	231.5
12	2.79	Low	111.3	7.70	Very high	245.8
13	3.14	Low	132.9	7.18	Very high	244.3
14	3.01	Low	124.9	6.70	Very high	242.0
15	4.51	Med-high	203.3	5.58	High	230.6

Table 24: Scotland Island summary P-sorption data.

Unit	A Horizon			B Horizon		
	Units	Rating	Mass (mg/kg)	Units	Rating	Mass (mg/kg)
Ridge	3.78	Medium	155.2	6.92	Very high	242.6
Slope	4.22	Medium	179.8	5.75	High	227.3
Swale	3.74	Medium	152.2	6.94	Very high	241.5
Hawkesbury group	3.87	Medium	157.5	6.31	Very high	228.7
Narrabeen group	3.95	Medium	165.4	6.61	Very high	239.9
Island Average	3.93	Medium	163.2	6.53	Very high	237.1
Std. Deviation	1.44	-	58.5	0.97	-	13.7

6.2 Storm Event Rainfall Data

A random sample of yearly rainfall records (15 years) from Newport bowling club were utilised to calculate the probability of exceedence for daily rainfall events. Exponential trend lines were fitted to the probability data and the resulting equations used to assess the degree of representation of the sample events. The cumulative daily rainfall recorded for each sample event is presented in Table 25.

Table 25: Cumulative rainfall (mm) recorded on Scotland Island during storm runoff sampling.

Time (hrs)	Event 1 21-10-95 (mm)	Time (hrs)	Event 2 28/10/95 (mm)	Time (hrs)	Event 3 18-20/11/95 (mm)	Time (hrs)	Event 4 5/12/95 (mm)	Time (hrs)	Event 5 10/12/95 (mm)
0	0	0	0	0	0	0	0	0	0
0.25	1.0	0.25	8.0	0.08	16.0	1.92	4.4	1.0	2
0.5	1.7	0.5	9.5	0.16	22.0	2.75	6.0	10.0	6
1.0	5.5			1.0	22.0	13.05	34.0	10.75	11.0
1.5	7.0			22.3	31.0				
2.0	8.5			37.4	55.0				
2.5	8.9								
3.0	9.0								
24 hour intensity			9.5		31		34		11

Mean 24 hour rainfall intensity varied between each storm. The first two events sampled were of relatively short duration but of significant intensity to create surface runoff and enable water sample collection from the sample catchments streams. Event 3 spanned 37.4 hours over three days (18 - 20/11/95). However, the initial 31 mm of the 55 mm total fell in the first 22.3 hours, and this figure was therefore taken as the mean 24 hour rainfall intensity.

Event 4 provided the highest 24 hour rain intensity with 34 mm being recorded in little over half a day. Rainfall intensity also varied considerably within each storm. For example, in Event 5 the majority of rainfall fell at the end of the storm while in Event 2 almost all the rainfall fell within the first 15 min. The low number of events, low number of samples and the non-uniform monitoring intervals imposed on the study preclude detailed analysis of contaminant transport during storms of various character.

The 24 hour rainfall recorded for each of the 5 sample events was substituted into the probability of exceedence equation calculated for each month of the year to indicate the range of probabilities that the sample events represent over the course of a calender year.

Table 26: Approximate annual recurrence intervals of sample storms for each calendar month. (Based on random sample of n = 15 years rainfall records from Newport Bowling Club 1931 - 1993) *(2.5 = 1 in 2.5 yr event)*. Shaded cells represent actual sampling events.

Month	Equation y=prob. x=Cum. Rain.	Event 1 9mm/day	Event 2 9.5mm/day	Event 3 31mm/day	Event 4 34mm/day	Event 5 11mm/day
Jan	$y = 61.464e^{-0.0453x}$ R2 = 0.7691	2.5	2.5	6.6	7.6	2.7
Feb	$y = 80.664e^{-0.0629x}$ R2 = 0.9873	2.2	2.3	8.7	10.5	2.5
Mar	$y = 55.694e^{-0.0277x}$ R2 = 0.7414	2.3	2.3	4.2	4.6	2.4
Apr	$y = 76.056e^{-0.0535x}$ R2 = 0.9628	2.1	2.2	6.9	8.1	2.4
May	$y = 77.487e^{-0.0588x}$ R2 = 0.9461	2.2	2.3	8.0	9.5	2.5
Jun	$y = 74.991e^{-0.0676x}$ R2 = 0.9648	2.5	2.5	10.8	13.3	2.8
Jul	$y = 48.871e^{-0.0325x}$ R2 = 0.5438	2.7	2.8	5.6	6.2	2.9
Aug	$y = 68.573e^{-0.0503x}$ R2 = 0.9091	2.3	2.4	6.9	8.1	2.5
Sep	$y = 70.847e^{-0.1121x}$ R2 = 0.8401	3.8	4.1	45.0	63.8	4.8
Oct	$y = 60.549e^{-0.0488x}$ R2 = 0.8027	2.6 Event 1	2.6 Event 2	7.5	8.7	2.8
Nov	$y = 63.85e^{-0.0497x}$ R2 = 0.859	2.4	2.5	7.3 Event 3	8.4	2.7
Dec	$y = 82.899e^{-0.0803x}$ R2 = 0.9814	2.4	2.6	14.5	18.5 Event 4	2.9 Event 5

The sample events are considered to adequately represent rainfall events with recurrence intervals of between 2 (median) and 10 years. Two significantly smaller probability figures were obtained for sample events 3 & 4 for the month of September when compared to probabilities obtained for the same events over the other 11 months of the year. This is a function of low rainfall during September in the randomly selected sample set of years used to calculate the equations.

6.3 Surface-Water Quality

6.3.1 Stream-Water Sampling

6.3.1.1 Concentration Data

Five storms were sampled during October and December 1995 as detailed in section 5.3. The following tables show the water quality results for each of the three sample catchments over a range of parameters.

Mean concentrations of the A and B samples were calculated to approximate the load generated in each event. This mean value represents the best estimate of the average storm concentrations possible with the limited number of samples available to the study.

Generally pollution concentrations are greatest at the start of an event and decrease exponentially with time (Martens, 1996). The A and B samples from Scotland Island do not uniformly demonstrate this trend, especially in the Catherine Park catchment where all the B samples contaminant concentrations exceed those of the A sample. This indicates that the A samples were not always taken in coincidence with the peak pollution discharge. Therefore, load estimates should be interpreted as approximate figures.

The C samples taken towards the end of the storm events generally display lower faecal coliform levels but similar levels of other parameters.

Table 27: Water quality results from storm runoff samples, Scotland Island.

A. CATHERINE PARK CATCHMENT

Catherine Park	Sample Number	pH	EC	Turbidity	TN	TP	SS	Filt. NOx	NH3-n	F. Coliform	Enterococci
			µs/cm	600=0 ffscale	mg/l	mg/l	mg/l	mg/l	mg/l	CFU/100 ml	CFU/100ml
Storm 1	SI UN 1a	5.61	205	600	3.61	0.93	11700	1.06	0.05	9000	20000
	SI UN 1b	5.71	238	600	4.06	0.152	1510	1.6	0.03	7700	3200
	mean a&b	**5.66**	**221.5**	**600**	**3.835**	**0.541**	**6605**	**1.33**	**0.04**	**8350**	**11600**
Storm 2	SI UN 2a	5.33	62	122	4.28	0.15	28900	1.9	0.05	5500	18000
	SI UN 2b	6.59	624	600	8.18	0.098	3180	6.22	0.04	28000	43000
	mean a&b	**5.96**	**343**	**361**	**6.23**	**0.124**	**16040**	**4.06**	**0.045**	**16750**	**30500**
Storm 3	*SI UN 3c*	*6.39*	*169*	*690*	*5.11*	*0.143*	*448*	*1.82*	*0.02*	*13000*	*20000*
	SI UN 3b	6.28	171	1590	5.44	0.233	816	1.57	0.02	84000	39000
	SI UN 3a	5.51	78	33200	4.26	0.218	24600	1.17	0.08	20000	15000
	SI UN 3(D) 23/11	-	-	-	*3.52*	*0.101*	*222*	*1.6*	*0.02*	*4500*	-
	mean a&b	**5.90**	**125**	**17395**	**4.9**	**0.2**	**12708**	**1.4**	**0.1**	**52000**	**27000**
Storm 4	SI UN 4b	-	-	-	6.38	0.252	3330	1.89	0.02	63000	120000
	SI UN 4c	-	-	-	5.24	0.212	206	1.65	0.02	17000	140000
	SI UN 4a	-	-	-	6.14	0.286	172	0.04	0.96	4500	70000
	mean a&b	**-**	**-**	**-**	**5.92**	**0.25**	**1236**	**1.19**	**0.33**	**28167**	**110000**
Storm 5	SI UN 5a	5.9	146	6100	8	0.194	11600	4.02	0.03	31000	100000
	SI UN 5b	6.3	143	2680	3.08	0.123	2440	0.87	0.04	100000	90000
	mean a&b	**6.1**	**145**	**4390**	**5.54**	**0.1585**	**7020**	**2.445**	**0.035**	**65500**	**95000**

Table 27 continued.

B. RICHARD ROAD CATCHMENT

Richard Rd	Sample Number	pH	EC	Turbidity	TN	TP	SS	Filt. NOx	NH3-n	F. Coliform	Enterococci
			µS/cm	600=0 ffscale	mg/l	mg/l	mg/l	mg/l	mg/l	CFU/100 ml	CFU/100ml
Storm 1	SI US 1a	6.16	472	600	6.2	1.2	2400	3.01	0.15	170000	130000
	SI US 1b	6.11	421	600	4.8	1.04	1130	1.57	0.05	110000	53000
	mean a&b	**6.14**	**447**	**600**	**5.50**	**1.12**	**1765**	**2.29**	**0.10**	**140000**	**91500**
Storm 2	SI US 2a	6.17	217	600	3.78	0.107	2060	1.31	0.04	170000	45000
	SI US 2b	6.64	295	600	3.51	0.129	1470	0.84	0.03	100000	21000
	mean a&b	**6.41**	**256**	**600**	**3.645**	**0.118**	**1765**	**1.08**	**0.04**	**135000**	**33000**
Storm 3	SI US 3-6 (3a)	6.33	273	1220	5.38	0.139	528	1.51	0.2	45000	38000
	SI US 3-9 (3b)	5.42	126	12600	3.49	0.249	10400	0.64	0.4	34000	19000
*	*SI US 3a (rd,19/11)*	*4.86*	*184*	*7700*	*3.07*	*0.097*	*3880*	*0.48*	*0.07*	*150000*	*15000*
*	*SI US 3 23/11*	-	-	-	*6.22*	*0.058*	*28*	*5.59*	*0.03*	*1600*	
	mean a&b	-	-	-	**4.435**	**0.194**	**5464**	**1.075**	**0.3**	**39500**	**28500**
Storm 4	SI US 4c (+4-3)	-	-	-	4.66	0.198	88	1.36	0.11	28000	73000
Storm 5	SI US 5a	6.3	159	2180	2.51	0.148	444	0.52	0.02	160000	70000
	SI US 5b	6.7	210	1220	3.75	0.152	782	0.82	0.02	220000	160000
	mean a&b	**6.5**	**210**	**1700**	**3.13**	**0.15**	**613**	**0.67**	**0.02**	**190000**	**115000**

C. HAROLD RESERVE CATCHMENT

Harold Reserve	Sample Number	pH	EC	Turbidity	TN	TP	SS	Filt. NOx	NH3-n	F. Coliform	Enterococci
			µS/cm	600=0 ffscale	mg/l	mg/l	mg/l	mg/l	mg/l	CFU/100 ml	CFU/100ml
Storm 1	SI BS 1a	6.45	493	600	2.36	0.78	904	0.26	0.04	110000	16000
	SI BS 1b	6.97	546	600	1.75	0.144	1490	0.08	0.04	75000	48000
	mean a&b	**6.71**	**520**	**600**	**2.055**	**0.462**	**1197**	**0.17**	**0.04**	**92500**	**32000**
Storm 2	SI BS 2a	5.55	188	600	2.13	0.102	4470	0.21	0.05	90000	24000
	SI BS 2b	6.92	236	600	1.77	0.064	1500	0.23	0.04	39000	20000
	mean a&b	**6.235**	**212**	**600**	**1.95**	**0.083**	**2985**	**0.22**	**0.045**	**64500**	**22000**
Storm 3	SI BS 3a	6.05	102	11400	2.24	0.135	7350	0.11	0.04	59000	17000
	SI BS 3b	6.23	168	2550	1.85	0.096	1050	0.16	0.04	51000	16000
*	*SI BS 3 23/11*				*1.63*	*0.044*	*18*	*0.4*	*0.01*	*600*	
	mean a&b	**6.14**	**135**	**6975**	**2.045**	**0.1155**	**4200**	**0.135**	**0.04**	**55000**	**16500**
Storm 4	SI BS 4a	-	-	-	5.32	0.54	3430	0.05	0.02	120000	540000
	SI BS 4b	-	-	-	2.02	0.192	1230	0.04	0.02	250000	140000
*	*SI BS patilda 4a*	-	-	-	*2.12*	*0.182*	*846*	*0.06*	*0.02*	*80000*	*90000*
	mean a&b	-	-	-	**3.67**	**0.366**	**2330**	**0.045**	**0.02**	**185000**	**340000**
Storm 5	SI BS 5a	6.7	157	1620	1.47	0.092	2040	0.5	0.01	670000	600000
	SI BS 5b	6.7	209	820	1.38	0.077	516	0.04	0.02	35000	85000
*	*SI BS patilda 5a*	*6.3*	*159*	*1320*	*1.73*	*0.114*	*1560*	*0.03*	*0.02*	*650000*	*300000*
*	*SI BS patilda 5b*	*6.2*	*329*	*760*	*1.45*	*0.101*	*1020*	*0.03*	*0.02*	*460000*	*220000*
	mean a&b	**6.7**	**183**	**1220**	**1.425**	**0.0845**	**1278**	**0.27**	**0.015**	**352500**	**342500**
	mean Pat a&b	***6.25***	***244***	***1040***	***1.59***	***0.1075***	***1290***	***0.03***	***0.02***	***555000***	***260000***

These results show that storm generated surface runoff on Scotland Island is generally of extremely poor quality. Nutrient levels are relatively high [including both phosphorus and nitrogen] in all storms and Faecal Coliform levels recorded are extreme and pose a significant health concern. Results are discussed further in section 7.4.

The Harold Reserve samples were intended to provide some indication of Island background water quality due to the lower housing density of the catchment. However, concentrations from Harold Reserve were also of poor quality indicating contamination with urban runoff and wastewater from on-site systems. This is associated with the importation of surface water to the catchment via road drainage infrastructure. Three samples were collected from Patilda Park catchment though these were also found to also be contaminated to levels far above possible background.

A small amount of dry weather flow was observed in the main drainage line of the southern urban catchment and can be attributed to emergence of wastewater from saturated wastewater disposal areas.

6.3.1.2 Contaminant Load and Generation Rates

Contaminant loads generated in surface runoff in each catchment were calculated (Table 28) using a range of runoff volumes estimated from a range of annual rainfall probabilities and runoff coefficients. Annual rainfalls were determined from those calculated by probability analysis of data from Newport in section 4. Runoff coefficients were estimated for the Island based on calculations made for open forest on moderate to steep slopes.

Table 28: Contaminant loads generated in surface runoff, Scotland Island. (Rainfall data, n = 62 years, Newport, Sydney)

Runoff Co-efficient = 0.20

			Runoff (ML) based on Annual Rainfall Ranges				
			mean	50%	20%	10%	2%
Catchment Identifier	**Catchment Area (ha)**	**Coverage %**	**1225**	**893**	**2007**	**2849**	**4808**
1 (Catherine Park)	8.975	16.4	21.99	16.03	36.03	51.14	86.30
2	1.535	2.8	3.76	2.74	6.16	8.75	14.76
3	5.5475	10.2	13.59	9.91	22.27	31.61	53.34
4	1.48	2.7	3.63	2.64	5.94	8.43	14.23
5	3.4475	6.3	8.45	6.16	13.84	19.64	33.15
6	2.5475	4.6	6.24	4.55	10.23	14.52	24.50
7	4.6125	8.4	11.30	8.24	18.51	26.28	44.35
8 (Richard Rd)	7.1575	13.1	17.54	12.78	28.73	40.78	68.83
9 (Harold Reserve)	4.99	9.1	12.23	8.91	20.03	28.43	47.98
10	2.57	4.8	6.30	4.59	10.32	14.64	24.71
11	3.265	5.9	8.00	5.83	13.11	18.60	31.40
12	1.54	2.8	3.77	2.75	6.18	8.77	14.81
13 (Patilda Reserve)	4.315	7.9	10.57	7.71	17.32	24.59	41.49
14	2.15	3.9	5.27	3.84	8.63	12.25	20.67
15	0.58	1.1	1.42	1.04	2.33	3.30	5.58
Total	54.7125	100	134.05	97.72	219.62	311.75	526.12

Table 28 continued.

Runoff Co-efficient = 0.25

			Runoff (ML) based on Annual Rainfall Ranges				
			mean	50%	20%	10%	2%
Catchment Identifier	Catchment Area (ha)	Coverage %	1225	893	2007	2849	4808
1 (Catherine Park)	8.975	16.4	27.49	20.04	45.03	63.92	107.88
2	1.535	2.8	4.70	3.43	7.70	10.93	18.45
3	5.5475	10.2	16.99	12.38	27.83	39.51	66.68
4	1.48	2.7	4.53	3.30	7.43	10.54	17.79
5	3.4475	6.3	10.56	7.70	17.30	24.55	41.44
6	2.5475	4.6	7.80	5.69	12.78	18.14	30.62
7	4.6125	8.4	14.13	10.30	23.14	32.85	55.44
8 (Richard Rd)	7.1575	13.1	21.92	15.98	35.91	50.98	86.03
9 (Harold Reserve)	4.99	9.1	15.28	11.14	25.04	35.54	59.98
10	2.57	4.8	7.87	5.74	12.89	18.30	30.89
11	3.265	5.9	10.00	7.29	16.38	23.25	39.25
12	1.54	2.8	4.72	3.44	7.73	10.97	18.51
13 (Patilda Reserve)	4.315	7.9	13.21	9.63	21.65	30.73	51.87
14	2.15	3.9	6.58	4.80	10.79	15.31	25.84
15	0.58	1.1	1.78	1.29	2.91	4.13	6.97
Total	**54.7125**	**100**	**167.56**	**122.15**	**274.52**	**389.69**	**657.64**

Runoff Co-efficient = 0.30

			Runoff (ML) based on Annual Rainfall Ranges				
			mean	50%	20%	10%	2%
Catchment Identifier	Catchment Area (ha)	Coverage %	1225	893	2007	2849	4808
1 (Catherine Park)	8.975	16.4	32.98	24.04	54.04	76.71	129.46
2	1.535	2.8	5.64	4.11	9.24	13.12	22.14
3	5.5475	10.2	20.39	14.86	33.40	47.41	80.02
4	1.48	2.7	5.44	3.96	8.91	12.65	21.35
5	3.4475	6.3	12.67	9.24	20.76	29.47	49.73
6	2.5475	4.6	9.36	6.82	15.34	21.77	36.75
7	4.6125	8.4	16.95	12.36	27.77	39.42	66.53
8 (Richard Rd)	7.1575	13.1	26.30	19.17	43.10	61.18	103.24
9 (Harold Reserve)	4.99	9.1	18.34	13.37	30.04	42.65	71.98
10	2.57	4.8	9.44	6.89	15.47	21.97	37.07
11	3.265	5.9	12.00	8.75	19.66	27.91	47.09
12	1.54	2.8	5.66	4.13	9.27	13.16	22.21
13 (Patilda Reserve)	4.315	7.9	15.86	11.56	25.98	36.88	62.24
14	2.15	3.9	7.90	5.76	12.95	18.38	31.01
15	0.58	1.1	2.13	1.55	3.49	4.96	8.37
Total	**54.7125**	**100**	**201.07**	**146.57**	**329.42**	**467.63**	**789.17**

From these relatively crude calculations (Table 28), an average year of rainfall would produce approximately 134 to 201 ML of surface water runoff. However, the net surface water discharge from Scotland Island would be significantly more in wetter years. For example during a 1 in 10 year, surface runoff would exceed 450 ML. In a one in 50 year rainfall year some 526 to 789 ML will be discharged from the Island's streams.

Calculation of the net exported load of contaminants from each of the Island's catchments via surface runoff is estimated using the mean annual rainfall and a runoff coefficient of 0.25 (Table 29). Water quality results for the four sampled catchments (catchments 1, 8, 9 & 13) were applied to adjacent catchments in order to estimate contaminant load generated from these and from this to estimate the total contaminant load exported from the Island (Figure 13).

Contaminant generation rates per unit area (ha) are also calculated (Table 29). It should be noted again that these estimates are based on limited data and an assumed mean catchment runoff coefficient of 0.25. Loads and generation rates are therefore crude estimates and further monitoring of creek flow regimes would be required to provide more accurate estimates.

Table 29: Estimated surface water contaminant loads and generation rates exported from Scotland Island [and individual catchments] during a mean rainfall (RC = 0.25).

Total Nitrogen			**TN**	**TN**	**TN**
Catchment Identifier	**Catchment Area (ha)**	**Coverage %**	mg/l	kg/ha/yr	kg/yr
1 (Catherine Park)	8.975	16.4	5.29	16.20	145.40
2	1.535	2.8	5.29	16.20	24.87
3	5.5475	10.2	5.29	16.20	89.87
4	1.48	2.7	5.29	16.20	23.98
5	3.4475	6.3	4.28	13.11	45.19
6	2.5475	4.6	4.28	13.11	33.39
7	4.6125	8.4	4.28	13.11	60.46
8 (Richard Rd)	7.1575	13.1	4.28	13.11	93.82
9 (Harold Reserve)	4.99	9.1	2.23	6.83	34.08
10	2.57	4.8	2.23	6.83	17.55
11	3.265	5.9	4.28	13.11	42.80
12	1.54	2.8	5.29	16.20	24.95
13 (Patilda Reserve)	4.315	7.9	1.77	5.42	23.39
14	2.15	3.9	5.29	16.20	34.83
15	0.58	1.1	5.29	16.20	9.40
Total	**54.71**	**100**			**703.97**

Total Phosphorus			TP	TP	TP
Catchment Identifier	Catchment Area (ha)	Coverage %	mg/l	kg/ha/yr	kg/yr
1 (Catherine Park)	8.975	16.4	0.25	0.78	6.98
2	1.535	2.8	0.25	0.78	1.19
3	5.5475	10.2	0.25	0.78	4.32
4	1.48	2.7	0.25	0.78	1.15
5	3.4475	6.3	0.36	1.10	3.80
6	2.5475	4.6	0.36	1.10	2.81
7	4.6125	8.4	0.36	1.10	5.09
8 (Richard Rd)	7.1575	13.1	0.36	1.10	7.89
9 (Harold Reserve)	4.99	9.1	0.24	0.74	3.67
10	2.57	4.8	0.24	0.74	1.89
11	3.265	5.9	0.36	1.10	3.60
12	1.54	2.8	0.25	0.78	1.20
13 (Patilda Reserve)	4.315	7.9	0.13	0.40	1.74
14	2.15	3.9	0.25	0.78	1.67
15	0.58	1.1	0.25	0.78	0.45
Total	**54.71**	**100**			**47.45**

Suspended Sediment			SS	SS	SS
Catchment Identifier	Catchment Area (ha)	Coverage %	mg/l	kg/ha/yr	kg/yr
1 (Catherine Park)	8.975	16.4	8722	26711	239732
2	1.535	2.8	8722	26711	41002
3	5.5475	10.2	8722	26711	148180
4	1.48	2.7	8722	26711	39532
5	3.4475	6.3	1939	5938	20472
6	2.5475	4.6	1939	5938	15128
7	4.6125	8.4	1939	5938	27390
8 (Richard Rd)	7.1575	13.1	1939	5938	42503
9 (Harold Reserve)	4.99	9.1	2398	7344	36646
10	2.57	4.8	2398	7344	18874
11	3.265	5.9	1939	5938	19388

12	1.54	2.8	8722	26711	41135
13 (Patilda Reserve)	4.315	7.9	1142	3497	15091
14	2.15	3.9	8722	26711	57429
15	0.58	1.1	8722	26711	15492
Total	**54.71**	**100**			**777994**

Oxidised Nitrogen			**Filt. NOx**	**Filt. NOx**	**Filt. NOx**
Catchment Identifier	**Catchment Area (ha)**	**Coverage %**	mg/l	kg/ha/yr	kg/yr
1 (Catherine Park)	8.975	16.4	2.09	6.40	57.45
2	1.535	2.8	2.09	6.40	9.82
3	5.5475	10.2	2.09	6.40	35.51
4	1.48	2.7	2.09	6.40	9.47
5	3.4475	6.3	1.30	3.98	13.73
6	2.5475	4.6	1.30	3.98	10.14
7	4.6125	8.4	1.30	3.98	18.36
8 (Richard Rd)	7.1575	13.1	1.30	3.98	28.50
9 (Harold Reserve)	4.99	9.1	0.17	0.52	2.60
10	2.57	4.8	0.17	0.52	1.34
11	3.265	5.9	1.30	3.98	13.00
12	1.54	2.8	2.09	6.40	9.86
13 (Patilda Reserve)	4.315	7.9	0.04	0.12	0.53
14	2.15	3.9	2.09	6.40	13.76
15	0.58	1.1	2.09	6.40	3.71
Total	**54.71**	**100**			**228**

Ammonia			**NH3-n**	**NH3-n**	**NH3-n**
Catchment Identifier	**Catchment Area (ha)**	**Coverage %**	mg/l	kg/ha/yr	kg/yr
1 (Catherine Park)	8.975	16.4	0.11	0.34	3.02
2	1.535	2.8	0.11	0.34	0.52
3	5.5475	10.2	0.11	0.34	1.87
4	1.48	2.7	0.11	0.34	0.50
5	3.4475	6.3	0.11	0.34	1.16
6	2.5475	4.6	0.11	0.34	0.86
7	4.6125	8.4	0.11	0.34	1.55
8 (Richard Rd)	7.1575	13.1	0.11	0.34	2.41
9 (Harold Reserve)	4.99	9.1	0.03	0.09	0.46

10	2.57	4.8	0.03	0.09	0.24
11	3.265	5.9	0.11	0.34	1.10
12	1.54	2.8	0.11	0.34	0.52
13 (Patilda Reserve)	4.315	7.9	0.02	0.06	0.26
14	2.15	3.9	0.11	0.34	0.72
15	0.58	1.1	0.11	0.34	0.20
Total	**54.71**	**100**			**15**

6.3.2 Street-water Quality

Several surface water samples were collected in the study, including both samples during dry- and wet weather. Samples were collected from pools present on the Island's dirt roads (Figure 6). However, at the time of writing, these results were not available. They shall be included in the final report.

6.4 Wastewater Disposal Systems

6.4.1 Drainfield Quality and Failure

In the majority of site inspections (30), the size of the effluent disposal area (drainfield) was very small (*i.e.* below AS1547 requirements). Total surface areas typically ranged between 10 - 30 m^2, although in several situations, small areas were utilised. Occasionally, drainfields were separated into two [and sometimes three] distinct disposal areas with upper slope areas gravity feeding those downslope. On average, disposal areas have an immediate total effluent application surface area of approximately 10-20 m^2 (2.5 x 4m and 4 x 5m). Such small areas have resulted in high hydraulic loads to the absorption trenches (see section 6.5) resulting in rapid effluent migration away from the disposal site. Drainfield failure is evident in many locations as seepage from effluent disposal areas to streets downslope of the drainfield was observed for 20% of sites.

Trenches have mostly been excavated into the impermeable B horizon. This inhibits effluent absorption into the surrounding soil, causing effluent to 'pool' at the base of the trench. Standing water levels of 20-30 cm were found in several of the trenches inspected. Preferential flow along the A/B horizon is therefore the most likely effluent exit mechanism from trenches. Shallow soil fill layers covering trenches suggest that little effluent 'treatment' actually occurs within the allocated disposal area.

Where grey and black water wastes are separated, only two disposal areas are typically used with each approximately 10m^2 in total surface area. Greywater wastes are usually surface discharged and receive little additional treatment. Free flowing surface water for up to several metres was frequently observed at grey water release points. Disposal of greywater into a separate greywater treatment and soil absorption system was not observed at any of the inspection sites.

It should be noted that in the case of some of the shoreline properties adjacent to Pittwater, effluent disposal is directly into the estuarine sands and thus out into Pittwater without any additional treatment. In some circumstances, tidal beach water accesses and 'flushes' the drainfield. Where this occurs, little post-disposal treatment is offered before effluent reaches Pittwater.

6.4.2 Trench Soil-Water Quality

Five septic trench sites were monitored for standing water quality: Cullen; Ode; Collins; Travers; Tay (Table 30). These indicated extremely high nutrient concentrations, very high sodium absorption ratios (SAR), and high EC. Total Nitrogen was approximately 300 % higher than that found by Martens (1996) in a septic drainfield with similar soil characteristics. Total phosphorus levels in the trench soil-water are extremely high on one site (Cullen) having a trench water concentration of 153 mg/L. These results are approximately 3 orders of magnitude higher than figures reported by Martens (1996) and indicate that large amounts of soluble phosphorus are present in the drainfield. This suggests that several of the trench soils have become saturated with phosphorus (ie. P-sorption sites are 'full'), and indicates that the element is free to leave the disposal area.

The sodium absorption ratio (SAR) of trench soil-water was calculated according to Equation 7 (Table 30). This is extremely high and indicates an excess of Sodium in trench water resulting from accumulation through the disposal of domestic effluent. Extremely high values suggest that hydraulic conductivities of trench walls, particularly those set in the B horizon, are greatly reduced [by up to two orders of magnitude].

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+}}} \qquad \text{Eq. 7}$$

where; SAR = Sodium Absorption Ratio
Na^{+} = Sodium
Ca^{2+} = Calcium
Mg^{2+} = Magnesium

Table 30: Soil-water quality in septic trenches on Scotland Island.

Parameter	Average	Std Dev	n
Total N (mg/L)	108.4	64.0	9
Ammonia (mg/L)	91.1	60.9	9
NO3-N (mg/L)	2.2	3.6	9
TP (mg/L)	33.5	58.3	9
K (µg/L)	54289	26290	9
Na (mg/L)	95000	67975	9
Ca (mg/L)	18611	8262	9
Mg (mg/L)	13197	3992	9
SAR	777	513	9
EC (mS/m)	144	61	9

6.4.3 Trench Soil Physiochemistry

Trench soil samples collected during installation of the porous ceramic cup soil-moisture samplers were analysed for pH, EC, cation and nutrient content (Table 31).

Both nitrogen and phosphorus are notably higher in the trench soils compared to native soil concentrations. Nitrate (NO3-N, mg/kg) in particular is significantly higher reflecting the ammonia contained in septic effluent being nitrified and stored in the soil as nitrate. Bray phosphate levels are extremely high, ranging between 3 and 225 mg/kg, some two orders of magnitude higher than that found in the native soils. This is a reflection of both the large amount of phosphorus sorbed to soil particles, but also of the high amounts of soluble phosphorus present in soil-water [in the soil sample, see section 6.4.2] at the time of sampling. Average P-sorption found in native soils was approximately 160 mg/kg. Results confirm that phosphorus levels in the soil effluent disposal areas are at or exceeding saturation (ie. maximum adsorption) levels.

Total carbon is also very high as a function of domestic organic waste materials entering the trench system. Exchangeable cations and cation exchange capacity are only slightly higher in trench soils than native soils. No real difference in sodicity between trench and native soils was found.

Table 31: Physiochemical characteristics of trench soils.

Parameter	Trench 1	Trench 2	Trench 3	Trench 4	Trench 5	Average	Std	Class
pH	5.94	4.84	3.95	4.82	3.82	4.67	0.85	V. acid
EC (dS/m)	0.08	0.32	0.16	0.21	0.25	0.20	0.09	non-sal.
Bray-P (mg/kg)	3	108	196	225	41	115	96	V. High
T. Carbon (%)	3.49	1.60	5.35	5.68	2.61	3.75	1.75	V. high
Al (cmol(+)/kg)	0.10	0.10	0.50	0.10	2.10	0.58	0.87	-
Mg (cmol(+)/kg)	1.80	1.40	1.50	2.70	1.90	1.86	0.51	Moderate
Ca (cmol(+)/kg)	11.30	4.00	2.60	10.20	2.10	6.04	4.37	Moderate
K (cmol(+)/kg)	0.44	0.60	1.08	1.07	0.75	0.79	0.28	High
Na (cmol(+)/kg)	0.30	0.60	0.50	0.80	0.60	0.56	0.18	Moderate
CEC (cmol(+)/kg)	13.90	6.60	5.60	14.80	5.40	9.26	4.68	Low
ESP %	2.2	9.1	8.9	5.4	11.1	7.3	3.5	Marginal
TN %	0.23	0.17	0.41	0.46	0.21	0.30	0.13	High
C/N ratio	15.2	9.4	13.0	12.3	12.4	12.5	2.1	Medium
NO3-N (mg/kg)	15.0	6.7	6.0	37.5	90.0	31.0	35.3	High

6.5 Water Budgeting from Effluent Systems

A climatic water balance was derived from monthly rainfall records (Table 32). A crop factor of 1.4, based on the results of a recent Public Works Department study (1992), has been utilised to estimate site evapotranspiration for the urban bushland common around most disposal areas.

Results indicate that water surpluses (ET-P) occur during June in a mean annual rainfall year. No water surpluses occur during the median year (50%). Calculations based on probability of exceedence equations derived from monthly rainfall data indicate that at or greater than the 20% probability level (1 in 5 year event or less frequent) surplus water occurs between April and July (4 consecutive months). In years where rainfall reaches or exceeds the 10 % probability level surplus water occurs between February and August (8 consecutive months).

Table 32: Scotland Island climatic water balance. Shaded values indicate monthly water surplus.

Month	Mean P (mm)	50% (mm)	20% (mm)	10% (mm)	2% (mm)	E (mm)	ET (mm)	ET-P (mm)	ET-P 50% (mm)	ET-P 20% (mm)	ET-P 10% (mm)	ET-P 2% (mm)
Jan	120	92	195	273	454	217	304	184	212	109	31	-150
Feb	125	93	202	284	476	176	247	122	154	45	-37	-229
Mar	141	108	218	302	496	164	230	89	122	12	-72	-266
Apr	116	81	197	285	489	123	172	56	91	-25	-113	-317
May	110	72	199	295	519	87	122	12	50	-77	-173	-397
Jun	132	96	216	308	519	78	109	-23	13	-107	-199	-410
Jul	75	51	129	188	324	84	117	42	66	-12	-71	-207
Aug	84	60	139	198	337	115	161	77	101	22	-37	-176
Sep	66	45	115	167	289	141	197	131	152	82	30	-92
Oct	82	63	128	178	294	177	247	165	184	119	69	-47
Nov	92	68	147	206	345	195	273	181	205	126	67	-72
Dec	82	64	122	165	266	233	326	244	262	204	161	60
Annual Total	**1225**	**893**	**2007**	**2849**	**4808**	**1789**	**2504**	**1279**	**1611**	**497**	**-344**	**-2303**

Table 33: Class A pan evaporation data from Sydney airport observation office.* Mean value used in water balance calculations.

Month	Mean (mm)	Maximum	Minimum
January	7	8.1	5.6
February	6.3	7.5	5
March	5.3	6.6	4.3
April	4.1	5.1	3.1
May	2.8	3.8	2.2
June	2.6	3.2	2.1
July	2.7	3.4	1.7
August	3.7	4.8	3.2
September	4.7	6.9	3.8
October	5.7	7.6	4.2
November	6.5	7.5	5.4
December	7.5	9.4	5.9

Utilising the daily household water use as determined by the SIRA water survey, irrigated wastewater depths have been calculated for a range of disposal area sizes between 5m^2 and 30m^2 (Table 34). These calculations have been repeated in Table 35 for the expected higher daily household water use figure recommended in AS1547. This second set of values approximates the irrigation depths expected if free access to the town water supply is achieved in the future and current wastewater disposal management practices are maintained.

Table 34: Irrigation depths in mm for various size disposal areas based on 109.7 L/person/day and 3 persons per household.

	109.7l/dy/person	Irrigation depths for various size disposal areas (mm).						
Month	**volume/hm/mth**	**5m^2**	**7.5m^2**	**10m^2**	**12.5m^2**	**15m^2**	**20m^2**	**30m^2**
January	10202	2040	1360	1020	816	680	510	340
February	9215	1843	1229	921	737	614	461	307
March	10202	2040	1360	1020	816	680	510	340
April	9873	1975	1316	987	790	658	494	329
May	10202	2040	1360	1020	816	680	510	340
June	9873	1975	1316	987	790	658	494	329
July	10202	2040	1360	1020	816	680	510	340
August	10202	2040	1360	1020	816	680	510	340
September	9873	1975	1316	987	790	658	494	329
October	10202	2040	1360	1020	816	680	510	340
November	9873	1975	1316	987	790	658	494	329
December	10202	2040	1360	1020	816	680	510	340
Annual Total	**120122**	**24024**	**16016**	**12012**	**9610**	**8008**	**6006**	**4004**

Table 35: Irrigation depths in mm for various size disposal areas based on 180 L/person/day personal usage and 3 persons per household.

	180l/dy/person	Irrigation depths for various size disposal areas (mm).						
Month	**volume/hm/mth**	**5m^2**	**7.5m^2**	**10m^2**	**12.5m^2**	**15m^2**	**20m^2**	**30m^2**
January	16740	3348	2232	1674	1339	1116	837	558
February	15120	3024	2016	1512	1210	1008	756	504
March	16740	3348	2232	1674	1339	1116	837	558
April	16200	3240	2160	1620	1296	1080	810	540
May	16740	3348	2232	1674	1339	1116	837	558
June	16200	3240	2160	1620	1296	1080	810	540
July	16740	3348	2232	1674	1339	1116	837	558
August	16740	3348	2232	1674	1339	1116	837	558
September	16200	3240	2160	1620	1296	1080	810	540
October	16740	3348	2232	1674	1339	1116	837	558
November	16200	3240	2160	1620	1296	1080	810	540
December	16740	3348	2232	1674	1339	1116	837	558
Annual Total	**197100**	**39420**	**26280**	**19710**	**15768**	**13140**	**9855**	**6570**

Annual totals using data from the water use survey indicate irrigation depths range from 24.0 m/m^2 over a 5m^2 disposal area to 4.0 m/m^2 over a 30m^2 disposal area. Figures calculated using the AS1547 personal water use figure of 180L/day result in a 61% increase in effluent irrigation depths. The 61% increase in effluent irrigation depths is considered to reflect a very significant potential increase in wastewater loads, resulting from a consistent water supply to the Island that a reticulated water supply would bring.

Results of saturated hydraulic conductivity tests of the soil on the Island indicate that the A horizon has a saturated hydraulic conductivity ranging between 299 mm/day and 2189 mm/day. Soil water balances in the absorption trenches were determined using [monthly] mean annual rainfall figures, a mean infiltration rate of 950 mm/day and a disposal area size of 15m^2 (Table 36).

Table 36: Trench soil water balance assessment for mean trench surface area of 15 m^2 [assuming mean annual rainfall and mean infiltration (K_{sat}) rate of 950 mm/day).

Month	**Mean P (mm)**	**Iri. Depth for 15m^2**	**Effective P - (mean P + Iri.)**	**ET**	**Infiltration 950 mm/day**	**ET - effp + Infil**
January	120	1360	1480	304	29450	28274
February	125	1229	1354	247	26600	25493
March	141	1360	1501	230	29450	28179
April	116	1316	1432	172	28500	27240
May	110	1360	1470	122	29450	28101
June	132	1316	1448	109	28500	27161
July	75	1360	1435	117	29450	28132
August	84	1360	1444	161	29450	28166
September	66	1316	1382	197	28500	27315
October	82	1360	1442	247	29450	28255
November	92	1316	1408	273	28500	27365
December	82	1360	1442	326	29450	28333
Annual Total	**1225**	**16016**	**17241**	**2504**	**346750**	**332014**

These results indicate that for medium sized disposal areas of 15 m^2, native A horizons have the capacity to transport the entire annual effluent load applied as sub-surface transport away from the disposal site. Therefore, there should be little risk of surface runoff of effluent from disposal sites of 15 m^2 or greater. Surface runoff therefore only occurs for brief periods when rainfall intensity exceed surface infiltration capacity. Observations made by SIRA members conducting storm event sampling indicated that the streams began to flow after approximately 5 mm of rainfall if this occurred in approximately 10 minutes.

These results suggest that during dry weather and light discontinuous rainfall no significant surface runoff of effluent occurs from the disposal areas greater than or equal to 15m^2. However, effluent is transported readily through the A soil horizon and at the impermeable boundary with the clay rich B soil horizon to emerge at drainage lines and streams.

6.6 Contaminant Budgeting from Effluent Systems

Effluent loads generated from individual households of approximately 3 people (at 109.7 L/person/day) are presented in Tables 37. These tables indicate contaminant loads in kg/m^2.

Table 37: Estimated effluent contaminant loadings calculated for various disposal area sizes.

	Total Nitrogen				Disposal Area Sizes					
					5m^2	7.5m^2	10m^2	15m^2	20m^2	30m^2
Month	Effluent loads mg/l	block usage l/mth	Load mg/mth	Load kg/mth	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2
January	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
February	98.4	9215	906736	0.91	0.181	0.121	0.091	0.060	0.045	0.030
March	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
April	98.4	9873	971503	0.97	0.194	0.130	0.097	0.065	0.049	0.032
May	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
June	98.4	9873	971503	0.97	0.194	0.130	0.097	0.065	0.049	0.032
July	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
August	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
September	98.4	9873	971503	0.97	0.194	0.130	0.097	0.065	0.049	0.032
October	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
November	98.4	9873	971503	0.97	0.194	0.130	0.097	0.065	0.049	0.032
December	98.4	10202	1003887	1.00	0.201	0.134	0.100	0.067	0.050	0.033
Annual Total	-	120122	11819956	11.82	2.36	1.58	1.18	0.79	0.59	0.39

	Total Phosphorus				Disposal Area Sizes					
					5m^2	7.5m^2	10m^2	15m^2	20m^2	30m^2
Month	Effluent loads mg/l	block usage l/mth	Load mg/mth	Load kg/mth	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2
January	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
February	24.6	9215	226684	0.23	0.045	0.030	0.023	0.015	0.011	0.008
March	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
April	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
May	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
June	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
July	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
August	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
September	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
October	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
November	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
December	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
Annual Total	-	120122	2954989	2.95	0.59	0.39	0.30	0.20	0.15	0.10

Sodium					**Disposal Area Sizes**					
					5m^2	7.5m^2	10m^2	15m^2	20m^2	30m^2
Month	Effluent loads mg/l	block usage l/mth	Load mg/mth	Load kg/mth	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2
January	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
February	73.8	9215	680052	0.68	0.136	0.091	0.068	0.045	0.034	0.023
March	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
April	73.8	9873	728627	0.73	0.146	0.097	0.073	0.049	0.036	0.024
May	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
June	73.8	9873	728627	0.73	0.146	0.097	0.073	0.049	0.036	0.024
July	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
August	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
September	73.8	9873	728627	0.73	0.146	0.097	0.073	0.049	0.036	0.024
October	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
November	73.8	9873	728627	0.73	0.146	0.097	0.073	0.049	0.036	0.024
December	73.8	10202	752915	0.75	0.151	0.100	0.075	0.050	0.038	0.025
Annual Total	-	120122	8864967	8.86	1.77	1.18	0.89	0.59	0.44	0.30

Magnesium					**Disposal Area Sizes**					
					5m^2	7.5m^2	10m^2	15m^2	20m^2	30m^2
Month	Effluent loads mg/l	block usage l/mth	Load mg/mth	Load kg/mth	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2	kg/m^2
January	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
February	9.84	9215	90674	0.09	0.018	0.012	0.009	0.006	0.005	0.003
March	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
April	9.84	9873	97150	0.10	0.019	0.013	0.010	0.006	0.005	0.003
May	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
June	9.84	9873	97150	0.10	0.019	0.013	0.010	0.006	0.005	0.003
July	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
August	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
September	9.84	9873	97150	0.10	0.019	0.013	0.010	0.006	0.005	0.003
October	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
November	9.84	9873	97150	0.10	0.019	0.013	0.010	0.006	0.005	0.003
December	9.84	10202	100389	0.10	0.020	0.013	0.010	0.007	0.005	0.003
Annual Total	-	120122	1181996	1.18	0.24	0.16	0.12	0.08	0.06	0.04

Potassium					Disposal Area Sizes					
					5m²	7.5m²	10m²	15m²	20m²	30m²
Month	Effluent loads mg/l	block usage l/mth	Load mg/mth	Load kg/mth	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²
January	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
February	24.6	9215	226684	0.23	0.045	0.030	0.023	0.015	0.011	0.008
March	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
April	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
May	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
June	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
July	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
August	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
September	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
October	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
November	24.6	9873	242876	0.24	0.049	0.032	0.024	0.016	0.012	0.008
December	24.6	10202	250972	0.25	0.050	0.033	0.025	0.017	0.013	0.008
Annual Total	-	120122	2954989	2.95	0.59	0.39	0.30	0.20	0.15	0.10

Calcium					Disposal Area Sizes					
					5m²	7.5m²	10m²	15m²	20m²	30m²
Month	Effluent loads mg/l	block usage l/mth	Load mg/mth	Load kg/mth	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²	kg/m²
January	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
February	45.9	9215	423144	0.42	0.085	0.056	0.042	0.028	0.021	0.014
March	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
April	45.9	9873	453368	0.45	0.091	0.060	0.045	0.030	0.023	0.015
May	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
June	45.9	9873	453368	0.45	0.091	0.060	0.045	0.030	0.023	0.015
July	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
August	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
September	45.9	9873	453368	0.45	0.091	0.060	0.045	0.030	0.023	0.015
October	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
November	45.9	9873	453368	0.45	0.091	0.060	0.045	0.030	0.023	0.015
December	45.9	10202	468480	0.47	0.094	0.062	0.047	0.031	0.023	0.016
Annual Total	-	120122	5515979	5.52	1.10	0.74	0.55	0.37	0.28	0.18

7. Impact Assessment

7.1 Island Water Absorption Capacity

Effluent loadings on the septic trench areas are high. However, hydraulic conductivity measurements indicate A horizons are typically capable of infiltrating and transporting the entire water wastewater load in a mean rainfall year. Therefore, in dry periods and during discontinuous low intensity rainfall, there should be no significant runoff of effluent due directly to excess water loadings.

It is worth noting that although the A horizon can accept high water loads, the treatment capacity of the soil is diminished by short retention times of water in the soil. The short retention times result from both terrain steepness and high hydraulic conductivity. B horizons mark the depth of an impermeable layer along which effluent and other shallow perched groundwater migrate to emerge in streams, along drainage lines, and as seepage at significant breaks in slope [such as at roadsides adjacent to house blocks]. The relative impermeability of the B horizon inhibits downward water percolation in trenches. Extremely high contaminant concentrations found in some trench water samples (section 6.4.3) indicates that a number of these trenches have been excavated partly into the impermeable B horizon, thereby 'ponding' effluent in the basal area.

There is little dry weather flow in the Islands ephemeral streams. Flow response to rainfall is rapid due to the steepness of the terrain. Field observations made by SIRA indicate water flows in streams occurs only minutes after moderate to heavy rainfall occurs. The surface K_{sat} values for the island range between 299 -2184 mm/day. These represent approximately rates of 12.5 - 91 mm/hour. However, because of the steep slopes, most intense thunderstorms cause rapid runoff over much of the island. In the heavily vegetated areas such as the Harold Reserve catchment, the response time is slower as water can more easily penetrate into the soil.

The rapid runoff flow regime identified in the Islands ephemeral streams may increase the likelihood of trench failure along the lower half of the Island which is most heavily populated. Surface runoff results in additional water to the already high load delivered to the wastewater trenches around the most heavily populated lower half of the island. This may result in some effluent movement away from the disposal site along the surface, within the A horizon or along the A / B horizon boundary preferentially. Clearly the potential for downslope trench failure induced by excessive runoff is greatest in low frequency intense rainfall events. The potential for mass transport of soil is also greatest in these situations.

7.2 Island Nutrient Assimilation Capacity

Results of the soil survey indicate that the Island's native soils contain extremely low concentrations of most major plant nutrients such as nitrogen and phosphorus. The low cation exchange capacity (CEC) indicates that native soils have very low capacity to hold and exchange cations. This, together with a uniformly acidic substrate is a major controlling agent of nutrient availability and soil assimilation capacity.

In general, conditions on the Island are conducive to nutrient and contaminant leaching from the septic drainfields. Existing native plants have typically low capacities for nutrient uptake and this favours the invasion of introduced species. It is therefore expected that the movement of more mobile constituents such as nitrate (NO3-N) occurs relatively rapidly after installation of the absorption field. Higher soil nitrate in Catherine Park, at the base of a large urban catchment, may indeed reflect the impact of mobile nitrate from septic systems in the catchment above. Less mobile contaminants such as phosphorus would only migrate from the effluent disposal area if adsorption sites had been full occupied.

Results in section 6.6 indicate that nutrient loading rates are high and that some excess phosphorus will result through the land application of wastewater from septic systems. This is common for the application of this nutrient. Data presented in Tables 23 and 24 indicate that phosphorus sorption capacity for A horizons is medium and for sub-soils is high to very high on the Island. P-sorption analyses may be used to provide a crude and conservative estimate of the ultimate phosphorus storage capacity of Island soils and therefore site longevity(pers. comm. Paul Milham, NSW Dept. Agriculture, 1994).

A simple model for predicting the removal of phosphorus via soil adsorption is given below in Equation 8, where T_x is the site longevity for a given soil depth of *x* m, S_p is the phosphorus storage capacity for a given volume of soil, I_p is the input phosphorus load, and H_p is the plant phosphorus usage for a given land area.

$$T_x = \frac{S_p}{I_p - H_p} \qquad \textbf{Eq. 8}$$

Phosphorus storage for individual household wastewater disposal sites can therefore be estimated from the following assumptions:

Assume: Wastewater P concentrations of 15 mg/L
Household wastewater flows of 330 L/day (from water survey)
Plant luxuriant P uptake of 50 kg/ha/year
A horizon P-sorption of 165 mg/kg (0-40cm)
B horizon P-sorption of 240 mg/kg (40-80 cm)
Soil density of 2.5 g/cm^3

Disposal area longevity, that is before adsorption sites are 'full', is therefore estimated as given in Table 38. This indicates that under the majority of situations, it would be expected that septic trench disposal areas become saturated with phosphorus some 3-7 years following construction (assuming normal operating conditions). Following saturation, phosphorus would be expected to migrate slowly away from the disposal area. Upon saturation, phosphorus levels in the disposal area would become highly concentrated with the on-set of supersaturated conditions. This condition would explain the extremely high phosphorus levels found in soil water at several of the trenches sampled. The situation is similar for the AWTSs as such systems do not normally actively remove phosphorus from effluent. However, larger surface areas used for surface [irrigation] disposal of up to 100 m^2 suggest that longevity in these situations would be increased four-fold.

Table 38: Disposal site phosphorus storage capacity and longevity (years) under various septic trench size scenarios.

Disposal trench surface area size (m^2)	Longevity in years 0.4 m soil depth (A horizon only)	Longevity in years 0.8 m soil depth (A and B horizon)
5	0.46	1.14
10	0.94	2.31
20	1.93	4.75
30	2.99	7.33
100	12.63	30.99

It is worth noting that should only the A horizon receive effluent [because sub-soil horizons are too impermeable], then the effective longevity of septic trench disposal areas is reduced to approximately 1-3 years.

The above methods are further applied, through GIS analyses (see Appendix III), to the entire Island to determine approximate net storage capacities of A and B soil horizons (Table 39). Under the assumption of one septic disposal system per 25 m^2 grid-cell, Equation 8 was used to combine various soil layers and construct a map of Island site longevity in terms of phosphorus storage capacity (Figure 14). Results are summarised in Table 40 and indicate that for more than 50 % of the Island, septic trench disposal areas can be expected to become saturated with phosphorus within 6 to 8 years of installation if effluent disposal occurs evenly in both A and B horizons. However, if B horizons are assumed to not absorb any effluent [and therefore only the A horizon operates as an effective effluent filtration] medium], then approximately 80 % of the island has an effluent disposal are longevity of 1-2 years only.

Table 39: Estimates for total phosphorus storage capacities for individual soil horizons.

Horizon	Total Island Phosphorus Storage (kg)	Average Phosphorus Storage per 25m^2 (kg)
A	57242.88	2.616
B	90479.41	4.134
Total	147722.29	6.750

Table 40: Aerial coverage of expected site longevity classes for phosphorus adsorption (years).

Longevity Class (years)	Aerial coverage (ha)	% of Area Covered
0 - 2	0.2550	0.47
2 - 4	0.5475	1.00
4 - 6	13.4600	24.60
6 - 8	31.0175	56.69
8 - 10	7.5425	13.79
> 10	1.8900	3.45
Total	**54.71**	**100.00**

7.3 Effluent Migration From the Wastewater Systems

Wastewater loads described in section 6.5 are high for the range of septic trench dimensions observed on the Island. The consequence of high irrigation depths on small disposal areas is that the trenches frequently exist in a continuously saturated state. Water migration to the surrounding soil is thus constant and maximum potential transport can therefore be approximated using K_{sat} values obtained in the field. Maximum effluent loss downslope from trenches is estimated at 262 L/day/trench based on Equation 9 below, using mean estimates of trench width; trench depth; hydraulic conductivity of the A and B horizon soil; and porosity of the surrounding A and B horizon's portion of the downslope trench wall area.

$$L_W = \eta \times (T_w \times T_D \times K_{SAT}) \qquad \textbf{Eq. 9}$$

Where;

L_w = *Water loss from trench (l/day)*
η = *Porosity of A-Horizon soil = 0.55, B horizon = 0.02*
T_w = *Mean trench width (5.0 m)*
T_D = *Mean trench depth (0.30 m = 0.1 m of A + 0.2 m of B horizon))*
K_{sat} = *Saturated hydraulic conductivity (950 mm/day - A horizon)*
(24 mm/day - B horizon)

These results suggest approximately 80% of the daily inflow to the septic tank may be transported from the adjoining trenches to the surrounding soil. This indicates that retention times in septic effluent disposal trenches are indeed potentially very short. This may be especially so if ponded water in the basal area of the trench reduces the effective area of the trench receiving effluent. Older trenches which have substantial clogging layers may have significantly lower downslope effluent losses, but may consequently have increased potential surface runoff.

Water soluble contaminants such as Nitrogen and the soluble cations accompany effluent lost from trenches. Conservative estimates of annual nitrogen accumulation within individual septic disposal trenches are presented in Table 41 (based on the load, soil loss and plant uptake capacity).

Table 41: Estimated Nitrogen accumulation rate in septic trench disposal areas on Scotland Island. (Plant uptake rates from CSIRO, 1995.)

		Plant Uptake			
Influent kg/year / trench	**Soil Loss** (at approx. 80%)	**Uptake** Cropped - $15m^2$	**Uptake** SGF $15m^2$	**Accumulation** on Cropped Area kg/yr/trench	**Accumulation** SGF kg/yr/trench
	80%	0.0135 $kg/m^2/yr$ (135 kg/ha/yr)	0.005 $kg/m^2/yr$ (50 kg/ha/yr)		
11.82	**9.46**	**0.2025**	**0.075**	**2.16**	**2.29**

Table 41 indicates that nitrogen in trenches may accumulate by approximately 2 kg/yr despite losses through soil transport and plant uptake. Clearly, current trench size is insufficient to cope with the nutrient loads applied. It should be noted that this estimate has not taken account of other nitrogen loss processes operating such as volatilisation and denitrification are not considered here because they are insignificant compared to the estimated loads.

Other contaminants present in the primary effluent are also accumulating in the disposal trenches. This is especially true for sodium, boron and chloride which are both soluble and not taken up by plants.

7.4 Island Surface Water Quality

Concentrations of Faecal Coliforms monitored in the five storms generally ranged from 10^4 to 10^5 CFU.100ml. These concentrations are several orders of magnitude above acceptable ANZECC levels and are considered to be a significant health risk with either primary or secondary contact.

Limited water quality testing of Pittwater by Council indicated elevated Faecal Coliform levels (830 CFU/100ml) occurred when sampling coincided with rain. These results suggest that surface runoff from Scotland Island may be [together with other surrounding urban areas] a source of bacterial pollution to Pittwater, although significantly diluted.

Summary results of storm monitoring are presented in Table 42 alongside indicative water-quality guidelines for surface-waters provided by ANZECC (1992).

Table 42: Comparison of surface-water quality (mean of A and B samples) with surface water guideline values (ANZECC, 1992).

Parameter	**Monitoring Average (mg/L) in Sampled Catchments on Scotland Island**			**Guideline: Surface-water (mg/L)**	**Guideline: Estuary (mg/L)**
	Catherine Park	Richard Rd	Harold Reserve		
TN	5.29	4.28	2.23	0.1 - 0.5	-
Oxidised Nitrogen	2.09	1.30	0.17	-	0.01 - 0.10
Ammonia Nitrogen	0.11	0.11	0.03	< 0.5	< 0.005
TP	0.25	0.36	0.24	0.005 - 0.050	-
Faecal Coliform (CFU/100ml)	34,150	106,500	149,900	< 150 (primary cont)	< 1500 (secon.cont)
Enterococci (organisms/100ml)	54,820	68,200	150,600	< 35 (primary cont)	< 230 (secon.cont)
Suspended Sediment	8722	1939	2398	-	-

The water quality results from all the sampled catchments on Scotland Island significantly exceed the ANZECC surface water quality guideline concentrations for all parameters monitored. Although these results have been calculated from a limited number of sample events, they exceed recommended levels by such a large degree that the Island is considered to export significant amounts of contaminants to the surrounding estuarine waters.

Contaminant concentrations determined from various studies for a range of landuse activities in NSW are presented in Table 43. Comparison of the results from Scotland Island with those for various landuse activities suggests that, in general, the Island maintains similar surface water concentrations of contaminants to that of other unsewered or developing urban areas.

The amount [or load] of material exported via surface runoff varies through time due to rainfall and surface water quality changes. However, given the lack of existing data, approximate annual load estimates to Pittwater have been made and are presented in Table 44.

Table 43: Summary data of runoff water quality in Australian unsewered, sewered residential, CSO, commercial, industrial and rural catchments.

Type	Source and Comment	Org-N mg/L	Amm-N mg/L	NOX-N mg/L	TN-N mg/L	TP mg/L	SS mg/L	BOD_5 mg/L
Developing urban	Hammerschmid (1991) 92.3 ha	2.79	0.13	1.13	4.05	0.476	1589	
Sewered residential	Smalls (1986), Parramatta				1.01	0.324	84	9.4
	Aitken & Moodie (1983) 26 % impervious, 94 ha, Canberra				1.89	0.420		
	McNamarra (1988), Jamison Park, 17.1 ha, storm data		0.37	0.75		0.100	239	
	McNamarra (1988), Jamison Park, 17.1 ha, dry-weather flow		1.29	1.21		0.880	37	
	Carleton (1990a), 52000 ha, Land Cove River						141	47
	SPCC (1989)				1.75	0.800	400	
	Hammschmid (1991) 10.2 ha, low density	1.32	0.20	0.69	2.21		155	
	Sim *et al.* (1993) 506 ha, low density				1.04 (TKN)	0.610	47	17
Unsewered urban	Martens (1996)	2.02	3.13	1.66	6.81	2.175	72	29
Combined (CSO)	Carleton (1990b), Sydney						78-360	39-142
Commercial	-	-	-	-	-	-	-	-
Industrial	-	-	-	-	-	-	-	-
Rural	Aitken & Moodie (1983) Grazed, 112 ha, Canberra				0.41	0.26		
	Hammeschmid (1991) 24.6 ha	2.00	0.89	0.14	3.03	1.13	114	
Forest	Sivakumar (1986)				0.38	0.040		

Note: See acronyms and abbreviations for key to symbols.

Table 44: Estimate of annual export load from Scotland Island to Pittwater. (Calculations are based on mean rainfall and storm event water quality monitoring results.)

Parameter	Mass exported from Scotland Island in mean rainfall year (kg)
Total nitrogen	704
Total phosphorus	47.5
Oxidised nitrogen	228
Ammonia - nitrogen	15
Suspended sediment	777,994

Mean contaminant generation rates (in kg/ha/yr, Table 45) calculated for the monitored catchments indicate that the Harold Reserve catchment has a somewhat lower generation rate than the two larger monitored urban catchments. Generation rates calculated for Catherine Park and Richard Rd. catchments are considered more indicative of the general Island environmental due to their larger size and high housing density.

Table 45 : Mean contaminant generation rates in the monitored catchments.

	Generation Rate kg/ha/yr		
Parameter	**Catherine Park**	**Richard Rd**	**Harold Reserve**
Total nitrogen	16.20	13.11	6.83
Total phosphorus	0.78	1.10	0.74
Oxidised nitrogen	6.40	3.98	0.52
Ammonia - nitrogen	0.34	0.34	0.09
Suspended sediment	26711	5938	7344

A summary of generation rates reported in other studies of various land-use activites of the greater Sydney region is presented in Table 46. Total Nitrogen generation rates for Scotland Island are similar to those reported for other unsewered areas and those obtained in regions where intensive agriculture is practiced. Total phosphorus generation is within the ranges calculated for other unsewered urban areas and urban sewered areas.

Table 46: Contaminant generation rates (in kg/ha/year) for various landuses in New South Wales.

Land-use Type	Source	TN-N	TP	SS
Natural / Forest	Marston (1993)	1.5 ±	0.10 ±	na
	Preston (1995)	0.5	0.1	270
		7.4	0.50	
Urban Sewered	EPA (1981)	9.7	0.65	270
	McNamarra (1988)	8.1	1.30	680
	Hammerschmid (1991)	15.3	6.30	900
CSO Urban	Preston (1995)	10.0	1.20	1170
Urban Unsewered	Lewis *et al.* (1984)	4.0 ±	0.60 ±	na
	Martens (1996)	3.0	0.3	92.66
		13.57	4.59	
Industrial / Commercial	Marston (1993)	6.0 ± 2.0	1.8 ± 0.4	na
Turf Farming	Marston (1993)	8.0 ± 3.0	8.0 ± 4.0	na
Unfertilised Grazing	Marston (1993)	0.9 ± 0.5	0.25 ± 1.1	na
Fertilised Grazing	Marston (1993)	8.0 ± 4.0	1.25 ± 0.5	na
Rural low (cleared)	Marston (1993)	1.0 ± 0.3	0.24± 0.06	na
Rural mod (vegetable growing)	Hammerschmid (1991)	12.6	0.6	119
	Marston (1993)	11.3 ± 1.3	1.13± 1.34	na
Rural high (intensive agriculture)	Marston (1993)	17.0 ± 6.0	5.00± 2.00	na

Suspended sediment concentrations found in this study were very high. This may be partly attributed to the fact that water samples were [generally] collected during the initial few hours of an event when suspended sediment loads are highest. Sediment loads exported from the Island in suspension may therefore be somewhat over-estimated. However, soil erosion, particularly from roads and building sites without sediment traps, has been of concern to the residents for some time, lending some credibility to the above results of 7-27 tonnes/ha/year.

The high estimated suspended sediment generation rates are of concern due to the deleterious effects to the Island environment and the impact of the sediment on the surrounding water bodies and ecosystems. The primary sources of sediment available on the Island are the roads, walking paths and construction sites. The suspended sediment concentrations are comparable to those determined by Hamerschmid (1991) for developing urban areas where significant soil material is typically lost from unsealed areas during rainfall induced surface runoff. Present drainage infrastructure is not adequate to control or minimise erosion.

Though no reliable control site could be located on the Island, the concentration of contaminants recorded in the sample storm events suggests that effluent from the disposal areas is the primary source of contaminants.

During dry weather, stream flow is considered to be predominantly associated with anthopogenic activities. However, during wet weather additional sources of contaminants also become available (ie. mobile). For example, rainfall also contributes contaminants to surface flows, although these are considered to be of minor importance in comparison to animal Faeces. Dumped garbage, and general household refuse may also contribute some contaminants. Visual observation of the Island revealed numerous small rubbish heaps adjacent to households and bushland areas which may also contribute to the currently degraded surface water resources.

7.5 Island Ground-water Quality Changes

This study has not measured the quality of groundwater on Scotland Island, hence the following estimates have been made. Additional contaminants exported from effluent disposal areas have the potential to alter the quality of the groundwater resource. Estimates of the contaminants delivered to the Island with rain in a mean rainfall year (1225 mm/yr) are listed in Table 47. A runoff coefficient of 0.25 is assumed, resulting in 25 % of rainfall forming surface runoff, the remainder recharging either perched shallow or deep groundwater.

A crude estimate of the annual loads of total nitrogen and total phosphorus generated by an average household of 3.1 people are presented in section 6.6. In the Table 47, the total additional load of nitrogen and phosphorus to groundwater (rainwater and domestic effluent) is estimated to assess the quality of groundwater recharge water.

These results suggest that annually, 4.2 tonnes of nitrogen and 0.9 tonnes of phosphorus may be delivered to groundwater on Scotland Island by rain and effluent disposal. Effluent disposal has therefore, from these estimates, potentially degraded the quality of rainwater recharging groundwater. Concentrations of combined rainwater / effluent recharge are approximately 8.9 mg/L and 1.8 mg/L for nitrogen and phosphorus. This represents a net increase of 500 % and 2500 % in background nitrogen and phosphorus concentrations associated with septic trench domestic wastewater disposal. It should be noted that other contaminants may also contribute to groundwater.

Table 46: Estimates of contaminant concentrations delivered to Scotland Island groundwater resource by rain in a mean rainfall year (1225 mm/yr) with runoff coefficient-efficient of 0.25; and by effluent water loss (rainfall concentration data sourced from Martens, 1996).

Parameter	Groundwater Recharge	Concentration in rainfall	Rainwater Load	Effluent Load	Annual Load to Groundwater	Current quality of recharge	Net change
	Mlitres	mg/l	kg/yr	kg/yr	kg/yr	mg/L	%
TN	502.67	1.38	694	3546	4240	8.43	511
TP	502.67	0.07	35.2	885	920	1.83	2510

7.6 Impact of Sodium in Effluent

Results of native soil Exchangeable Sodium Potential (ESP%) determinations indicate non to marginally sodic conditions in most A horizons, but sodic conditions in many of the Islands B horizons. This, combined with the extremely high Sodium Absorption Ratio (SAR) of septic effluent in disposal trenches (average 777, section 6.4.2) and that the soils tend to be dispersive (particularly B horizons with Ca:Mg ratios on average 0.1), indicate that soil dispersion, blockage of soil pore space and greatly reduced hydraulic conductivity of soils can be expected with prolonged contact with effluent (Patterson, 1990). This is notably so when effluent contacts with the B horizons. It is highly likely that only limited amounts of effluent would be allowed to penetrate through B horizons following some period of clogging layer establishment.

Spatially variable ESP% on the Island, associated with both geologic variations and sea-breeze related effects (eg. sodium, Figure 12) are also important considerations in the design of improved on-site wastewater treatment facilities.

7.7 Effluent Migration and Vegetation Dieback

Tree dieback is generally defined as the dying off of a tree progressively from the periphery of the crown. The first sign of this is usually the appearance of leafless twigs followed by a general thinning of foliage. Trees undergoing dieback stresses (eg. Eucalyptus) may begin to form epicormic growth shoots in an attempt to maintain vascular processes.

The factors contributing to vegetative, notably tree, dieback are frequently complex and difficult to determine and decipher. Several factors include;

1. Insect defoliation
2. Waterlogging
3. Saline and hyper-saline soil-water conditions
4. Lack of adequate water supply
5. Contaminated soils (eg. phosphorus toxicity)
6. Fungal attack (eg. *Phytophthera* or *Armilleria*)
7. Root disturbance
8. Lack of fire

Some trees have noticeably senesced on the Island. These trees are noticeably visible from the surrounding areas and are best observed by boat. The location of the majority of dead or dying trees appears to be downslope of effluent disposal areas and adjacent to larger drainage lines (eg. Richard Rd. catchment, Figure 15).

Dieback is greatest on the southern side of the Island, notably in gullies and ravines where pan evaporation rates are lowest. This suggests that lack of adequate water supply is not likely to be the cause of dieback.

Close proximity of dead trees to septic trenches and ravines [where water and contaminants are concentrated] suggests that the cause of dieback in several [but not all] areas may be associated with soil toxicity. Extremely high supersaturated levels of phosphorus in the septic trenches (section 6.4.2) indicates that significant phosphorus would be available for migration during and briefly following extended rainfall. Elevated phosphorus levels in all surface waters supports this contention. This, combined with increased waterlogging, may lead to conditions that favour insect or fungal attack.

7.8 Current Performance of Existing Systems.

In general, the current performance of existing ST/SAS's examined is inadequate. Although only 30 systems were visually inspected, this has been taken to be broadly indicative of the general situation. Systems frequently fail and the result of this has been the significant deterioration of surface-water quality on the island and probable cause of Eucalyptus dieback in several locations on the Island. Failure is defined as situations where significant proportions of effluent may leave the disposal site, either by way of surface runoff or sub-surface seepage. This allows both contaminants and pathogens to migrate away from the disposal area in poorly treated states.

Failure is obviously manifested where disposed effluent resurfaces at or near the drainfield and exits the site as surface runoff. More frequently however, surface runoff is not observed, but seepage downslope of disposal areas occurs. Seepage usually occurs where breaks in slope are found, such as where the house block boundary meets the road. The effect is that effluent is transported to impervious roads and therefore rapidly to stream.

The principal causes of trench failure include:

1. hydraulic overloading due to undersized disposal areas;
2. premature clogging due to carryover of solids from poorly maintained septic tanks;
3. poorly designed effluent trenches;
4. inappropriate site conditions such as slopes greater than 20 %, low soil permeability (notably trench installation in B horizons), where less than 0.5 m of depth exists between base of trench and an impermeable layer (clay or rock), and excessive rainfall;
5. close proximity to shallow groundwater; and
6. poor location of trenches (eg. significant slope breaks, foreshores, gullies, where upslope runoff enters the trench)

The implications of failure include increased mosquito populations; risk of viral and bacterial infection; odours; nutrient migration away from disposal areas; tree decline; degradation of Island surface- and ground-water resources; and significant health risks to Island inhabitants.

8. Summary of Findings

8.1 Land Capability

The capability of land on Scotland Island to accept, accommodate and treat on-site domestic effluent is severely limited. These limitations are imposed by locally steep slopes, limited soil depth, extremely impermeable sub-soils and close proximity to numerous small ephemeral waterways which drain the Islands 15 catchments. The spatial distribution of these factors have been combined using a weighted multiple index overlay algorithm (WMIOA) with the assistance of the GIS system to produce a land capability map (Figure 16). The technique and procedural flow are summarised in Appendix III. Thematic maps, map weights and scores are provided in Table 47.

Table 47: Attribute tables for land capability assessment of on-site effluent disposal, showing thematic maps, map weights, classes, class scores, and class legend.

Class	Score	Legend
A Horizon K_{sat}, mm/day (SCOTKSA1)		**Weight = 1**
0	0	Sea
1	8	L (< 480)
2	10	M (480-1440)
3	6	H (> 1440)
Slope, % (SCOTSLO3)		**Weight = 5**
0	0	Sea
1	10	Low (< 5%)
2	8	Mod (5-10%)
3	5	Ste (10-20%)
4	2	V.Ste (> 20%)
Depth of A Horizon, m (SCOTDPA1)		**Weight = 3**
0	0	Sea
1	1	< 0.25
2	5	0.25 - 0.50
3	7	0.50 - 0.75
4	9	0.75 - 1.00
5	10	> 1.00
Distance to Streams, m (SCOTSTDS)		**Weight = 2**
0	0	Sea
1	1	< 20
2	7	20 - 50
3	9	50 - 100
4	10	> 100

The results of the WMIOA were reclassified into four suitability classes: Unsuitable; Marginal; Moderate; and Suitable. The spatial distribution of these are shown in Figure 16 with results summarised in Table 48. The suitability classes are interpreted as follows:

1. Unsuitable: These locations typically exhibit at least two factors which are highly unsuitable for on-site effluent disposal. In most instances, this is due to the combination of very steep slopes, shallow A horizons, and the location in a major drainage line [ephemeral streams].
2. Marginal: These locations typically exhibit at least one factor which is highly unsuited to on-site effluent disposal. On-site effluent treatment and disposal on these areas is typically regarded as undesirable because of steep slopes and close proximity to streams. Bedrock outcrops limiting soil depth for effluent disposal, are likely in this class.
3. Moderate: Although not ideal, on-site disposal of effluent is possible on these sites due to the presence of good drainage, slightly lower slopes, and sufficient distances from principal drainage lines. A horizons are still in most instances shallow, although bedrock outcropping is unlikely.
4. Suitable: In these areas, most of the required site conditions such as slope, soil depth and distance from streams, are favourable for the on-site disposal of domestic wastewater. However, areas indicated as suitable adjacent to Pittwater are associated with flatter land. In these circumstances, effluent should not be disposed of into tidal-water affected areas.

Table 48: Spatial coverages of land capability classes, including class, description, weighted score range ($\bar{S}$), coverage and comment.

Class	Description	Weighted Score ($\bar{S}$)	Area (ha)	Coverage (%)
1	Unsuitable	0 - 4	2.1575	3.94
2	Marginal	4 - 6	21.7525	39.75
3	Moderate	6 - 8	26.9100	49.17
4	Suitable	8 - 10	3.9025	7.14
Total	-	-	54.7255	100.00

Table 48 indicates that approximately 40 % of the entire Island can be classified as unsuitable or marginal for effluent disposal. Approximately 50 % can be classed as moderately suitable, and less than 10 % maintains site conditions well suited to disposal. It is important to note that the land capability map should, in Part 2 of the study, ideally be combined with land-use zoning (eg. location of parks) to determine the final locations of moderately suitable and suitable potential effluent disposal regions on the Island.

The map presented in Figure 16 can also be viewed as a sensitivity map. Areas which are more suitable to on-site effluent disposal are likely to be less sensitive to environmental degradation because the risk of effluent loss from disposal areas is reduced.

8.2 Environmental Impact of Current Wastewater Systems

Under the current management of domestic wastewater, the environmental impact of on-site wastewater treatment facilities on Scotland Island (predominantly septic tank and soil absorption systems) appears to be substantial. Shallow effective soil depths (< 40 cm), together with high wastewater irrigation depths [associated with small disposal areas], moderate to high soil hydraulic conductivity, steep slopes and subsequent short retention times in the trenches have resulted in the continual seepage of effluent from the disposal areas to the surrounding soil. Therefore, the quality of surface and shallow groundwater around the Island can be considered to be degraded and a potential health risk when exposed at the surface along drainage lines and in streams.

From the results of the brief surface-water quality sampling programme, it appears that significant proportions of contaminated water are entering Island streams during rainfall, either by sub-surface or direct surface runoff. The impact is extremely high concentrations of bacteria and nutrients in overland flow.

Of the trenches examined, they are generally excavated partly into the impermeable B horizon. Clay rich B horizons are highly prone to clogging and do not provide an adequate solution for wastewater disposal. Effluent disposed into this layer is ponded and ultimately overflows, particularly during wet-weather conditions, migrating to downslope areas as surface and/or sub-surface flow. High effluent SARs in the trench are also likely to greatly reduce the hydraulic conductivity of typically heavy clay subsoils because of clay dispersion initiated by an excess of sodium ions. This further inhibits effective treatment of the effluent in the soil.

The soil's phosphorus storage capacity has been exceeded in most disposal areas examined. Trenches are now becoming supersaturated with phosphorus. This is evidenced by the extremely high soil phosphorus concentrations found in the disposal sites. The majority of nitrogen from trenches is likely to be lost to downslope areas. In the case of AWTUs, this loss is somewhat reduced due to the generally larger surface over which treated effluent is irrigated. Significant losses of other soluble contaminants from disposal areas are also likely.

Simple mass balance calculations indicate that up to 80 % of domestic effluent is free to migrate away from the disposal areas and into the adjacent ephemeral streams and ultimately into Pittwater. At present, it is likely that effluent from most systems reaches Pittwater [at least in part], in less than 3 years following land application.

During rainfall, the potential for runoff accumulation in downslope trench areas initiating trench failure exists, especially where trenches or other construction activity has artificially lowered the slope of the land.

Suspended sediment concentrations were high in all storms sampled. This, in conjunction with observations of actively eroding cuttings, tracks and roads, indicates that the Island is also a significant source of both suspended and bedload sediment to Pittwater.

The results of this study clearly indicate that existing septic systems on the Island are deleterious to the environment. Physiochemical soil degradation due to effluent disposal is expected to be widespread and both surface- water and ground-water resources are expected to be polluted. The implications of this are that nutrient sensitive native vegetation may be placed at risk (Ozanne and Specht, 1981). Evidence of *Eucalyptus* dieback has been documented on the Island and this is likely to be partly attributed to nutrient toxicity, particularly downslope of trenches.

Under the current wastewater treatment and disposal management practices, significant amounts of contaminants are likely to continue to accumulate within Island soils. The long term environmental implications of this situation are that surface and ground-water resources are likely to continue to degrade until some new equilibrium is reached. It is not possible, under the given data provided by this study, to determine when such an equilibrium would be reached. However, supersaturated phosphorus levels in current septic trenches indicate that phosphorus saturation of soils downslope of trenches is likely. Based on the Island's low P-sorption levels, threshold levels of saturation in the urban areas may be reached in the next 50 years.

Importantly, continuing degradation of soil structure and consequent soil loss from the Island, shall result in diminishing the 'soil resource'. This effectively further reduces the amount of soil available for effluent treatment and contributes to the degradation of Island water resources.

These conclusions have predominantly been drawn from analyses incorporating mean and derived climatic conditions. The deleterious impacts of the septic systems on the Island's environment is expected to be significantly higher during wet years. Increased rainfall would result in increased surface and groundwater flows facilitating an increase in contaminant export. The potential for sediment movement is also greatest in wet periods.

Finally, it should be noted that the impact of current systems would also be significantly increased if town water were supplied to each household. Section 4.2.3 indicates that significant increases in the amount of water reaching already overloaded wastewater disposal areas would follow the introduction of a fully reticulated town water supply. This in turn would lead to greater effluent migration from the disposal area.

8.3 Health Impact of Current Systems

The monitored surface water indicate bacterial levels (Faecal Coliforms, Streptococci, and Enterococci) illustrate that the quality of ephemeral stream runoff is extremely poor. Bacterial indicator levels are extremely high and exceed recommended ANZECC guidelines for primary and secondary contact by several orders of magnitude. Island surface water consequently represents a serious health threat in situations where direct contact with exposed skin or ingestion occurs.

Existing septic systems are considered to be the primary source of contaminants in surface waters. However, significant contamination is also likely to occur due to animal droppings. Faecal Coliform to Faecal Streptococci ratios [for storm one only] vary considerably but suggest that significant portions of surface runoff are also contaminated by dog/cat Faeces.

The long term health implications of current wastewater treatment practices are that the current degraded water quality situation is likely to remain and worsen with time.

8.4 Impact of Current Systems on Pittwater

The primary impact of the septic systems on surrounding Pittwater is the export substantial sediments, contaminants and bacterial pathogens from the Island. Although there would be significant dilution of water entering Pittwater, the export from the Island of an estimated 700 tonnes of suspended sediment in any year with average rainfall, may significantly influence local Island shore platform ecology. Increased bacterial pathogen levels 100m offshore from Tennis Wharf has been demonstrated in coincidence with rainfall. Though other unsewered areas along the Pittwater foreshore contribute additional effluent to the estuary, it does appear that local seawater pathogen concentrations may be elevated in association with poor quality surface runoff emanating from the Island.

Some dry weather flow was observed in streams on the southern side of the Island (<500 L/day). This source of this flow is considered to be the effluent enriched shallow groundwater that emerges in drainage lines and streams to runoff directly into Pittwater (sampling is recommended).

8.5 Climatic Concerns

The analyses undertaken in this study predominantly utilise the mean or median years cumulative monthly rainfall and daily rainfall intensity. Results presented suggest that under these average climatic conditions or drier there is little risk of surface runoff of effluent from the disposal areas.

However, climatic variability is characteristic of the area and during wetter periods characterised by consecutive months of greater than mean monthly rainfall, the environmental impact of the existing systems is expected to worsen. The incidence of trench failure would rise in association with increased hydraulic loads resulting in shortened effluent retention times and flows of contaminated surface and groundwater. The potential volume of sediment eroded from the Island would also subsequently rise.

Very intense rainfall events are experienced on the Island and these also have the potential to initiate trench failure, especially in downslope areas as well as generating increased surface runoff and net export of contaminants to Pittwater. Severe soil erosion hazards exist on the Island in these conditions.

8.6 Time as an Element of Change

This study has shown that in several trenches, the capacity for on-site disposal of domestic wastewater has already been reached for some parameters such as phosphorus. In these situations, new land treatment systems are required. However, it is important to note that the current situation is not in equilibrium. The Island's ecology is expected to continue to change in response to the increased contaminant loads associated with wastewater systems. Impacts of current management practices will therefore increase over the next 10-50 years as the total Island capacity for contaminant assimilation is reached. Surface- and ground-water quality is therefore also expected to deteriorate with time.

Island population dynamics play an important role in the impact of current wastewater treatment/disposal systems. Increasing Island population over the next 20 years would serve to place further stresses on the Island's already stressed and partially degraded ecosystem.

9. Conclusions and Recommendations

9.1 Recommendations

This investigation into current wastewater disposal practices and surface water quality on Scotland Island has revealed several important findings. Although sites sampled were limited, large amounts of data were collected from each of the monitoring programmes: surface water sampling; soil survey; effluent and trench water quality; and soil physiochemistry in trench disposal areas. Several important recommendations concerning management of wastewater and related issues on the Island can be drawn from these:

1. Effluent Disposal and Wastewater Management

a. Effluent disposal on steep slopes with local grade greater than 20 % is not recommended. These areas typically have shallow soils and are in the upper reaches of Island gullies.

b. Current grey-water disposal activities are not suitable and are likely to be contributing to environmental degradation. Greywater treatment prior to discharge is required.

c. Current trench surface areas are frequently too small to accommodate effluent contaminant loads. Disposal area sizes should be increased (to the minimum AS1547 requirements) so that effluent may be more effectively absorbed and further treated.

d. Subsoils are impermeable and sodic. Trench excavation and effluent disposal into subsoils is therefore not recommended.

e. Higher permeability of the A horizon ensures that little surface runoff from effluent disposal areas occurs. However, during wet weather, significant amounts of wastewater are exported from trenches as sub-surface flow. Some form of wet-weather retention is required to ensure that effluent is not disposed of during intense rainfall.

f. Some 4 % of the Island is unsuitable for the disposal of domestic effluent (see Land Capability map, Figure 16). New development in unsuitable areas be avoided. Effluent disposal on the foreshores which are affected by tidal water should also be avoided.

g. Current wastewater treatment and disposal practices are inadequate and have seriously affected the local environment. Investigation into other suitable technologies for treating and disposing of domestic wastewater is required

h. A community education program recommending low Phosphorus and low Sodium detergents and cleaning agents is recommended.

2. Protection of Ephemeral Streams and Gullies.

a. The existing quality of surface runoff in the ephemeral creeks is severely degraded. Continued monitoring of several Island creeks is recommended on a catchment by catchment basis.

b. A minimum building buffer distance of 20m to Island ephemeral streams is recommended to provide some protection to both surface water resources and riparian vegetation

c. Urban runoff from streets is highly contaminated. Although space is limited, storm runoff retention and treatment facilities are required to improve runoff quality before discharging into Pittwater.

3 Prevention of Health Risks

a. The quality of surface water in surface ponds and creeks is such that direct contact with skin or ingestion may incur serious heath risks. Contact with all ponded water during either wet or dry conditions should be avoided.

b. A community education programme is recommended that provides information on proper wastewater management practices and informs Island residents about the quality of Island surface water.

4. Ground-water Sampling

a. High infiltration rates of A horizons indicates that significant sub-surface flows occur in Island soils during rain. Shallow groundwater sampling, predominantly in some of the lower gullies is therefore recommended to determine the nature and extent of ground-water degradation.

5. Soil Conservation and Erosion Control

a. Significant soil loss is occurring from the Island from roads, walking tracks and construction sites. Soil erosion control measures are recommended to improve this situation and prevent degradation of Island foreshore ecosystems.

b. Construction areas on the Island frequently do not utilise erosion control measures but are located on steep unstable land which is highly prone to erosion. Strict erosion and sediment control measures should be in place during construction activity. Storage of construction refuse on site should be limited and removal expedited.

c. The majority of post-disposal effluent treatment occurs in the A horizon. Precautions should be taken to prevent or minimise the removal of the A horizon soil due to its limited thickness and the impermeability of the B horizon.

6. Native and Existing Vegetation

a. Future development sites should be carefully selected so as to conserve and enhance the remnant native vegetation.

b. It is likely that tree dieback is being caused by several factors, of which effluent disposal is only one. A more detailed tree dieback study is recommended which takes account of location and proximity to effluent disposal systems.

7. Water Supply

a. Under current management practices, the continuous supply of reticulated town water would make existing septic trench disposal ecologically unsustainable due to increased hydraulic and contaminant loads to the disposal area.

b. The existing emergency water supply should be upgraded due to the present risk of groundwater exfiltration of effluent. This is particularly the case in small street depressions where effluent and degraded street runoff accumulate.

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11. Appendix I: List of Relevant Studies

1. Water usage survey: Scotland Island Residents Committee
2. Institute of Coastal Resource Management, University of Technology (1994) Scotland Island Management Report, Miscellaneous Publication No. 29
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5. Pittwater Council (1995) Draft Management Plan for Church Point
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8. Cunningham, G. (1994) Vegetation Study of Barrenjoey Peninsula and Adjoining Lands, Natural Resource Consultants Pty Ltd
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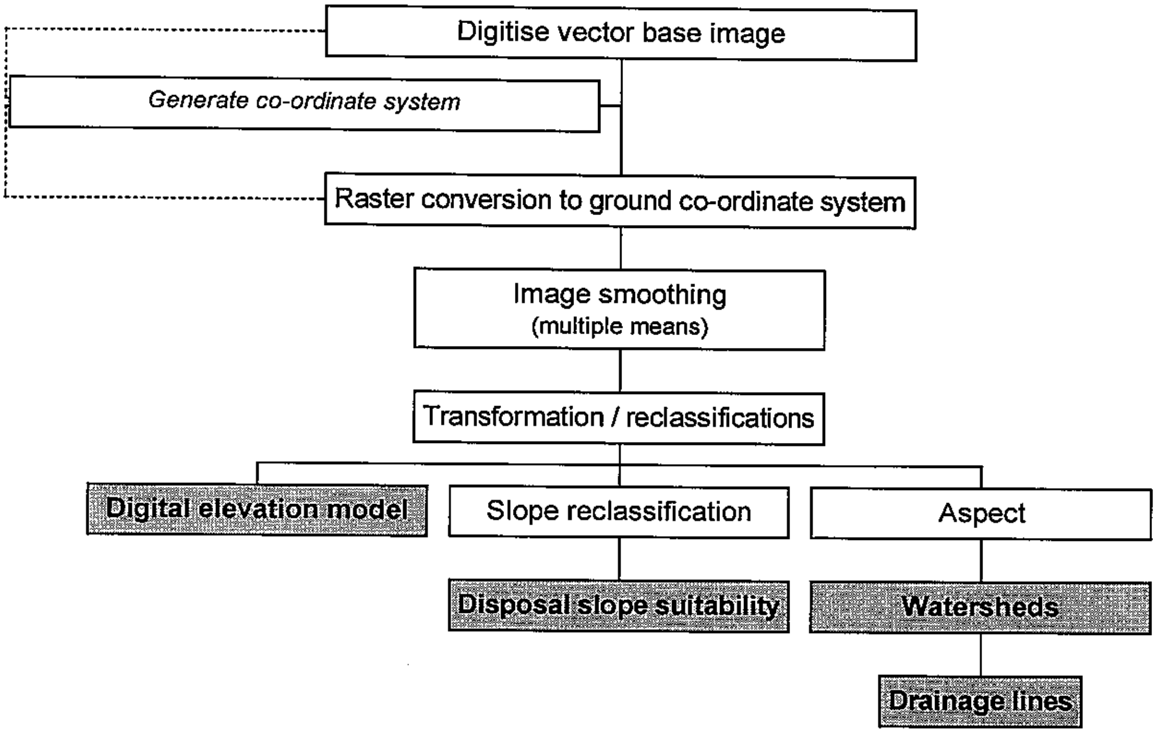
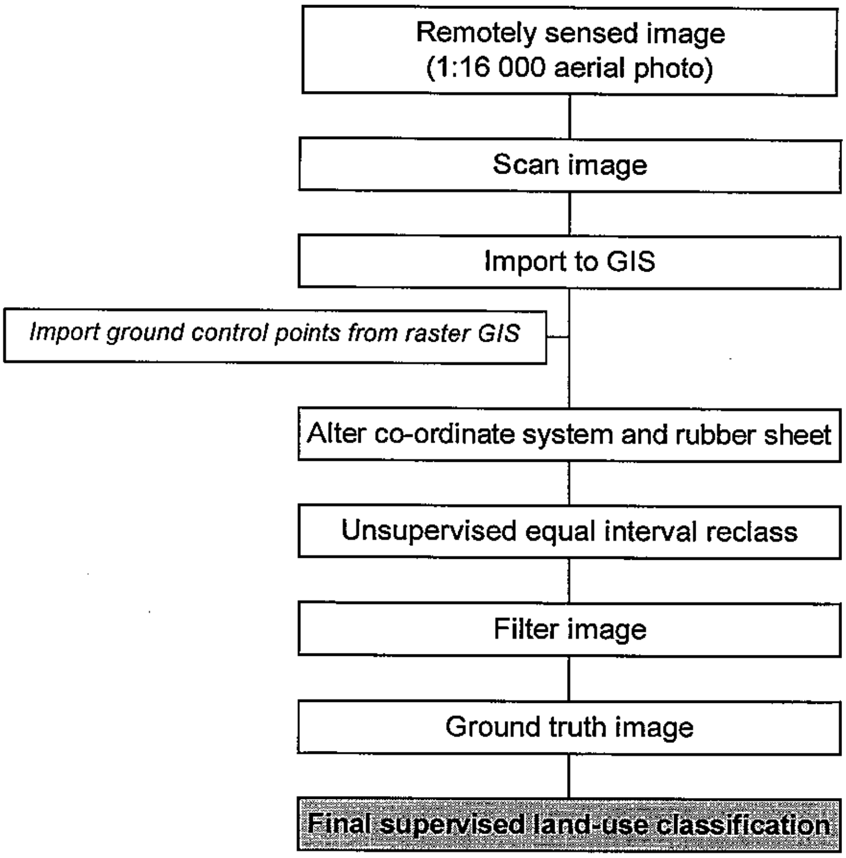
10. Patterson Britton & Partners Pty Ltd (1994) Ingleside Warriewood Urban Release Area Water Cycle Management Study Final Report

12. Appendix III: GIS Control Flow Algorithm Structures

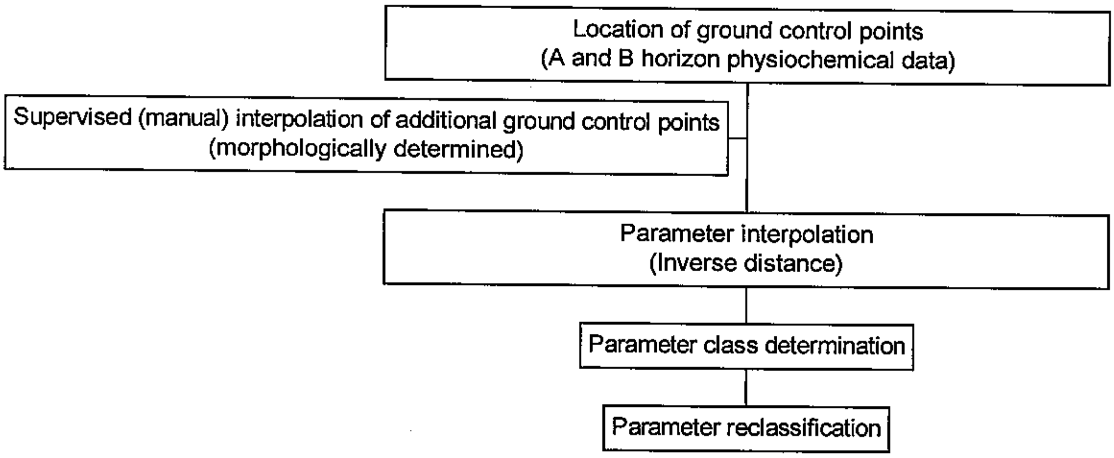
TOPOGRAPHIC ANALYSIS SCHEME



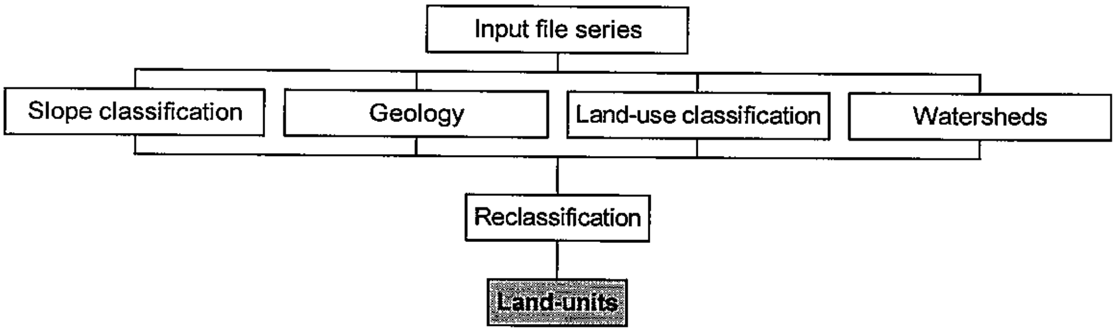
LAND-USE CLASSIFICATION SCHEME



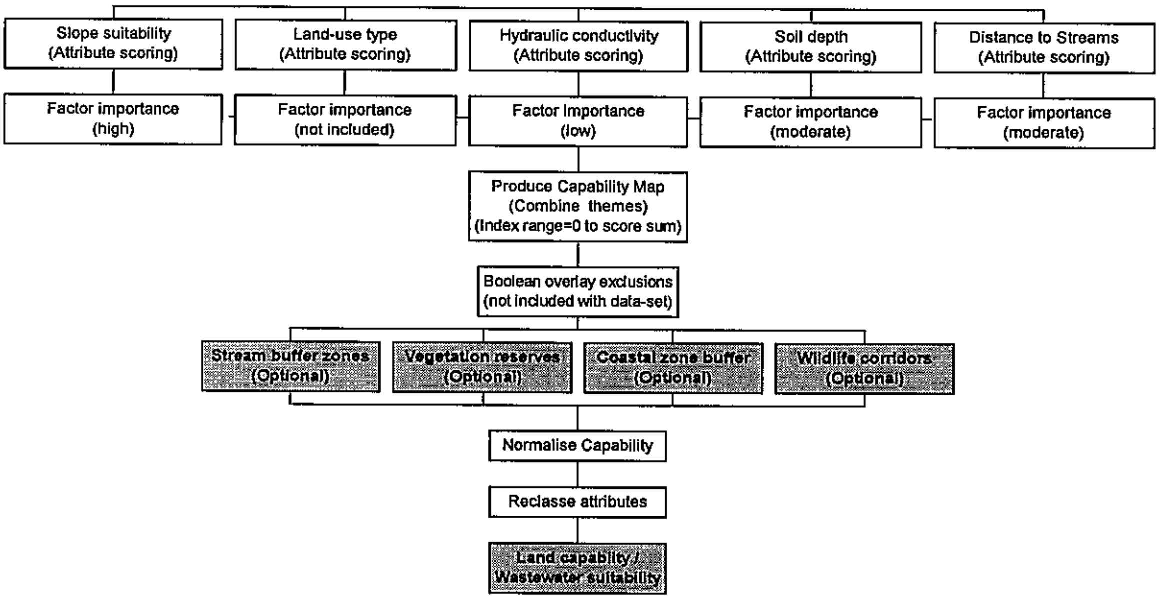
ISLAND SOIL PHYSIOCHEMICAL INTERPOLATION SCHEME



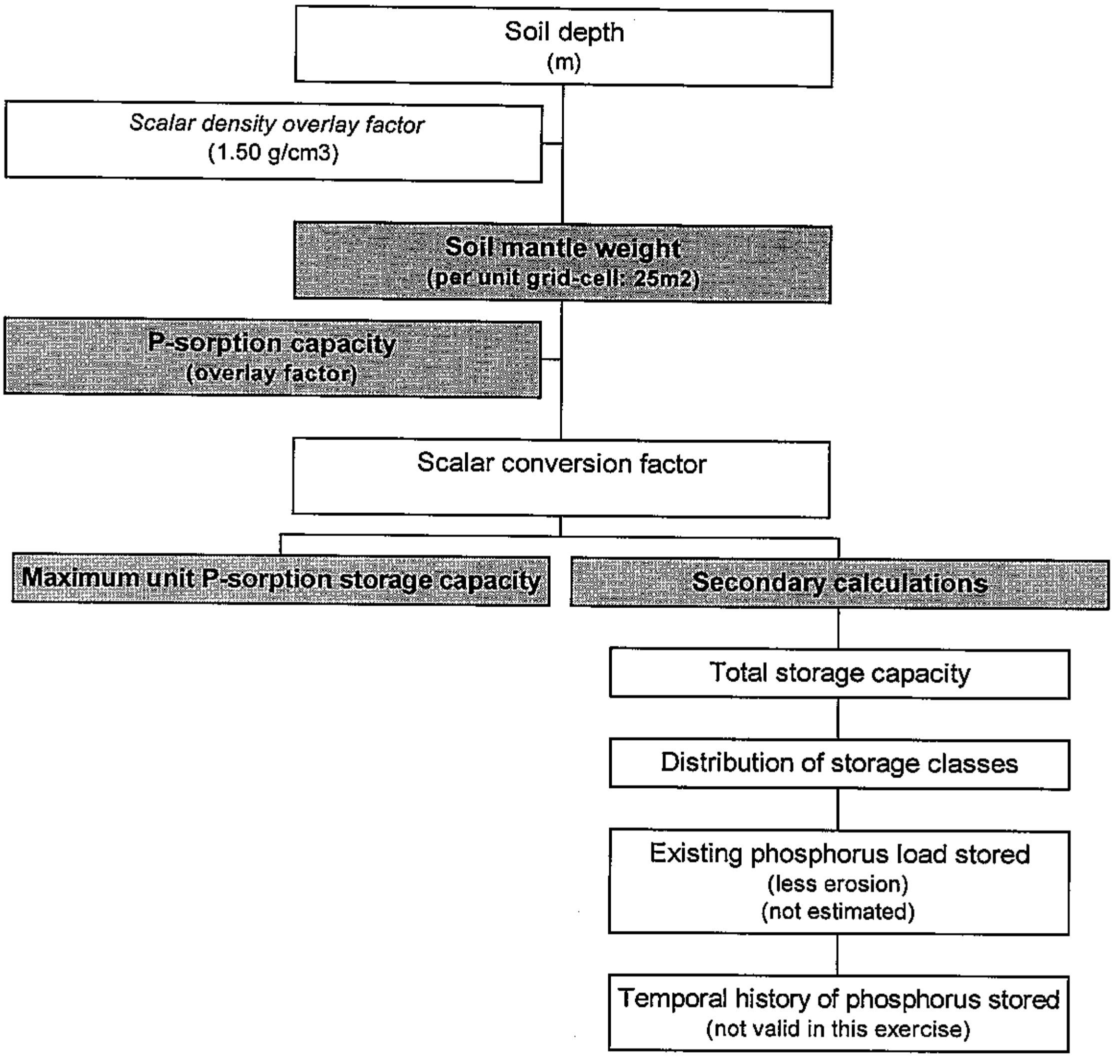
LAND-UNIT CLASS CLASSIFICATION SCHEME



LAND CAPABILITY / WASTEWATER SUITABILITY ASSESSMENT



SOIL PHOSPHORUS SORPTION CAPABILITY



13. Appendix III: List of GIS data files

NAME (.ima/.doc)	RES (c,r)	DESCRIPTION
scotala	190x190	Aluminium (cmol(+)/kg): A Horizon
scotalb	190x190	Aluminium (cmol(+)/kg): B Horizon
scotasp	190x190	Aspect
scotbase	190x190	Base map for other map overlays of Island
scotbpa	190x190	Bray phosphate (mg/kg): A horizon
scotbpb	190x190	Bray phosphate (mg/kg): B horizon
scotcaa	190x190	Calcium (cmol(+)/kg): A Horizon
scotcab	190x190	Calcium (cmol(+)/kg): B Horizon
scotcea	190x190	CEC (cmol(+)/kg): A Horizon
scotceb	190x190	CEC (cmol(+)/kg): B Horizon
scotdp	190x190	Total soil thickness (A+B, m)
scotdpa	190x190	Thickness of A horizon (m)
scotdpb	190x190	Thickness of B horizon (m)
scoteca	190x190	Electrical conductivity (dS/m): A horizon
scotecb	190x190	Electrical conductivity (dS/m): B horizon
scotelf1	190x190	Digital elevation model (DEM)
scotesa	190x190	Exchangeable sodium (%): A Horizon
scotesb	190x190	Exchangeable sodium (%): B Horizon
scotgeol	190x190	Geological units
scothill	190x190	Shaded relief map
scotka	190x190	Potassium (cmol(+)/kg): A Horizon
scotkb	190x190	Potassium (cmol(+)/kg): B Horizon
scotksat	190x190	Raw saturated hydraulic conductivity data
scotksa1	190x190	Saturated hydraulic cond. classes: A horizon
scotland	190x190	Land capability classes for effluent disposal
scotlong	190x190	Site longevity a
scotlon1	190x190	Total site longevity
scotmga	190x190	Magnesium (cmol(+)/kg): A Horizon
scotmgb	190x190	Magnesium (cmol(+)/kg): B Horizon
scotnaa	190x190	Sodium (cmol(+)/kg): A Horizon
scotnab	190x190	Sodium (cmol(+)/kg): B Horizon
scotnoa	190x190	NO3-nitrogen (mg/kg): A horizon
scotnob	190x190	NO3-nitrogen (mg/kg): B horizon
scotpha	190x190	pH: A horizon
scotphb	190x190	pH: B horizon
scotpsa	190x190	Raw P-sorption: A horizon
scotpsa1	190x190	P-sorption unit classes: A horizon
scotpsb	190x190	Raw P-sorption: B horizon
scotpsb1	190x190	P-sorption unit classes: B horizon
scotpsa2	190x190	P-sorption (mg/kg): A Horizon
scotpsb2	190x190	P-sorption (mg/kg): B Horizon
scotroad	190x190	Road network
scotslo3	190x190	Slope classes
scotstds	190x190	Distance from stream network classes
scotstre	190x190	Stream network (raster)
scottca	190x190	Total carbon (%): A horizon

scottcb	190x190	Total carbon (%): B horizon
scottna	190x190	Total nitrogen (%): A horizon
scottnb	190x190	Total nitrogen (%): B horizon
scotveg8	190x190	Landuse and vegetation map

14. Appendix IV: Soil Pit log sheets.

PROFILE No. 1 **SURVEY DATE: 6/10/95**

GEOLOGY: Hawkesbury sandstone
VEGETATION: see notes
SLOPE: v. low
ASPECT: none
DESCRIPTION; Top of western most hill, site adjacent to walking track and permanent seat structure.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A	0 - 2	LS	10yr 3/3 dark brown	none	sandy & unconsolidated some root mass shallow, unstructured and homogeneous
A	2 - 16	LS	10yr 3/3 dark brown	none	sandy & unconsolidated some root mass shallow, unstructured and homogeneous
C	16+	weathered rock	10yr 4/4 weak red	n/a	some clay, grains easily abraded from surface

CLASSIFICATION Red / Brown Podzolic

PROFILE No. 2 **SURVEY DATE: 6/10/95**

GEOLOGY: Hawkesbury sandstone
VEGETATION: E. maculata, Xanrthorea, recently burnt, less than 10mm of charcoal on surface
SLOPE: low (10 to 20%)
ASPECT: SW
DESCRIPTION; Saddle between two hills.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 21	SL	10yr 4/3 dark brown	none	roots unconsolidated weak peds <2mm
A2	21 - 25	SI	10yr 4/3 dark brown	none	roots unconsolidated weak peds <2mm sharp contact with B horizon
B	25 - 50	SCL	10yr 5/3 brown	none	sandstone floaters
C	50+				

CLASSIFICATION Gradational earth

PROFILE No. **3** **SURVEY DATE: 6/10/95**

GEOLOGY: claystone, top of narrabeen group.
VEGETATION: E. maculata, Xanrthorea, recently burnt, less than 10mm of charcoal on surface, Casuarina
SLOPE: low (10 to 20%)
ASPECT: NNE
DESCRIPTION; Ridge line.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 7	LS	10yr 4/3 dark brown	none	gradational change between A and B horizon, large floater evident >100mm b-axis
A2	7 - 23	LS	10yr 4/3 dark brown	none	
B	23 - 50		10yr 3/3 dark brown	none	discontinuous, soft and hard floaters evident sandy
C	50+		5yr 5/8 yellowish red		weathered rock, easily abraded

CLASSIFICATION Red Podzolic

PROFILE No. **4** **SURVEY DATE: 6/10/95**

GEOLOGY: Narrabeen group.
VEGETATION: Wet Schlerophyll
SLOPE: steep
ASPECT: S
DESCRIPTION; Swale near drainage line, in dense vegetation

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
O	0 - 5	humus	black	none	
A	5 - 50	LS	10yr 3/3 dark brown	none	sandy, unconsolidated, weathered sandstone floaters common (20cm depth) sharp contact with the B horizon
B	50 - 97	LC	10yr 6/8 brownish yellow & 10yr 7/4 Very pale brown	none	cohesive, light mottling, no sand clay rich root depth to 40cm
C		weathered rock			

CLASSIFICATION Brown Podzolic

PROFILE No. **5** **SURVEY DATE: 6/10/95**

GEOLOGY: Hawkesbury sandstone
VEGETATION: Dry Schlerophyll
SLOPE: 20 - 30%
ASPECT: N
DESCRIPTION; Biribe road cutting

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A	0 - 23	LS	10yr 3/3 dark brown	none	common sandstone floaters <50mm b-axis sharp contact with the B horizon
B	23 - 60	CS	10yr 5/3 brown	none	
C	60+	Weathered rock	5yr 4/6 yellowish red	none	

CLASSIFICATION Red Podzolic

PROFILE No. **6** **SURVEY DATE: 6/10/95**

GEOLOGY: ?
VEGETATION: cleared, partially revegetated by adjacent landholder
SLOPE: steep
ASPECT: N
DESCRIPTION; Next to house with scarecrows.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A	0 - 68	LS	5yr 2.5/1 black grades to 5yr 2/2 V. dark brown	none	common sandstone floaters <5mm b-axis gradational soil homogeneous, only one sample taken unconsolidated and sandy. no B horizon evident
C	68+	weathered rock			

CLASSIFICATION Gradational soil / Colluvium

PROFILE No. **7** **SURVEY DATE: 6/10/95**

GEOLOGY: Narrabeen group
VEGETATION: Degraded dry Schlerophyll
SLOPE: 20 - 30%
ASPECT: N
DESCRIPTION; To the west and above the park at Tennis wharf.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A	0 - 33	LS	10yr 4/6 dark yellowish brown	none	unconsolidated and sandy
B	33 - 98	LC light clay	10yr 5/8 yellowish brown	none	cohesive & malleable
C	98+	weathered rock			

CLASSIFICATION Yellow Podzolic

PROFILE No. **8** **SURVEY DATE: 6/10/95**

GEOLOGY: Narrabeen group
VEGETATION: Grassed park at Tennis wharf
SLOPE: Flat
ASPECT: N
DESCRIPTION; In main park at Tennis wharf.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
O	0 - 3	grass	green		maintained public lawn
A	3 - 36	SL	10yr 2/2 V.dark brown	none	high organics well drained despite being low lying
B	36 - 83+	SCL	10yr 5/4 yellowish brown	none	cohesive & malleable
C	?	weathered rock			

CLASSIFICATION Yellow Podzolic

PROFILE No. **9** **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen group
VEGETATION: Mature Acacia, Asparagus fern, daisies, Lilli Pilli, Spotted gum (E. maculata)
SLOPE: Moderate
ASPECT: W
DESCRIPTION; Above road in front yard.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 17	LS	10yr 4/3 dark brown (grades to A2)	none	dense root mass between 0 - 17. unconsolidated and sandy, common floaters floaters increase in frequency with depth
A2	17 - 44	LS	10yr 5/6 yellowish brown	none	gradational change to B
B	44 - 95	LS	10yr 6/8 brownish yellow	minor blocky structure	unconsolidated, floater rich. Soil horizons is gradational in colour but with fairly uniform texture.
C	95+	weathered rock			

CLASSIFICATION Yellow Podzolic

PROFILE No. **10** **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen group
VEGETATION: Medium density ground cover, disturbed, mature maculata & casuarina.
SLOPE: Moderate
ASPECT: S
DESCRIPTION; Adjacent to road.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A	0 - 30	LS	10yr 3/3 dark brown	none	high root mass sharp contact with B
B	30 - 105	CL	5yr 5/6 yellowish red	slight blocky structure	cohesive, weak structure gradational change to C
C	105+	weathered rock			

CLASSIFICATION Yellow Podzolic

PROFILE No. 11 **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen group
VEGETATION: Dense, Wet Sclerophyll
SLOPE: Moderate
ASPECT: S
DESCRIPTION; Alluvial and Colluvial site adjacent to creek with significant dry weather moisture

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 58	S	10yr 2/1 black	none	organic rich, unconsolidated sand gradational change to A2
A2	58 - 110	S	2.5yr 5/4 light olive brown	none	leached sand, low organics, colour change Sharp contact with B.
B	110 - 185	SCL	5yr 5/8 yellowish red	none	
C	185+	weathered rock			

CLASSIFICATION Very sandy alluvium with remnant clay rich B Horizon

PROFILE No. 12 **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen group
VEGETATION: Dry Sclerophyll - E. maculata, bracken fern, Personia, seedling Turpentines, Pittosporum
SLOPE: Steep
ASPECT: SE
DESCRIPTION; Alluvial and elluvial site adjacent to creek with significant dry weather moisture

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 33	LS	10yr 3/2 V.dark greyish brown	none	sand, unconsolidated, high organic content gradational change to A2
A2	33 - 54	LS	10yr 4/3 brown	none	sand, unconsolidated sharp contact with B
B	54 - 98	SL	10yr 5/6 yellowish brown	none	shear marks in auger plug
C	98+	weathered rock			

CLASSIFICATION Yellow Podzolic

PROFILE No. 13 **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen group
VEGETATION: E. maculata, Casuarina, maiden hair, Lantana, Xanthorea
SLOPE: 20 - 30%
ASPECT: S
DESCRIPTION; Above road.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
O	0 - 5		red brown staining	none	humus
A1	5 - 24	LS	10yr 2/2 very dark brown	none	sand, unconsolidated sharp contact with A2
A2	24 - 38	LS	10yr 3/4 dark yellow brown	none	sandy, non-cohesive sharp contact with B.
B	38 - 90	SCL	2.5yr 5/8 red	minor blocky peds	clay rich and cohesive
C	90+		5yr 5/6 yellowish red		

CLASSIFICATION Red Podzolic

PROFILE No. 14 **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen / Hawkesbury boundary
VEGETATION: E. maculata, open and disturbed garden area, some grass.
SLOPE: Steep
ASPECT: S
DESCRIPTION; Road cutting.

HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 27	LS	10yr 2/2 V.dark brown	none	sandy, unconsolidated
A2	27 - 65	LS	10yr 3/4 dark yellow brown	none	sandy, unconsolidated sharp contact with B
B	65 - 155	SCL	10yr 6/8 brownish yellow 10yr 7/8 yellow 10yr 7/1 light grey	V. minor blocky peds	all colours present. light grey is associated with tight veins of white clay. This cutting was adjacent to a large sandstone floater.
C	155+	weathered rock			

CLASSIFICATION Yellow Podzolic

PROFILE No. **15** **SURVEY DATE: 10/10/95**

GEOLOGY: Narrabeen
VEGETATION: Mature E. maculata, open and disturbed garden area, some grass & juvenile Casuarina.
SLOPE: Moderate to low
ASPECT: E
DESCRIPTION; Above road, front yard.

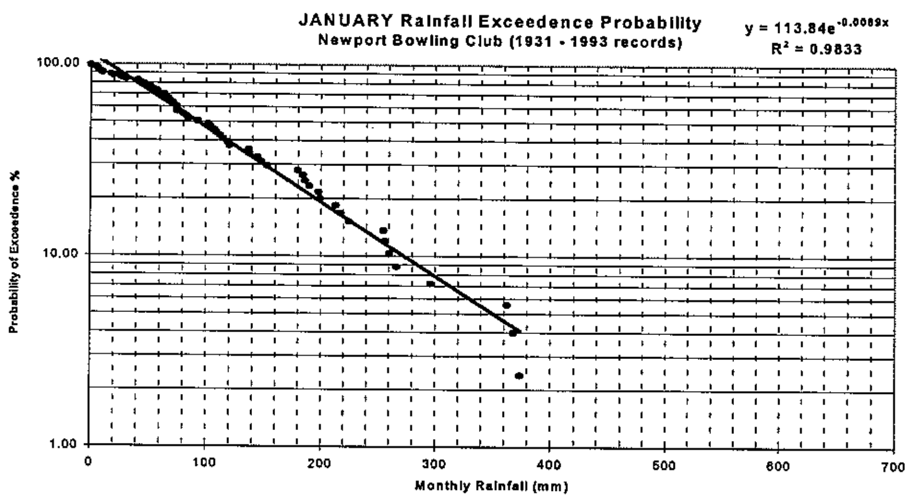
HORIZON *SKETCH*	DEPTH cm	TEXTURE	COLOUR	STRUCTURE	COMMENTS
A1	0 - 15	LS	10yr 4/3 brown	none	sandy, unconsolidated. Shallow soil here. A1 appears to have been lost therefore, depth of A1 has been estimated.
A2	15 - 25	LS	10yr 3/4 dark yellow brown	none	sandy, unconsolidated
B	25 - 50	LC (or silty clay loam)	10yr 5/6 yellow brown	minor blocky peds	clay rich, cohesive.
C	50+				

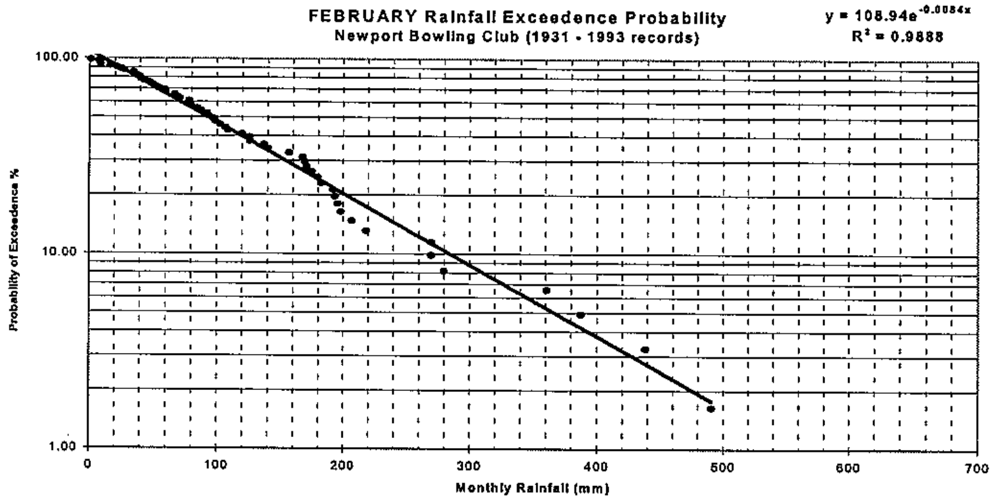
CLASSIFICATION Yellow / brown Podzolic

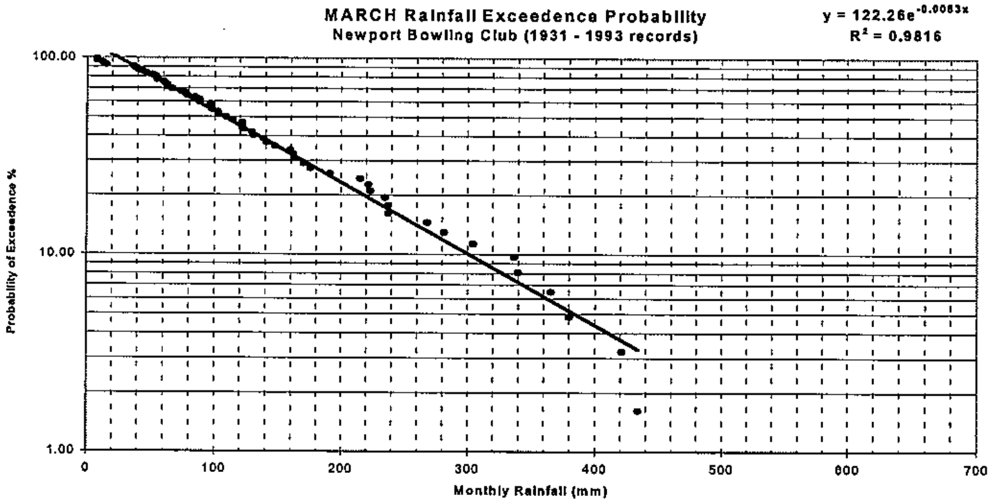
15. Appendix V: Soil physiochemical test results.

16. Appendix VI: Climatic data analyses.

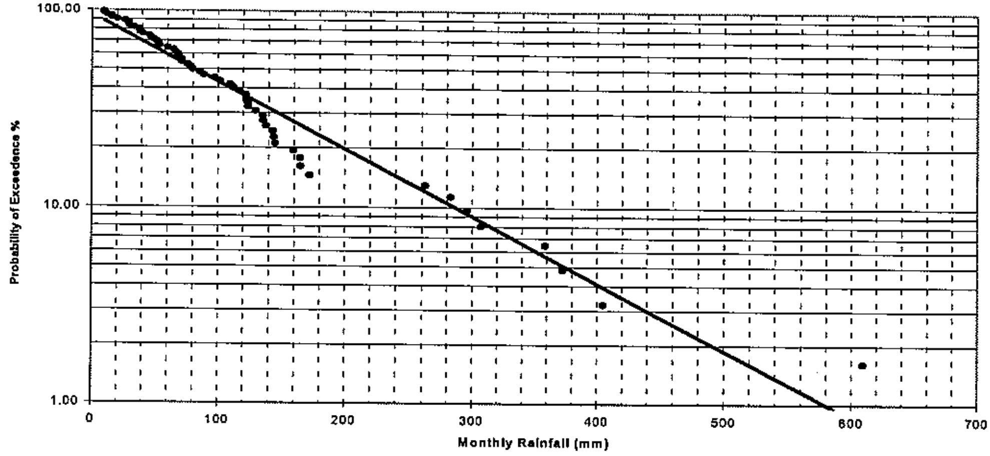
Probability of exceedence curves for cumulative monthly rainfall.



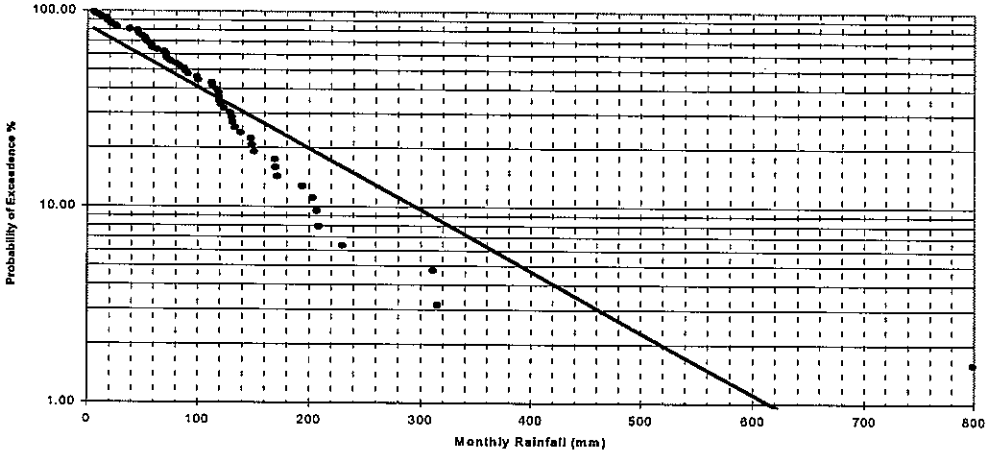




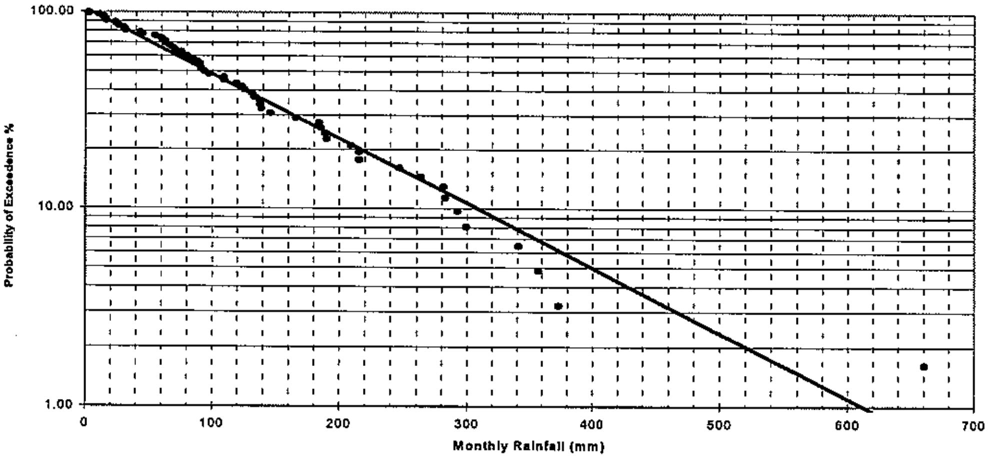
APRIL Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



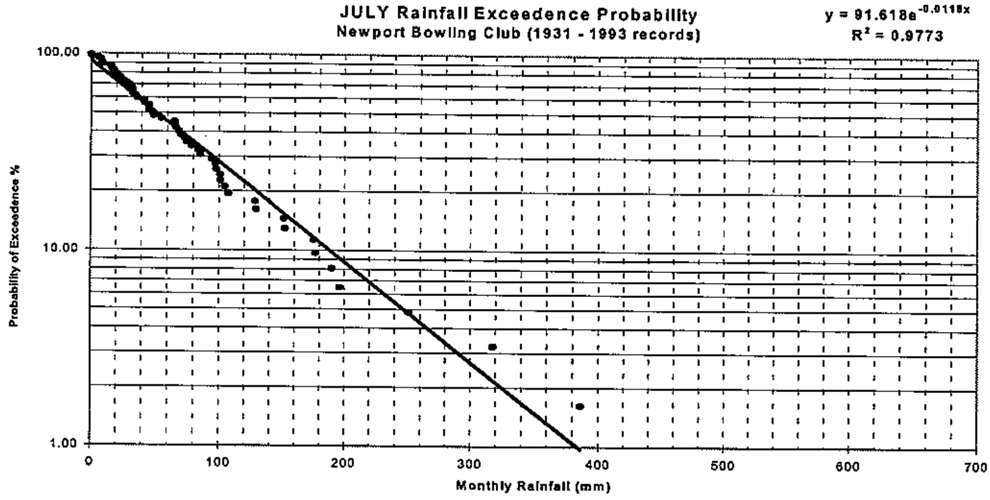
MAY Probability of Exceedence
Newport Bowling Club (1931 -1993 records)



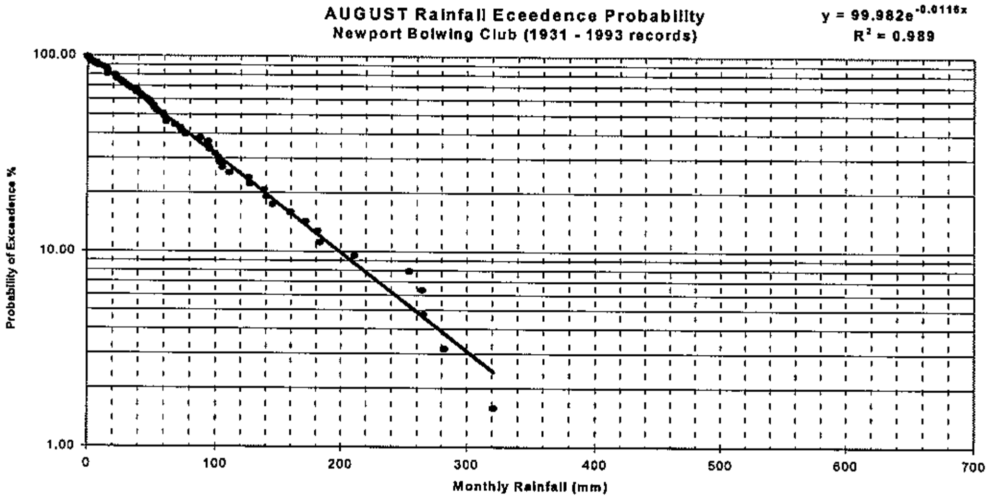
JUNE Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



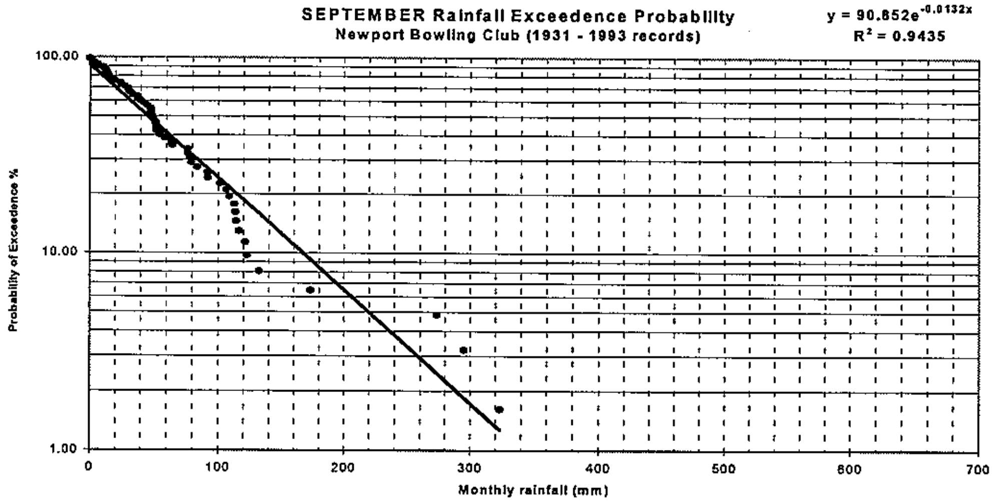
JULY Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



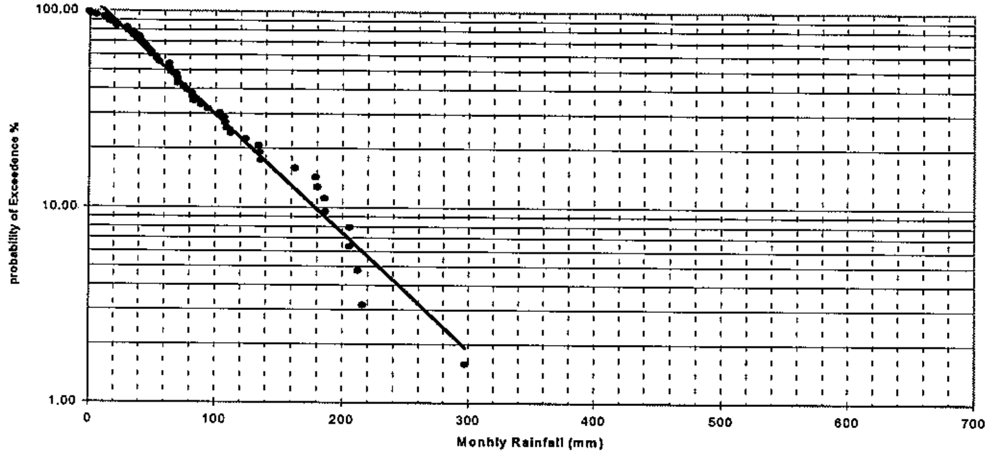
AUGUST Rainfall Eceedence Probability
Newport Bolwing Club (1931 - 1993 records)



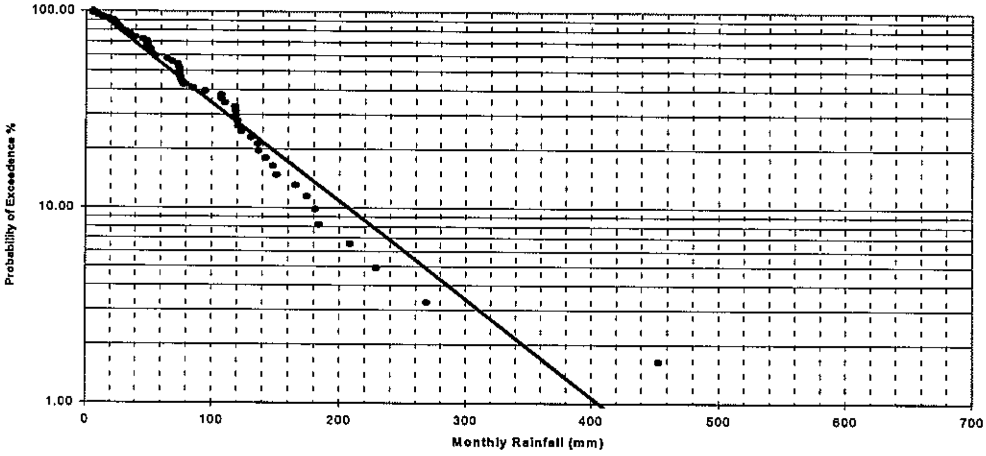
SEPTEMBER Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



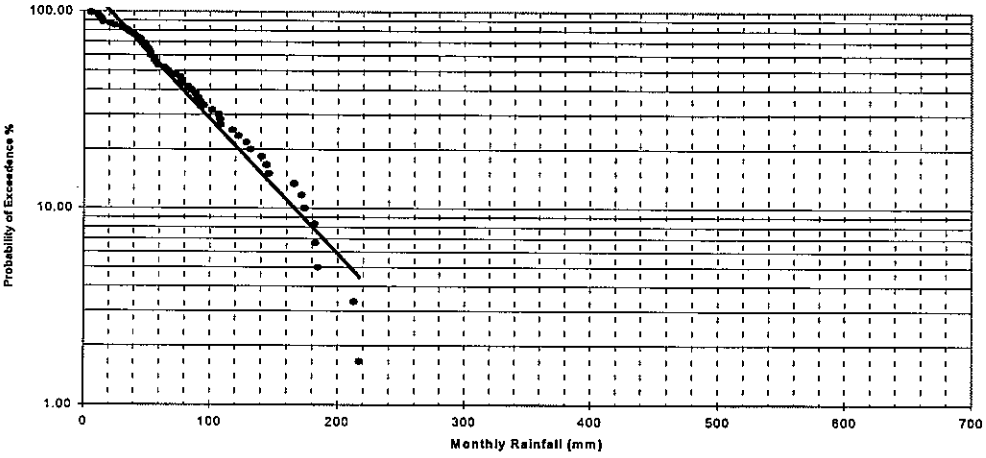
OCTOBER Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



NOVEMBER Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



DECEMBER Rainfall Probability Exceedence
Newport Bowling Club (1931 - 1993 Records)

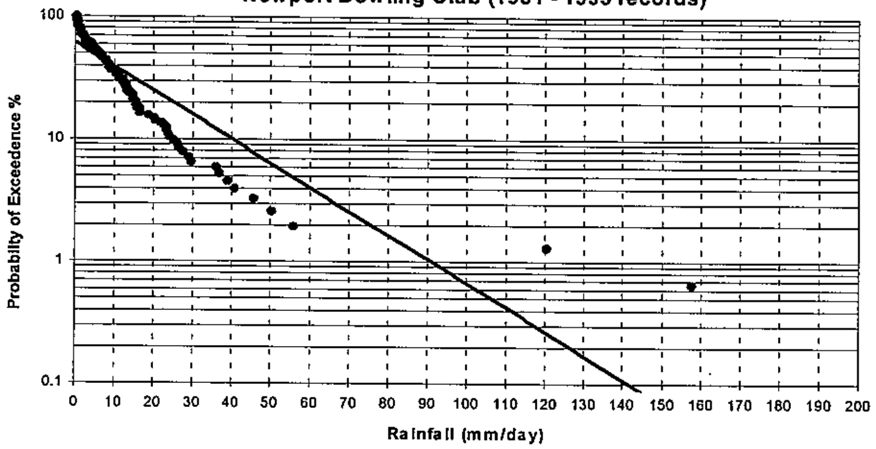


Probability of exceedence curves for daily rainfall Intensity.

(from random 15 year sample)

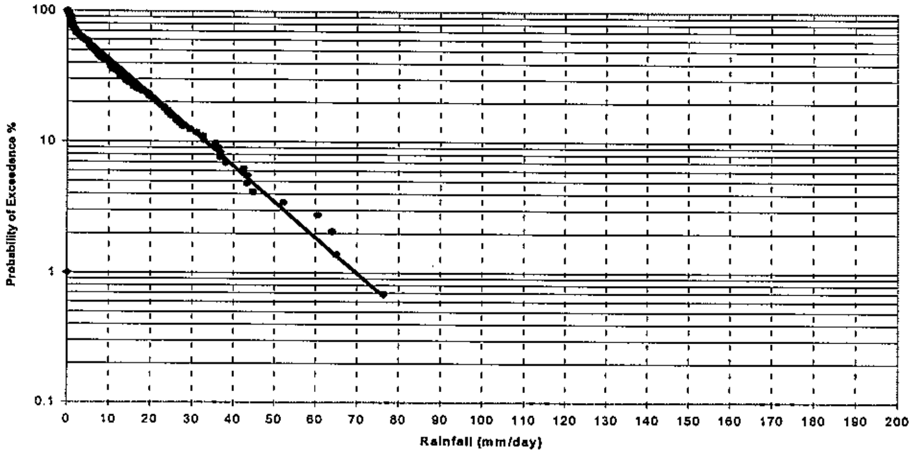
JANUARY Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 61.464e^{-0.0453x}$
$R^2 = 0.7691$



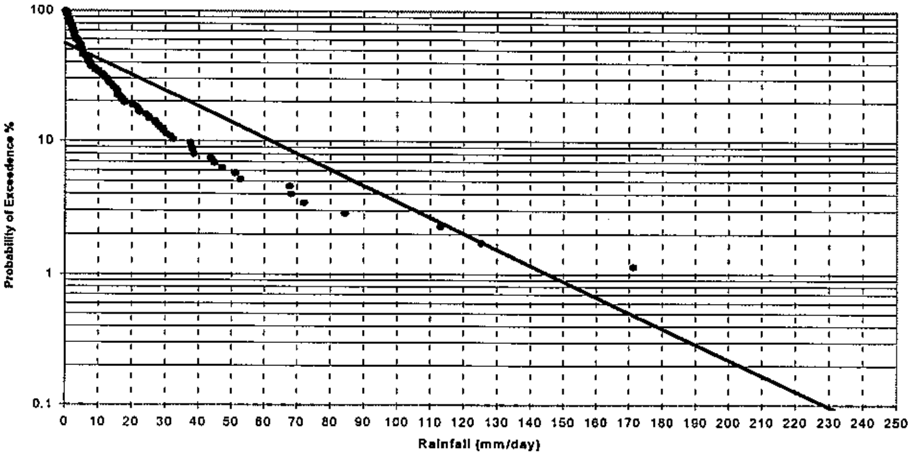
FEBRUARY Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

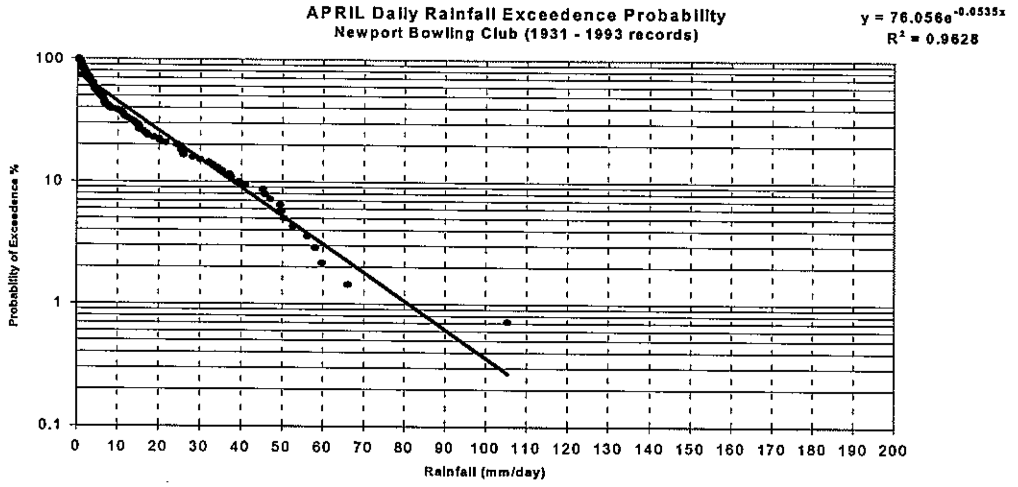
$y = 80.664e^{-0.0629x}$
$R^2 = 0.9873$



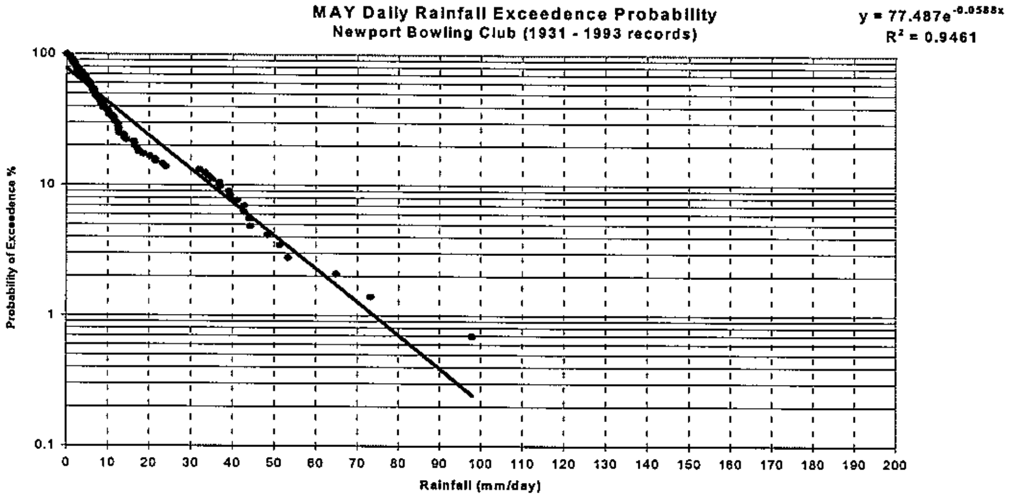
MARCH Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 55.694e^{-0.0277x}$
$R^2 = 0.7414$

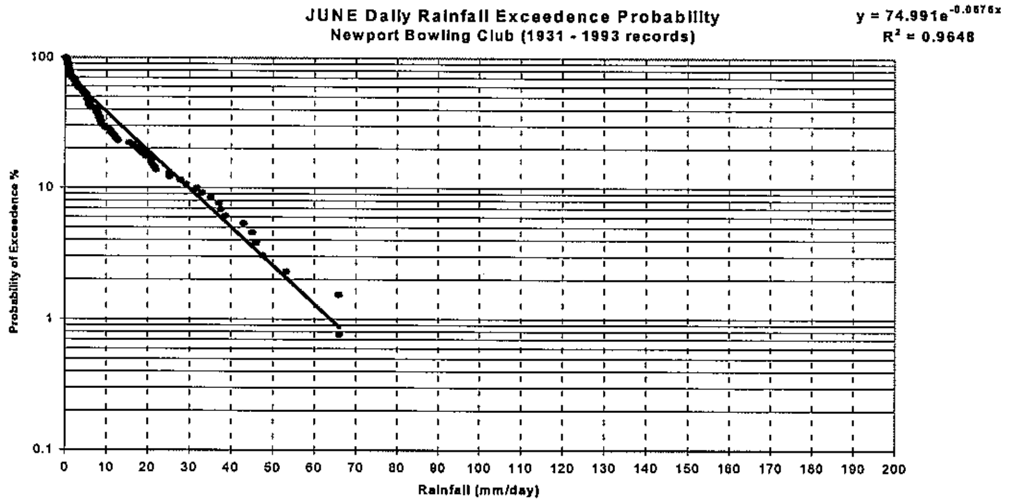




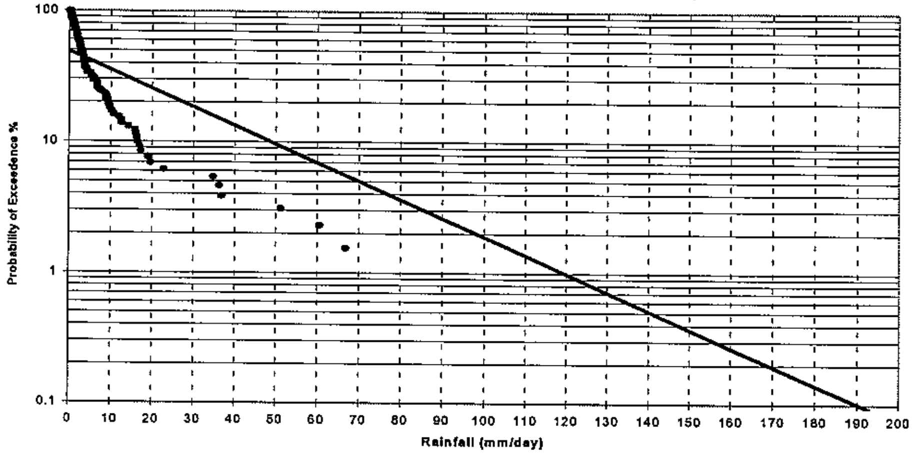
APRIL Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



MAY Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

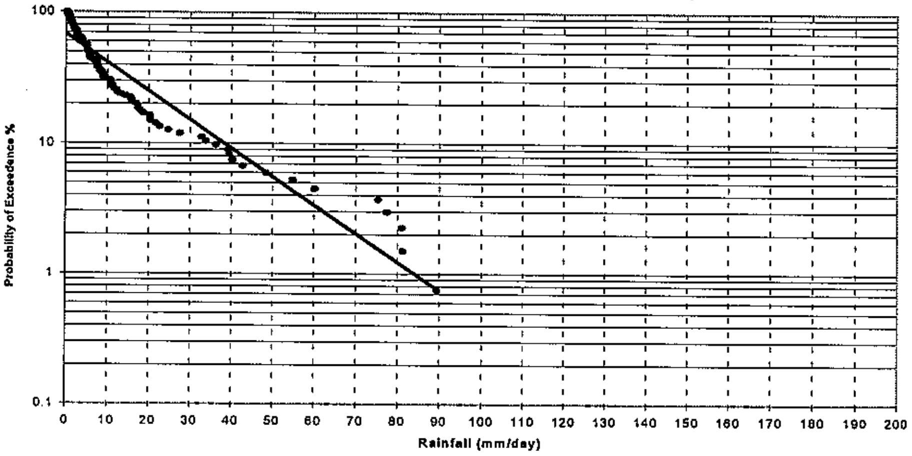


JUNE Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)



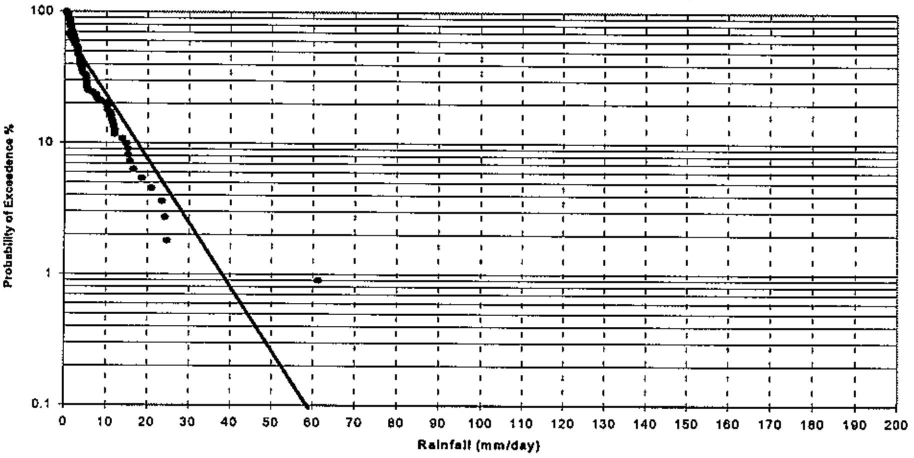
JULY Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 48.871e^{-0.0325x}$
$R^2 = 0.5438$



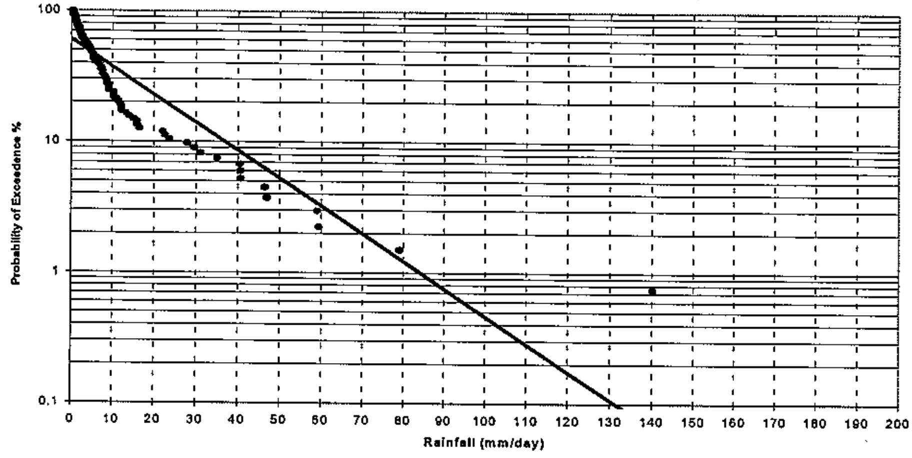
AUGUST Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 68.573e^{-0.0503x}$
$R^2 = 0.9091$



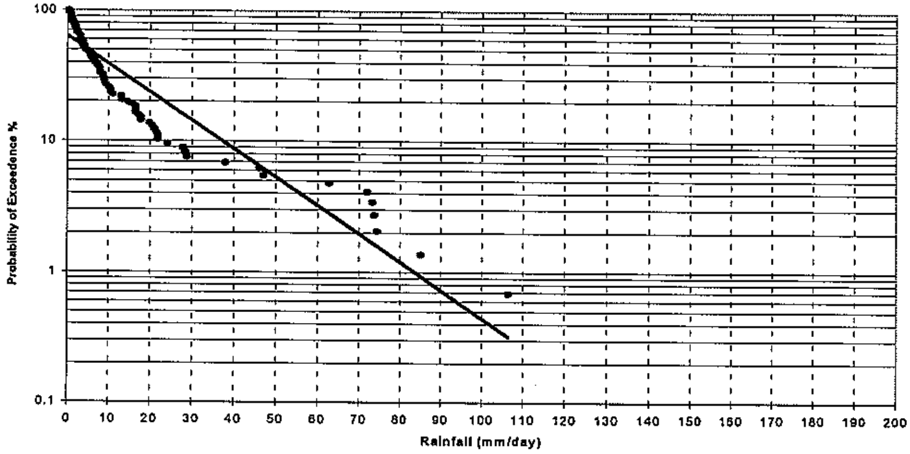
SEPTEMBER Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 70.847e^{-0.1121x}$
$R^2 = 0.8401$



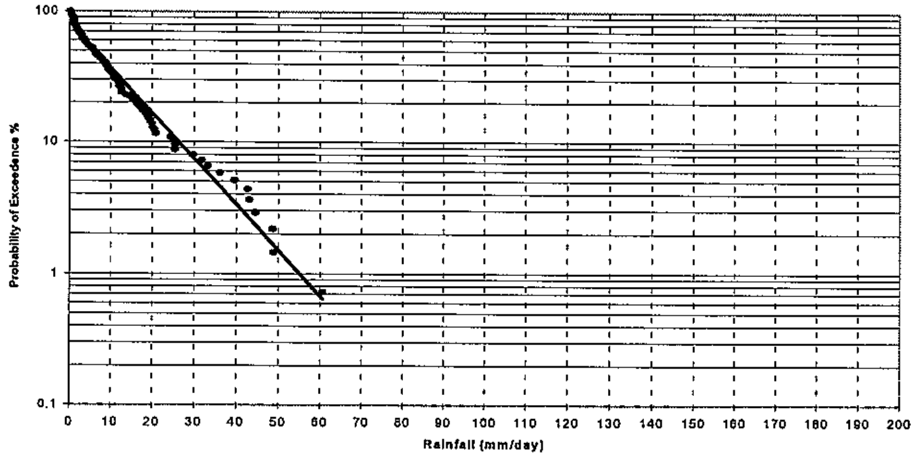
OCTOBER Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 60.549e^{-0.0488x}$
$R^2 = 0.8027$



NOVEMBER Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 63.85e^{-0.0497x}$
$R^2 = 0.859$



DECEMBER Daily Rainfall Exceedence Probability
Newport Bowling Club (1931 - 1993 records)

$y = 82.899e^{-0.0803x}$
$R^2 = 0.9814$

Summary Table: Probability of exceedence equations calculated using monthly and daily rainfall data recorded at Newport Bowling Club between 1931 & 1993.

Month	Cumulative Monthly Rainfall	Daily Rainfall Intensity
	Equation y=prob. x=Cum. Rain.	
Jan	$y = 61.464e^{-0.0453x}$ $R^2 = 0.7691$	$y = 61.464e^{-0.0453x}$ $R^2 = 0.7691$
Feb	$y = 80.664e^{-0.0629x}$ $R^2 = 0.9873$	$y = 80.664e^{-0.0629x}$ $R^2 = 0.9873$
Mar	$y = 55.694e^{-0.0277x}$ $R^2 = 0.7414$	$y = 55.694e^{-0.0277x}$ $R^2 = 0.7414$
Apr	$y = 76.056e^{-0.0535x}$ $R^2 = 0.9628$	$y = 76.056e^{-0.0535x}$ $R^2 = 0.9628$
May	$y = 77.487e^{-0.0588x}$ $R^2 = 0.9461$	$y = 77.487e^{-0.0588x}$ $R^2 = 0.9461$
Jun	$y = 74.991e^{-0.0676x}$ $R^2 = 0.9648$	$y = 74.991e^{-0.0676x}$ $R^2 = 0.9648$
Jul	$y = 48.871e^{-0.0325x}$ $R^2 = 0.5438$	$y = 48.871e^{-0.0325x}$ $R^2 = 0.5438$
Aug	$y = 68.573e^{-0.0503x}$ $R^2 = 0.9091$	$y = 68.573e^{-0.0503x}$ $R^2 = 0.9091$
Sep	$y = 70.847e^{-0.1121x}$ $R^2 = 0.8401$	$y = 70.847e^{-0.1121x}$ $R^2 = 0.8401$
Oct	$y = 60.549e^{-0.0488x}$ $R^2 = 0.8027$	$y = 60.549e^{-0.0488x}$ $R^2 = 0.8027$
Nov	$y = 63.85e^{-0.0497x}$ $R^2 = 0.859$	$y = 63.85e^{-0.0497x}$ $R^2 = 0.859$
Dec	$y = 82.899e^{-0.0803x}$ $R^2 = 0.9814$	$y = 82.899e^{-0.0803x}$ $R^2 = 0.9814$

Monthly Rainfall Data - Newport Bowling Club, Sydney.

Source: National Climate Centre via the Bureau of Meteorology

	Monthly Rainfall (mm)											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1931							386.1	22.2	108.9	40.6	118.2	57.8
1932	5.1	78.3	96.5	123.5	83.0	23.5	49.3	94.1	173	35.1	52.1	43.8
1933	111.9	8.1	75.3	164.8	116.7	43.2	68.9	6.7	106	134.1	120.6	217
1934	74.1	197.9	54	159.3	118.8	137.8	196.4	127	273.4	53.4	150.9	66.8
1935	79.7	106.7	63.2	20	56.2	133.2	27.7	2.3	114.2	88.8	48.7	92.6
1936	197.9	125.3	138.2	52.4	69.2	76.6	23.5	27.9	31.3	19.1	5.1	107.9
1937	63.4	40.1	159.2	97.4	17.1	281.2	66.4	125.8	14.3	103.4	107.5	90.4
1938	256.5	78.1	60.9	46.6	99.1	10.5	48.8	210.6	42.5	106.9	39.4	10.9
1939	74.3	1.1	268.1	144.9	79.9	14.2	45.5	54.2	58.6	107.9	23.9	11.6
1940	10.1	21.1	7.9	143.3	131.5	16.1	101.1	52.5	76.5	63.5	136.1	184.6
1941	71.9	66.7	36.9	68.3	49.3	70.6	30.6	46.6	51.3	69.6	24.9	39.2
1942	8.2	24.7	421	29.6	26.7	131.5	70	51.8	15.2	135	142.1	51.6
1943	57.2	8.6	43.1	28.8	310.9	31.6	7.4	159.6	116.2	45.6	180.9	63.8
1944	92.4	59	54.6	78.2	57.8	75.6	152.6	111	47.2	30.1	17.8	14
1945	58	109	60.3	282.9	123.6	208.7	75.3	58.8	6.4	39.3	45.6	59.2
1946	26.1	68.5	103.2	372.2	53.7	137.5	0	1.1	29.5	40.1	118.7	24.1
1947	46.5	136.9	109.2	112.1	118.9	87.9	14.7	38.5	27	49.1	118.6	181.8
1948	224.1	46.7	88	38	113.2	165.6	22.9	13.2	77.9	16	31.5	48.7
1949	260.2	182.1	130.2	64.7	138.7	372.7	94.2	171.7	295	53.7	74.5	95.1
1950	152.6	174.8	147.1	122.5	193.9	660.4	250.7	88.1	132.1	109	122.8	45.9
1951	368.1	79.7	140.9	49.2	147.6	299.1	16	76.8	48.6	42.8	9	41.2
1952	42.5	42.8	122	307.2	52.4	109.7	317.7	321.1	40	162.5	75.2	45.3
1953	84.2	169	102.5	45.7	798.8	60.6	83.8	49.8	76.5	63.4	35.3	5.6
1954	144.2	279.5	13.2	26.3	58.5	16.1	129.2	34.1	54.5	135.7	165.6	128.4
1955	212.9	269.8	237.3	129.6	208.7	90.1	42.2	15.7	37.3	55.6	208.1	144.3
1956	101.8	490.9	380	40.1	129.3	263.3	65.5	95.5	47.2	81.6	13.4	52.9
1957	68.2	98.6	121.5	53.6	7.1	25.9	128.5	138.3	13.7	12	27.4	49.2
1958	114.5	191.5	433.6	117.1	17.8	184.0	34.6	72.5	45.1	69.8	9.8	174
1959	184	206.8	221.2	33.4	51.7	119.2	151.9	94	49.5	205.4	50.3	76.5
1960	74.9	27.2	54.9	28.8	99.8	125.6	79	61.7	33.2	212.1	174.2	212.6
1961	50.9	54.3	66.9	85.6	18.0	44.9	32.3	254.1	51.1	83.5	453.2	131.6
1962	136.5	139.8	169.9	75.5	229.9	1.8	65.6	103.4	91.7	47.2	23	171.5
1963	147.2	84.5	304.3	296.2	207.0	188.2	45.4	265.4	24	70	73.2	140.6
1964	51.6	34.8	162.3	88.8	45.0	340.9	8.9	22.9	19.6	70.1	84.9	32.8
1965	19.3	48.9	8.1	71.3	46.0	138.5	175.5	14.5	92.2	178.7	51.6	78
1966	17.4	119.6	98	165.1	88.4	84.3	17.5	73.4	52.3	44.9	120	85.4
1967	185.7	170.6	190.8	51.1	46.4	185.2	36.4	182.7	83.7	93.9	94.7	36.5
1968	217.4	51.3	78.5	15.9	75.2	31.2	55.2	41.2	1.3	5.6	25.4	101.4
1969	64.4	269.7	63	135.4	38.1	190.1	32.5	145.2	113.5	75.1	228.7	14.7
1970	189.4		121.5	37.1	10.4	24.2	0.8	21.5	323.2	21.4		
1971	136.6	218	97.3	69.1	130.7	59.0	25.9	25.9	30	1.5	77.4	145.9
1972	373.7	102.5	222.9	70.6	119.2	123.2	5.6	105.5	10.1	215.8	76.4	52.8
1973	118.1	387.5	76.9	121.7	20.6	63.3	107.6	99.4	79.2	205.4	107.4	72.6
1974	255.3	92	281.3	138	314.8	215.2	7.7	140.6	18	64.3	64.9	30
1975	40.7	167.4	236.8	123.6	5.7	282.7		29.4		112.3	48.4	

1976	0	179.2	336.7	79.7	71.1	145.7	190.1	68.6	122.6	185.9	74.8	12.6

Rainfall data table continued,

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	119.9	125.9	339.9	37.7	150.6	109.5	19.9	15.5	63.7	15.8	49.5	34.9
1978	362.4	16.2	365.3	109.8	171.2	356.8	32.6	48.9	121.2	77.6	110	56
1979	82.4	7.2	114	9.6	112.6	215.4	16	6.7	12.4	30.2	73.8	15.2
1980	108.4	96.7	14.9	11.8	120.3	80.2	45.9	15.7	3.4	12.6		51
1981	54.2	193.2	11.6	101.8	24.4	69.0	41.2	8.8	1.4	123.6	74.5	
1982					21.0							
1983	3	39.6	234.4	262.5	203.2	90.5	31.3	102.2	64.2	180	28.8	122.2
1984	179.4	87.1	161.6	135.6	87.2	97.4	176.9	2	23.8	82.1	269	106.6
1985	6.4	59.8	51.2	358.6	90.7	66.2	98	31.6	101.4	186	68.8	88.9
1986	199.4	195.4	46.2	15.6	71.0	14.2	21	264.3	47.6	41.4	131	21
1987	30.2	34.4	129	60	63.2	63.4	97	282	5.6	297.3	184	82.8
1988	266.5	156.6	84.4	609	71.8	91.2	104.8	61.6	112.8	0	136.6	108.4
1989	296	93.2	215	404.8	169.8	292.2	18.2	60	0	36.4	34.6	117.6
1990	103.4	438	175	172	148.2	29.4	100.9	181.1	37.8	30.8	21.4	56
1991	107	36.8	40	10.4	169.0	246.6	85.4	0	11	20.8	53	165.7
1992	67	360.6	38.2	144.2	133.6	93.7	8.6	43.2	12.6	49.6	147.8	182.2
1993	70.6	71	88.2	66.2	12.6	54.8	73.4	38.4	51.8	64.7	55.4	77.7

Figures

Figure 1: Scotland Island monthly precipitation probability of exceedence distributions and maximum recorded events.

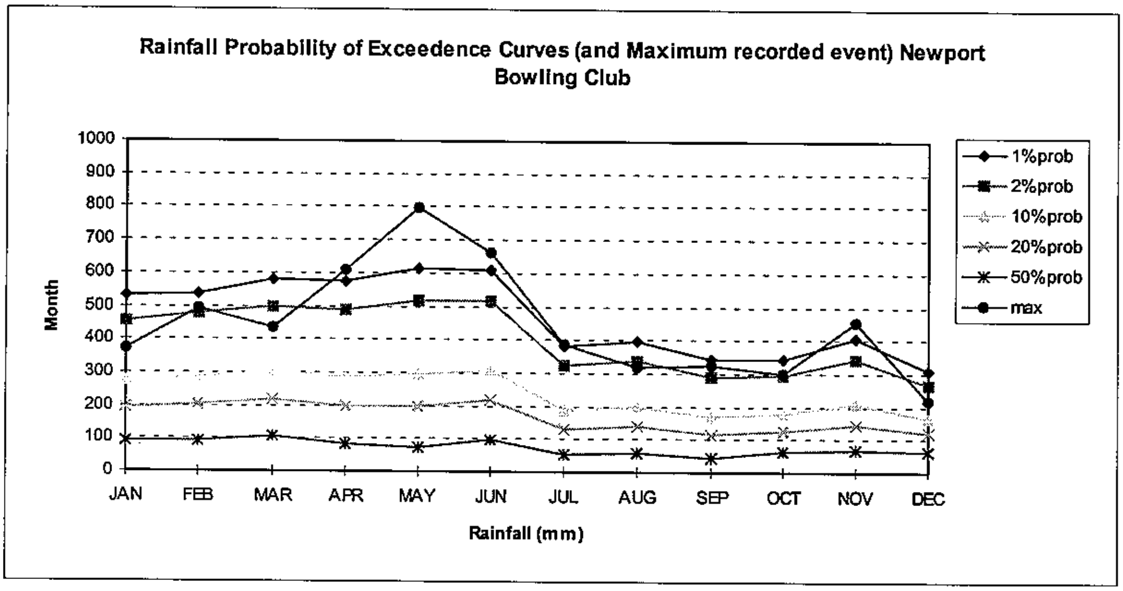


Figure 2: Scotland Island contour map (modified from NSW Dept. of Lands. Contour interval is 5 m except for the first contour which is at 1 m.

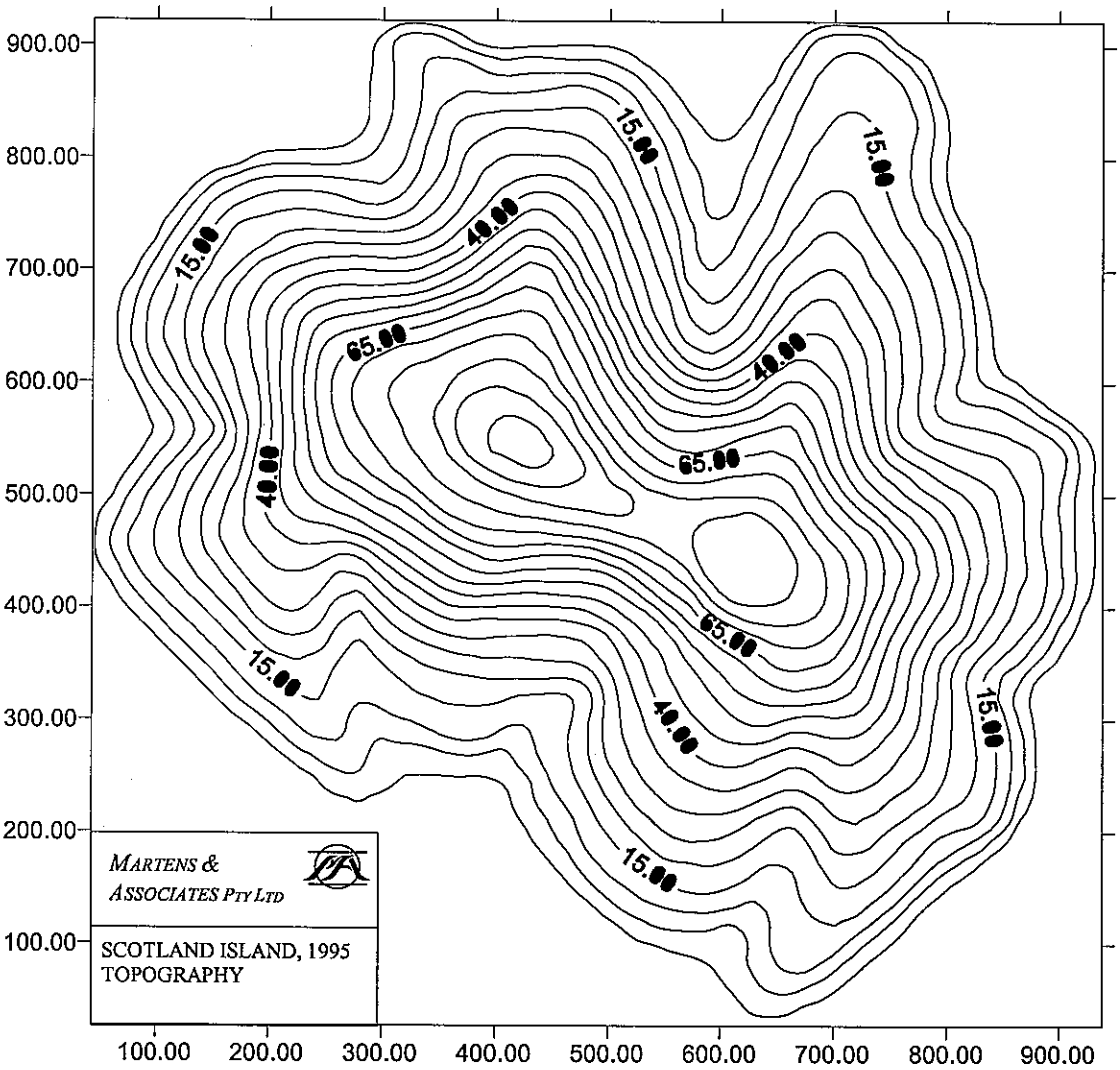


Figure 3: Cross-section of Scotland Island elevation (in m west-east).

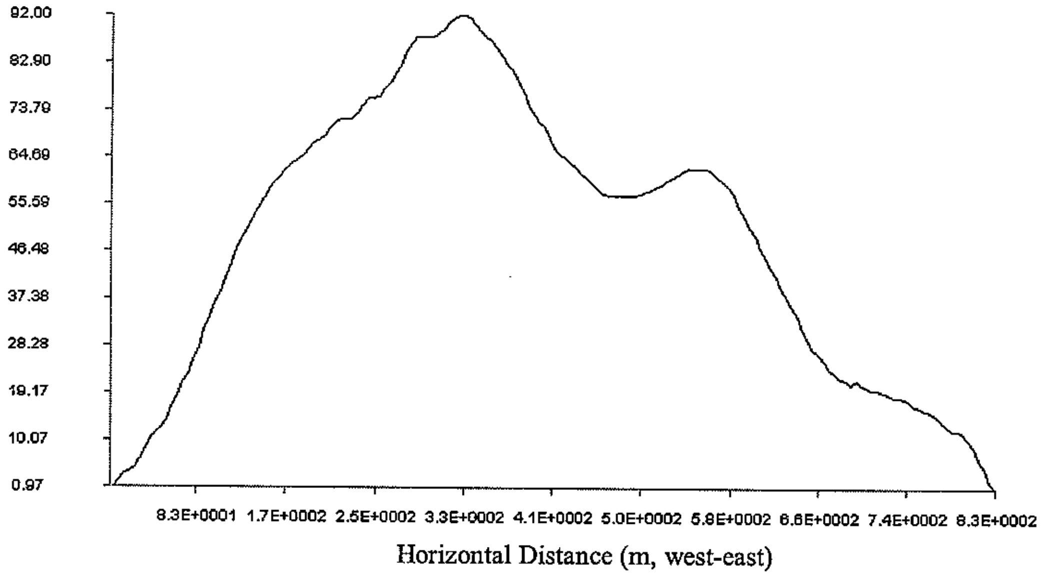


Figure 4: Scotland Island digital elevation model (SCOTELF1).

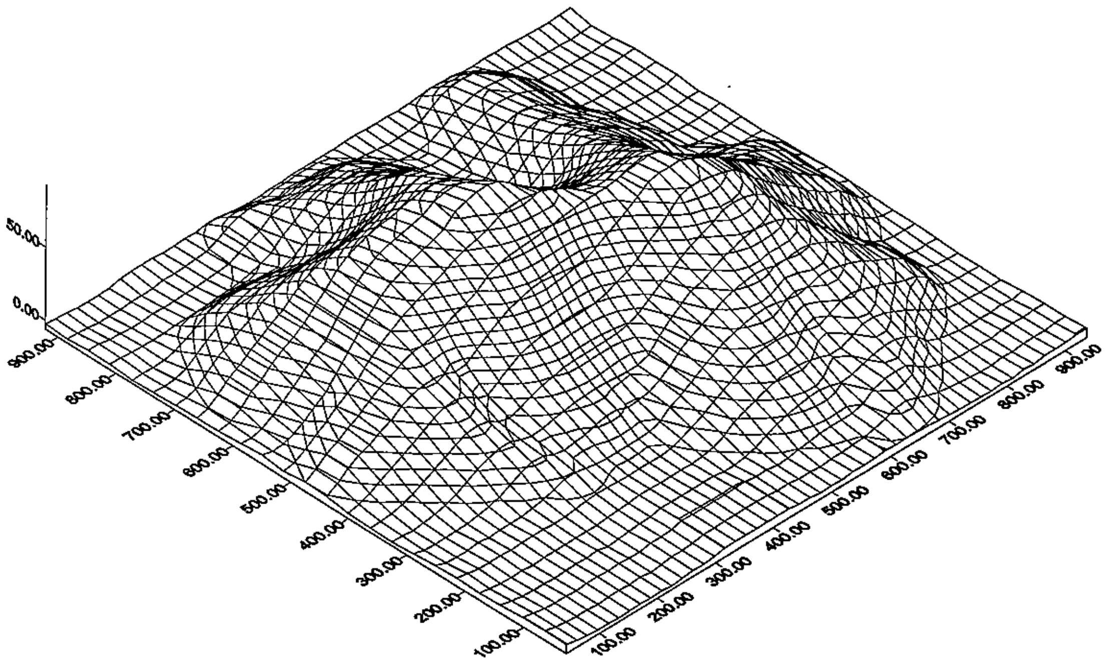


Figure 5: Scotland Island shaded relief map (SCOTHILL).

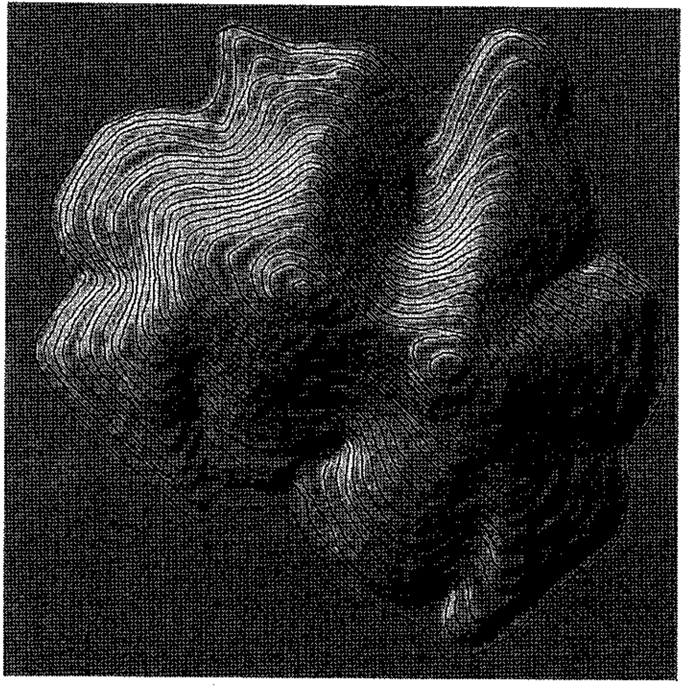


Figure 6: Scotland Island catchments and stream networks including locations of storm event water sampling and locations of street runoff sampling.

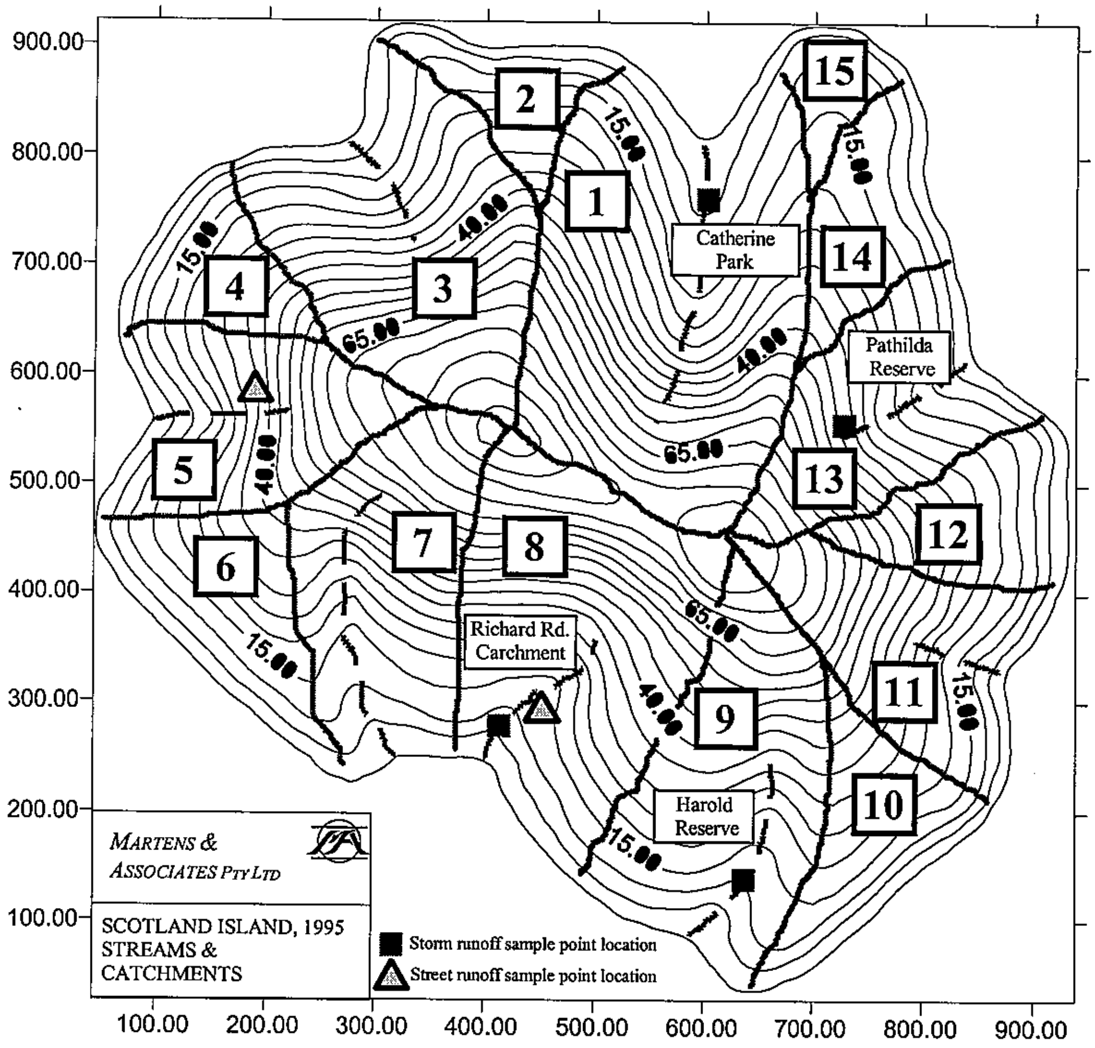


Figure 7: Scotland Island road network.

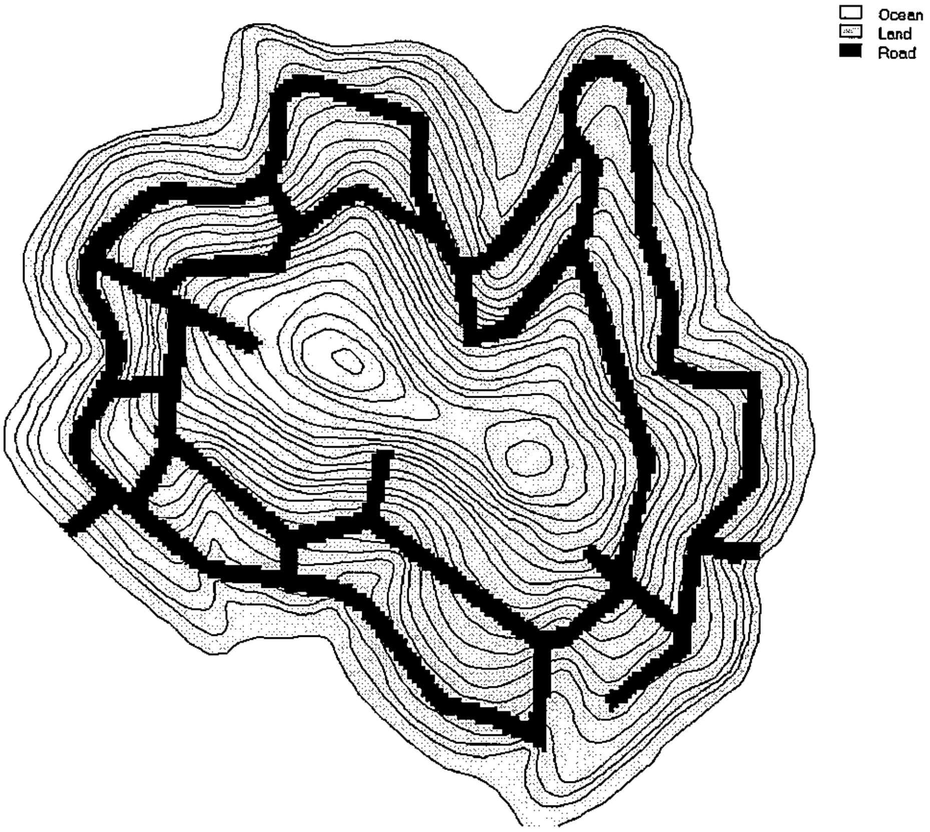
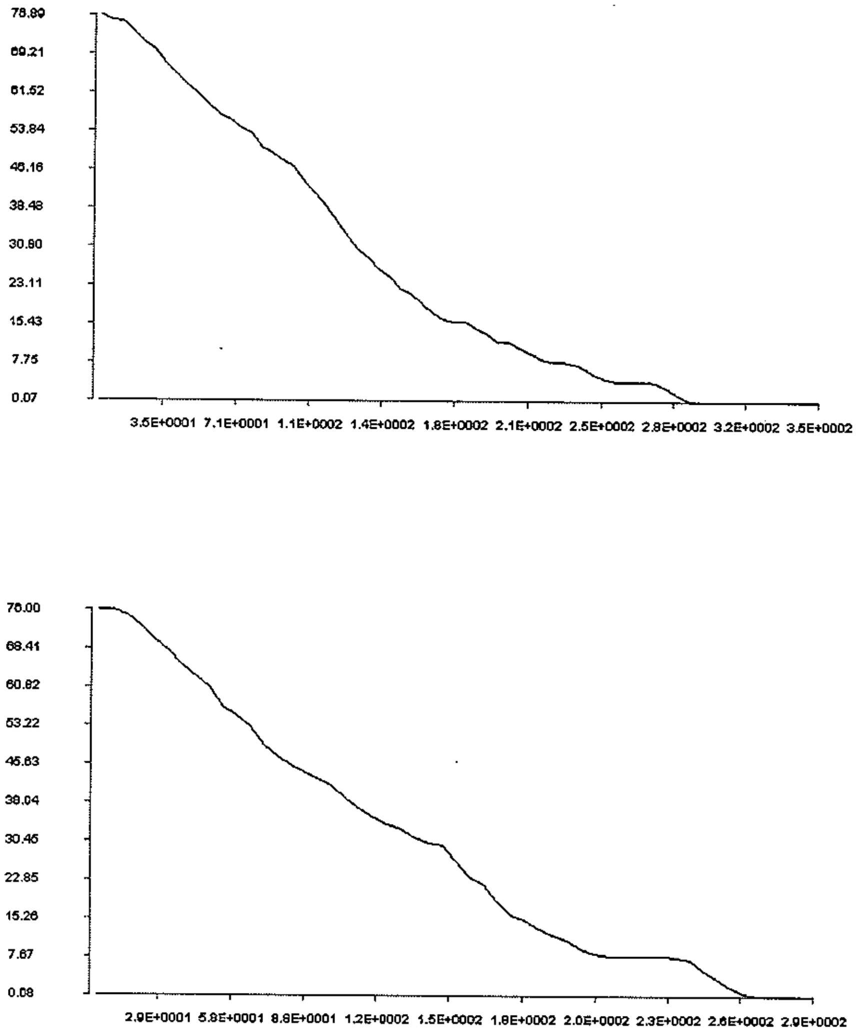


Figure 8: Stream long profiles (a) Catherine Park catchment; (b) Richard Rd. catchment.



(a)

(b)

Figure 9: Scotland Island land-cover classes (taken from 1:16,000 colour aerial photograph, Department of Lands, 1994)

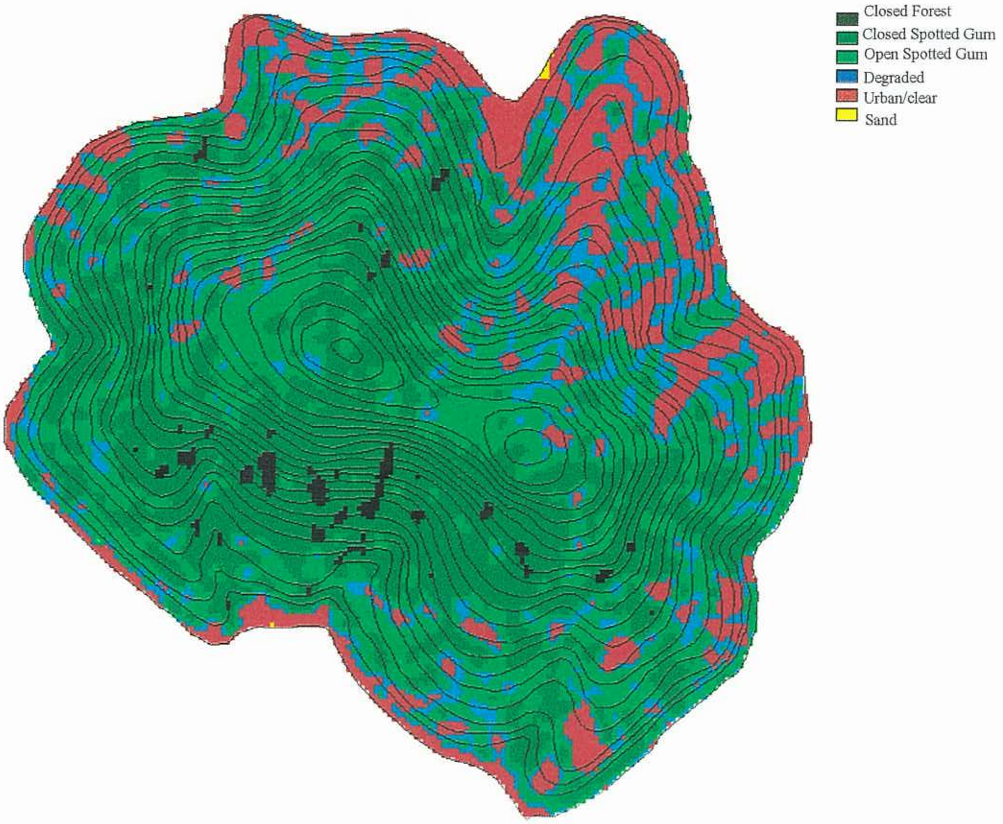


Figure 10: Location of soil sampling sites.

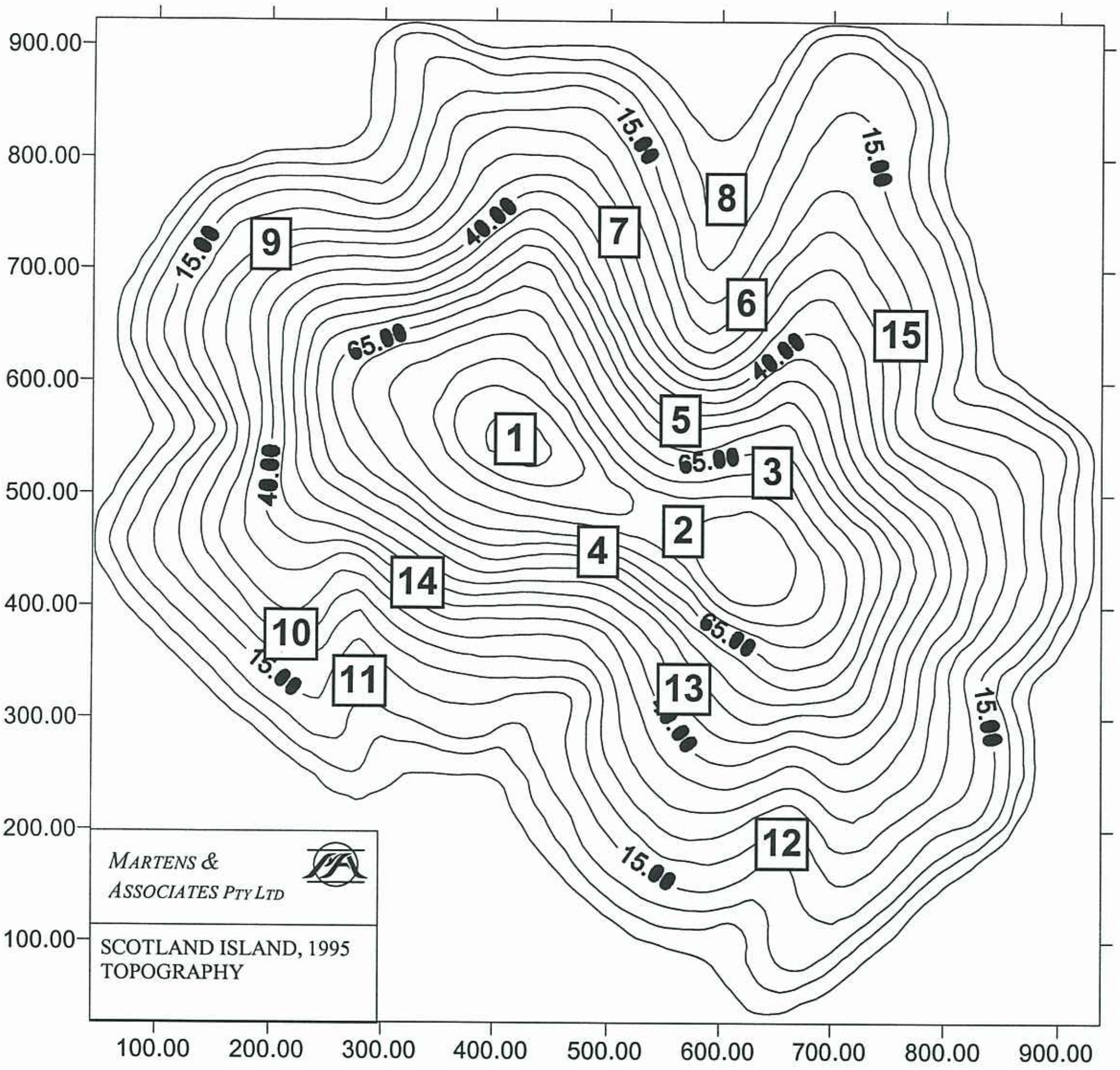


Figure 11: Scotland Island soil magnesium (Mg, cmol(+)/kg) levels. (a) A horizon. (b) B horizon.

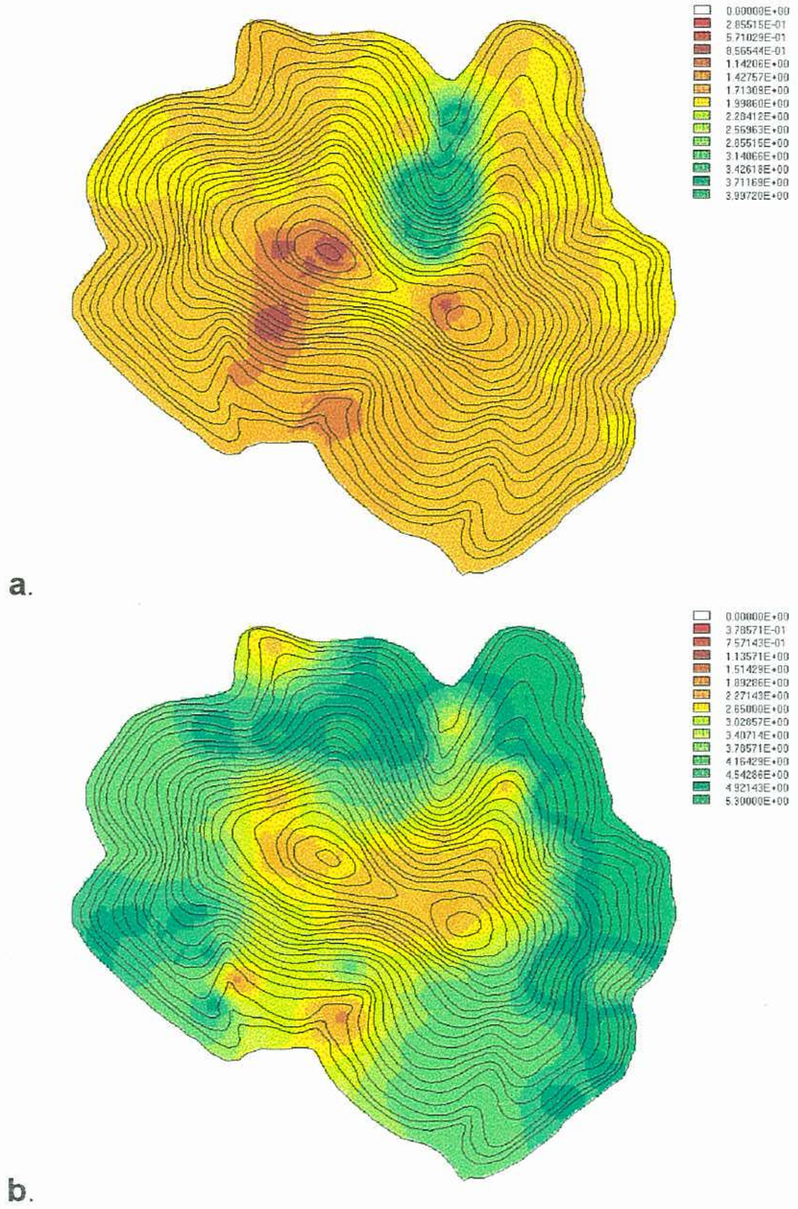


Figure 12: Scotland Island soil sodium (Na, cmol(+)/kg) levels. (a) A horizon. (b) B horizon.

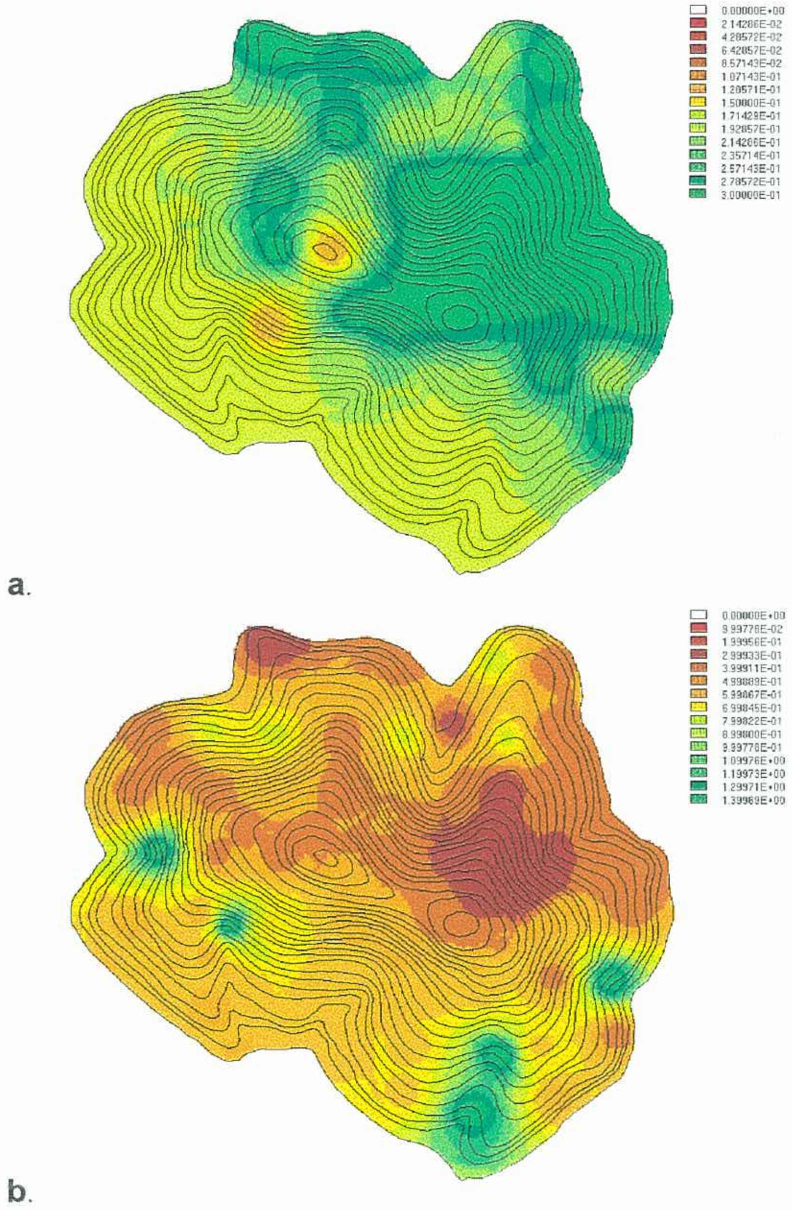
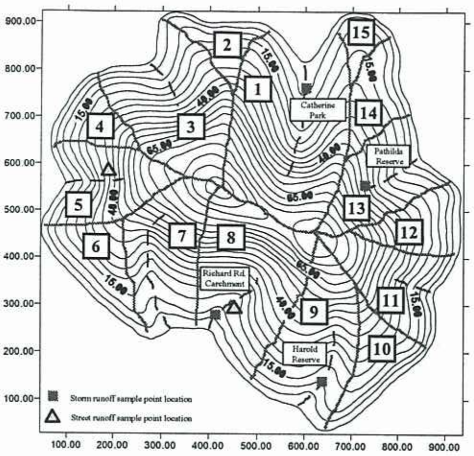


Figure 13: Application of WQ results from sampled catchments to remaining catchments.



Catchment ID	Water Quality Results Used (source catchment ID)
1	**1**
2	1
3	1
4	1
5	8
6	8
7	8
8	**8**
9	**9**
10	9
11	8
12	1
13	**13**

Figure 14: Site longevity estimates of effluent phosphorus loads for individual 25m^2 grid-cells. [Assumes a single on-site wastewater disposal system per grid-cell through both A and B horizons with vegetative uptake rates of approximately 50 kg/ha/year.]

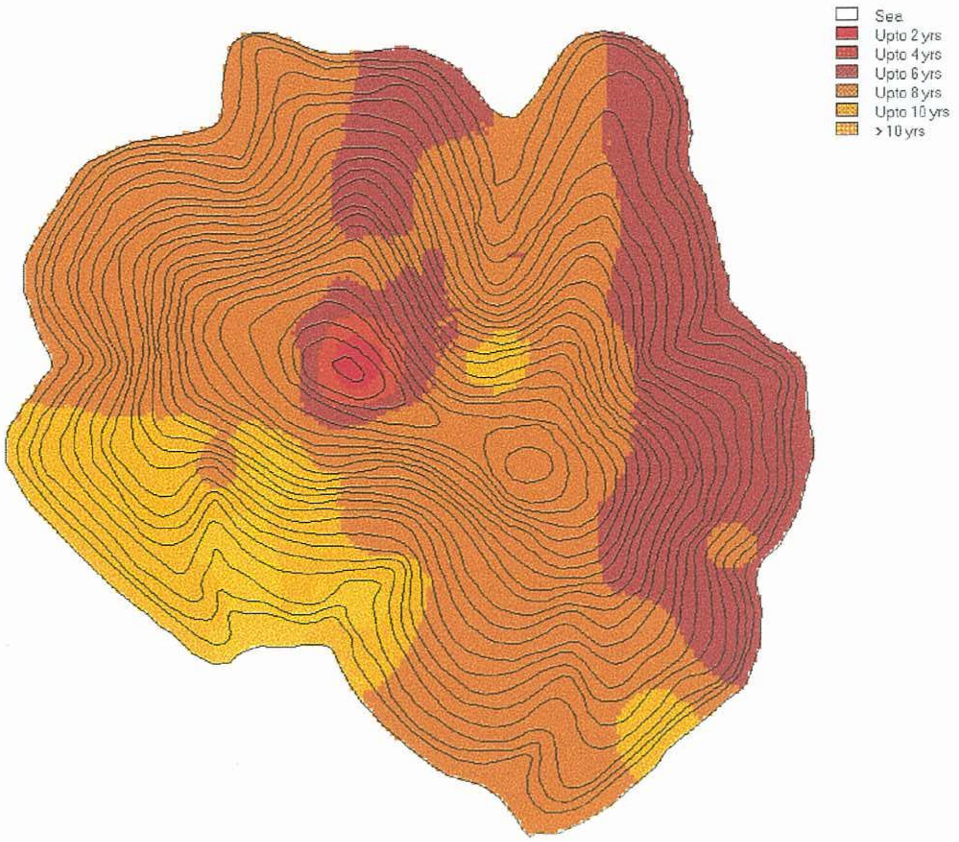
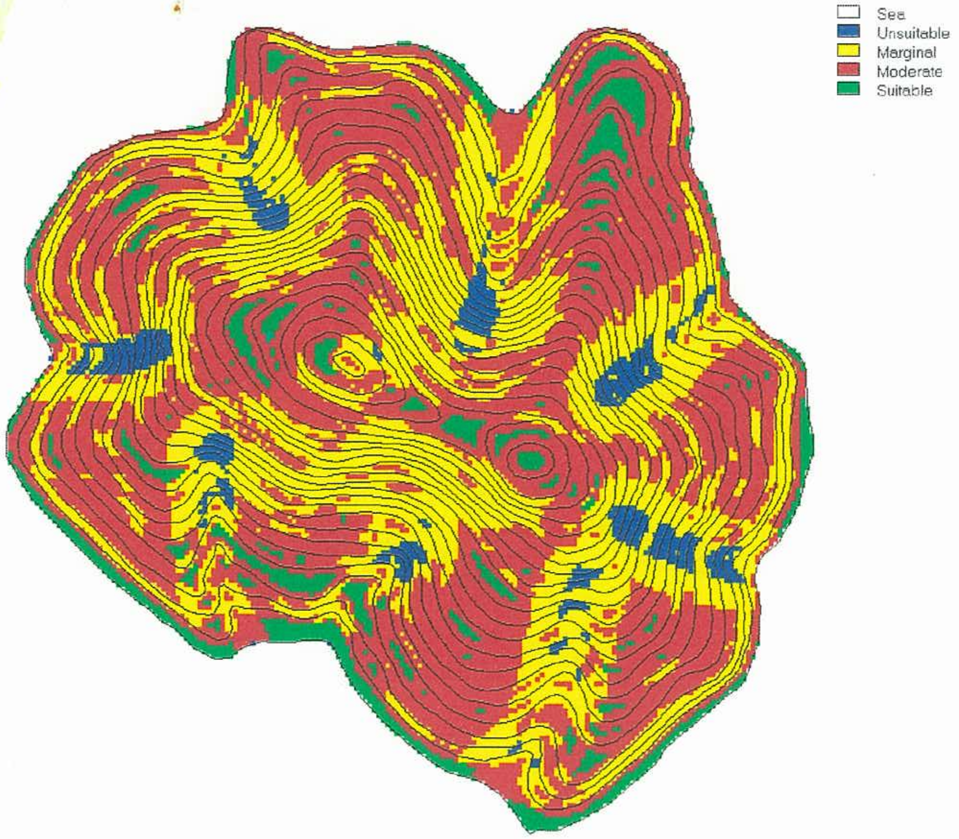


Figure 15: View of Richard Rd. catchment indicating *Eucalyptus* dieback adjacent to stream gully.

Figure 16: Scotland Island land capability classes for on-site effluent disposal.



SCOTLAND ISLAND WASTEWATER IMPACT STUDY:

IMPACT ASSESSMENT OF WATER AND WASTEWATER ON ENVIRONMENTAL QUALITY AND PUBLIC HEALTH, SCOTLAND ISLAND, SYDNEY, 1995/96/97.

Report 96/019A

July, 1997

A NATIONAL LAND CARE FUNDED PROJECT

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1. Summary

A Landcare Grant awarded to the Scotland Island Landcare Group funded this investigation into the environmental and public health impacts of the current on-site wastewater disposal, predominantly through septic tank treatment and soil absorption disposal systems. Data were collected to determine: 1. island soil characteristics and land capability to accept treated domestic wastewater; 2. surface-water quality in the Island's ephemeral streams; 3. effectiveness of current on-site wastewater management systems; and 4. estimated annual sediment nutrient loads to Pittwater from the Island.

1. Land Capability

Scotland Island is a steep bedrock island located in Pittwater. More than 30% of the Island has slopes greater than 20%. Stream gradients are steep and flow is ephemeral. Stream response to rainfall is rapid with runoff occurring only several minutes after high intensity rain events. In general, soils are predominantly shallow podzolics with sandy, permeable topsoils (< 40 cm depth) and impermeable, clay-rich, sodic sub-soils (40-50 cm depth). Soil nutrient levels are very low with acidic conditions dominant.

An assessment of the Island's capability for on-site disposal using a geographical information system (GIS) together with a weighted multiple index overlay algorithm (WMIOA), indicated that approximately 44% of the Island is unsuitable for existing effluent disposal systems. Low P-sorption capacity is frequently exceeded in current land application areas. Low cation exchange capacities combine with low pH to severely limit the soil's capacity to accept and treat domestic effluent. As a result, effluent is dispersed from land application areas via sub-surface flow and surface run-off. Such conditions are generally unsuitable for on-site wastewater disposal as limited on-site effluent rejuvenation occurs.

2. Surface-Water Quality

A surface-water monitoring programme of three larger catchments and surface ponds was undertaken by Island residents under the supervision of Martens & Associates Pty Ltd, with two successive water samples being taken during each storm event for a total of five storm events. Monitoring identified elevated nutrient, sediment and bacterial concentrations in ephemeral streams in each study area. Bacterial levels were several orders of magnitude higher than ANZECC (1992) recommendations for primary and secondary contact indicating a potential health risk to Island residents during wet weather. However, recent water sampling results in Pittwater close to Scotland Island by Harbourwatch, an E.P.A. / Pittwater Council programme, has shown low levels of bacteria, generally below ANZECC and NHMRC levels for primary contact. This suggests that the Island is not presently having a significant impact on water quality in Pittwater.

Stream runoff samples contained suspended sediment concentrations exceeding 1,000 mg/L, and frequently exceeded 10,000 mg/L. The source of this sediment may be soil loss from roads and exposed surfaces. A Sediment Erosion Impact Study is being undertaken to further investigate the extent of this problem.

3. Effectiveness of On-Site Wastewater Systems

Of the 30 on-site wastewater management facilities visually inspected in this study, most were inadequate and did not effectively further treat domestic wastewater. Factors contributing to this condition included:

1. the high density of wastewater systems (> 4 systems per acre in residential areas);
2. disposal areas were frequently smaller than those recommended in the current Australian Standard (AS1547, 1994);
3. poor maintenance of existing systems;
4. poor design and siting of land application areas; and
5. hydraulic over-loading of treatment units and land application areas.

High levels of nutrients (averages of 108.4 mg TN/l and 33.5 mg/L) and bacterial contamination found in disposal areas were attributed to the small land application areas. Eucalyptus dieback, common downslope of effluent disposal areas and in Island gullies, is possibly partly attributed to pollution from domestic wastewater systems. A further study is being undertaken to investigate the extent and possible causes of dieback on the Island.

4. Estimate Nutrient and Sediment Loads to Pittwater

Nutrient export from the Island was estimated to range between 7 - 10 kg nitrogen/ha/yr and 0.7 - 1.1 kg phosphorus/ha/yr, and was comparable with other high density unsewered urban areas in the Sydney area. Estimated suspended sediment loads from the major catchments were high, ranging between 1939 - 8722 kg/ha/yr, a total mass of almost 780 tonnes per year. This indicates that soil erosion on the Island is a major mechanism for sediment and contaminant transport to Pittwater.

5. Water Supply

Some residents supplement their rainwater supply through the use of an emergency water supply connected to mains water. The present emergency water supply pipeline does not conform to the accepted standards and is at risk of infiltration by contaminated surface- and ground-water. However, an improved town water supply is expected to increase the severity of wastewater related pollution due to subsequent increase in daily effluent loads to on-site land application areas [including absorption trenches and irrigation areas]. It is therefore imperative that the problems of water supply and wastewater disposal be addressed in an integrated manner.

6. Recommendations

The following recommendations are made on the basis of the findings of this report:

1. Existing septic tank and trench absorption systems (including combined and separate systems for grey- and black-water) are in most cases not suitable for the Island environment and are likely to cause further degradation. The Stage 2 Report for this project will examine possible wastewater options and changes that will need to be implemented.
2. Given the poor quality of surface runoff in the Island's ephemeral streams, development buffer zones of a minimum of 20 m from watercourses are recommended for all new developments or redevelopments.

3. Skin contact with surface water in creeks and ponded water should be avoided due to the potential health hazard, especially after high flow events when surface-water quality may be poor.
4. Soil erosion control measures and urban runoff retention facilities are required on existing roads and new developments.
5. Community education on proper wastewater management practices is recommended.
6. The reticulated water supplies should not be increased unless current wastewater treatment and disposal systems are improved.

2. Introduction

2.1 Background

Scotland Island covers an area of approximately 55 ha and is one of several islands in the lower Hawkesbury/Nepean estuarine system. It is one of only a few islands on which development has occurred. More than 300 houses occupy the shores and slopes of the island yet there is no true town water supply and sewage disposal and treatment is predominantly by septic tank and soil absorption systems (ST/SAS). In some instances separate grey water discharge (GWD) or Aerobic Wastewater Treatment Units (AWTUs) are utilised.

Wastewater treatment and the implications of on-site sewage disposal are high priority issues on Scotland Island. Currently, there are several perceived problems associated with existing water and wastewater management practices including:

1. possible health risks associated with wastewater disposal;
2. vegetation dieback associated with water logging and phosphorus toxicity;
3. degradation of surface-water quality in streams;
4. poor quality of stormwater runoff and surface ponds in streets during dry weather; and
5. high densities of human occupation and development

2.2 About This Study

In response to these pressing environmental and public health issues, the Scotland Island Residents Association (SIRA) and the Scotland Island Landcare Group (SILG) applied for a Landcare grant in 1994 to provide funding for a detailed study of water and wastewater issues on the Island. The application was successful. *Martens & Associates Pty. Ltd.* were appointed to carry out the study after a selective tender process. This study addresses the first objective of the Landcare grant which is to determine the impact of existing wastewater treatment and disposal strategies on the environment. The Scotland Island landcare group remained closely involved throughout the consultancy process, assisting with methodology, water sampling, and review of documents.

3. Study Objectives and Approach

3.1 Study Objectives

(a) To explore the impact of wastewater disposal on the environment and ecology

There are several potential and existing environmental problems associated with on-site wastewater treatment and disposal practices on Scotland Island. Some of these include *Eucalyptus* dieback, contaminated surface ponds, polluted creeks and degraded ground-water. The primary objective of this work is to resolve the relative importance of some of these problems through monitoring of Island soils, surface-waters, and soils and soil-water in wastewater disposal areas. This includes the determination of water balances and contaminant budgets for both individual effluent disposal areas and the entire Island.

(b) To determine the impacts of wastewater systems on public health

The second major objective of this work is to assess the possible impacts of present wastewater disposal practice on public health by monitoring of faecal indicator species and other bacteria in surface ponds and creeks, on the Island. This also allowed for an assessment of potential future risks to public health.

3.2 Study Approach

The Catchment Management Act (NSW) 1989 attempts to promote better coordination amongst land users and regulatory authorities towards sustainable use of natural resources. The Total Catchment Management (TCM) approach, adopted in this study, recognises that the interrelationships between physical and biological systems are best described and managed within an integrated catchment framework.

Scotland Island is an isolated ecosystem which must be kept in balance to ensure the long-term sustainability of the remnant natural ecosystems and the existing urban development. Adequate water and wastewater management are considered of vital importance to the sustainable use of the Island due to the Islander's reliance on tank water and on-site disposal of domestic wastewater.

The entire Island has been examined and each individual catchment has been assessed for environmental issues inherent to the aims of the project. Data gathered is presented in such a manner that it may be seamlessly integrated into future project stages and community education programmes. Close liaison with both the SIRA/SILG groups and local government has been maintained during the course of the study.

Following a detailed description of the environs and soil physiochemical features, the mass budgets for water and contaminants stemming from wastewater disposal systems are calculated. These parameters account for and characterise each of the major sources and sinks of pollution present on the island.

All spatial data gathered in the project have been stored digitally in a raster based Geographical Information System (GIS) system. The package chosen for this work was IDRISI™ and the primary datafiles are in the default file format (*.DOC and *.IMG). These may be converted to other data formats so that data may be interchanged with other GIS packages. The database includes: all physiochemical soil information [for both A and B horizons]; streams; catchment boundaries; roads; land-use and vegetation; phosphorus storage capacity; and land capability. Disks containing the digital information are attached.

4. Description of Environment

4.1 Island Physical Environment

4.1.1 Location and Access

Scotland Island is a small and generally steep bedrock island of approximately 55 ha located in Pittwater, the southern arm of Broken Bay, some 25 km north of Sydney's central business district. The Island is bounded on all sides by 500 -1000 m of sea water with access restricted to private boat or ferry. Five wharves are available for public access: Tennis Court; Eastern; Carols; Bell; and Cargo.

4.1.2 Climate

There is significant variability in the amount of rainfall received over the Sydney region primarily due to the influences of topography and distance from the coast. Mean annual rainfall is highest at Turramurra (1432 mm) and along the coastal ridges within which Scotland Island is situated. The mean annual rainfall record at Newport is 1225 mm, based on records obtained from the National Climate Centre via the Bureau of Meteorology, for the years spanning 1931 to 1993 (62 years).

In Sydney the summer months are generally wetter than winter months though intense large events can occur at any time of the year (Linacre and Hobb, 1977). This weak seasonal trend is observed in the probability of exceedence values calculated for monthly rainfall totals using all records from the Newport shown in Table 1 and illustrated in Figure 1. A plot of the maximum monthly totals also illustrated in Figure 1 demonstrates that monthly rainfall totals in excess of 25% of the annual mean have been recorded in each month of the year.

Table 1: Monthly rainfall totals (mm) over a range of probabilities (calculated using n=62 years or 100% of Newport monthly rainfall records).

Month	1%prob	2%prob	10%prob	20%prob	50%prob
JAN	531	454	273	195	92
FEB	538	476	284	202	93
MAR	579	496	302	218	108
APR	576	489	285	197	81
MAY	615	519	295	199	72
JUN	611	519	308	216	96
JUL	383	324	188	129	51
AUG	397	337	198	139	60
SEP	342	289	167	115	45
OCT	343	294	178	128	63
NOV	405	345	206	147	68
DEC	311	266	165	122	64
Total	5631	4808	2849	2007	893

Observations made from Observatory hill (39 m ASL) near the southern approaches to the Harbour Bridge indicate temperature ranges from a low of 2.1 degrees Celsius to a maximum of 45.3 degrees Celsius. The daily maximum may exceed 30 degrees from September to April and may fail to reach 15 degrees between April and October. Fogs are rare in the eastern coastal suburbs. The broad scale wind pattern is easterly in the summer and westerly in the winter. However during the summer months the coastal wind regime, in which Scotland Island is situated, is dominated by local sea breezes. Dense bushland adjacent to urban development such as occurs on the Island poses a threat of bushfire outbreak on days of high temperature associated with strong winds (Chapman, 1991).

4.1.3 Geology/geomorphology

Scotland Island is a steep sided bedrock outcrop situated within Pittwater on the boundary of two physiographic units of the Sydney region, the Hornsby Plateau and the Erina Hills. To the west of the island an escarpment of Triassic aged Hawkesbury Sandstone marks the end of the Hornsby Plateau. To the east the Erina Hills, comprised of the Triassic aged Narrabeen Group outcrop to form the present bedrock configuration at the coast (Chapman and Murphy, 1989). Scotland Island possesses a Hawkesbury Sandstone cap underlain by the more lithologically diverse units of the Narrabeen Group comprised of interbedded sandstone, shale and claystone.

Pittwater forms part of the Broken Bay drowned river valley estuary that evolved during the Postglacial Marine Transgression (PMT) at the mouth of the Hawkesbury river. Stream incision and valley widening processes formed deep and steep sided valleys that were progressively drowned by the rising sea level and infilled by fluvial sands overlain by estuarine basin sediments. Marine sand composed mainly of quartz with variable shell content derived from the continental shelf has been transported in an onshore direction with the rising sea level and form the flood and ebb tide deltas at the mouth of Broken Bay. A full discussion of the evolution of Broken Bay may be found in Roy *et. al.*, (1980).

Previous stratigraphic studies indicate that in Pittwater the accumulated thickness of estuarine and fluvial sediments may be up to 40m thick (Roy *et al.*, 1980). However, immediately surrounding Scotland island the depth of Holocene surface sediments and underlying Quaternary sediments is expected to vary considerably due to the close proximity of the Island to the mainland and the variable bedrock topography underlying the unconsolidated deposits. Modification of the surface sediment in Pittwater is continuing as a result of contributions from terrestrial and insitu biogenic sediment sources and continuing bioturbation.

4.1.4 Slopes and Topography

Topography on the island is largely the result of underlying geology. The Island's topography and slopes were assessed using derived 4m contour interval orthophoto maps provided by the NSW Department of Lands (Figure 2). In general, local relief is approximately 30-90m and slopes are frequently moderate to steep (> 20 %). The Island rises to a central ridge and saddle unit composed of Hawkesbury sandstone at an elevation of 80-90 mAHD. The western ridge top represents the highest point on the Island reaching approximately 92 mAHD (Figure 3).

A digital terrain model of the island (DEM) was constructed by digitising the 4 m contour intervals (Figure 4). This DEM was subsequently used to determine the nature and coverage of each slope class and provide a shaded relief map of the Island (Figure 5).

For the purpose of assessing wastewater disposal systems four main percentage based slope categories are recommended for use in AS1547. These classes are: low (< 5 %); moderate (5-10 %); steep (10-20 %); and very steep (>20 %). Table 2 summaries the aerial coverage of each of the slope categories and reveals that only limited areas of the Island are suitable for wastewater disposal. More than 80 % of the Island contains slopes greater than 10 % and almost a third of the Island contains slopes greater than 20 %. Very steep areas (> 20 %) are unsuitable for on-site wastewater disposal (AS1547, 1994) unless slopes are reduced through site landscaping.

Table 2: Scotland Island slope categories and aerial coverages.

Category	Slope (%)	Aerial coverage (ha)	Aerial coverage (%)
Low	< 5	4.3425	7.93
Moderate	5 - 10	4.7550	8.72
Steep	10 - 20	29.3925	53.71
Very steep	> 20	16.2225	29.64
TOTAL	**na**	**54.7125**	**100.00**

4.1.5 Catchments and Stream Hydrology

The surface-water hydrology of Scotland Island is relatively complex. Rugged undulating terrain descends rapidly into Pittwater resulting in 15 individual catchments (Figure 6). The largest of these include catchments 1 (Catherine Park) and 3 on the northern side, and catchments 7,8 (Richard Rd) and 9 (Harold Reserve) on the south facing slopes. Approximate catchment areas of each of these are given in Table 3.

Table 3: Approximate areas of sub-catchments on Scotland Island. Figure 6 contains locations of individual sub-catchments

Catchment Identifier	Catchment Area (ha)	Coverage %
1 (Catherine Park)	8.9750	16.4
2	1.5350	2.8
3	5.5475	10.2
4	1.4800	2.7
5	3.4475	6.3
6	2.5475	4.6
7	4.6125	8.4
8 (Richard Rd)	7.1575	13.1
9 (Harold Reserve)	4.9900	9.1
10	2.5700	4.8
11	3.2650	5.9
12	1.5400	2.8
13 (Patilda Reserve)	4.3150	7.9
14	2.1500	3.9
15	0.5800	1.1
Total	54.7125	100.00

Stream catchment areas are complicated by the existing road network which circumnavigates the Island in two primary ring-roads (Figure 7). Roads serve to increase the net volume of water entering several streams by providing increased sealed areas but also by redirecting flow across catchment topographic boundaries. The effect is particularly evident in portions of Thompson St. A newly constructed drain just south of the intersection of Elsie and Thompson Streets redirects street runoff from the upper portions of catchments 11 and 13 into the Harold Reserve catchment (9). This indicates that water entering Harold Park Reserve may contain significant portions of urban runoff during storm runoff periods. The lower portion of Harold Reserve was initially chosen and monitored as a control water-quality sampling site. However, the above indicates that the site should also be classified as urban.

Streams have also been affected by other modifications including: drainage directed from walking tracks; rudimentary drainage works; exotic weed invasions; and sediment build-up.

Stream long-profiles are extremely steep with average grades ranging between 15 - 20% (Figure 8). Pool and riffle sequences are limited to non-existent with little development of alluvial morphologic features. Runoff in streams is therefore rapid and responds quickly to precipitation as there is little in-channel storage of water. Consequently, there is little time delay between rainfall and stream flow response on the Island.

Estimates of travel time from top to bottom of catchment were made using the following simple empirical equation (FAA, 1970).

$$t_0 = \frac{1.8(1.1 - C)(3.28D)^{1/2}}{S^{1/3}} \qquad \textbf{Eq. 1}$$

where; t_0 = overland flow time (min)
C = runoff coefficient
D = travel distance (m)
S = overland slope (%)

Although the above method is crude and does not account for in-channel storages, estimates indicate that for the Richard Rd. and Catherine Park catchments (1 and 8), travel times from top to bottom of catchment are approximately 15-17 minutes (Table 4).

Table 4: Estimated travel times for several larger catchments on Scotland Island (slope assumed to be approximately 30 %).

Catchment	Travel distance (m)	Runoff coefficient	Max. Travel time (min)
Catherine Park	350	0.20-0.30	15.7 - 17.7
Richard Rd.	300	0.20-0.30	14.6 - 16.4
Harold Reserve[1]	340	0.10-0.20	19.4 - 21.5

[1] May be somewhat longer due to additional contributions from catchments 11 and 13.

Stream flow on the Island is predominantly ephemeral, with contributing watersheds having insufficient catchment area to produce perennial flow. However, field observations indicate that the two larger southern catchments (7 and 8, Figure 6) do appear to maintain some limited base-flow during non-rain and extended dry periods. Flow volumes are extremely small at less than 500 L/day and may be attributed to wastewater disposal systems.

4.1.6 Soil Landscapes

Soils of Scotland Island approximate those described in the Watagan Soil Landscape that occur on rolling hills to very steep small hills atop the rocks of the Narrabeen Group (Chapman and Murphy, 1989). Observations atop the Hawkesbury Sandstone cap indicate soil in this region to be discontinuous and shallow with common rock outcrops. Because of the limited extent of the Hawkesbury sandstone the Watagan soil landscape is considered dominant on the island.

In general the Watagan soils are strongly acidic, have low to moderate available water capacities, low nutrient status, low nitrogen, very low phosphorus and low to moderate Cation Exchange Capacity (CEC). The subsoils may possess low permeabilities and pronounced aluminium toxicity. Although the Watagan soil horizons are considered to have low to moderate erodibility, the steep slopes on which the soil has developed result in an extreme erosion hazard for both non-concentrated flows and concentrated flows. A summary of the dominant soil materials is presented in Table 5.

Table 5: General character of soils on the Watagen Soil landscape (Chapman and Murphy, 1989).

Watagen Soil Landscape Horizons	General Character
A1	Loose, stony, brownish-black

	sandy loam
A2	Hardsetting, brown sandy clay loam
B1	Strongly pedal, yellowish brown fine sandy clay (atop sandstone bedrock)
B2	Strongly pedal clay (atop shale or siltstone bedrock)

4.1.7 Land-use and Vegetation

Native vegetation of Scotland Island varies significantly both between ridges and gullies, and between northern and southern sides of the Island. Several vegetation communities have been identified including: Closed Forest (CF); Spotted Gum Forest (SGF); degraded bushland near urban areas; coastal fringe vegetation (eg. Banksias); and Intertidal Mangrove forest. Taller open forests occur predominantly on the drier and more exposed slopes and crests. CF occurs in small pockets on the sheltered slopes on the southern side of the Island.

Tree species are dominated by communities of Spotted gum (*Eucalyptus maculata*) and Grey Gum (*E. punctata*) which occur predominantly in the OF. Spotted gums are widely distributed throughout the Island. However, their association with the Grey gum is limited to the central and northern sections of the Island. Smooth Barked Apples (*Angophora costata*) tend to occur on Hawkesbury sandstone substrate where soils are significantly sandier. Tree height is generally over 20m, with some individual trees reaching 30m on the southern and northern slopes. Dominant tree species are listed in Table 6.

Table 6: Scotland Island vegetation assemblages and common species.

Vegetation Assemblage	**Common Species**
Spotted Gum Forest	*E. maculata* (Spotted gum) *E. paniculata* (Grey Ironbark) *E. punctata* (Grey gum) *E. botryoides* (Bangalay) *Syncarpia glomulifera* (Turpentine) *Angophora floribunda* (Rough Barked Apple) *Allocasurina torulosa* (Forest Oak)
Closed Forest	*Acmena smithii* (Lillipilly) *Glochidion ferdinandi* (Cheese Tree) *Livistona australis* (Cabbage Tree)

A comprehensive vegetation survey of the Island is currently in progress (pers. comm. Diane Campbell, Pittwater Council, 1995).

A land-cover map (Figure 9) was produced from a 1994 1:16000 colour aerial photograph. This (together with several other previous aerial photographs) was scanned and digitally processed (Appendix III) and reclassed to produce six general land-cover classes (Table

7). The classification scheme is described below. Importantly, the map is not absolute, and still requires some further ground truthing. This should be done following the completion of the comprehensive Island vegetation survey. Also, two distinct groups of SGF were found. These were for the sake of convenience, termed Open SGF and Closed SGF, with the Closed SGF appearing to have greater occurrences of the Forest Oak understorey.

1. Closed Forest: Mostly confined to gullies and steeper slopes on the southern side of the Island.
2. Spotted Gum Closed Forest: *Eucalyptus* with an understorey of Forest Oak (*Allocasuarina torulosa*) to a height of approximately 15 m.
3. Spotted Gum Open Forest: *Eucalyptus* with limited Forest Oak understorey.
4. Degraded: This land cover type refers to grounds which have been disturbed by urbanisation. Typically it includes urban dwellings with significant tree (mostly *Eucalyptus*) surrounds.
5. Urban / Cleared: This class indicates regions with high urban development and a high proportion of native tree cover removal.
6. Sand: Sandy soil/ beaches on the Island at the time of observation.

Table 7 indicates that the majority of the Island is still covered relatively undisturbed SGOF (68.7 %). Only a small portion of the Island's more protected southern side contains CF type communities (1.8 %). However, approximately 30 % of the Island shows signs of significant human related disturbance to the original land cover.

Table 7: Summary statistics for Scotland Island land-use classes.

Class	Land-use Type	Area (ha)	Coverage (%)
0	Closed Forest	0.6500	1.8
1	SGCF.	18.3225	33.3
2	SGOF	19.5025	35.4
3	Degraded	7.0900	13.0
5	Urban / cleared	9.1275	16.5
6	Sand	0.0200	< 0.01
Total		**54.7125**	**100.00**

4.1.8 Erosion

Erosion on Scotland Island has been of concern to the residents Landcare group for some period and has culminated in the development of a management plan by the NSW Department of Conservation and Land Management Soil Conservation Service in 1993.

In 1993 inspection of the Island's ring roads and walking tracks indicated that all were in reasonable to poor condition. Most suffered from inadequate surface drainage. The Soil Conservation Service reported that most tracks were suitably situated (with some notable exceptions) and should be maintained in their present position.

Subsequent observations made during the course of this study suggest significant improvement is still required, as many surface drains were blocked with sediment and vegetation debris. The Soil Conservation Service report identified the biggest drainage problem as the lack of drainage easements, especially between the lower ring road and Pittwater.

In addition to the erosion of walking tracks and access roads, observations made during the course of this study suggest the clearing of vegetation and subsequent excavations for construction purposes are important sources of erodible sediment, especially considering the steepness of the terrain and the lack of formal drainage networks and erosion and sediment control measures. None of the half dozen houses presently being constructed had employed any erosion control measures. There is also a general lack of knowledge by residents about the value of retaining native vegetation to minimise soil erosion. Estimated soil losses for the first twelve months of urban development range from 372t/ha for topsoil and 547t/ha for subsoil in the Watagan soil landscape (Chapman and Murphy, 1989). The Watagan soil landscape is generally considered not capable of urban development because of the potential for mass movement and rockfall, steep slopes and extreme erosion hazards. Estimated yields of suspended sediment in an annual rainfall year [using a runoff co-efficient of 0.25] suggest that Scotland Island contributes in excess of 14 t/ha/yr of suspended sediment to Pittwater (see section 6.3.1.2).

Clearly future drainage and sediment control measures should address issues stemming from continued housing development and re-development as well as maintenance of walking tracks and access ring roads.

4.2 Island Human Environment

4.2.1 Population and Growth Issues

Historical information provided by SIRA indicate the Island was first sighted in 1788 by Governor Phillip and first granted to Andrew Thompson in 1810. Originally let to a single person the island was subdivided into 121 blocks in 1911. A further subdivision was carried out in 1926 by Mr H. J. Fitzpatrick. At present there are some 350 blocks on the island.

A recent residents survey (1993) of 40% of the islands households indicated that on average 3.1 people lived in each house. Therefore, there are presently approximately 1000 residents on the island. Some fluctuation in this figure is expected due to the presence of many holiday homes. Despite a semi-urbanised visual quality that the island possesses when viewed from surrounding areas, the density of dwellings and people on the island represents a mature urban environment [at just below 2.5 houses per acre] that has developed without the usual urban drainage and sewage infrastructure.

Presently, not all the blocks are developed. Therefore, some moderate increase in the Island's population is expected over the next 10-50 years culminating in a population of more than 1000 people based on average occupancy numbers.

4.2.2 Water Supply and Storage

The Island's residents water supply is comprised of rainwater tanks supplemented by purchases of water from an emergency supply that circles the island in the form of an exposed polythene pipe. Results from the SIRA water survey (December, 1993) indicate an average water tank capacity of 25,000 L, well below the 45,000 L recommended by Council. Only 35% of people have sufficient water supply to last more than 16 weeks without rain. Slightly less than 27% of residents were found to have sufficient water storage capacity to never use the emergency water supply. Clearly the water collection and storage capacity of most residences is insufficient to satisfy normal water use.

The emergency water supply line from which residents supplement tank water is in poor condition. In March 1992 Warringah Council notified the Residents Association that the line was sub-standard and should be repaired or removed. The pipe is exposed in many locations throughout the island and is susceptible to puncture, burning and melting. Observations made of the pipe line during the course of this study indicate that it leaks and is at risk of wastewater infiltration.

Warringah Pittwater Bush Fire Service's investigation into the need for increased water storage capacity on the Island concluded that the Island's water supply was inadequate to effectively fight any significant outbreak of fire. The fire service also concluded that in the event of fire the potential for loss of life and property is high.

4.2.3 Water Usage

Wastewater flows generated on the Island have been estimated using the data supplied by the SIRA water use survey (1993) (Tables 8 and 9) while flows determined from the current AS-1547 were used to approximate the level of use that might be expected if a free town water supply was installed on the island. The smaller usage figure estimated from the water use survey reflects restrictions on water use imposed on residents by their dependence on tank water and supplements from the emergency water supply.

Table 8: Water use statistics based on SIRA water use survey (1993).

SIRA water use survey, results summary	**Amount**
Mean tank water use (weighted mean based on mean tank size and distributed water usage)	298 l/dy/hse
Mean amount of water purchased (weighted mean)	6700 l
Mean number of times water is purchased per year	1.69
Mean amount of water purchased per day	31 l/dy
Total weighted mean water usage per household	329.1 l/dy
Daily water use per person based on 3 people per house (including holiday houses)	109.7 l/day
Daily water use per person based on AS1547	***180 l/dy***

Table 9: Household and Island- wide water use estimates per month, based on SIRA survey and AS1547 guidelines.

Month	Lot Water Use (survey data) l/hm/mth	Island Water use (survey data) l/mth	Lot Water Use (AS1547 data) l/hm/mth	Island Water Use (AS1547 data) l/mth
January	10202	3060630	16740	5022000
February	9215	2764440	15120	4536000
March	10202	3060630	16740	5022000
April	9873	2961900	16200	4860000
May	10202	3060630	16740	5022000
June	9873	2961900	16200	4860000
July	10202	3060630	16740	5022000
August	10202	3060630	16740	5022000
September	9873	2961900	16200	4860000
October	10202	3060630	16740	5022000
November	9873	2961900	16200	4860000
December	10202	3060630	16740	5022000
Total litres	120121	36036450	197100	59130000
Total Megalitres	**0.12**	**36.04**	**0.2**	**59.13**

4.2.4 Wastewater Treatment

Effluent disposal information is based on the 1993 SIRA survey (section 4.2.1). Septic systems account for 91% of effluent disposal. Of the surveyed systems, 21% received only black wastewater, while 79% received both grey and black wastewater. An additional 8% have aerobic wastewater treatment units (AWTS) and 1% have composting toilets. The septic systems are of various ages, 23% are over 15 years old and 16% have no record of ever being pumped out.

4.2.5 Effluent Disposal

The majority of the Island utilises soil absorption trenches for the disposal of domestic wastewater from septic tank systems. Typically, 20 % of sites utilise separate grey and black water systems and 80 % utilise combined grey/black treatment / disposal. Those few sites utilising AWTSs treat combined wastes and irrigate the effluent over varying sizes of land up to 50 m^2.

4.2.6 Traffic and Vehicular Usage

Historical information provided by SIRA indicate that construction of the Island's ring roads commenced in 1926 and was carried out by hand. The road remains unsealed to this day and is poorly maintained. At present there are up to 50 operating vehicles on the island, whilst light trucks regularly traverse the roads, carrying building materials to construction sites. Little formal drainage work has been associated with the road network and evidence of significant erosion from cuttings is exemplified by slumping and undercutting of road cutting in some areas and the common occurrence of accumulated sediment blockages in the surface drains.

5. Study Methods and Data Collection

5.1 Literature Search and Existing Studies

Prior to commencement of work, existing literature relevant to the Island was gathered and collated. Several sources of information for the Island were available to the study including: previous reports; site maps and aerial photographs. Reports included: an Island management report; a bushfire risk assessment and management document; the draft Locality plan; vegetation surveys; a walking track management plan; the water survey results; bush regeneration reports; and several nearby water cycle and flood studies. These are listed in Section 11.

5.2 Collection of Non-Field Data

A 1994 colour 1:16 000 aerial photograph of the Island was supplied by Pittwater Council. This provided important information on current land-cover and usage characteristics of the Island. The photograph was scanned and digitally processed and reclassified for various parameters using the GIS to produce thematic maps used to describe the Island and assess the land capability for effluent disposal (see section 5.4 and Appendix III).

Daily and monthly rainfall data were obtained for the Newport Bowling club rain gauge which was the closest monitoring site (3.4 km SE of Island Centre) with continuously recorded data for more than 50 years (62 years). Data were collected from the Bureau of Meteorology's National Climate Centre. Daily rainfall data available (16 years record) from the Islands privately administered rain gauge (Mr Steve Crosby) were used as a basis of comparison with the Newport dataset.

5.3 Field Data Collection Programme

5.3.1 Soil Survey

A detailed reconnaissance field survey of Island soils was conducted between 20/9/95 and 6/10/95. The aim of the soil sampling programme was to determine the precise nature of native (*i.e.* undeveloped) soils on the Island and to provide important baseline information for assessing the suitability of on-site wastewater disposal.

Due to the cost and difficulties of grid sampling type methods, several A and B horizon samples were collected from each of the significant land unit elements including: ridges, slopes and swales. Samples were collected from both the Hawkesbury (upper) and Narrabeen (lower) sedimentary rock units. In total, 15 Soil sampling locations were chosen from these morphologic units. Table 10 outlines the sampling methodology and Figure 10 shows the locations of soil sampling sites.

Table 10: Summary of soil sampling sites.

Site	Samples	Landform Type
1	A only	Hill top
2	A, B	Upper slope
3	A, C	Upper ridge north
4	A, B	Upper swale south
5	none	Upper swale north
6	A only	Mid slope north
7	A, B	Lower slope north
8	A, B	Lower swale north
9	A, B	Lower ridge north
10	A, B	Lower ridge south
11	A, B	Lower swale south
12	A, B	Mid swale south
13	A, B	Mid ridge south
14	A, B	Mid slope south
15	A, B	Mid slope north

Soil profiles were logged at each site (see Appendix IV). Included at each site were descriptions of horizonal depth, total soil depth, texture, colour variations, root material, cobbles and surface stones and vegetation.

Field determinations of saturated hydraulic conductivity (K_{sat}) were made at each site and calculated according to Equation 2. The Constant Head Well Permeameter (Talsma and Hallam, 1980) was chosen because of its continued acceptance and usage. If an impermeable layer existed below the auger hole and if $S > 2H$ (where S = depth to impermeable layer below bottom of hole and H is depth of ponded water), Equation 3 was used (Jones, 1951).

$$K_{sat} = \frac{Q\left\{\sinh^{-1}(H/\mathrm{R}) - 1\right\}}{2\pi H^2} \qquad \textbf{Eq. 2}$$

where; Q = steady outflow rate (cm^3/minute)
H = depth of ponded water in auger hole (cm)
R = auger hole radius (cm)

$$\mathrm{K_{sat}} = \frac{3Q\ln(H/\mathrm{R})}{\pi H(3H + 2S)} \qquad \textbf{Eq. 3}$$

where; Q = steady outflow rate (cm^3/minute)
H = depth of ponded water in auger hole (cm)
R = auger hole radius (cm)
S = distance to impermeable layer below base of auger hole (cm).

Following collection, samples were analysed by the Department of Agriculture's Biological and Chemical Research Institute (BCRI) at Rydalmere. Further analyses included: pH; electrical conductivity (EC, dS/m); Bray phosphate (Bray-P, mg/kg); total carbon (TC, %);

cation exchange capacity and exchangeable cations (CEC, Na, Ca, Mg, K, cmol(+)/kg); aluminium (Al, cmol(+)/kg); total nitrogen (TN, %); nitrate (NO3-N, mg/kg); and phosphorus sorption (P-sorp, units). Three representative sites (both surface and subsoil samples) were further analysed for organic matter (OM, %) and grainsize characteristics (clay, slit, fine sand, and coarse sand). Grainsize data were used to determine USDA texture classes as a basis of comparison with field texture estimates.

5.3.2 Surface-Water Quality

Three initial surface-water sampling sites were selected to provide baseline information on the quality of creek water during wet-weather. Sampling sites were selected near the lowest point of each catchment to maximise the amount of water reaching the sampling point. The locations of these sites are indicated on Figure 6 and included:

1. Catherine Park;
2. Richard Rd catchment; and
3. Harold Reserve.

Catherine Park (north) and Richard Rd (south) catchments were selected as representing urban areas, while Harold Reserve catchment was initially chosen as a control site having far fewer houses than the other sites. However, a drain constructed during the observation period diverted significant quantities of urban runoff from the upper portions of catchments 11 and 13 into the Harold Reserve catchment. All three sites were therefore regarded as representative of urban areas. An additional site in the upper portions of Patilda Reserve catchment was also monitored.

Wet-weather storm runoff samples were collected on five occasions between 21/10/95 and 10/12/95. Initial samples (A) were collected approximately 10-20 minutes after the onset of rain. A second sample (B) was collected approximately 1 hour after the onset of rain. On several occasions, a third sample (C) was collected after extended rainfall. Samples A and B were used to crudely determine the occurrence of any significant storm pollutant flushing effects. Sample C provided data on surface-water quality following any 'first-flush' effects.

Several water samples were also collected during dry-weather to determine dry- and wet-weather differences in surface-water quality. These included: dry-weather creek flow in the Richard Rd catchment; and ponded water in street puddles during dry-weather. The locations of street samples are given in Figure 6.

5.3.3 Storm Event Rain Data

Rainfall data during each of the storm water runoff sampling events were collected from the Island's privately administered rain gauge (Mr Steve Crosby). The derived rainfall intensity information provided a basis for comparing storm events with the longer term data set from the Newport gauge and examining intensity-concentration relations.

5.3.4 Wastewater Systems

5.3.4.1 System Inspections

There are approximately 320 wastewater systems on the Island. However, within the study time frame and due to access restrictions, it was logistically impossible to investigate each site. However, 30 sites were inspected during fieldwork for the following:

1. method used for effluent disposal (separate/combined grey and black water);
2. condition of trenches;
3. effluent leakage and migration from trenches; and
4. total surface effluent disposal area.

5.3.4.2 Drainfield Soil-water Quality

Porous ceramic cup soil moisture samplers (Wagner, 1962) were installed in five separate disposal drainfields receiving septic effluent only (Cullen, Ode, Collins, Travers, and Tay). The majority of these received both grey and black water except at the Cullen site. However, at the Cullen site, greywater discharge occurred adjacent to and over the drainfield, so that both disposal sites could be regarded as one unit. High effluent concentrations in the drainfield indicate that sampling errors associated with adsorption onto the ceramic cup surface are negligible (Martens and Warner, 1995). Time and site selection difficulties prevented the monitoring of several of the existing Island's AWTSs.

5.3.4.3 Effluent Quality

A review of Water Use Survey 1993 data supplied by SIRA indicated that sampling of the septic tank effluent on the Island could not be carried out effectively. This was due to the limited number of samples economically possible to assess a large number of systems of variable age with incomplete maintenance histories. For example, the SIRA water Survey found that of the septic systems on the island 20% have separate grey/black treatment / disposal systems while 80 % have combined grey/black treatment / disposal. Typically, where grey and black water wastes are separated only two disposal areas are used each with each approximately 10 m^2 in surface area.

For these reasons, septic tank effluent quality measured over a range of contaminants was estimated using published data (Tables 11 and 12) and adjusted according to low per capita water use documented by the SIRA using the following formula. Effluent quality was calculated assuming 100% combined black/grey water (Equation 4). Due to the limited number of AWTS systems present on the Island, these were not considered.

$$C_r = \frac{L_t}{L_r} \times C_r \qquad \textbf{Eq.4}$$

Where;

C_r = Expected mean domestic effluent concentration (mg/L).
C_t = Mean domestic effluent concentration from systems on town water (mg/L).
L_t = Water flow if connected to town water (L/day).
L_r = Water flow if tankwater used (L/day).

Table 11: Quality characteristics of black-, grey-, and combined- wastewater. All concentrations in mg.L^{-1} except for conductivity (μS/cm), Faecal Coliforms (cfu/100mL) and pH (Petrozzi and Martens, 1995).

Parameter	Black Water #	Grey Water*	Combined***
pH	-	7.4	7.0
BOD_5	208-556	175-417	250
COD	944-1929	481-694	500
TOC	111	222	250
Suspended Solids	556	120-231	220
Conductivity	-	580	-
Organic-N	55.6	6.5-16.6**	25
Ammonia	13.9	1.9-5.5	25
TKN	69.4	12.0-18.5	50
Oxidised Nitrogen	0.42	0.31-0.50	0
Total-N	70-167	9.3-12.3**	50
Total-P	7.63	27.8-37.0	12
Faecal Coliforms (cfu/100 mL)	$5.3x10^7$	2.3×10^7	-
Sodium	-	70	-

Adapted from Laak (1986) and Canter & Knox (1988) based on per capita blackwater flow of 72 l.day^{-1}

* Data from Brisbane City Council (1992) and Canter & Knox (1988).

** Date not provided in source - estimated by subtraction or addition of mean concentrations.

*** Gray (1989) - United States data.

Table 12: Estimated mean effluent quality from septic tanks (combined grey/black water) on Scotland Island.

Contaminant	Typical Effluent Quality mg/litre
TN	60
TP	15
Na	45
K	15
Ca	28
Mg	6

5.4 GIS Analyses

5.4.1 Parameter Mapping

Each of the soil parameters were digitally mapped. Using physiochemical data gathered from the 15 field inspected soil pits, 39 additional sites were located on the Island. These were allocated attributes according to their spatial and morphological location (eg. sites on the same ridgeline are likely to have similar soil characteristics). Using both the field and manually located sites, the GIS was used to interpolate a digital surface model by means of a distance-weighted (distance weight exponent = 2) average procedure. Some error in the technique is expected due to the limited number of field collected data. However, this is likely to be balanced by the relatively homogeneous nature of many of the Island's soils.

5.4.2 Data Transformation

Digital maps of soil and topographic data were further transformed to produce secondary maps of the Island. Transformation types may be categorised into:

1. direct transformation (eg. slope map derivation from elevation);
2. general reclassification (eg. slope classes from primary slopes); and
3. map combinations and thematic overlay algorithms (eg. longevity from P-sorption and soil depth).

A summary of the types of data transformations performed using the GIS is provided in Appendix III.

5.4.3 Land Capability Determination

Land capability to accommodate on-site disposal of wastewater was determined through a weighted multiple index overlay algorithm (WIMOA, Bonham-Carter, 1994). In this procedure, map classes are assigned different scores as well as the maps receiving different weights. Scores were allocated according to a uniform ranking scale and weights were chosen according to the relative importance of individual thematic maps. These are stored in an attribute table for use in the GIS. The average score for each grid-cell (25 m^2) is then defined by Equation 5.

$$\bar{S} = \frac{\sum_{i}^{n} S_{ij} . W_i}{\sum_{i}^{n} W_i} \qquad \textbf{Eq. 5}$$

where; $\bar{S}$ = Weighted score per object (pixel/polygon)
S_{ij} = Score of the j'th clas of the i'th input map
W_i = Weight of the i'th input map
n = Number of thematic maps included in analysis

6. Results and Data Analyses

6.1 Native Soil Physiochemical Properties

In general, soils exhibit strong duplex characteristics with clear boundaries between horizons. Depth varies between shallow to moderate (< 1.25 m) with loosely coherent sandy loam A horizons and well structured clayey B horizons. Soil profiles indicate predominantly in-situ weathering (ie. on parent material and not alluvium or colluvium), with erosion rates low enough to allow for sufficient time for profiles to differentiate. Occasionally a sub-soil red enough to be called a Red Podzolic occurs but this is referred to [for the purposes of this report] as a Yellow Podzolic as the implications for effluent disposal are the same. Occasionally B horizons may also be sufficiently brown to be called a Brown Podzolic. These differences are related to poorer drainage. However, these soils are also referred to as Yellow Podzolics.

Summary data for individual soil parameters are provided as well as spatial variations as interpolated through the GIS. Data are summarised for each of the major morphologic units as well as for the two major geological associations, the Hawkesbury sandstone and Narrabeen sandstones and shales. Summarised morphologic units include: ridge; slope; and swale.

6.1.1 Soil Depth

Soil depth, including the depths of A and B horizons, for each sampling site are given in Appendix IV. Surveying revealed that much of the Island soil cover is only moderate with total depth (A and B horizons) averaging slightly below 1.00 m (Table 13). The GIS interpolation analyses reveals that only approximately 7 % of the Island contains soils which exceed a total depth of 1.25 m.

Native A horizons are characteristically thin with approximately 0.45 m average thickness. They frequently exist in a somewhat degraded (compacted) state and have been eroded to some extent, further reducing their thickness. This is particularly so in areas close to urban establishments. Spatial variations in A horizon thickness related to both the morphologic land unit (and therefore catenary or slope position) and the underlying rock type. In general, soil thickness, notably that of the A horizon, increases from ridge units through to swales. The average depth of A horizons in swales (0.60 m) is approximately twice that of the ridges (0.35 m). Results indicate that A horizons are slightly thinner on the Hawkesbury group than on the Narrabeen rocks. No differences in B horizon thickness were found to occur between these two groups.

Table 13: Scotland Island summary soil depth data.

Site Type	A Horizon (m)	B Horizon (m)	Total depth (m)
Ridge	0.35	0.52	0.87
Slope	0.46	0.57	1.03
Swale	0.60	0.54	1.14
Hawkesbury group	0.31	0.54	0.85
Narrabeen group	0.52	0.54	1.06
Island Average	0.46	0.54	0.92
Island Std. Dev.	0.24	0.24	0.40

6.1.2 Grainsize Characteristics

Complete grainsize analyses were determined on six samples. These came from A and B horizon samples at three sites (sites 10, 11 and 15), representing three distinct morphological units; ridge (site 10); slope (site 15); and swale (site 11). Results (Table 14) suggest that clay content decreases and coarse sand content increases through the catenary sequence from ridge to swale. This trend is evident in both A and B horizons.

Significant differences in grainsize composition are evident between A and B horizons. A horizons are typically high in sand content (> 70 %) and relatively low in clay content (< 15 %). In contrast, B horizons contain very high proportions of clay of up to 50 % (average 39 %) as well as high proportions of sand up to 50 %, except in one swale with colluvium present.

Table 14: Grainsize characteristics of native soils on Scotland Island.

	Clay		Silt		Sand		Coarse Sand	
Horizon	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Ridge	19.7	50.3	18.5	19.2	56.9	28.9	5.3	3.0
Slope	15.7	41.6	13.0	10.8	50.8	42.4	19.6	6.0
Swale	6.5	23.9	6.8	4.6	48.6	39.6	35.0	31.9
Average	13.3	38.6	12.8	11.5	52.1	37.0	20.0	13.6

6.1.3 Texture / Structural Classification

Results of field determined texture (McDonald *et al.*, 1990) are presented in Table 15. This also contains texture as determined from the laboratory grainsize analyses (Table 14) and interpreted under the USDA soil texture classification system.

In general, A horizons at most sites were classified as either sandy loams (SL) or loamy sands (LS) depending on catenary location. At one swale (valley floor) site, site 11, the A horizon consisted of predominantly sand indicating alluvial transport of sediments downslope through several of the Island gullies. Soil structure was predominantly absent in the A horizon with most sites classified as single grained apedal.

B horizons texture determinations ranged from sandy clay loams (SCL) through to clay (C), strongly contrasting the A horizon and reflecting the strong duplex nature of native soils on the Island. Structural development was moderate with predominantly polyhedral peds well formed (< 50mm) but not distinct in undisplaced soil. Adhesion between peds was typically strong except where the profile was substantially dry due to prolonged exposure.

Table 15: Field texture determinations of native soils on Scotland Island. Numbers in brackets indicate texture classes determined from USDA grainsize classifications.

Site	Texture (A horizon)	Texture (B horizon)
1	LS	-
2	SL	SCL
3	LS	CL
4	LS	LC
5	LS	CS
6	LS	-
7	LS	C light
8	SL	SCL
9	LS	LS
10	LS (SL)	CL (C)
11	S (S)	SCL (SCL)
12	LS	SL
13	LS	SCL
14	LS	SCL
15	LS (SL)	CL (SC)

Note: LS = Loam sand, SL = Sandy loam, S = Sand, SCL = Sandy clay loam, CL = Clay loam, LC = Loamy clay, CS = Clayey sand, C = Clay.

6.1.4 Hydraulic Properties

Initially, field determination of saturated hydraulic conductivity for both A and B horizons was attempted. However, B horizons proved to be too impermeable to make field measurement possible. At one site, a zero reading was taken after an hour of measurement. Hydraulic conductivities for subsoil horizons were therefore estimated according to their textural characteristics (AS1547, 1994).

Results of A horizon field measurements using the constant head well permeameter varied significantly between 363 mm/day and 2184 mm/day (Table 16). Approximately 80 % of the Island had surface hydraulic conductivities which were moderate (20-60 mm/hour, Hazelton and Murphy, 1992). Some 12 % maintained lower hydraulic conductivities, while approximately 6 % was highly permeable (> 60 mm/hour). From the perspective of effluent disposal, these rates are optimum for ensuring that effluent enters the soil and does not resurface rapidly and migrate away from the site as surface runoff. However, they are high and indicate that soil water retention times would be limited. It is important to note that the effective depth of highly conductive materials (ie. A horizon) is limited to frequently less than 40 cm.

Given that B horizons predominantly vary in texture from light clays to sandy clay loams permeability's are probably in the range of < 30 mm/day (AS1547, 1994), and in many situations, likely to be less than 12 mm/day. The implications for effluent disposal are that the B horizon, because of its low permeability, presents a relatively impermeable boundary to effluent disposal on the Island. Wastewater disposal within the B horizon would be almost totally bound by the surrounding soil and ponded within the trench.

Table 16: A horizon saturated hydraulic conductivity, K_{sat} (mm/day).

Site	K_{sat} (mm/day)	Classification
1	2184	High
2	830	Moderate
3	787	Moderate
4	673	Moderate
5	-	-
6	2051	High
7	1363	Moderate
8	363	Low
9	376	Low
10	1025	Moderate
11	1521	High
12	299	Low
13	614	Moderate
14	531	Moderate
15	707	Moderate

Some variation between the morphologic units was observed (Table 17). Ridges and slope were approximately similar with saturated hydraulic conductivities of approximately 1000 mm/day. Swales (except for site 11 which was on alluvial material) maintained hydraulic conductivities approximately half (400-500 mm/day) that of ridges and slopes. It also appeared that the Hawkesbury group was somewhat more permeable than the Narrabeen group, although the statistical validity of this has not been confirmed.

Table 17: Summary data for A horizon saturated hydraulic conductivity, K_{sat} (mm/day).

Unit	K_{sat} (mm/day)	Classification
Ridge	997	Moderate
Slope	1096	Moderate
Swale (not 11)	445	Low
Hawkesbury Group Average	1119	Moderate
Narrabeen Group Average	814	Moderate
Average	952	Moderate
Standard deviation	608	Moderate

Variations in A horizon saturated hydraulic conductivity did not significantly correlate with other soil parameters (eg. ESP).

6.1.5 pH and EC

pH and electrical conductivity (EC on 1:5 soil suspension) were determined for each collected sample. pH, an important characteristic of the chemical environment of the soil, was extremely acidic for much of the Island with little difference found between A and B horizons. All sites had pH levels < 5 with several sites < 4 (Table 18). At these pH levels, many plant nutrients [such as N, P, K, Ca and Mg] become unavailable for uptake.

EC measurements indicate that the islands soils are non-saline (Table 18). Measures ranged between 0.05 - 0.06 dS/m for A horizons and between 0.07 - 0.11 dS/m for B horizons.

Table 18: Summary data for Scotland Island soil pH and EC (dS/m). Classifications are according to Bruce and Rament (1982) and Richards (1954).

Unit	A	Classification	B	Classification
pH				
Ridge	4.10	Extr. Acid	4.12	Extr. Acid
Slope	4.08	Extr. Acid	4.04	Extr. Acid
Swale (not 11)	4.13	Extr. Acid	3.84	Extr. Acid
Hawkesbury Group Average	4.16	Extr. Acid	4.37	Extr. Acid
Narrabeen Group Average	4.08	Extr. Acid	3.87	Extr. Acid
Average	4.10	Extr. Acid	4.00	Extr. Acid
Standard deviation	0.24	-	0.34	-
EC (dS/m, 1:5 suspension)				
Ridge	0.05	Non-saline	0.08	Non-saline
Slope	0.05	Non-saline	0.09	Non-saline
Swale (not 11)	0.06	Non-saline	0.11	Non-saline
Hawkesbury Group Average	0.05	Non-saline	0.07	Non-saline
Narrabeen Group Average	0.05	Non-saline	0.10	Non-saline
Average	0.05	Non-saline	0.09	Non-saline
Standard deviation	0.02	-	0.05	-

6.1.6 Cation Content

Cation exchange capacity is the capacity of the soil to hold and exchange cations. It is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH, and the soils reaction to fertilisers and other ameliorants. CEC measurements at all sites were low to very low (Table 19), increasing slightly with depth (A to B horizon). The Narrabeen group average was slightly higher than the Hawkesbury indicating increased nutrient availability on lower slopes. Summaries for individual cation concentrations are given in Appendix V.