KINHILL

FLOODPLAIN MANAGEMENT STUDY FOR

NARARA CREEK AND LOWER NARARA CREEK

TRIBUTARIES WEST OF HANLAN STREET

FINAL REPORT

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FOREWORD

The New South Wales Government's flood policy is directed at providing solutions to existing flooding problems in developed areas, as well as ensuring that new development is compatible with the flood hazard, and that it does not create additional flooding problems in other areas.

Under the policy, the management of flood-prone land remains the responsibility of local government. The State government subsidises flood mitigation works to alleviate existing problems, and provides specialist technical advice to assist councils in the discharge of their floodplain management responsibilities.

The flood policy provides for technical and financial support by the government through the following four sequential stages:

- Flood study: Determines the nature and extent of the flood problem;
- Floodplain management study: Evaluates management options for the channel in respect of both existing and proposed development;
- Floodplain management plan: Involves formal adoption by Council of a plan of management for the channel;
- Implementation of the plan: Involves construction of flood mitigation works to protect existing development. Also, use of local environmental plans to ensure new development is compatible with the flood hazard.

The floodplain management study for the creeks west of Hanlan Street constitutes the second stage of the management process and has been prepared for Gosford City Council to evaluate the management options.

SUMMARY

The Floodplain Management Study for Narara Creek and Lower Narara Creek tributaries west of Hanlan Street has been undertaken to formulate a management plan that provides appropriate levels of flood protection to existing and future development. The study area, west of Hanlan Street includes three creeks and associated tributaries and extends the existing study previously carried out for the lower reaches of Narara Creek.

The flood standard adopted by the Gosford City Council is the 1% annual exceedence probability (AEP) flood event and this has been used to prepare the management plan. The proposed plan examines a range of design floods. Design flood profiles are given for each of the creeks, with recommendations of the works that should be undertaken.

A proposed prioritization of works within the management plan has been prepared to facilitate a staged implementation of the plan consistent with available funding.

Recommended management options include creating wet basins, raising roads and channel improvement works. Only one property acquisition is recommended for immediate implementation, ie. Lot B DP 393508 corner of Fountains Road and Hanlan Street, as it is floodprone for the 1% AEP event. All other works discussed are long-term flood management proposals.

This study also discusses future road options that have been proposed for the area and considers the possible effects on flooding that these proposals may have.

1 INTRODUCTION

1.1 GENERAL

A flood study and floodplain management plan has been prepared for Lower Narara Creek downstream of the crossing of Hanlan Street (PWD 1988, Kinhill 1991a and 1993). Three creeks west of Hanlan Street contribute discharge to Lower Narara Creek; they are Narara Creek, Fountain Creek and Reeves Creek.

Partial development has already occurred in the Reeves Creek catchment and in order to ensure that any future development in any of the catchment does not exacerbate flooding problems, the Lower Narara Creek Flood Study and Lower Narara Creek Floodplain Management Study (FPMS) are to be extended to included these creeks.

This study is also to review the development control plan (Narara Development Control Plan [1991]) that has been prepared for the area.

A recent flood study (Kinhill Engineers 1996) established the hydrologic and hydraulic models and design flood profiles for the study area. This report documents the floodplain management options for the study area.

The principal aims of this floodplain management study have been to:

- establish a cost-effective flood management plan;
- recommend a staged implementation of the management plan.

The detailed study of each of the three creeks is presented under Sections 3 and 4 comprising:

- evaluation of flood management options;
- recommended flood management plan;
- priority ranking of recommendations;
- estimated costs of management options.

Generally, the management options are discussed under two headings namely:

- immediate flood management proposals;
- long term flood management proposals;
- water quality and erosion control proposals.

Section 5 discusses future road options that have been prepared for the area and the most appropriate drainage structures for the stream crossings.

1.2 STUDY AREA

The study area west of Hanlan Street is shown in Figure 1.1 In addition to the main creeks identified, several minor tributaries flow into Fountain Creek and are included in this study. The catchment areas for the sections of Narara Creek, Fountain Creek and its tributaries and Reeves Creek modelled in this study are 14.1, 4.3 and 0.4 km^2 respectively.

The catchment varies from severe relief at the upstream end to mild relief at the downstream end. Upstream, is predominantly natural bushland falling steeply from the Somersby plateau at +220 m AHD to +10 m AHD at the upper limit of the study area. The Sydney–Newcastle Freeway runs along the Somersby plateau within the Lower Narara Creek catchment boundary. The catchment within the study area is relatively flat, with only a few metres difference in elevation between the upper limit and the downstream limit at Hanlan Street. The upper reaches of Narara Creek are very sandy, with large areas of deposited sand. The downstream reaches of Narara Creek, Fountain Creek and Reeves Creek are naturally eroded channels with thickly vegetated channel banks. The creek floodplain is generally open pasture away from the creek banks.

The upper study limit is the proposed road reserve between the Strickland State Forest and the Narara Agricultural Research Station; the existing transmission line across Fountain Creek, approximately 600 m upstream from the crossing of Reeves Road and the base of the escarpment for the minor creeks flowing into Fountain Creek.

Reeves Creek is a relatively minor creek and was modelled downstream of the crossing of Reeves Road.

The downstream limit of the study area has been taken as where Narara Creek crosses Hanlan Street and approximately 45 m upstream of the north-south alignment of Hanlan Street for Fountain Creek and Reeves Creek. This represents the upper limit of the Lower Narara Creek Floodplain Management Study (FPMS) (Kinhill 1991a).

1.3 PREVIOUS STUDIES AND DATABASE

1.3.1 PREVIOUS STUDIES

Lower Narara Creek, downstream of Hanlan Street has been the subject of previous flood studies. These included a flood study (PWD 1988), a floodplain management study (Kinhill 1991a and 1993) and a floodplain management plan (Kinhill 1991b). The floodplain management study (Kinhill 1993) includes a revision to the PWD flood study (PWD 1988) and reviews the initial study (Kinhill 1991a) for the February 1992 flood event. This present study is an extension to these studies.

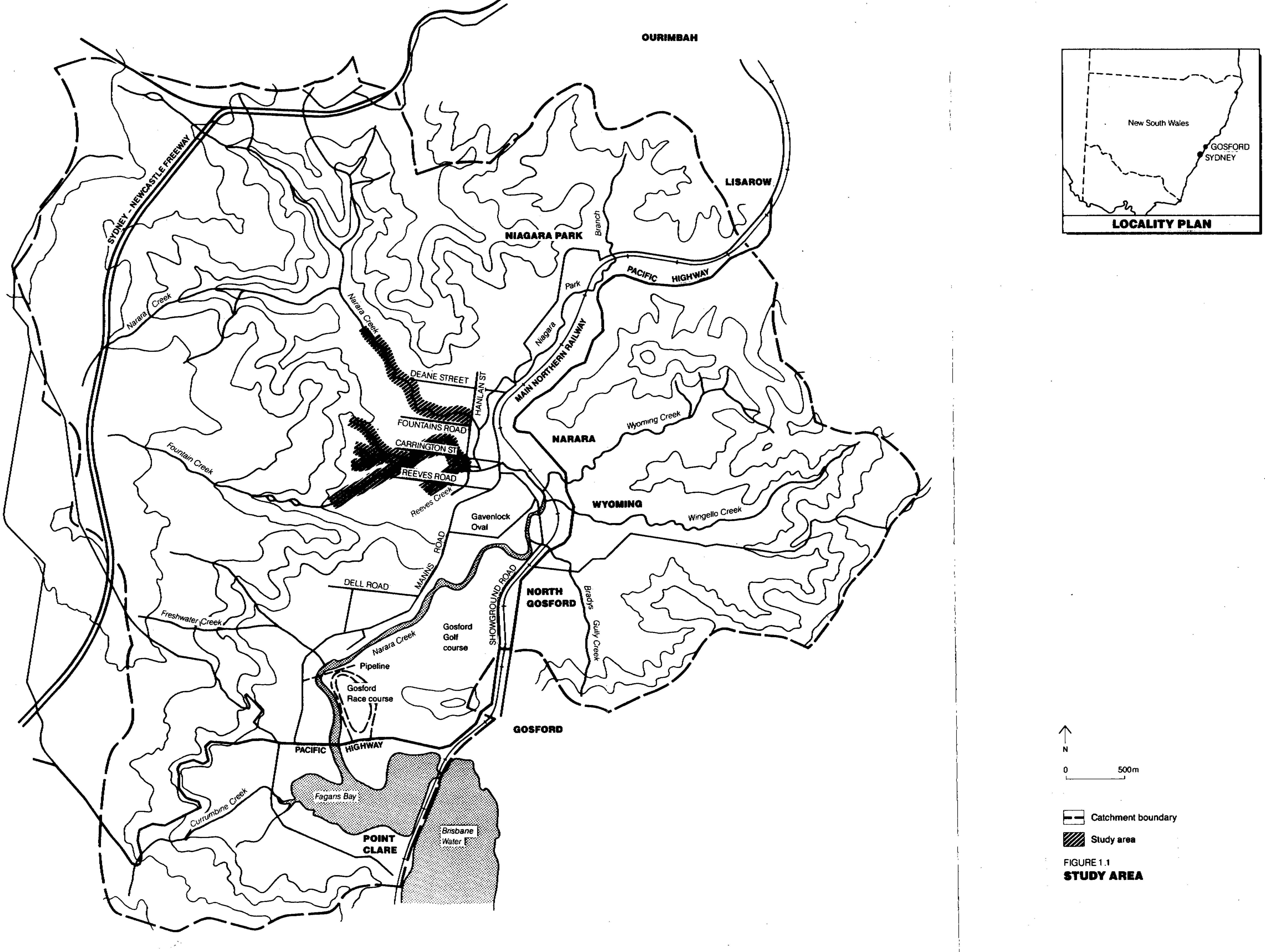


FIGURE 1.1
STUDY AREA

In addition, a study was carried out in 1991 for the Narara School Flood Access Study (Kinhill 1991c) in which the hydrologic model used in the Lower Narara Creek Flood Study was modified to determine creek flows in the area of Reeves Street, Hanlan Street and Carrington Street.

1.3.2 TOPOGRAPHIC DATA

Most topographic information was obtained from the following maps:

- 1:4,000 map based on 1985 aerial photograph

  Gosford U2797-2
  Gosford U2797-5

- 1:25,000 topographic map

  Gosford 9131-2-S

A specific field survey was undertaken by J.T.S. Ryan Firth and Co. Registered Surveyors, under the instruction of Kinhill Engineers. The survey included:

- 30 channel and overbank cross-sections;
- details of all culverts and bridges in the study area;
- flood heights identified by resident interviews for historic floods;
- floor levels of buildings likely to be flood affected.

The following Table 1.1 identifies all properties with houses in the floodplain as surveyed by Ryan Firth (Sept. 1992).

Table 1.1 **Design 1% AEP flood and building levels**

Address	Surveyed floor level (m AHD)	1% AEP Flood level
95 Deane Street	9.52	8.75
93 Deane Street	9.36	8.70
24 Deane Street (shed)	8.24	8.45
24 Deane Street	15.27	8.50
79 Deane Street	13.25	7.7
79 Deane Street (shed)	11.25	7.7
19 Deane Street	15.08	7.2
63/65 Deane Street	17.49	7.1
Lot 1 DP 116038 Hanlan Street	15.17	6.9
290 Hanlan Street	10.61	6.5

Table 1.1 **Design 1% AEP flood and building levels (Cont'd)**

Address	Surveyed floor level (m AHD)	1% AEP Flood level
40 Hanlan Street	9.46	6.4
500 Hanlan Street	10.40	6.45
42 Fountains Street	13.51	7.35
38 Fountains Street	12.60	7.2
34 Fountains Street	9.34	7.1
23 Fountains Street	6.61	6.3
23 Fountains Street	6.74	6.2
2 Pandala Road	8.2	5.9
Cnr Hanlan & Fountains Streets (Lot B DP393508)	5.68	6.65 *
Top of levee, cnr Hanlan & Fountains Streets	6.92	6.70
29 Hanlan Street	10.70	5.40
2/6 Hanlan Street—house	6.89	5.25
2/6 Hanlan Street—garage	4.37	5.25 *
2/1 Hanlan Street	6.03	5.23

*Note: * denotes house floor level below 1% flood level*

1.3.3 HISTORIC FLOOD DATA

Details of rainfall and flood levels for historical events have been documented in the Flood Study for Narara Creek and Lower Narara Creek Tributaries west of Hanlan Street (Kinhill 1996).

1.3.4 URBAN DEVELOPMENT OF THE CATCHMENT

The study catchment forms part of the environs of Gosford. On the steep slopes of the escarpment of Somersby plateau there is no development, whereas on the lower slopes there is increasing low density development. This study considers the maximum possible urbanization consistent with the current land zonings.

1.3.5 DESIGN FLOOD DATA

Design rainfall data were extracted from the 1987 edition of *Australian Rainfall and Runoff* (Canterford 1987) for the catchment. The critical storm duration for the study area was found to vary between two hours at the upstream end to six hours at the downstream end.

The downstream design flood levels as determined in the Lower Narara Creek FPMS were adopted as the downstream control levels for this study.

1.4 STUDY METHODOLOGY

1.4.1 GENERAL

The adopted study approach involved:

- collection of survey data;
- collection of flood and rainfall data for the February 1990 and February 1992 events;
- establishing the hydrologic and hydraulic models;
- calibration of the hydrologic and hydraulic models;
- determination of design flood profiles using the calibrated model.

The adopted mathematical modelling approach was to use a hydrologic model to determine design flows in the study area and then use a hydraulic model to determine peak flood levels in the study area.

1.4.2 HYDROLOGIC MODELLING

The flows in the catchment were modelled using the runoff routing model RORB (Laurenson and Mein 1985). Runoff routing models estimate the flood hydrographs in the catchment after routing of rainfall excess through a network of storages within the catchment.

The RORB model was chosen for this study as it had already been established and calibrated for the Lower Narara Creek Flood Study. The catchments for the creeks West of Hanlan Street were included in the RORB model and only minor modifications were required to adapt it for this study.

1.4.3 HYDRAULIC MODELLING

Hydraulic models are used to determine flow patterns, flood levels and velocities. Flood behaviour is assessed by numerically calculating flow conditions throughout the channels and floodplain. There are several types of hydraulic model available. The steady state model HEC-2 calculates the water surface profile for steady one-dimensional flow in irregular channels. The model can be used for subcritical and supercritical flow in channels of simple or compound cross-sections. The effects of weirs, bridges and culverts can also be taken into account.

Due to the simplicity of the HEC-2 model and its recognized usage in Australia it was adopted in this study.

1.4.4 MODEL CALIBRATION

Calibration is the process whereby the correct values of the model parameters are established to ensure that the model simulates recorded discharge or flood level data using adequately defined rainfall patterns. Usually the calibration of hydrologic and hydraulic models is an iterative process.

There are four main calibration parameters in the RORB model:

- initial loss;
- continuing loss;
- storage parameter k_C;
- non-linearly exponent m.

The RORB calibration parameters were determined in the Lower Narara Creek FPMS and were modified for the Narara School Flood Access Study. These modified parameters were adopted for this study. However to gain confidence in the model, the design peak discharges obtained by the RORB model were compared to those obtained using the Probabilistic Rational Method (Pilgrim 1987).

Calibration of the hydraulic model HEC-2 was performed by varying the Manning roughness coefficient 'n'. These values were initially determined from field inspection but were adjusted in order to give an acceptable flood profile for the February 1990 and February 1992 events.

1.5 RELATION OF THIS STUDY TO THE LOWER NARARA CREEK FLOODPLAIN MANAGEMENT STUDY

In the Lower Narara Creek FPMS (Kinhill 1991a) and Review (Kinhilll 1993) certain works were proposed for the upper reaches of Lower Narara Creek downstream of Hanlan Street. To avoid adverse impacts on these reaches, the recommended works for the Narara Creek and its tributaries west of Hanlan Street must be co-ordinated with the downstream mitigation works.

Those recommended immediate proposals that will not affect Lower Narara Creek downstream of Hanlan Street should all be implemented as soon as practical.

For immediate proposals that may affect the creeks downstream of Pacific Highway, such as lining of the immediate upstream sections, works should only commence when the downstream improvement works as recommended by the Lower Narara Creek Floodplain Management Study Report (Kinhill 1991a) have been implemented.

2 FLOODPLAIN MANAGEMENT OPTIONS

2.1 GENERAL

Narara Creek and Lower Narara Creek tributaries west of Hanlan Street were divided into sixteen areas for investigation prior to the preparation of the management plan. The areas are:

- Narara Creek
  - NA1 Hanlan Street culvert
  - NA2 Fountains Road upgrade
  - NA3 Hanlan Street wet basin (1)
  - NA4 Hanlan Street to Deane Street floodway
  - NA5 Nursery Street flood proofing
  - NA6 Narara Agricultural Research Station.
  - NA7 Property Acquisition - Lot B DP 393508
- Fountain Creek and Reeves Creek
  - FR1 East Hanlan Street channels
  - FR2 Hanlan Street wet basin (2)
  - FR3 Carrington Street floodway
  - FR4 Carrington Street bridges
  - FR5 Carrington Street culvert
  - FR6 Fountain Creek tributaries
  - FR7 Reeves Street causeway
  - FR8 Reeves Street detention basin
  - FR9 Reeves Street culvert.

Both structural and non-structural measures were evaluated for inclusion in the floodplain management scheme. Possible structural measures could include:

- levee construction
- floodways
- stream enlargement and clearing
- detention basins
- culvert amplification.

The non-structural measures that could be incorporated in a management plan include:

- flood warning

- flood education
- restrictive land use
- flood-proofing
- voluntary purchase (sale) of properties.

As well as measures that directly affect the hydraulic characteristics of the floodplain, water quality and sediment control measures were evaluated for inclusion in the floodplain management plan. Possible inclusions are:

- wetlands for nutrient reduction
- sedimentation ponds.

The purpose of a floodplain management plan is to reduce the potential for damage to a flood affected area by any cost-effective means. This could involve either reducing the flood hazard, and therefore allowing properties to be evacuated during flood times, or by removing flood affected properties from the area. An alternative would be to provide flood-proofing that would not adversely affect other flood affected areas or create any new flood hazards.

The overall floodplain management study evaluates the benefits of floodplain management measures to the community. In some instances, it may be necessary to take measures that, while adversely affecting local areas, would benefit the community as a whole.

2.2 STRUCTURAL MEASURES

The measures evaluated in the Management Options are discussed in detail in Sections 3 and 4. However further general discussion on certain topics is included in the following sections.

2.2.1 PRIVATE CULVERTS AND BRIDGES

Throughout the length of the creeks and tributaries there are numerous small timber bridges and culverts that are privately owned. These have been modelled where they were considered sufficiently sound not to be washed away during the high flood flows. However the floodplain management plan has not been extended to include these bridges.

2.2.2 STREAM ENLARGEMENT AND FLOODWAYS

In several options, channel enlargement and stream clearance has been proposed in the recommended option. It is however recognised that straightening the channel and forming a regular trapezoidal channel is unnatural and not in keeping with the existing creek system. The natural features of the creeks should be maintained.

2.3 NON-STRUCTURAL MEASURES

The only non-structural measure proposed in this study is the voluntary purchase of the property on the corner of Fountains Road and Hanlan Street South as described in Section 3. However a general recommendation is that the land within the 1% AEP flood extent be maintained as a floodway and that no construction be allowed within the designated flood extents. Where development already exists within the floodway, restrictions should be made such that no further development or change of land use occurs.

2.4 WATER QUALITY AND SEDIMENT CONTROL MEASURES

The proposed development in the areas shown in the Narara Development Control Plan (1991) will require a strategy to manage stormwater quality in order to mitigate the effects of increases in sediment and pollutant loads. The main features of such strategy would include the following:

- investigation of the existing and future pollutants of the receiving waters and consideration of what pollution control is required to return pollutant exports to acceptable levels;

- minimization of amount of the material that washes off a land surface by on-site activities especially during construction. Control measures for sediment runoff during construction have been developed by the EPA, the Soil Conservation Service and are also included in Gosford City Council's Erosion and Sediment Code of Practise.

Reduction of pollutants and sediment off-site requires a management system which would include some or all of the following:

- grass floodways
- gross pollutant traps (GPT)
- trash racks
- sedimentation basins
- pollution control ponds (Wetlands).

2.4.1 WETLANDS

Significant reductions in pollutant concentrations are possible by passing stormwater through basins with a permanent pool of water. Since many pollutants in urban runoff are associated with particulate matter, wet retention basins are regarded by the former state Pollution Control Commission (SPCC), (1989) as usually the most cost effective means of stormwater control.

By incorporating Wetlands downstream of a development, the velocity of the runoff is also reduced allowing particles to settle.

A typical Wetland is illustrated in Figure 2.1 and it comprises an inlet zone, a macrophyte zone and an open water zone. The inlet zone or gross pollutant trap (GPT) is to reduce the velocity of inflowing water and remove larger particulates such as cans. The macrophyte zone is implemented to trap the sediment and litter and is effective in absorbing nutrients and toxicants from water that flow through them.

To improve the water quality discharging into Narara Creek it is recommended to implement gross pollutant traps and wetland basins.

2.4.2 WETLAND LAYOUT

The layout and depth of Wetlands depend on the topography of the land where they are located. Generally the guidelines are as follows:

- ponds should have a length/width ratio 2:1 to 3:1;
- edges should be graded to 1:8, down to a depth less than 1 m, to allow for emergent macrophyte growth;
- maximum basin depth should be greater than 2 m and less than 8 m;
- greater than 25% of the area should have a depth less than 1 m;
- if possible, a small island should be constructed on the upstream side of the basin to reduce water velocities, prevent short circuiting and promote aquatic plant growth;
- grassed or vegetated buffer area of about 20 metres wide should be established around the wetland;
- variety of plant species should be planted;
- the basin should be desilted when the development upstream is finally stabilised and maintained by Council on a regular basis.

2.4.3 LOCATION AND SIZE OF WETLANDS

Wetlands within the proposed development areas, were located using the 1:2000 CMA orthophotomaps and these are discussed further in Sections 3 and 4.

The preliminary size of each wetland was calculated using the Water Pollution Control Guidelines prepared by the Water Research Centre of the University of Canberra (1990). The approach is to estimate the mean annual runoff, which is calculated as 30% of the mean annual rainfall for a developed catchment. The average retention time is calculated as the volume of the pond divided by the mean annual runoff. When a suitable pond volume has been computed, a further 20% volume is added to allow for sedimentation.

Using the above criteria and an average yearly rainfall of 1,969 mm for the area (average of 1988, 1989 and 1990), a volume of 408 m^3/ha was adopted for the two wetlands. This volume is preliminary and may change slightly at the detailed design stage.

3 NARARA CREEK MANAGEMENT OPTIONS

3.1 GENERAL

The Narara Creek flow regime changes from the steep slopes of the Somersby plateau escarpment to the relatively flat open pasture of the study area. This change of regime results in a large amount of sand being deposited in the upper reaches of the study area and the flood flow spreading out over the low lying land. In the downstream reaches, overbank flow passes south over Fountains Road and into Fountain Creek. Only two houses have a history of flooding, they are Lot 14 DP 738338 Nursery Street and Lot B DP 393508 Fountains Road on the corner of Hanlan Street. However, the house at Lot 14 Nursery Street has recently been raised and is not floodprone during the 1% AEP event. The various options considered in this study are shown in Figures 3.1, 3.2 and 3.3.

A summary of the proposals, their priority and the estimated costs is presented in Table 3.2. A detailed breakdown of the costs is included in Appendix A.

3.2 IMMEDIATE FLOOD MANAGEMENT PROPOSALS

3.2.1 PROPERTY ACQUISITION (NA7)

Lot B DP 393508 Fountains Road is floodprone for the 1% AEP design event and so its acquisition by Council is the only immediate flood mitigation work proposed. As indicated in table 1.1 sheds and garages on two other properties are also floodprone, however, these have generally been constructed without Council approval and will not be considered in the assessment of flood damages.

Lot B on the corner of Fountains Road and Hanlan Street is partly protected by a levee bank which has been constructed without Council permission. The levee only continues part of the way around the property along Fountains Road side and it is considered that during a 1% AEP event flood flows would enter the property from the rear regardless of the levee. In addition to this, access to the property from the adjoining streets would be poor during a major flood event. The levee has therefore been ignored for the purposes of this study and therefore the property is considered to be floodprone for the 5% and 20% AEP events also.

3.3 LONG TERM FLOOD MANAGEMENT PROPOSALS

3.3.1 HANLAN STREET CULVERT (NA1)

The existing culvert under Hanlan Street is a 750 mm diameter culvert. The upstream and downstream opening to the culvert are approximately 4.5 m wide and 0.7 m deep but funnel into the 750∅ pipe under the road. A trash rack has recently been installed at the upstream face of the road crossing. This culvert regularly overtops during minor rainfall events and the road is flooded. When the road is overtopped, even during minor events, the road can remain inundated for several hours. The delay in the reduction of flood level is due to the continuing flow from the large upstream catchment, the constriction of the existing culvert and the inability of the flood waters to pass downstream through the dense bush.

For storm events in excess of the 20% AEP event, the capacity of the existing culvert was found to be limited to approximately 2 m^3/s with almost all flow overtopping Hanlan Street. The afflux at this road crossing for existing conditions is therefore only approximately 0.06 m.

For the 1%, 5% and 20% AEP events modelled, the starting downstream water level at Hanlan Street is in excess of 2 m above the existing road level at the Narara Creek crossing. Therefore flood free access cannot be provided for these events without significant road raising and culvert amplification.

A range of culvert upgrading options were investigated in order to provide a degree of improvement to flood access at the Hanlan Street culvert.

An assessment of the capacity of the various options to improve flood access at the crossing for more frequent events than the 20% AEP event required an assumption of the tailwater levels and flow. Peak flows and flood levels were not determined for floods smaller than the 20% AEP event in the previous Lower Narara Creek Floodplain Management Study or the Flood Study (1996) for West of Hanlan Street.For comparison purposes, the 100% AEP event was estimated to constitute a peak flow at Hanlan Street of approximately 50 m^3/s and a tailwater level downstream of the crossing of approximately RL5.0 m AHD.

Options investigated are summarised in Table 3.1 and results provided for the 1%, 20% and 100% AEP events. Estimates of culvert capacity, a preliminary assessment of flood hazard using velocity—depth relationships and the impacts on upstream flood levels are also tabulated.

Initially options involving maintaining the existing road level, amplification of the culvert and lowering the water main constricting the downstream invert level were investigated using the HEC–2 model. Results indicated that for the 1%, 5% and 20% AEP events, there was no significant reduction in flood levels, although flows conveyed through the culvert were increased significantly. Flood hazard was improved slightly but still considered to be high. It was considered that these options would improve flood access for more frequent events than the 100% AEP. Additional modelling of the

Table 3.1 **Hanlan Street culvert upgrading options**

	Options detail	Estimated capacity (m^3/s)	Depth over road (m)			Velocity/ depth relationships			Flood mitigation @
			1% AEP	20% AEP	100% AEP#	1% AEP	20% AEP	100% AEP#	
1.	Existing 750∅RCP (Do nothing)	2	2.6	2.29	1.2	4.3	2.5	1.5	None
2.	Lower water main and 3 (1.5 x 2.7) RCBC	28	2.6	2.27	1.2	2.1	1.3	1.1	No significant effect on 1% and 20% AEP flood levels (levels lowered 0.05m for 1% AEP event)
3.	Lower water main and 3 (1.5 x 3.6) RCBC	40	2.6	2.27	1.2	2.1	1.3	1.1	No significant effect on 1% and 20% AEP flood levels (levels lowered 0.05m for 1% AEP event)
4.	Lower water main and 4 (1.5 x 3.6) RCBC	40	2.6	2.28	1.2	2.1	1.4	1.1	No significant effect on 1% and 20% AEP flood levels (levels lowered 0.07m for 1% AEP event)
5.	Raise road to RL5.0 and 3 (2.1 x 3.0) RCBC	44	1.38	1.07	0.5	1.5	1.0	0.5	No significant effect on 1% and 20% AEP flood levels (levels lowered 0.01m for 1% AEP event)
6.	Raise road to RL5.0 and 3 (2.1 x 3.6) RCBC*	45	1.38	1.07	0.5	1.4	0.9	0.4	No significant effect on 1% and 20% AEP flood levels (levels raised 0.01m for 1% AEP event)
7.	Raise road to RL6.0 and 3 (2.7 x 3.6)	52	0.55	0.37	-	1.10	0.7	-	1%, 20% AEP flood levels raised approximately 0.54m and 0.57m respectively
8.	Raise road to RL6.0 and 4 (2.7 x 3.6)	50	0.55	0.38	-	1.2	0.7	-	1%, 20% AEP flood levels raised approximately 0.56m and 0.58m respectively
9.	Raise road to RL6.5 and 4 (3.3 x 3.6)	47	0.56	0.38	0.10	1.3	0.7	0.1	1%, 20% AEP flood levels raised approximately 1.05m and 1.08m respectively

Note: * *denotes option includes lowering of water main*
 # denotes 100% AEP results estimated for comparison purposes
@ denotes impact on flood levels is typically the maximum effect upstream of Hanlan Street

more frequent events would be required to confirm the tailwater levels, flows and hence capacities.

Road raising to various levels combined with a range of culvert sizes was investigated. An attempt to achieve a 20% AEP solution was made by raising the road to 6.5 m AHD. A range of culverts were modelled to provide sections up to approximately twice the width of the existing culvert approaches. This was found to reduce flood hazard, however, it is also resulted in an increase in flood levels upstream of Hanlan Street of over 1.0 m, which is unacceptable.

Similarly, road raising to RL6.0 m AHD was found to result in increases in flood levels of approximately 0.6 m upstream of Hanlan Street as indicated in Table 3.1. This increase was also considered unacceptable.

Raising the road to RL5.0 m AHD reduced flood hazard significantly and only resulted in minor afflux which was not considered significant, however, 0.05 m is above Council's standard of 0.01 m. Road raising for this option would prove costly as the extent of upgrading required would extent over approximately 100 m, however, it has been included as a long-term recommendation for further consideration.

It should be emphasised that the ability to provide flood free access at Hanlan Street is dictated more by the high tailwater levels than culvert waterway area for the existing road levels. Even minor events are estimated to have tailwater levels higher than the existing road level at the creek crossing.

A limit to the acceptable width of culvert was found for each of the road raising options. Increasing the width of culvert beyond approximately 12 m was found to increase flood levels at the crossing and upstream of Hanlan Street due to high expansion and contraction losses between the existing narrow creek sections upstream and downstream of the wider culvert section.

In order to gain any benefit from culvert amplification beyond the widths tabulated, significant channel widening both upstream and downstream would be required. This is considered a low priority and only recommended for future consideration.

3.3.2 FOUNTAIN ROAD UPGRADE (NA2)

During the 1% AEP event, flood flow overtops Fountains Road and passes south into Fountain Creek. Fountains Road is considered one of the major access routes for future development and so maintaining the road open is considered desirable. Similarly raising the road above the 1% AEP would also increase the amount of flood free land available south of Fountains Road.

The recommended proposal is to raise Fountains Road from the junction of Fountains Road and Hanlan Street to +6.0 m AHD. Additional roadworks would also be required along Hanlan Street to tie in with the existing road surface. The alternative of an embankment along Fountains Road to tie in with the existing embankment at the junction of Hanlan Street and Fountains Road is not considered a viable alternative.

Although this would prevent flow across Fountains Road, flood levels in Hanlan Street would be raised by 0.78m. This option has therefore not been considered further.

3.3.3 HANLAN STREET TO DEANE STREET FLOODWAY (NA4)

Narara Creek between Deane Street and Hanlan Street follows a circuitous route across the low lying floodplain. In order to reduce the amount of flood prone land the creek bed could be formalized and an embankment constructed on the northern side of the creek. The bed width of the floodway would be 25–35 m wide to accommodate the 1% AEP flows. However such channel works and the destruction of the natural creek are not considered justified as the flood mitigation impact is negligible.

This option has therefore not been considered further.

3.3.4 NURSERY STREET FLOOD ACCESS IMPROVEMENTS (NA5)

The house at the junction of Nursery Street and Deane Street is one of the two houses in the study area that is affected by the floods. However the house floor level has recently been raised and is now 0.8 m above the predicted 1% AEP flood level. Only access to and from the house is affected.

The proposal to achieve flood free access for the house, is to raise Nursery Road above the 1% AEP level of 9.50 m AHD or to construct a footbridge from the house to the flood free section of Nursery Street. If Nursery Street is raised, then 1.20 m of fill is required in sections and a significant number of culverts are required to prevent the raised road causing an impedance to the natural flow path. If a footbridge is constructed, then this would need to be 60 m long. Neither proposals are considered justified.

Upstream of Nursery Street, the natural creek turns through two 90° bends before flowing to the south of the junction of Nursery Street and Deane Street. During high flows, the creek overtops the bank at approximately cross-section 24 and takes the more direct path towards cross-section 23. The recommended works are to realign the creek as shown on Figure 3.2 in order to reduce the amount of overland flow. There are two privately owned bridges along this section and these would need to be replaced. As no houses are flood affected by the existing creek, this is considered a long term option.

3.3.5 NARARA AGRICULTURAL RESEARCH STATION DETENTION BASIN (NA6)

One option considered was to construct a detention basin upstream of cross-section 25 (refer figure 6.4), with an embankment to +12 m AHD. The average ground level at this section varies from +8.00 m AHD to +9.5 m AHD and so the embankment would be 4 m high in places. The storage achieved by this embankment is 90,500 m^3 which is insignificant when compared to the estimated 1,200,000 m^3 required for a 50% reduction in flows. With this 50% reduction in flows the maximum reduction in water level is only 0.35 m at cross-section 24. With 90,500 m^3 storage the reduction in flows and resultant reduction in flood levels would be negligible. This option was therefore not considered further.

3.4 WATER QUALITY AND SEDIMENT CONTROL PROPOSALS

3.4.1 HANLAN STREET WET BASIN NO. 1 (NA3)

The proposed Hanlan Street Wet Basin No. 1, which is illustrated in Figure 3.2, is located in Narara Creek just upstream of the Hanlan Street culvert. This area is currently open pastoral land. The estimated required volume, using the method described in Section 2 is 24500 m^3. This volume was calculated based on 60 ha of developed area within the Narara Creek catchment upstream of Hanlan Street. The estimated surface water area, assuming an average depth of 1.5 m in the wetland, is 16300 m^2.

This basin is recommended as a long-term option. However, it should not be constructed before the sediment trap at the Narara Agricultural Research Station is constructed as prior construction may cause major problems with sedimentation in the wet basin.

3.4.2 NARARA AGRICULTURAL RESEARCH STATION SEDIMENT TRAP (NA6)

An alternative to creating a detention basin upstream of cross-section 25 in the Agricultural Research Station would be to create a sedimentation basin to trap the large amount of sediment coming off the Somersby plateau and escarpment. The recommended proposal is to build an embankment to +10 m AHD with a 2.1 m diameter outlet pipe for low flows. Any flow above 10 m^3/s, corresponding to 1–3 month ARI, would be retarded in the basin allowing the sediment to drop out. Major flood flows would pass over the embankment and a spillway would need to be constructed along the crest of the embankment to direct the overflow back into the natural creek. The ponded area created by the embankment would allow a sufficiently long detention time for the sediment to settle out.

The sediment deposited would need to be regularly removed to maintain an effective sedimentation basin. Removal for commercial purposes would be subject to environmental issues and this would need to be resolved before this proposal is carried out.

GOSFORD CITY COUNCIL

LEGEND

EXISTING CREEK ALIGNMENT

Notes:

1. FLOOD LEVELS HAVE BEEN CALCULATED AT CROSS SECTION LOCATIONS ONLY.
2. FLOOD LEVELS AND FLOOD CONTOURS BETWEEN CROSS SECTIONS HAVE BEEN LINEARLY INTERPOLATED.
3. FLOOD CONTOURS DEPICT APPROXIMATE WIDTHS OF FLOODING ONLY.
4. THE POSITION OF THE FLOOD EXTENT RELATIVE TO PROPERTY BOUNDARIES IS APPROXIMATE ONLY AND SHOULD BE VERIFIED BY SURVEY.
5. FLOOD LEVELS ARE GIVEN IN METRES TO AUSTRALIAN HEIGHT DATUM.
6. "FLOOD EXTENTS UPSTREAM OF THIS LINE SUPERSEDES THAT OF THE LOWER NARARA CREEK FMS.

Narara Creek & Lower Narara Creek Tributaries
FLOODPLAIN MANAGEMENT STUDY

FLOODPLAIN MANAGEMENT OPTIONS

FIGURE 3.1 SHEET 1 of 2

	195C	195D
211B	212A	212B
211D	212C	212D

KEY TO ADJOINING SHEET

CENTRAL MAPPING AUTHORITY
MAP REFERENCE
GOSFORD U2797-21

FIGURE 3.1

GOSFORD CITY COUNCIL

LEGEND

EXISTING CREEK ALIGNMENT

Notes:
1. FLOOD LEVELS HAVE BEEN CALCULATED AT CROSS SECTION LOCATIONS ONLY.
2. FLOOD LEVELS AND FLOOD CONTOURS BETWEEN CROSS SECTIONS HAVE BEEN LINEARLY INTERPOLATED.
3. FLOOD CONTOURS DEPICT APPROXIMATE WIDTHS OF FLOODING ONLY.
4. THE POSITION OF THE FLOOD EXTENT RELATIVE TO PROPERTY BOUNDARIES IS APPROXIMATE ONLY AND SHOULD BE VERIFIED BY SURVEY.
5. FLOOD LEVELS ARE GIVEN IN METRES TO AUSTRALIAN HEIGHT DATUM.
6. FLOOD EXTENTS UPSTREAM OF THIS LINE SUPERSEDES THAT OF THE LOWER NARARA CREEK FPMS.

Narara Creek & Lower Narara Creek Tributaries
FLOODPLAIN MANAGEMENT STUDY

FLOODPLAIN MANAGEMENT OPTIONS

FIGURE 3.2 SHEET 2 of 3

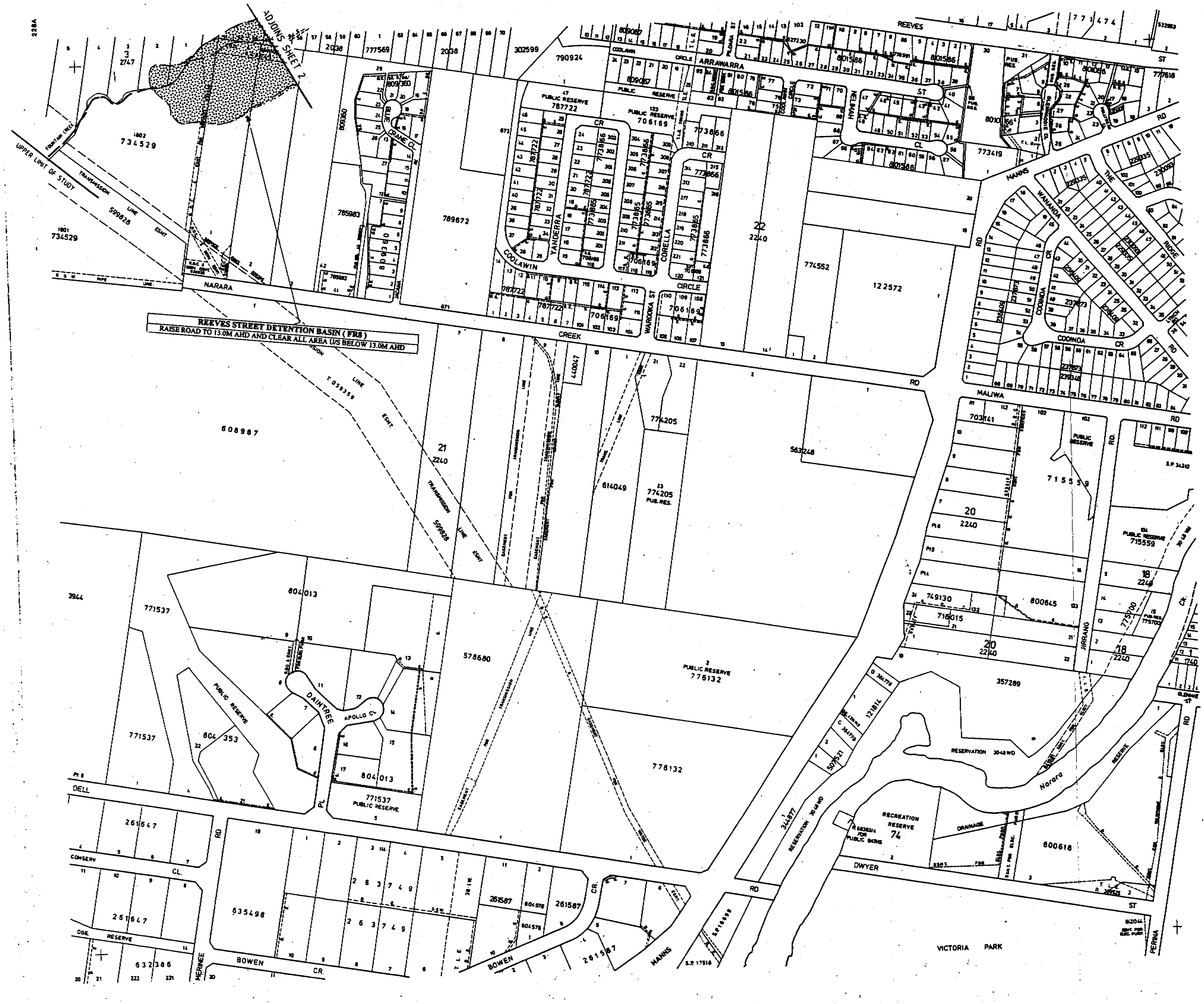
	212A	212B
211D	212C	212D
227B	228A	228B

KEY TO ADJOINING SHEETS

CENTRAL MAPPING AUTHORITY
MAP REFERENCE
GOSFORD 2797-2-3

FIGURE 3.2

GOSFORD CITY COUNCIL



LEGEND

EXISTING CREEK ALIGNMENT

Notes:

1. FLOOD LEVELS HAVE BEEN CALCULATED AT CROSS SECTION LOCATIONS ONLY.
2. FLOOD LEVELS AND FLOOD CONTOURS BETWEEN CROSS SECTIONS HAVE BEEN LINEARLY INTERPOLATED.
3. FLOOD CONTOURS DEPICT APPROXIMATE WIDTHS OF FLOODING ONLY.
4. THE POSITION OF THE FLOOD EXTENT RELATIVE TO PROPERTY BOUNDARIES IS APPROXIMATE ONLY AND SHOULD BE VERIFIED BY SURVEY.
5. FLOOD LEVELS ARE GIVEN IN METRES TO AUSTRALIAN HEIGHT DATUM.
6. *FLOOD EXTENTS UPSTREAM OF THIS LINE SUPERSEDES THAT OF THE LOWER NARARA CREEK FPMS.

Narara Creek & Lower Narara Creek Tributaries
FLOODPLAIN MANAGEMENT STUDY

FLOODPLAIN MANAGEMENT OPTIONS

FIGURE 3.3 SHEET 3 of 3

211D	212C	212D
227B	228A	228B
227D	228C	228D

KEY TO ADJOINING SHEET

METRES

CENTRAL MAPPING AUTHORITY
MAP REFERENCE
GOSFORD U2797-51

FIGURE 3.3

Table 3.2 **Narara Creek Management Options**

	Option	Details	Comments	Costs ($1,000's)	Flood mitigation impact	Recommen-dations	Priority Ranking
NA1	Hanlan Street culvert	Raise road to RL5.0 m AHD. Upgrade existing culvert to 3 No. 1.8 x 2.7 rcbc's. Channel clearance upstream and downstream.	Designed for approx. 6–9 month flow–minor channel widening for transitions.	274	Minimal as levels dictated by Lower Narara levels. Reduction in period of flooding, and hazard for minor events	Long-term recommendation	2
NA2	Fountain Road upgrade	Raise road or build embankment to a +6.0 mAHD; embankment could tie in with existing house @ junction.	Designed for 1% AEP flows, embankment the cheaper alternative.	181	Prevepnts Fountains Road overtopping and flood extent for Fountain Creek. Raises flood levels by approximately 0.78m.	Not recommended.	
NA3	Hanlan Street Wet Basin (1)			552	Minimal as small storage.	Long term recommendation	9
NA4	Hanlan Street to Deane Street floodway	Formalize and straighten channel between cross-section 20 and 22. Floodway bedwidth 25–35 m.	Need embankment along northern side to prevent flooding of low lying land.	–	Negligible flood mitigation impact, destructive to natural creek therefore not justified	Not recommended.	
NA5	Nursery Street flood proofing	Raise road adjacent to house to 9.50 mAHD so flood free access.	Road would need raising 1.2 m in sections and would create impedence to flow unless culverts put in.	–	Raises flood levels.	Not recommended.	

Table 3.2 **Narara Creek Management Options (continued)**

	Option	Details	Comments	Costs ($1,000's)	Flood mitigation impact	Recommen-dations	Priority Ranking
NA5 cont'd	Nursery Street flood proofing	Straighten channel and channel clearance upstream of house, possible bank protection and levee on northern side.	Would prevent flow breakout upstream of house and localised flow path between house and stables.	363	Would prevent local drainage path around house.	Long term recommendation	5
NA6	Narara Agricultural Research Station	Create detention basin upstream of cross-section 25. Embankment to +12.0 m AHD.	4.0 m high embankment required with only nominal storage unless a lot of additional excavation.	–	Minimal, insufficient storage available to cause significant detention.	Not recommended.	
		Construct sediment trap upstream of cross-section 25. Embank-ment to +10.0 mAHD with 2.1 m pipe for low flows.	Low flow sand will pass through. High flow will settle out upstream of embankment and could be mined.	53	Minimal.	Long term recommendation	7
NA7	Property Acquisition	Lot B DP 393508 to be acquired	House is floodprone for the 1% AEP event	150	Would prevent flooding of this property	Immediate implementation recommended	1

4 FOUNTAIN CREEK AND REEVES CREEK MANAGEMENT OPTIONS

4.1 GENERAL

Several problems causing flooding have been identified in Fountain Creek. However these are not isolated to within the study area, as downstream flooding is exacerbated by the flow across Fountains Road from Narara Creek and the high tailwater levels in Lower Narara Creek. Flow from Narara Creek has already been addressed in Section 3 and the recommended works described.

The effect of the high tailwater levels extend up to the first Carrington Street crossing. However the channel improvement works proposed in the Lower Narara Creek FPMS are unlikely to reduce the level by more than 100 mm for the 1% AEP event and so the effects of these downstream mitigation works have not been taken into account.

Flooding in Reeves Creek is not considered a problem, as only the land in the lower reaches is inundated during the 1% AEP event. This is as a result of the high flood levels in Lower Narara Creek.

The various options considered in this study are shown in Figures 3.1, 3.2 and 3.3.

A summary of the proposals, their priority and estimated costs is presented in Table 4.1. A detailed breakdown of costs is included in Appendix A.

4.2 IMMEDIATE FLOOD MANAGEMENT PROPOSALS

No houses are flood prone for the 1% AEP design event and so no immediate flood mitigation works are proposed.

4.3 LONG TERM FLOOD MANAGEMENT PROPOSALS

4.3.1 EAST HANLAN STREET CHANNELS (FR1)

Within the confines of Carrington Street, Manns Road and Reeves Street, the flowpaths for Fountain Creek, Reeves Creek and Narara Creek are not clearly defined. Fountain Creek meanders through open pasture before joining Lower Narara Creek. Reeves Creek similarly meanders through an open swampy area before joining Lower Narara Creek further downstream.

Within the Lower Narara Creek FPMS; it is proposed to realign Narara Creek between Carrington Street and Manns Road and add rock protection as required.

In this study it is proposed that similar grassed floodway be adopted for Fountain Creek and Reeves Creek and that they be combined to form one channel before discharging into Narara Creek. The layout of this proposal is shown in Figure 3.2. Floodway widths are typically 20 m for Fountain Creek and 5 m for Reeves Creek. Fill from the excavated floodway should be totally removed out of the floodplain.

Due to the high tailwater levels in Lower Narara Creek, this channelization will not significantly effect the flood levels and so has not been modelled.

The average ground levels between Fountain Creek and Reeves Creek is +3.5 m to +4.0 m AHD; flood levels in Lower Narara Creek vary from +4.6 m AHD for the 20% AEP event to +5.1 m AHD for the 1% AEP event. Consequently the Lower Narara Creek will flood the area between Fountain Creek and Reeves Creek for all but the minor events unless levees are constructed on both embankments. Formalization of the channels as described above is likely only to be beneficial for these minor events (less than the 50% AEP). A significant amount of fill would be required to reduce the flooding for events greater than this 50% AEP event and is therefore considered impractical at this stage.

4.3.2 CARRINGTON STREET FLOODWAY (FR3)

In the last ten years, Fountain Creek has been realigned between the two Carrington Street crossings to flow parallel and adjacent to Carrington Street. A 600 mm diameter pipe culvert passes under Pandala Road near the junction with Carrington Street. Low flows are contained within the new creek, but during floods, the creek reverts back to its old alignment between Carrington Street and Fountains Road, overtopping Pandala Road halfway along. Floodwaters extend from Carrington Street to this point.

Two alternatives were considered to reduce the flood extents:

- Formalise and increase the channel waterway area adjacent to Carrington Road and upgrade the culvert under Pandala Road.
- Realign the channel back to its old existing alignment and provide a new culvert under Pandala Road.

Formalization of channel adjacent to Carrington Street

The present creek adjacent to Carrington Street is an eroded excavated channel. The proposal is to upgrade the channel by further excavation and by rock lining or grassing the formed channel. The proposed bed width would be 15 m which would accommodate a 1% AEP flow under steady state flow. The culvert under Pandala Road would similarly upgraded to 5 No. 0.9 x 2.7 m box culverts. These culverts are designed to accommodate the 3 year ARI flow under inlet control. Twelve culverts would be required to prevent overtopping the road during the 1% AEP flood. The reduction in flood levels from these works was found to be negligible due to the downstream water level and the restriction of the first bridge on Carrington Street.

In addition the flood extents between Pandala Road and the Carrington Street crossing were only marginally reduced due to the low lying road to the north of Carrington Street.

In order to make the lots developable along the northern side of Carrington Street, a levee would be required with access ways across the floodway. The levee would be formed by the excavated material from the floodway.

Realignment of channel back to existing alignment

The proposed works are similar to those proposed for the present alignment of the creek. That is, a 15 m wide floodway and new culverts under Pandala Road. However any effect of the works are overshadowed by the downstream water levels and the flood profile for the 1% AEP event was identical for the upgrade of the present creek.

Similarly an embankment would be required along the formalized channel to prevent flooding of the low lying land between Pandala Road and Carrington Street. The advantages of this option is that the size of developable lots is maximised between Carrington Street and Fountains Road.

However in the Gosford Development Control Plan, it is proposed to close Carrington Street to through traffic. Consequently the costs of the above mentioned works were not considered justified for a short term alleviation of the flooding problem. Neither alternative was therefore considered further.

4.3.3 CARRINGTON STREET BRIDGES (FR4)

The two bridges along Carrington Street are both undersized for the 1% AEP event and cause significant afflux. Both bridges frequently overtop although the lower Carrington Street can accommodate flows just below 20% AEP flood. If the bridges were upgraded to accommodate a 20% AEP event, 3 No. 2.1 x 2.7 RCBC's would be required for the lower Carrington Street bridge and 5 No. 1.2 x 2.7 RCBC's would be required for the upper Carrington Street bridge. Culvert dimensions have been based on the existing creek invert level and road top levels. Significant earthworks would also be required upstream and downstream to accommodate the culverts. However as mentioned in Section 4.3.2 it is proposed to close Carrington Street and so the cost of replacing the culverts was not considered justified. This option was not considered further.

4.3.4 CARRINGTON STREET CULVERT (FR5)

This pipe culvert just upstream of the upper Carrington Street bridge causes a significant restriction to the flow. It used to provide access to Lot 2, DP520858 but has been replaced by an access downstream of the Carrington Street bridge.

As a long term improvement for the channel regime of Fountains Creek it is recommended that this culvert be removed.

4.3.5 FOUNTAIN CREEK TRIBUTARIES (FR6)

Two new roads are not included in the Gosford City Council Development Control Plan; Cross Street between Carrington Street and Reeves Creek and an extension to the existing Carrington Street. If increased development of the areas was to proceed, then sizing of these culverts are provisional as they are dependent on the finished road levels. Three 1.2 x 3.0 RCBC's would be required for the Cross Street crossing, although due to the well defined channel it could be replaced by a bridge. Three 0.9 x 3.3 RCBC's are required for the culvert under the Carrington Street culvert. Both culverts are designed for the 5% AEP flow. The Carrington Street culvert results in a local afflux of 0.25 m just upstream due to increased local velocities, however, further upstream flood levels are reduced slightly.

A causeway and 2 No. 900 mm diameter pipe culverts already exist on the Right of Way off Carrington Street. If the Carrington Street alignment does not proceed these culverts should be upgraded to ensure a flood free access. This upgrading depended on the ownership of the Right of Way and so has not been considered further in this study.

4.3.6 REEVES STREET CAUSEWAY (FR7)

The existing flood path across Reeves Street is two 900 mm diameter pipes and a causeway at a level below the soffit of the 900 mm pipes. The causeway is frequently overtopped. It is intended in the Gosford Development Control Plan that Reeves Road be developed as a major access route from the Somersby plateau to Manns Road. To achieve this, the Reeves Street culverts should be upgraded to accommodate a 1% AEP flood. The 1% AEP flow is 56 m^3/s and so new culverts are not considered practical due to the number required (12 No. 0.9 x 2.7 m RCBC's). It is recommended that an elevated causeway or bridge at approximately +10.0 m AHD be constructed along the existing alignment of Reeves Street across Fountains Creek.

4.3.7 REEVES STREET DETENTION BASIN (FR8)

A possible solution to the problem of the culverts overtopping along Fountain Creek is to create a detention basin in the upper reaches of Fountain Creek. To maximise the benefit of the basin, the location would need to be upstream of Reeves Street so that the flows through the culverts under Reeves Road and Carrington Street would be reduced. To achieve the required detention storage, Reeves Street should be raised to 13.0 m AHD to form the downstream embankment of the basin. All the upstream catchment below the +13.0 m AHD should be cleared and any minor land irregularities removed. No major earthworks are envisaged although bush clearing would be required due to the dense bush upstream of Reeves Street. The cleared area should be grassed and could be used for recreational purposes.

The resultant flood profile is similar to that predicted if all the works along Carrington Street are carried out (Section 4.3.2 and Section 4.3.3). However formation of the basin would result in approximately 6 ha of land being flooded during the 1% AEP event and a large area of natural bushland being destroyed. Additionally raising Reeves Street to +13.0 m AHD would create an embankment 5.5 m high with a storage capacity of 140,000 m^3 which is classified as a referable dam under the Australian National Committee on Large Dams (ANCOLD) classification (ANCOLD 1986). The embankment would therefore be subject to ANCOLD recommendations for spillway provision and safety levels.

Due to the amount of land flooded, problems associated with constructing such an embankment and the minimal flood mitigation benefit, this option is not considered a viable proposal.

4.3.8 REEVES STREET CULVERT (FR9)

A minor creek crosses Reeves Street approximately 300 m from the junction of Manns Road and Reeves Street. The existing culvert was only 900 mm diameter and frequently overtopped. The capacity of the culvert before it overtopped was only 1.5 m^3/s whereas the 50% AEP flood discharge is 3.7 m^3/s. It was determined that if the culvert was upgraded to accommodate a 20% AEP flood, 2 No. 0.9 x 1.05 RCBC's would be required. To upgrade it for a 2% AEP flood, 3 No. 1200mm diameter RCP's would be necessary. Culvert dimensions are based on the existing creek invert level and road top levels.

These works do not effect flood levels upstream or downstream but would make Reeves Street flood free up to a 2% AEP event. The recommended proposal is to upgrade the culvert to 3 No. 1200mm diameter RCP's. This work was completed late in 1993.

4.4 WATER QUALITY AND SEDIMENT CONTROL PROPOSALS

4.4.1 HANLAN STREET WET BASIN NO. 2 (FR2)

The proposed Hanlan Street Wet Basin No 2, which is illustrated in Figure 3.2, is located at the confluence of Fountain Creek and Reeves Creek just south of Carrington Street. The area is currently open swampy land. The estimated volume required for a developed area of 125 ha, estimated from the Narara Development Control Plan, is 51,000 m^3. The estimated surface water area assuming an average depth of 1.5 m in the wetland is 34000 m^2. This basin is recommended as a long-term option.

Table 4.1 **Fountain Creek and Reeves Creek Management Measures**

	Option	Details	Comments	Costs ($1,000's)	Flood mitigation impact	Recommendations	Priority ranking
FR1	East Hanlan Street channels	Form grassed floodways 20 m bed width for Fountain Cr, 5 m bed width for Reeves Cr. Combine channels before discharging into Narara Cr.	Continuation of channel work in Lower Narara FPMS.	216	No impact on flood level. No reduction in flood extent if no fill as all land low lying.	Long term recommendation	8
FR2	Hanlan Street Wet Basin (2)	At confluence of Fountain Creek and Reeves Creek.		1,030	Minimal as small storage.	Long term recommendation	10
FR3	Carrington Street floodway	Form grassed channel parallel to road or along old alignment 15 m bed width. Upgrade culvert under Pandala Rd to 5 No. 0.9 x 2.7 rcbc's.	Channel adjacent to road will require access to lots. Channel along old alignment will maximise lots but longer flowpath. Culvert under Pandala Road will only take 3 year ARI flows. No good without FR4 due to backwater.	–	Minimal.	Not recommended	
FR4	Carrington Street bridges	Upgrade 2 bridge crossings to accommodate a 20% AEP event. 3 No. 2.1 x 2.7 and 5 No. 1.2 x 2.7 rcbc's required respectively.	Culvert will only take 20% AEP flows; marginal justification to renew.	–		Not recommended	

Table 4.1 **Fountain Creek and Reeves Creek Management Measures (continued)**

	Option	Details	Comments	Costs ($1,000's)	Flood mitigation impact	Recommendations	Priority ranking
FR4 (continued)	Carrington Street bridge	Replace bridge u/s by 5 No. 1.2 x 2.7 rcbc's.	Culverts will only take 20% AEP flows.	–		Not recommended	
FR5	Carrington Street culvert	Remove pipe culvert at cross-section 6.	Old accessway; no longer used and possibly privately owned.	1.4		Recommended to be done immediately as funds permit	6
FR6	Fountain Creek tributaries	New 3 No. 0.9 x 3.3 m RCBC on alignment of Carrington Street	Will be required for future expansion. Only designed for 20% AEP flow. Dependent on final road levels.	94	Minimal.	No further consideration Not identified in DCP works	3
		New 3 No. 1.2 x 3.0m RCBC on alignment of Cross Street	Will be required for future expansion. Designed for 5% AEP flows. Well defined channel so bridge may be more acceptable.	88	Minimal.	No further consideration Not identified in DCP works	
FR7	Reeves Street causeway	Replace existing pipe culverts by elevated causeway or bridge	Road top level will be above 1% AEP level	2,595	Minimal.	Long term recommendation	4

Table 4.1 **Fountain Creek and Reeves Creek Management Measures (continued)**

	Option	Details	Comments	Costs ($1,000's)	Flood mitigation impact	Recommendations	Priority ranking
FR8	Reeves Street detention basin	Raise road level along Reeves St +13.00 mAHD with 1 No. 2.4ø pipe. Clear away all area below +13.0 contour–use natural basin.	No houses affected but very dense bush to be cleared–also 6 ha flooded for 1% AEP event.	–	Minimal.	Not recommended	
FR9	Reeves Street culvert	Replace existing pipe culvert by 3 No. 1.2ϕ RCP.	Culverts will make Reeves Street flood-free for 2% AEP event	35	Minimal	Completed 1993.	N/A

5 FUTURE ROAD PROPOSALS

5.1 GENERAL

As part of the review of the Development Control Plan for Narara, several options for new roads have been proposed. The purpose of these roads is to ensure flood-free access to the area and also to provide a flood-free access route from Manns Road and Reeves Street to the Pacific Highway in the north. During flood events, Manns Road is overtopped in several places causing major diversions to traffic.

In addition, Reeves Street is to be upgraded for traffic from the proposed Somersby Development Area. This road also allows direct access up to the Sydney–Newcastle freeway.

Four road options are proposed that cross Narara Creek, Fountain Creek, Niagara and Reeves Creek. These stream crossings have been divided into two types:

- high level crossings which are flood-free for the 1% AEP event;
- low level crossings where the section of the road system is to be maintained at the existing road level.

The layouts of the four options are shown in Figures 5.1 to 5.4. The objective of this study is to approximately size and assess the practicality of the various stream crossings required.

5.2 METHODOLOGY

In order to assess the stream crossings, flood levels and discharges were determined for each crossing. Flood levels were determined from the hydraulic modelling in the Lower Narara Creek FPMS as the majority of the crossings were outside the study area for this report. Discharges were similarly determined from the RORB modelling. These are detailed in Table 5.1.

Flood levels and discharges are for existing conditions. These are greater than those predicted following the proposed works and are considered conservative. However, this is justified as these roadworks may proceed before the flood mitigation works.

Due to the complexity of the flow network, it is also beyond the scope of this study to include the proposed stream crossings in the hydraulic model. Individual hydraulic

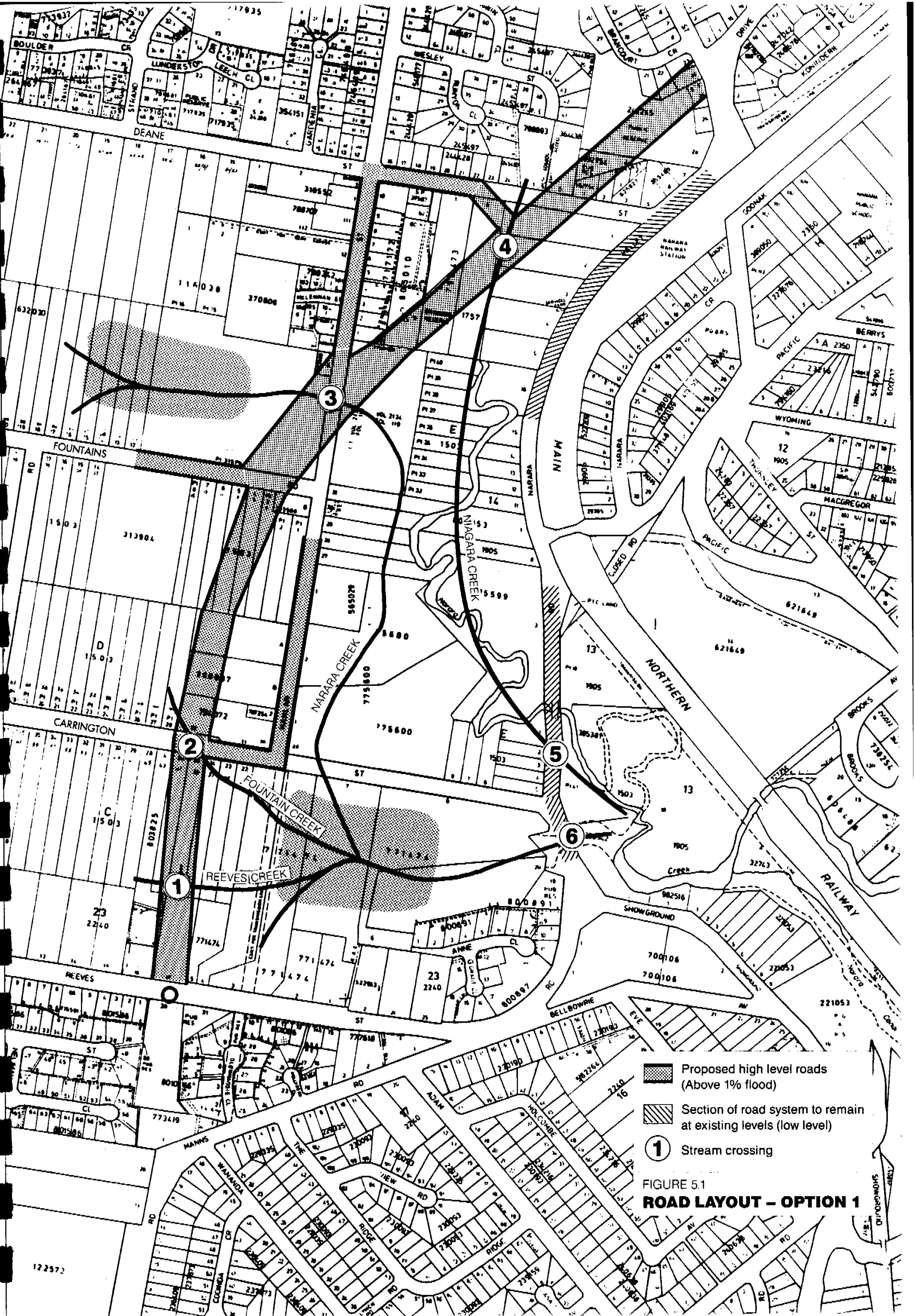


FIGURE 5.1

ROAD LAYOUT – OPTION 1

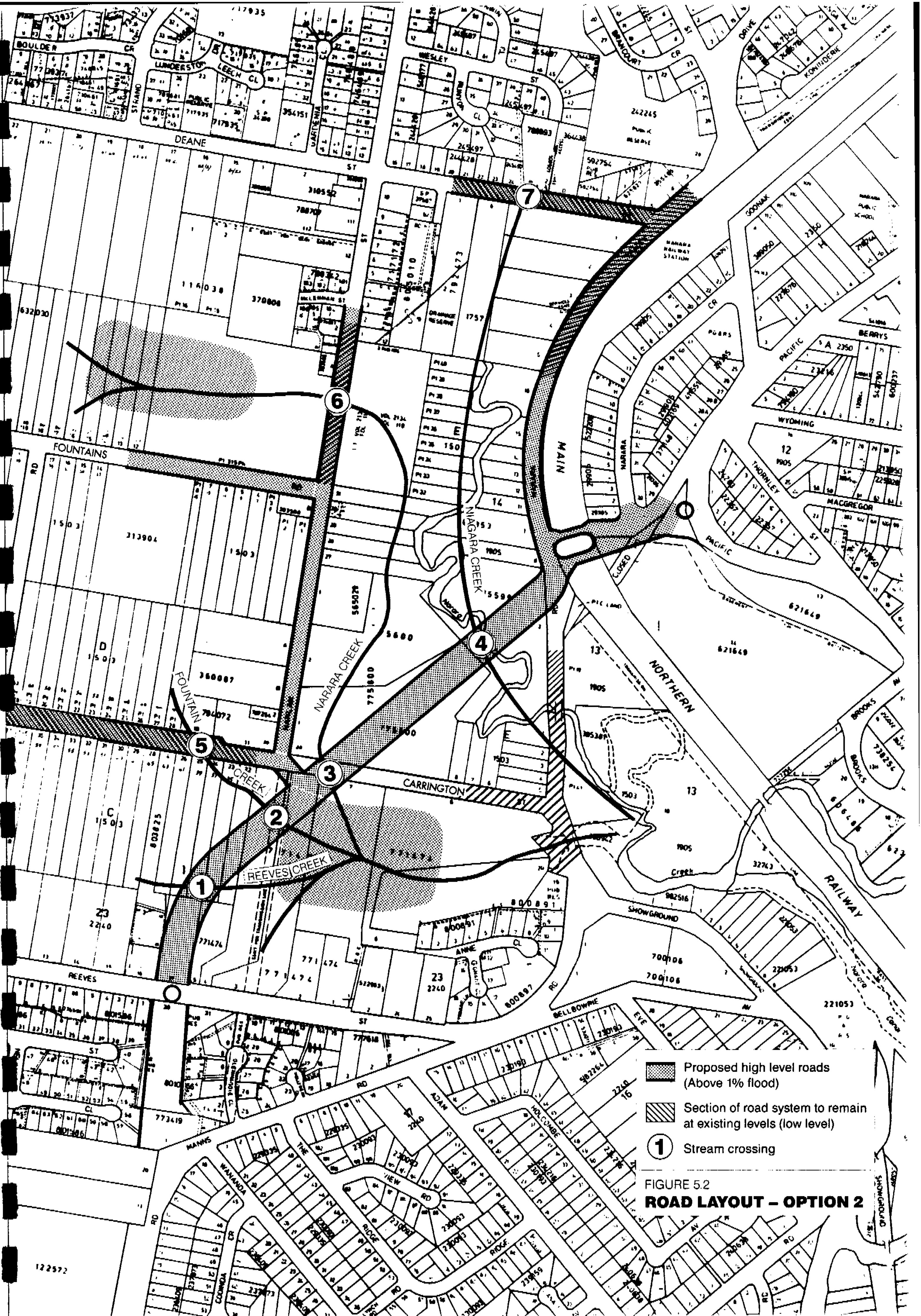


FIGURE 5.2
ROAD LAYOUT – OPTION 2

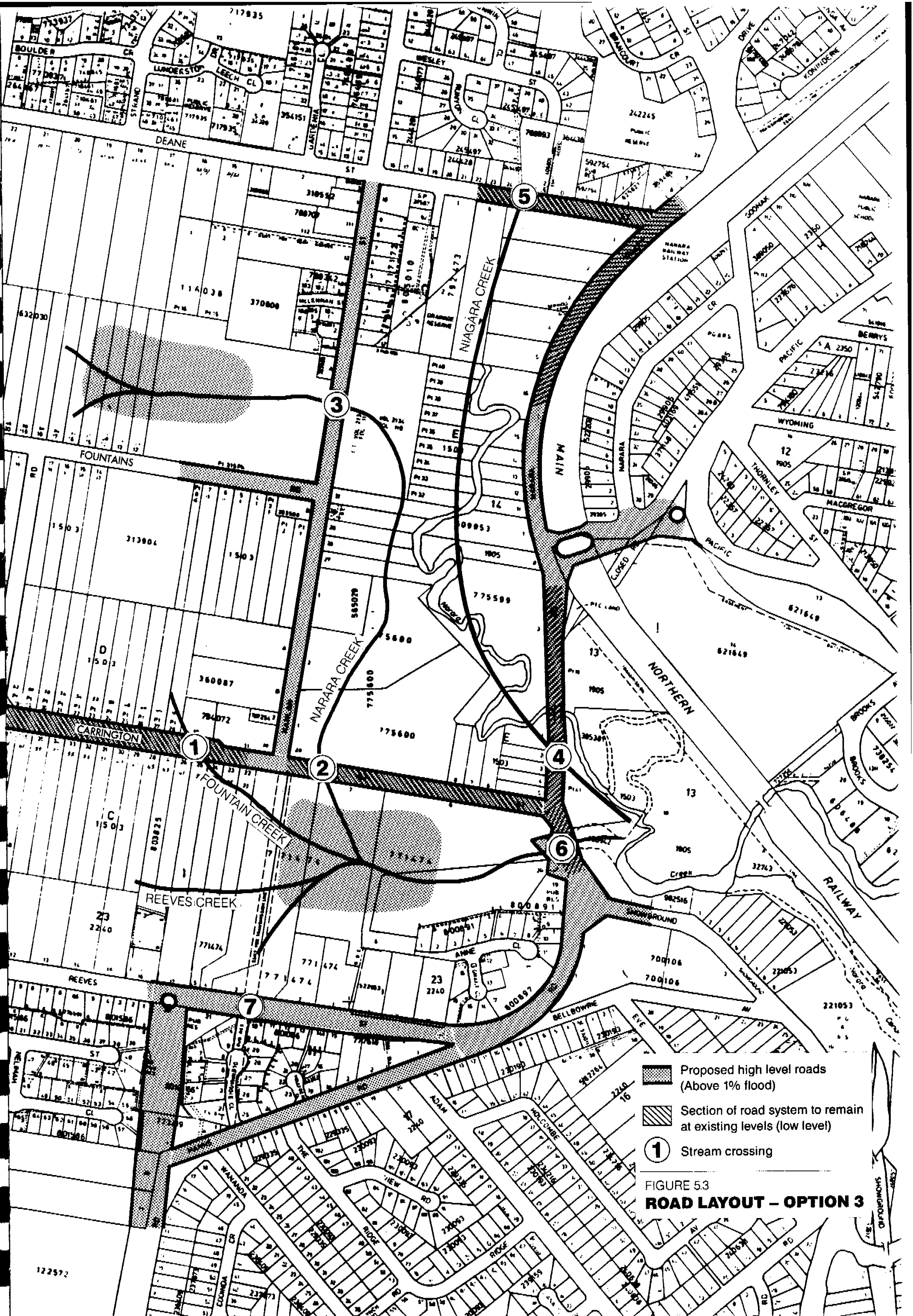


FIGURE 5.3

ROAD LAYOUT – OPTION 3

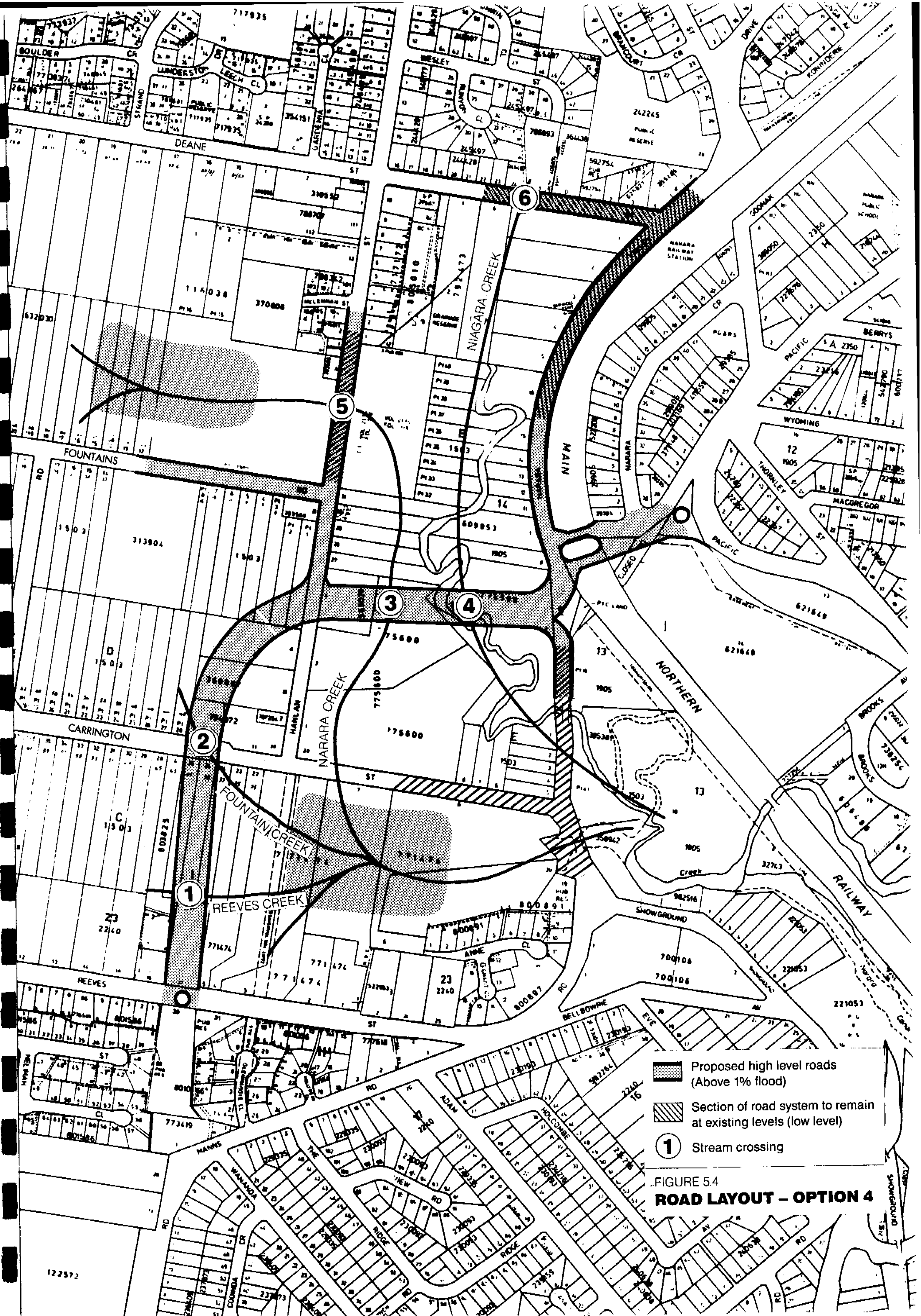


FIGURE 5.4

ROAD LAYOUT – OPTION 4

Table 5.1 **Proposed Stream Crossings--Discharges and Flood Levels**

Creek		Location	Type	1% AEP Flood Disch (m3/s)	1% AEP Flood Flood Level mAHD)	2% AEP Flood Disch (m3/s)	2% AEP Flood Flood Level mAHD)	Existing Ground Level** (approx)	Existing Road Level**	Creek IL
OPTION 1										
1	Reeves	North-South Road	High	5.8	5.10	3.3	4.75	3.00	--	2.66
2	Fountain	North-South Road	High	76.0	5.15	42.0	4.95	4.00	4.80	1.06
3	Narara	North-South Road	High	170.0	6.40	113.0	6.10	5.50	4.50	2.65
4	Niagara	North-South Road	High	110.0	7.90	79.0	7.20	6.00		4.60
5	Niagara	Manns Road	Low	110.0	4.60	79.0	4.10	4.00	3.85	3.15
6	Narara	Manns Road	Low	251.0	4.60	141.0	4.10	4.00	3.65	-1.05
OPTION 2										
1	Reeves	North-South Road	High	5.8	5.10	3.3	4.75	3.00	--	2.66
2	Fountain	North-South Road	High	76.0	5.10	42.0	4.75	4.00	--	1.06
3	Narara	North-South Road	High	170.0	5.05	113.0	4.70	3.50	4.50	0.86
4	Niagara	North-South Road	High	110.0	5.30	79.0	5.00	4.50	--	3.45
5	Fountain	Carrington Street	Low	76.0	5.15	42.0	4.95	4.00	4.80	2.26
6	Narara	Hanlan Street	Low	170.0	6.40	113.0	6.10	5.50	4.50	2.65
7	Niagara	Deane Street	Low	110.0	7.90	79.0	7.40	6.88	6.87	4.70
8#	Narara & Niagara (3 & 4)		High	351.0	5.30	220.0	5.00	4.50	--	0.86
OPTION 3										
1	Fountain	Carrington Street	Low	76.0	5.15	42.0	4.95	4.00	4.80	2.26
2	Narara	Carrington Street	Low	170.0	5.05	113.0	4.70	3.50	4.50	0.86
3	Narara	Hanlan Street	High	170.0	6.40	113.0	6.10	5.50	4.50	2.65
4	Niagara	Manns Road	Low	110.0	4.60	79.0	4.10	4.00	3.85	3.15
5	Niagara	Deane Street	Low	110.0	7.90	79.0	7.40	6.88	6.87	4.70
6	Narara	Manns Road	Low	251.0	4.60	141.0	4.10	4.00	3.65	-1.05
7	Reeves trib	Reeves Street	High	14.0	5.05	8.6	4.75	5.80	5.80	4.60
OPTION 4										
1	Reeves	North-South Road	High	5.8	5.15	3.3	4.75	3.00	--	2.66
2	Fountain	North-South Road	High	76.0	5.20	42.0	4.95	4.00	4.80	2.26
3	Narara	North-South Road	High	170.0	5.70	113.0	5.50	4.50	--	1.35
4	Niagara	North-South Road	High	110.0	5.70	79.0	5.40	0.45	--	3.45
5	Narara	Hanlan Street	Low	170.0	6.40	113.0	6.10	5.50	4.50	2.65
6	Niagara	Deane Street	Low	110.0	7.90	79.0	7.40	6.88	6.87	4.70
7#	Narara & Niagara (3 & 4)		High	351.0	5.30	220.0	5.00	4.50	--	0.86

*Note: **--road levels and ground levels are best estimates from limited survey available*

 # This stream crossing is an alternative to crossings 3 and 4 and would require realignment of Narara Creek to combine with Niagara Creek.

assessment of each proposed crossing was therefore undertaken. All the crossings were sized so that the head loss across the structure was less than 0.30 m and at each crossing three types of crossings were considered:

- bridges
- multi-cell culverts
- minimum energy culverts.

Table 5.2 lists the proposed structures at each crossing and the estimated costs. These are discussed in detail in the following sections.

The structures for the high level crossings were determined assuming that road would be on a raised embankment with two (horizontal) to one (vertical) side slopes.

Costing for the structures is only for the structure and does not include costs for the connecting roadworks. These costings are only approximate but do give an idea to the overall cost of the stream crossings. More exact costings would require inclusion of all the associated roadwork quantities.

5.3 OPTION 1

A new high level road is proposed from the junction of Manns Road and Wanada Road, running north to a roundabout on Reeves Street and continuing north across Carrington Street, Hanlan Street and Deane Street. The layout is shown in Figure 5.1. Sections of Hanlan Street, Fountains Road and Deane Street are also to be raised to above the 1% AEP flood level.

This option allows flood-free access from Manns Road, and Reeves Street to the north on the western side of the railway.

Four high level crossings are required in this proposal, the crossings of Reeves Creek, Fountain Creek and Niagara Creek can be by box culverts, but due to the large flows in Narara Creek, a bridge is required near Hanlan Street. An alternative box culvert requirement would be 7 No. 3.3 x 3.3 m RCBC's, which would have an overall bedwidth of 25 m and is considered impractical.

The two bridges on Manns Road are to be maintained as low level crossings. Unless these are upgraded, these will still overtop for a 20% AEP event.

Table 5.2 **Proposed Stream Crossings--Crossings and Costs**

	Creek	Location	Type	Existing Crossing	Proposed Crossing	Estimated Cost
OPTION 1						
1	Reeves	North-South Road	High	*	2.7*1.2 RCBC	$56,000
2	Fountain	North-South Road	High	timber bridge	3 No 3.3*3.3 RCBCs	$305,200
3	Narara	North-South Road	High	0.60 m pipe	15 m span bridge	$1,500,000
4	Niagara	North-South Road	High	*	5 No 3.0*3.0 RCBCs	$403,400
5	Niagara	Manns Road	Low	bridge	--	--
6	Narara	Manns Road	Low	bridge	--	--
OPTION 2						
1	Reeves	North-South Road	High	*	2.7*1.2 RCBC	$56,000
2	Fountain	North-South Road	High	*	3 No 3.3*3.3 RCBCs	$305,200
3	Narara	North-South Road	High	timber bridge	15 m span bridge	$1,500,000
4	Niagara	North-South Road	High	*	5 No 3.0*3.0 RCBCs	$403,400
5	Fountain	Carrington Street	Low	timber bridge	--	--
6	Narara	Hanlan Street	Low	0.60 m pipe	--	--
7	Niagara	Deane Street	Low	timber bridge	--	--
8#	Narara & Niagara (3 & 4)		High	--	25 m span bridge	$2,500,000
OPTION 3						
1	Fountain	Carrington Street	Low	timber bridge	--	--
2	Narara	Carrington Street	Low	timber bridge	--	--
3	Narara	Hanlan Street	High	0.60 m pipe	15 m span bridge	$1,500,000
4	Niagara	Manns Road	Low	timber bridge	--	--
5	Niagara	Deane Street	Low	timber bridge	--	--
6	Narara	Manns Road	Low	timber bridge	--	--
7	Reeves trib	Reeves Street	High	0.90 m pipe	3 No 1.5*1.2 RCBCs	$86,000 (completed)
OPTION 4						
1	Reeves	North-South Road	High	*	2.7*1.2 RCBC	$56,000
2	Fountain	North-South Road	High	timber bridge	3 No 3.3*3.3 RCBCs	$305,200
3	Narara	North-South Road	High	*	15 m span bridge	$1,500,000
4	Niagara	North-South Road	High	*	5 No 3.0*3.0 RCBCs	$403,400
5	Narara	Hanlan Street	Low	0.60 m pipe	--	--
6	Niagara	Deane Street	Low	timber bridge	--	--
7#	Narara & Niagara (3 & 4)		High	--	25 m span bridge	$2,500,000

Note: # *This stream crossing is an alternative to crossings 3 and 4 and would require realignment of Narara Creek to combine with Niagara Creek. The cost of the major channel works have not been included in the cost estimate*

5.4 OPTION 2

A new high level road is proposed from the junction and Manns Road and Wanada Road, running north to a roundabout on Reeves Street and continuing north across Carrington Street to join Manns Road at the bridge over the railway. The layout is shown in Figure 5.2. Sections of Fountains Road and Hanlan Street are also to be raised above the 1% AEP flood level.

This option allows flood-free access for Manns Road and Reeves Street to the Pacific Highway. All residential areas have flood-free access except for a small number of properties along Carrington Street and Hanlan Street. Properties to the north-west, along and adjacent to Deane Street also will not have flood-free access in the 1% AEP Flood event.

This option, which requires a shorter section of raised road than Option 1, still requires four high-level crossings. As with Option 1, the stream crossings of Reeves Creek, Fountain Creek and Niagara Creek can be by box culverts, but Narara Creek would require a bridge. However, due to the closeness of the structures, it could be more practical to realign Narara Creek and combine it with Niagara Creek. The combined flow would require a 25 m span bridge at an approximate cost of $2.5 million. In addition major channel works would be required to combine the creeks and this has not been included in the Floodplain Management Plan for Lower Narara Creek. Combining the flows of Narara Creek and Fountain Creek is not possible due to the required access from Hanlan Street.

The existing bridges for Fountain Creek on Carrington Street and Niagara Creek on Deane Street are to be maintained as well as the Narara Creek culvert on Hanlan Street. All structures overtop for the 5% AEP event.

The present alignment of the north–south road is through the proposed wet basin for Fountain and Reeves Creek. This could be moved, but the efficiency of the basin would have to be reviewed.

5.5 OPTION 3

This option proposes the minimum amount of road upgrade as only part of Hanlan Street and Fountain Road are to be raised to above the 1% AEP flood level. The layout is shown in Figure 5.3. No access route is proposed between Manns Road and Reeves Street and the Pacific Highway, although sections of Manns Road and Reeves Street are to be upgraded to allow flood-free access from the top end of Showground Road.

This option only requires two new stream crossings, which are on Hanlan Street for Narara Creek and on Reeves Street for the Reeves Creek tributary. As with Option 1, a bridge is necessary for the Narara Creek crossing. Box culverts are required on Reeves Street. All other existing crossings are to be maintained, but these all overtop during the 5% AEP event.

5.6 OPTION 4

A new high level road is proposed from the junction of Manns Road and Wanada Road, running north to a roundabout on Reeves Street and continuing north across Carrington Street and Hanlan Street to join Manns Road at the bridge over the railway. The layout is shown in Figure 5.4. Sections of Fountain Road and Hanlan Street are also raised to above the 1% AEP flood level.

This option allows flood-free access from Manns Road and Reeves Street to the Pacific Highway. All residential areas have flood-free access, except for a number of properties along Carrington Street, Hanlan Street and Deane Street. Properties to the north-west along and adjacent to Deane Street are assumed to have flood-free access to the north along Hanlan Street (pedestrian only).

The stream crossings in this option are very similar to Option 2 as there is negligible difference in the flows and flood levels. Four high level crossings are required, three of which could be box culverts. However, a 15 m span bridge is required over Narara Creek. Combining the flows of Narara Creek and Niagara would reduce the number of crossings, but the cost of the required 25 m span bridge would be greater than two separate crossings, without including the additional channel earthworks.

The existing bridge at Deane Street and the pipe culvert on Hanlan Street would still be overtopped for the 5% AEP event.

5.7 COMPARISON OF OPTIONS

The four options proposed would provide vehicular flood-free access from most residential areas in West Narara. During flood events, some areas would be isolated and it would not be possible to get in and out of the area. It is assumed that the houses on the western end of Carrington Street will have a flood-free pedestrian access to Fountains Road.

Options 1, 2 and 4 also provide access from Manns Road to Pacific Highway and so reduce major traffic diversions during flooding. However, the costs of these options which are all similar, is $0.68 million greater than Option 3, where this access is not provided. This excludes the cost of the roadworks, which would be significant for an arterial road on a 1.5–2.0 m high embankment.

Should, however, funding permit, and either Option 1, 2 or 4 be possible, the Option 4 would be the preferred option when considering the stream crossings. This option does not encroach on the proposed wetland and there is potential to combine the flows of Narara Creek and Niagara Creek, despite a more costly structure. However, this decision would need to be made in conjunction with the cost of the roadworks.

6 RECOMMENDED MANAGEMENT OPTIONS

The recommended management options as indicated in Tables 3.2 and 4.1 have been modelled in combination. The resultant 1%, 5%, 20% and 2 x 1% AEP flood profiles for the combined works proposed are shown in Figures 6.1, 6.2 and 6.3 for Narara Creek, Fountains Creek, Reeves Creek and tributaries. Flood extents and flood contours are shown in Figures 6.4, 6.5 and 6.6.

Tables 6.1 and 6.2 list the 1% AEP flood levels with relevant section velocities.

The resultant flood profiles after the completion of the recommended works are dependent on the adopted road option. However, the proposed stream crossings assumed in this report have been based on a maximum afflux in flood levels upstream of 300 mm. This has therefore been adopted in determining the flood profiles.

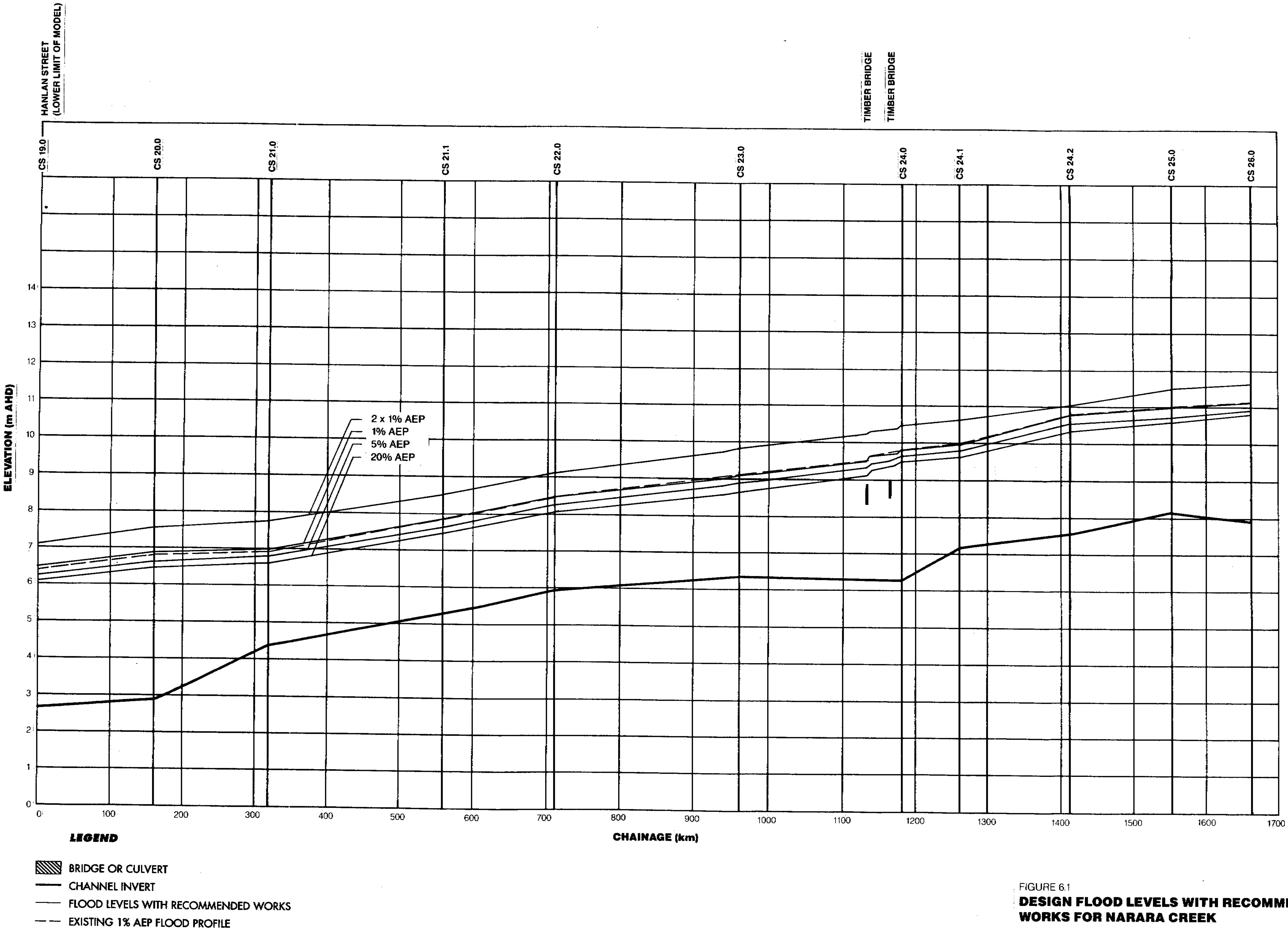


FIGURE 6.1
DESIGN FLOOD LEVELS WITH RECOMMENDED WORKS FOR NARARA CREEK

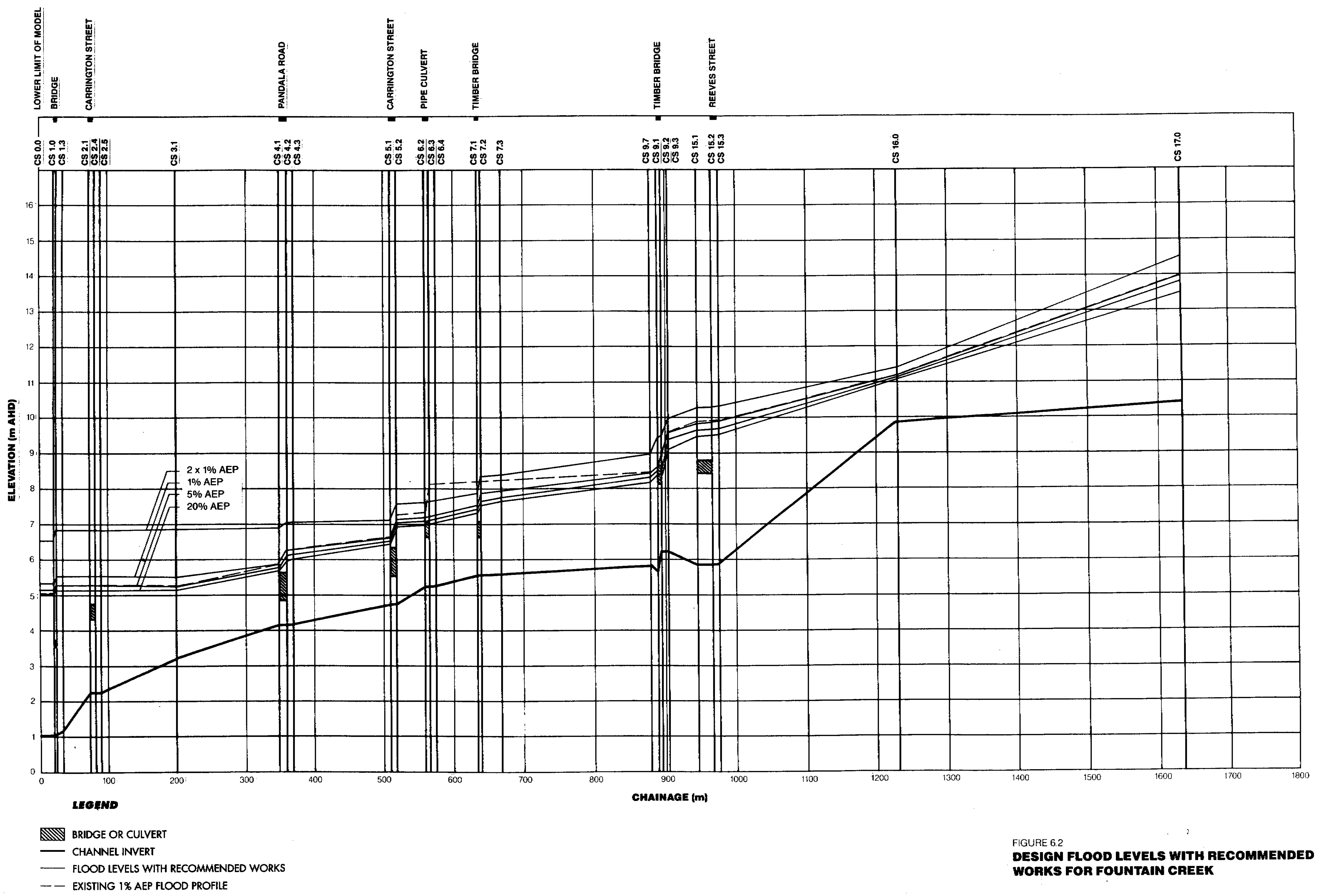


FIGURE 6.2
DESIGN FLOOD LEVELS WITH RECOMMENDED WORKS FOR FOUNTAIN CREEK

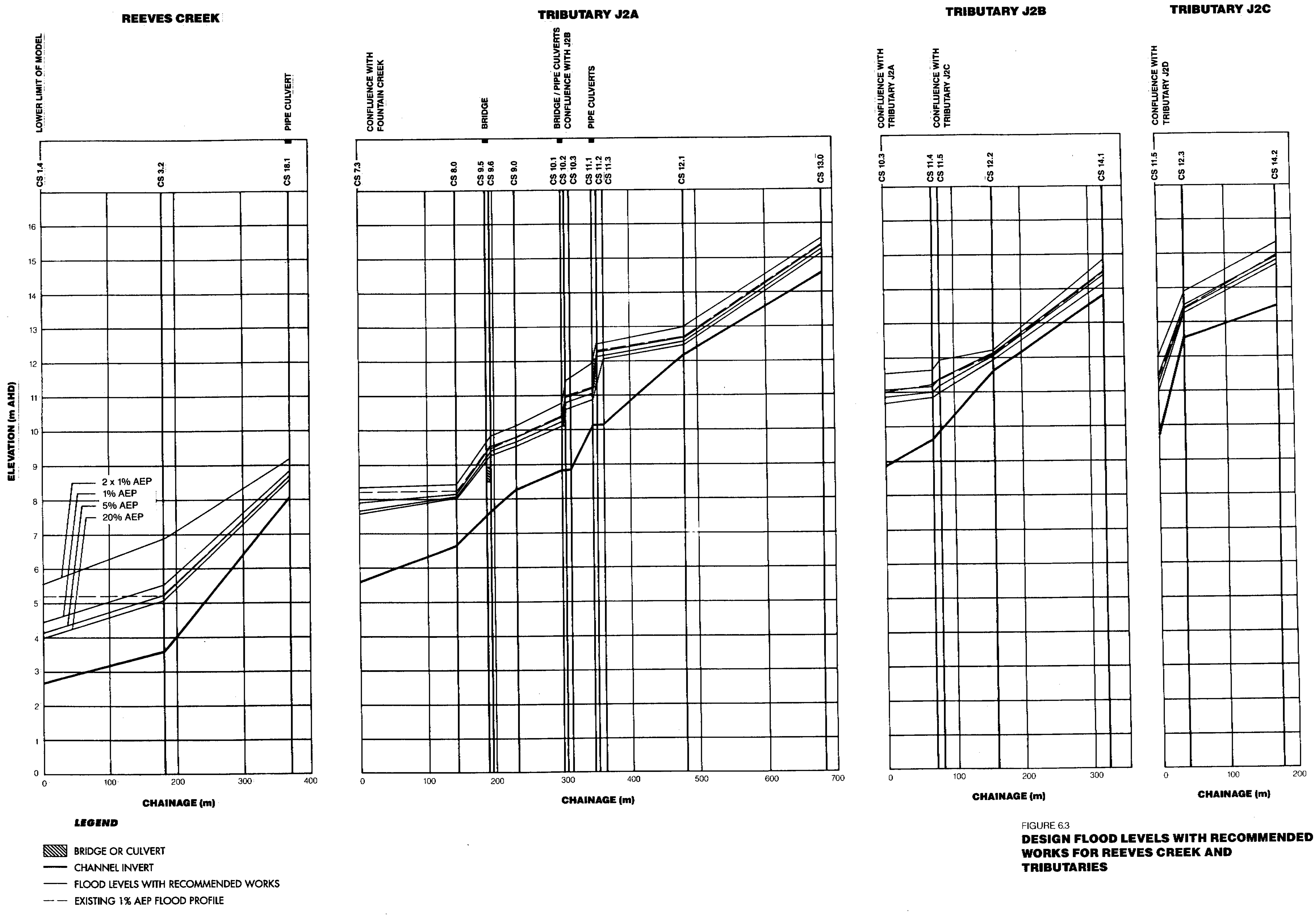


FIGURE 6.3

DESIGN FLOOD LEVELS WITH RECOMMENDED WORKS FOR REEVES CREEK AND TRIBUTARIES

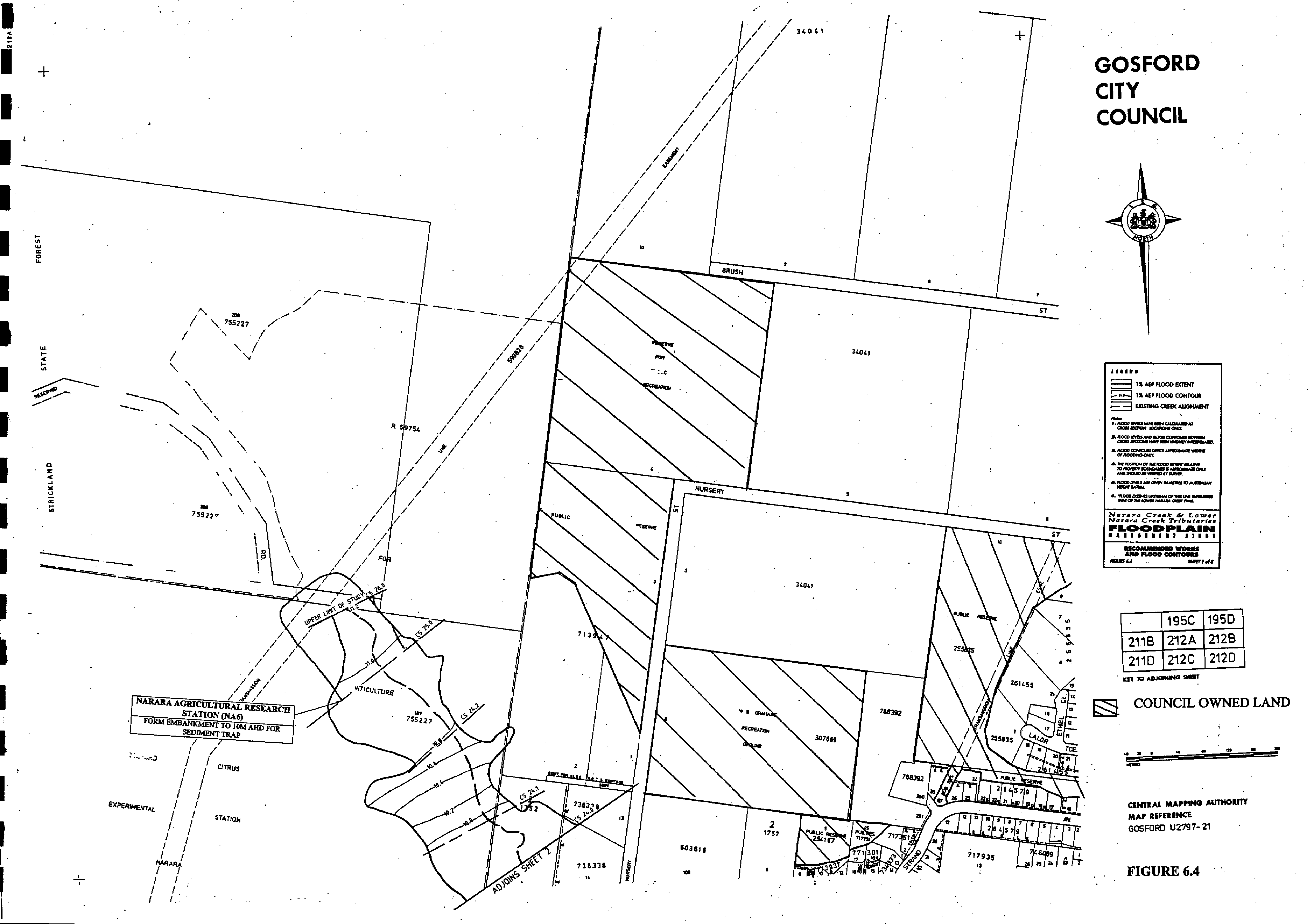

GOSFORD
CITY
COUNCIL
NORTH
LEGEND
1% AEP FLOOD EXTENT
1% AEP FLOOD CONTOUR
EXISTING CREEK ALIGNMENT
Narara Creek & Lower
Narara Creek Tributaries
FLOODPLAIN
MANAGEMENT STUDY
RECOMMENDED WORKS
AND FLOOD CONTOURS
195C
195D
211B
212A
212B
211D
212C
212D
KEY TO ADJOINING SHEET
COUNCIL OWNED LAND
CENTRAL MAPPING AUTHORITY
MAP REFERENCE
GOSFORD U2797-21
NARARA AGRICULTURAL RESEARCH STATION (NA6)
FORM EMBANKMENT TO 10M AHD FOR SEDIMENT TRAP
UPPER LIMIT OF STUDY
CS 26.0
CS 25.0
CS 24.2
CS 24.1
CS 24.0
VITICULTURE
755227
BRUSH ST
NURSERY ST
34041
307669
788392
713947
603616
738338
1757
261455
255835
PUBLIC RESERVE
W B GRAHAME RECREATION GROUND
RESERVE FOR RECREATION
EASEMENT
599828
R 69754
STRICKLAND
STATE
FOREST
CITRUS
EXPERIMENTAL
STATION
NARARA
ADJOINS SHEET 2
STRAND
LALOR
ETHEL
TCE
717935
746489

FIGURE 6.4


GOSFORD
CITY
COUNCIL
NURSERY STREET FLOOD ACCESS IMPROVEMENTS (NA5)
CLEAN AND STRAIGHTEN CHANNEL
HANLAN STREET CULVERT (NA1)
ROAD RAISED TO 5.0M AHD AND UPGRADE CULVERT.
REFER TO NOTE 6
(NA7)NON STRUCTURAL MEASURE
AQUISITION OF LOT (DP 393508)
HANLAN STREET WET BASIN (1) (NA3)
USE LOW LYING LAND FOR NUTRIENT REMOVAL
TIMBER BRIDGE
FOUNTAIN CREEK TRIBUTARIES (FR6)
PROVIDE NEW CULVERTS
LOWER NARARA FPMS
ROCK PROTECTION AS REQUIRED AND CREEK REALIGNMENT
CARRINGTON STREET CULVERTS (FR5)
REMOVE PIPE CULVERT
HANLAN STREET WET BASIN (2) (FR2)
USE LOW LYING LAND TO CREATE WET BASIN FOR NUTRIENT REMOVAL
REFER TO NOTE 6
EAST HANLAN STREET CHANNELS (FR1)
REALIGN CREEKS TO FORM ONE CHANNEL AND FORMALIZE FLOODWAYS
REEVES STREET CAUSEWAY (FR7)
UPGRADE PIPE CULVERTS AND RAISE ROAD LEVELS
REEVES STREET CULVERT (FR2)
UPGRADE CULVERTS
GOSFORD CITRUS EXPERIMENTAL STATION NARARA
ADJOINS SHEET 1
ADJOINS SHEET 3
UPPER LIMIT OF STUDY
LOWER LIMIT OF NARARA FPMS
LOWER LIMIT OF THIS STUDY
FOUNTAINS RD.
RESEARCH RD.
CARRINGTON ST.
REEVES ST.
HANL. ST.
CROSS ST.
PILDARA ST
ARRAWARRA ST
CIRCLE
KOORA RD.
NURSERY ST.
DEANE
BOULDER CR.
STRAND
UNDERSTON DR
LEECH CL.
GARDENIA CL.
MCLENNAN ST
ORCHARD DOWNS RD.
GLENWOOD RD.
TREELINE CL.
PUBLIC RESERVE
TRANSMISSION LINE EASEMENT
NARARA CREEK
FOUNTAIN CREEK
REEVES CREEK
TRIBUTARY 2A
TIMBER BRIDGE
NORTH
LEGEND
1% AEP FLOOD EXTENT
1% AEP FLOOD CONTOUR
EXISTING CREEK ALIGNMENT
Narara Creek & Lower Narara Creek Tributaries
FLOODPLAIN MANAGEMENT STUDY
RECOMMENDED WORKS AND FLOOD CONTOURS
FIGURE 6.5
SHEET 2 of 3
212A 212B
211D 212C 212D
227B 228A 228B
KEY TO ADJOINING SHEETS
COUNCIL OWNED LAND
CENTRAL MAPPING AUTHORITY
MAP REFERENCE
GOSFORD 2797-2-3
FIGURE 6.5


GOSFORD
CITY
COUNCIL
NORTH
LEGEND
1% AEP FLOOD EXTENT
1% AEP FLOOD CONTOUR
EXISTING CREEK ALIGNMENT
Notes:
1. FLOOD LEVELS HAVE BEEN CALCULATED AT CROSS SECTION LOCATIONS ONLY.
2. FLOOD LEVELS AND FLOOD CONTOURS BETWEEN CROSS SECTIONS HAVE BEEN LINEARLY INTERPOLATED.
3. FLOOD CONTOURS DEPICT APPROXIMATE WIDTHS OF FLOODING ONLY.
4. THE POSITION OF THE FLOOD EXTENT RELATIVE TO PROPERTY BOUNDARIES IS APPROXIMATE ONLY AND SHOULD BE VERIFIED BY SURVEY.
5. FLOOD LEVELS ARE GIVEN IN METRES TO AUSTRALIAN HEIGHT DATUM.
6. FLOOD EXTENTS UPSTREAM OF THIS LINE SUPERSEDES THAT OF THE LOWER NARARA CREEK FPMS.
Narara Creek & Lower
Narara Creek Tributaries
FLOODPLAIN
MANAGEMENT STUDY
RECOMMENDED WORKS
AND FLOOD CONTOURS
FIGURE 6.6
SHEET 3 of 3
211D
212C
212D
227B
228A
228B
227D
228C
228D
KEY TO ADJOINING SHEET
COUNCIL OWNED LAND
METRES
CENTRAL MAPPING AUTHORITY
MAP REFERENCE
GOSFORD U2797-51
ADJOINS SHEET 2
UPPER LIMIT OF STUDY
REEVES ST
ARRAWARRA
CIRCLE
COOLAWIN
PILOARA ST
NELIMAH
YANDERRA
CORELLA
WAROOKA ST
BLUE CRANE CL
JACANA
NARARA
CREEK
RD
MANNS
WANANDA
THE RIDGE
COOINDA
CR
MALIWA
JIRRANO
DAINTREE
APOLLO CL
PUBLIC RESERVE
DELL
CONSERV
BOWEN
MERINEE
CR.
DWYER
RD
ST
PERINA
VICTORIA PARK
RECREATION RESERVE
74
RESERVATION
Narara
DRAINAGE
TRANSMISSION LINE ESMT
608987
578680
776132
774552
122572
563248
789672
804013
771537
357289
800618
635498
PUB.RES.

FIGURE 6.6

Table 6.1 **Narara Creek 1% AEP flood levels and velocities, after works**

Location	Cross-section	Flood levels (mAHD)	Velocity		
			Left overbank (m/s)	Channel (m/s)	Right overbank (m/s)
Hanlan Street	19.00	6.42	0.3	0.8	0.2
	20.00	6.84	0.6	0.6	0.0
	21.00	6.94	0.5	0.8	0.1
	21.10	7.85	0.9	1.6	0.7
	22.00	8.46	0.5	0.7	0.5
Nursery Street	23.20	9.10	0.5	0.8	0.6
Timber bridge	23.42	9.57	0.8	1.6	0.7
	23.45	9.63	0.7	1.5	0.7
Timber bridge	23.52	9.71	0.7	1.4	0.7
	23.55	9.79	0.7	1.3	0.6
	24.00	9.83	0.7	0.8	0.6
	24.10	9.94	2.7	2.5	0.0
	24.20	10.77	0.9	0.6	0.9
	25.00	10.99	0.6	0.6	0.8
	26.00	11.15	1.6	1.1	0.0

Table 6.2 **Fountain Creek and Reeves Creek 1% AEP flood levels and velocities, after works**

Location	Cross-section	Flood levels (mAHD)	Velocity		
			Left overbank (m/s)	Channel (m/s)	Right overbank (m/s)
Fountain Creek					
Hanlan Street	0.00	5.3	0.2	0.1	0.2
	1.00	5.3	0.2	0.1	0.2
Concrete bridge	1.10	5.5	0.1	0.1	0.2
	1.30	5.5	0.2	0.1	0.2
	2.10	5.5	0.2	0.1	0.1
Carrington St bridge	2.20	5.5	0.2	0.2	0.3
	2.30	5.5	0.2	0.2	0.3
	2.40	5.5	0.2	0.1	0.1
	2.50	5.5	0.2	0.1	0.1
	3.00	5.5	0.2	0.1	0.2
	4.10	5.9	1.6	1.5	2.1
Pandala Road culvert	4.20	6.3	0.7	0.5	0.8
	4.30	6.3	0.7	0.5	0.7
Carrington St bridge	5.10	6.6	1.6	1.7	1.6
	5.20	7.2	0.8	0.6	0.7
Pipe culvert	6.20	7.3	1.1	0.8	0.4
Timber bridge	7.10	7.5	0.9	1.3	2.2
	7.20	7.8	0.7	0.7	1.3
Junction–J2A	7.30	7.9	0.4	0.7	0.6
	9.70	8.5	0.7	1.3	0.5
Timber bridge	9.10	8.5	0.0	3.2	0.0
	9.20	9.1	0.7	2.5	0.6
	9.30	9.6	0.5	1.3	0.5
	15.10	9.8	0.4	0.4	0.3
Reeves Street	15.20	9.8	0.4	0.4	0.3
	15.30	9.8	0.4	0.4	0.3
	16.00	11.2	1.6	2.7	1.7
	17.00	14.0	0.6	0.9	0.6
	-7.30	7.9	0.2	0.3	0.3
	8.00	8.2	0.8	2.6	1.7
Bridge	9.50	9.3	0.9	1.7	0.6
	9.60	9.5	0.8	1.3	0.5
	9.00	9.8	0.8	0.8	0.6
Bridge/pipe culverts	10.10	10.3	0.7	2.0	0.0
	10.20	10.5	0.8	1.65	0.0
Junction–J2B	10.30	10.7	0.3	0.6	0.0
Pipe culverts	11.10	11.2	0.0	2.9	0.0
	11.20	12.3	0.3	0.5	0.3
	11.30	12.3	0.3	0.5	0.3
	12.10	12.6	0.0	14	0.0

Table 6.2 (cont) **Fountain Creek and Reeves Creek 1% AEP flood levels and velocities, after works**

Location	Cross-section	Flood levels (mAHD)	Velocity		
			Left overbank (m/s)	Channel (m/s)	Right overbank (m/s)
	13.00	15.0	0.0	1.8	0.0
Tributary J2B					
	-10.30	10.7	0.5	0.9	0.3
	11.40	11.2	0.0	1.7	0.0
Junction–J2C	11.50	11.4	0.0	0.4	0.0
	12.20	12.1	0.0	1.8	0.0
	14.10	14.5	0.0	0.6	0.0
Tributary J2C					
	-11.50	11.4	0.0	0.6	0.0
	12.30	13.4	0.0	2.2	0.0
	14.20	15.0	0.5	0.9	0.6
Reeves Creek					
	-3.00	5.4	0.0	0.0	0.0
	18.10	8.8	0.0	2.5	0.0

7 FORMULATION OF DRAFT FLOODPLAIN MANAGEMENT PLANS

The Draft Floodplain Management Plan was prepared following the evaluation of selected options. The plans incorporated the preferred works options.

Formulation of the management plan was undertaken by:

- identifying possible flood mitigation measures;
- reviewing the measures to identify a range of feasible options. The review was based on hydraulic, social, ecologic, economic and hazard criteria;
- hydraulic modelling to determine the effects of the proposed works;
- costing of the works;
- a benefit cost analysis assessing the cost effectiveness of proposed works;
- preparation of a draft plan (preliminary);
- public comment on the draft plan;
- preparation of the final plan.

Details of the flood damage assessment and benefit-cost analysis undertaken are included in Appendices C and D.

Appendix A
REFERENCES

Appendix A
REFERENCES

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Appendix B

COST ESTIMATES

Appendix B
COST ESTIMATES

Item	Unit	Quantity	Rate ($)	Value ($)
NARARA CREEK MANAGEMENT OPTIONS				
(NA1) Hanlan Street culvert				
• Fill road embankment	m^3	70	960	67,200
• 3 (1.8 x 2.7) RCBC	m^2	4,353	12	52,236
• reconstruct road pavement	m^2	40	1,659	67,600
• remove existing culvert	unit	1	–	1,000
• demolish existing road & cycleway	m^2	2.5	1,650	4,125
• lower water main	unit	1	-	25,000
• minor channel widening works	unit	1	–	10,000
• reinstate pipe rail fence	m	72	16	1,152
• contingency 20%				45,663
Total				273,976
(NA2) Fountain Road upgrade				
• scarify existing road	m^2	3,700	1.17	4,325
• subgrade 300 mm thick	m^2	4400	9.64	6,110
• sub-base 150 mm thick	m^2	3,700	17.3	64,015
• road base 150 mm thick	m^2	3,700	16.1	59,700
• bitumen seal	m^2	3,700	4.6	15,700
• contingency (20%)	m^2			30,200
Total				180,040
(NA3) Hanlan Street wet basin(1)				
• initial clearing	m^2	20,000	5.3	105,210
• excavation	m^3	30,000	11.7	350,700
• spillway	unit	1	–	2,925
• bank stabilization	m^2	1,200	1	1,400
• contingency (20%)				92,050
Total				552,285

Cost estimates (continued)

Item	Unit	Rate ($)	Quantity	Value ($)
NARARA CREEK MANAGEMENT OPTIONS				
(NA5) Nursery Street flood access improvements				
• initial clearing	m^2	5.3	7,000	36,825
• excavate and fill new channel	m^3	11.7	12,000	140,280
• bank stabilization	m^2	1.17	7,000	8,180
• replace two new footbridges	unit	–	2	116,900
• contingency (20%)				60,440
Total				362,625
(NA6) Narara Agricultural Research Station sediment trap				
• initial clearing	m^2	5.3	4,500	23,670
• excavate to form embankment	m^3	11.7	500	5,850
• embankment protection	m^2	29.2	260	7,595
• bank stabilization and grassing	m^2	1.17	520	610
• channel transition	m^3	11.7	100	1,170
• 2.10 m dia. outlet pipe	m	397	12	4,770
• contingency				8,730
Total				52,395
(FR1) East Hanlan Street channels				
• initial clearing	m^2	5.3	5,900	31,035
• excavation of floodway	m^3	11.7	11,000	683,865
• bank stabilization	m^2	1.17	5,900	6,895
• rock protection	m^3	70	200	14,030
• contingency (20%)				36,110
Total				216,660
FOUNTAIN CREEK AND REEVES STREET MANAGEMENT OPTIONS				
(FR2) Hanlan Street wet basin (2)				
• initial clearing	m^2	5.3	32,500	170,965
• excavation	m^3	11.7	58,500	683,865
• spillway	unit	–	–	2,920
• bank stabilization	m^2	1	1,200	1,400
• contingency (20%)				171,830
Total				1,030,980

Cost estimates (continued)

Item	Unit	Rate ($)	Quantity	Value ($)
(FR5) Carrington Street culvert				
• remove existing culvert	unit	–	1	1,170
• contingency (20%)				235
Total				1,405
(FR6) New culverts on Fountain Creek tributaries				
(for culverts only)				
• supply 3(0.9 x 3.3) RCBC	m	4,842	15	72,642
• supply 3(1.2 x 3.0) RCBC	m	4,386	15	65,795
• excavate/ install culverts	m	450	30	13,500
• contingency (20%)				30,387
Total				182,324
(FR7) Reeves Street causeway				
• bridge 185 m long x 10 m wide	m^2	1,170	1,850	2,162,650
• contingency (20%)				432,530
Total				2,595,180
(FR9) Reeves Street culvert *				
• trench excavation and backfill	m^3	25.7	36	925
• 2 No. 1.2 x 0.9 RCBC's	m	307.7	20	6,156
• floor slab	m^3	853	9	7,680
• head walls	unit	2,010	2	4,020
• resurface road	m^2	47	30	1,400
• contingency (20%)				4,040
Total				24,220

* Completed 1993

Appendix C

FLOOD DAMAGE ASSESSMENT

Appendix C

FLOOD DAMAGE ASSESSMENT

Flood damages for the Narara Creek area have been assessed for existing conditions and for after completion of the combined recommended works. The damage assessment procedure used to estimate average annual damage is presented in Figures C1 and C2 for existing conditions and after works respectively.

This procedure is comparable to the procedures utilised in flood damages computer programs such as ANUFLOOD. Damage curves and relationships have been derived from a range of previous reports including the ANUFLOOD Field Guide (Taylor , Greenaway, Smith. 1983).

Where property levels have not been surveyed or are not available, they have been assumed to be 0.5m below the surveyed property house floor level for the purposes of this study. The levee at Lot B DP393508 Fountains Road has been ignored as mentioned previously.

FLOOD LEVELS, INUNDATION DEPTHS AND AVERAGE ANNUAL DAMAGE SUMMARY

EXISTING CONDITIONS

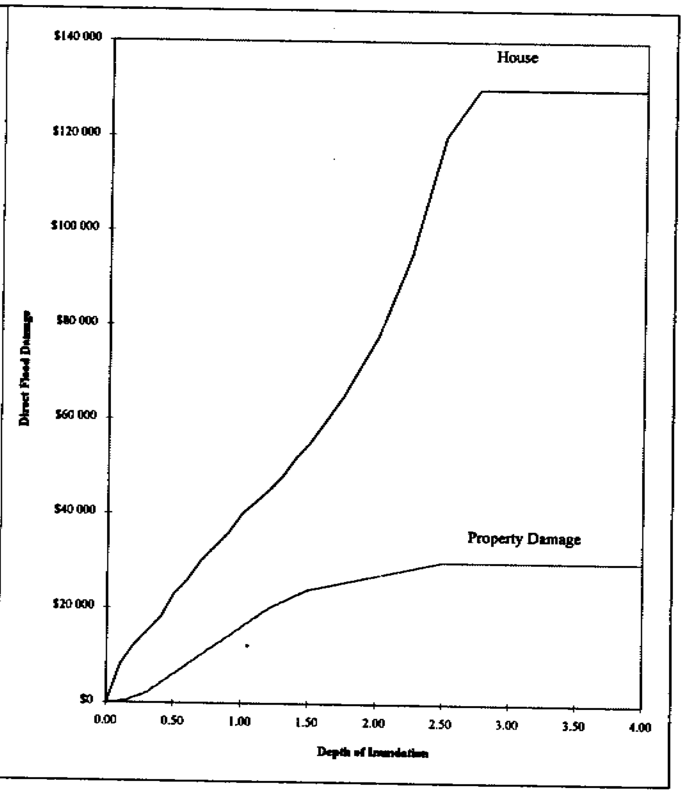
Address	Floor Level (m)	Property Level (m)	2 x 1% AEP Flood: Flood Level (m)	Depth Floor (m)	Depth Property (m)	Velocity (m/s)	Hazard	1% AEP Flood: Flood Level (m)	Depth Floor (m)	Depth Property (m)	Velocity (m/s)	Hazard
95 Deane St	9.52	9.0	9.5	0.0	0.5			8.8	-0.8	-0.3		
93 Deane St	9.36	8.9	9.4	0.0	0.5			8.7	-0.7	-0.2		
24 Deane St	15.27	8.2	9.1	-6.1	0.9			8.5	-6.8	0.3		
79 Deane St	13.25	11.3	8.5	-4.8	-2.8			7.7	-5.6	-3.6		
19 Deane St	15.08	14.6	8.1	-7.0	-6.5			7.2	-7.9	-7.4		
63/65 Deane St	17.49	17.0	7.7	-9.8	-9.3			7.1	-10.4	-9.9		
Lot 1 DP116038	15.17	14.6	6.9	-8.3	-7.7			6.9	-8.3	-7.7		
290 Hanlan St	10.61	10.1	6.9	-3.7	-3.2			6.5	-4.1	-3.6		
40 Hanlan St	9.46	9.0	6.9	-2.6	-2.1			6.4	-3.1	-2.6		
500 Hanlan St	10.40	9.9	8.1	-2.3	-1.8			6.5	-3.9	-3.4		
42 Fountains Rd	13.51	13.0	8.1	-5.4	-4.9			7.4	-6.1	-5.6		
38 Fountains Rd	12.60	12.1	7.9	-4.7	-4.2			7.2	-5.4	-4.9		
34 Fountains Rd	9.34	8.8	7.6	-1.7	-1.2			7.1	-2.2	-1.7		
23 Fountains Rd	6.61	6.1	7.6	1.0	1.5			6.3	-0.3	0.2		
23 Fountains Rd	6.74	6.2	6.6	-0.1	0.4			6.2	-0.5	0.0		
2 Pandala Rd	6.82	6.3	6.9	0.1	0.6			5.9	-0.9	-0.4		
Lot B DP393508	5.68	5.2	7.0	1.3	1.8			6.7	1.0	1.5		
29 Hanlan St	10.70	10.2	6.7	-4.0	-3.5			5.4	-5.3	-4.8		
2/6 Hanlan St	6.89	4.4	6.6	-0.3	2.2			5.3	-1.6	0.9		
2/1 Hanlan St	6.03	5.5	6.6	0.6	1.1			5.2	-0.8	-0.3		
Number of houses flooded				5	9				1	4		

Address	5% AEP Flood: Flood Level (m)	Depth Floor (m)	Depth Property (m)	Velocity (m/s)	Hazard	20% AEP Flood: Flood Level (m)	Depth Floor (m)	Depth Property (m)	Flood Level (m)	Depth Floor (m)	Depth Property (m)	Velocity (m/s)	Hazard	Flood Level (m)	Depth Floor (m)	Depth Property (m)	Velocity (m/s)	Hazard
95 Deane St	8.5	-1.0	-0.5			8.3	-1.2	-0.7										
93 Deane St	8.5	-0.9	-0.4			8.3	-1.1	-0.6										
24 Deane St	8.3	-7.0	0.1			8.1	-7.2	-0.1										
79 Deane St	7.7	-5.6	-3.6			7.5	-5.8	-3.8										
19 Deane St	7.2	-7.9	-7.4			7.0	-8.1	-7.6										
63/65 Deane St	6.7	-10.8	-10.3			6.5	-11.0	-10.5										
Lot 1 DP116038	6.2	-9.0	-8.4			6.1	-9.1	-8.5										
290 Hanlan St	6.2	-4.4	-3.9			6.1	-4.5	-4.0										
40 Hanlan St	6.2	-3.3	-2.8			6.1	-3.4	-2.9										
500 Hanlan St	7.2	-3.2	-2.7			7.0	-3.4	-2.9										
42 Fountains Rd	7.2	-6.3	-5.8			7.0	-6.5	-6.0										
38 Fountains Rd	7.0	-5.6	-5.1			6.8	-5.8	-5.3										
34 Fountains Rd	6.6	-2.7	-2.2			6.4	-2.9	-2.4										
23 Fountains Rd	6.6	0.0	0.5			6.4	-0.2	0.3										
23 Fountains Rd	5.8	-0.9	-0.4			5.8	-0.9	-0.4										
2 Pandala Rd	6.1	-0.7	-0.2			6.0	-0.8	-0.3										
Lot B DP393508	6.2	0.5	1.0			6.1	0.4	0.9										
29 Hanlan St	5.2	-5.5	-5.0			5.0	-5.7	-5.2										
2/6 Hanlan St	5.0	-1.9	0.6			4.9	-2.0	0.5										
2/1 Hanlan St	5.0	-1.0	-0.5			4.9	-1.1	-0.6										
Number of houses flooded		1	4				1	3		0	0				0	0		

Note: 1) Where inundation depths are negative they refer to freeboard above the flood level.

STAGE DAMAGE CURVES

Inundation Depth	Direct damage to House	Direct damage to Property	Timber Warehouse
0.00	$0	$0	$0
0.05	$4 000	$100	
0.10	$8 000	$250	
0.15	$10 000	$500	
0.20	$12 000	$1 000	
0.25	$13 500	$1 500	
0.30	$15 000	$2 000	
0.35	$16 500	$3 000	
0.40	$18 000	$4 000	
0.50	$23 000	$6 000	
0.60	$26 000	$8 000	$440 000
0.70	$30 000	$10 000	
0.80	$33 000	$12 000	
0.90	$36 000	$14 000	
1.00	$40 000	$16 000	
1.10	$42 500	$18 000	
1.20	$45 000	$20 000	
1.30	$48 000	$21 400	
1.40	$52 000	$22 800	
1.50	$55 000	$24 000	
1.75	$65 000	$25 500	
2.00	$77 500	$27 000	
2.25	$95 000	$28 500	
2.50	$120 000	$30 000	
2.75	$130 000	$30 000	
3.00	$130 000	$30 000	$625 000
4.00	$130 000	$30 000	



DAMAGES CAUSED BY FLOOD EVENTS

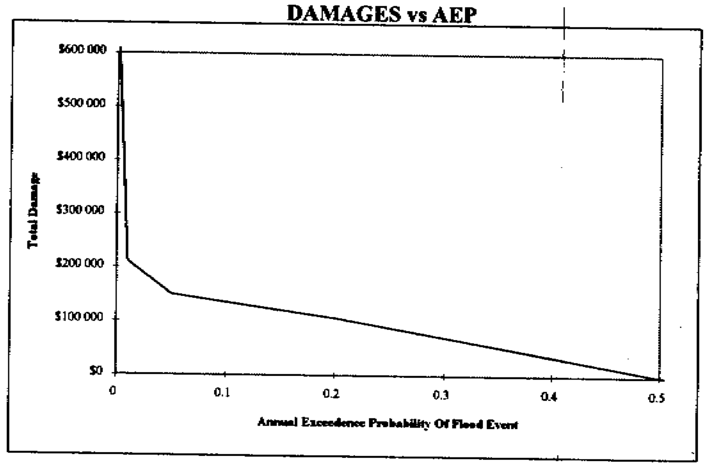
EVENT: Recurrence Interval (years)	AEP	TANGIBLE DAMAGES: Residential Damage: Direct Building Damage	Direct Property Damage	Total Direct Damage	Indirect Residential	Industrial Damage: Direct Building Damage	Direct Property Damage	Total Direct Damage	Indirect Industrial	Infrastructur Damage	Total Tangible Damages	INTANGIBLE DAMAGES: Residential Properties Flooded	Total Intangible Damages	TOTAL DAMAGES
1	1	$0	$0	$0	$0					$0	$0	0	$0	$0
2	0.5	$0	$0	$0	$0					$0	$0	0	$0	$0
5	0.2	$18 000	$20 000	$38 000	$11 000					$19 000	$68 000	1	$38 000	$106 000
20	0.05	$23 000	$30 000	$53 000	$16 000					$27 000	$96 000	1	$53 000	$149 000
100	0.01	$36 000	$39 000	$75 000	$23 000					$38 000	$136 000	1	$75 000	$211 000
PMF	0	$111 000	$126 000	$237 000	$71 000					$119 000	$427 000	5	$237 000	$664 000

INDIRECT AND INTANGIBLE

Tangible	
Residential indirect as % of direct	30%
Industrial indirect as % of direct	50%
Infrastructure as % of total direct	50%
Intangible	
Social Damage	
Residential as % of direct	100%
Industrial as % of direct	50%
Enviromental	N/A
Actual damage as % of potential	100%

* The Annual Average Damage has been calculated as the area under the Damages vs AEP graph. The area between the 0 and 0.01 AEP (PMF and 100yr ARI) events has been calculated using Simpson rule while the rest have been calculated by trapezoids.

DAMAGES vs AEP



AVERAGE ANNUAL DAMAGE*

For Events of	Damage
2yr to 5yr ARI	$16 000
5yr to 20yr ARI	$19 000
20yr to 100yr ARI	$7 000
100yr ARI to PMF	$4 000
(It was estimated that an event of 2yr ARI magnitude or greater is required to cause damage)	
Total Average Annual Damage	
Potential	$46 000
Actual	$46 000
Present Worth of Damage	
Term = 20yrs, Interest = 7%pa	$490 000
Term = 20yrs, Interest = 4%pa	$630 000
Term = 20yrs, Interest = 10%pa	$390 000
Term = 50yrs, Interest = 7%pa	$630 000

FLOOD LEVELS, INUNDATION DEPTHS AND AVERAGE ANNUAL DAMAGE SUMMARY

WITH RECOMMENDED WORKS

Address	Floor Level (m)	Property Level (m)	2 x 1% AEP Flood: Flood Level (m)	Depth: Floor (m)	Depth: Property (m)	Velocity (m/s)	Hazard	1% AEP Flood: Flood Level (m)	Depth: Floor (m)	Depth: Property (m)	Velocity (m/s)	Hazard
95 Deane St	9.52	9.0	9.5	0.0	0.5			8.8	-0.8	-0.3		
93 Deane St	9.36	8.9	9.4	0.0	0.5			8.7	-0.7	-0.2		
24 Deane St	15.27	8.2	9.1	-6.1	0.9			8.5	-6.8	0.3		
79 Deane St	13.25	11.3	8.5	-4.8	-2.8			7.7	-5.6	-3.6		
19 Deane St	15.08	14.6	8.1	-7.0	-6.5			7.2	-7.9	-7.4		
63/65 Deane St	17.49	17.0	7.7	-9.8	-9.3			7.1	-10.4	-9.9		
Lot 1 DP116038	15.17	14.6	6.9	-8.3	-7.7			6.9	-8.3	-7.7		
290 Hanlan St	10.61	10.1	6.9	-3.7	-3.2			6.5	-4.1	-3.6		
40 Hanlan St	9.46	9.0	6.9	-2.6	-2.1			6.4	-3.1	-2.6		
500 Hanlan St	10.40	9.9	8.1	-2.3	-1.8			6.5	-3.9	-3.4		
42 Fountains Rd	13.51	13.0	8.1	-5.4	-4.9			7.4	-6.1	-5.6		
38 Fountains Rd	12.60	12.1	7.9	-4.7	-4.2			7.2	-5.4	-4.9		
34 Fountains Rd	9.34	8.8	7.6	-1.7	-1.2			7.1	-2.2	-1.7		
23 Fountains Rd	6.61	6.1	7.6	1.0	1.5			6.3	-0.3	0.2		
23 Fountains Rd	6.74	6.2	6.6	-0.1	0.4			5.9	-0.8	-0.3		
2 Pandala Rd	6.82	6.3	6.9	0.1	0.6			5.9	-0.9	-0.4		
Lot B DP393508	5.68	5.2		Purchased					Purchased			
29 Hanlan St	10.70	10.2	6.7	-4.0	-3.5			5.4	-5.3	-4.8		
2/6 Hanlan St	6.89	4.4	6.6	-0.3	2.2			5.3	-1.6	0.9		
2/1 Hanlan St	6.03	5.5	6.6	0.6	1.1			5.3	-0.7	-0.2		
Number of houses flooded				4	8				0	3		

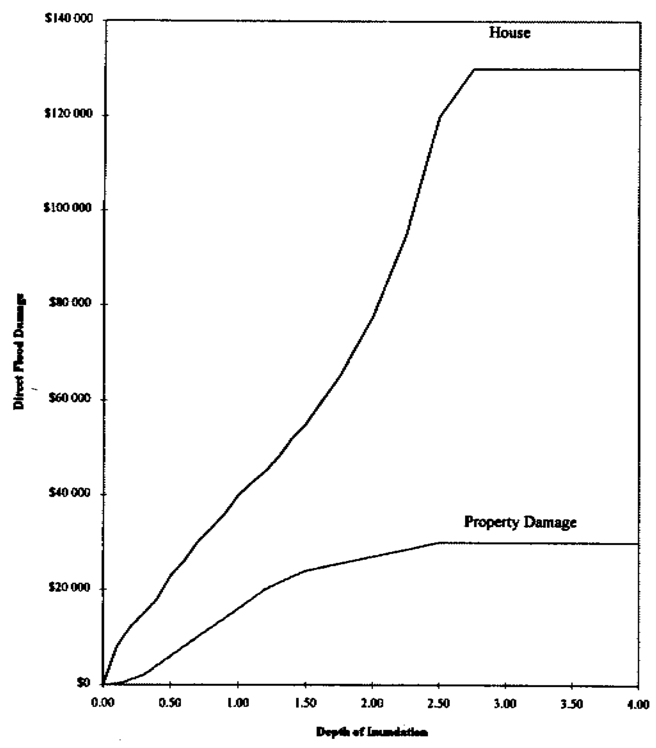
Address	5% AEP Flood: Flood Level (m)	Depth: Floor (m)	Depth: Property (m)	Velocity (m/s)	Hazard	20% AEP Flood: Flood Level (m)	Depth: Floor (m)	Depth: Property (m)
95 Deane St	8.5	-1.0	-0.5			8.3	-1.2	-0.7
93 Deane St	8.5	-0.9	-0.4			8.3	-1.1	-0.6
24 Deane St	8.3	-7.0	0.1			8.1	-7.2	-0.1
79 Deane St	7.7	-5.6	-3.6			7.5	-5.8	-3.8
19 Deane St	7.1	-8.0	-7.5			6.9	-8.2	-7.7
63/65 Deane St	6.7	-10.8	-10.3			6.5	-11.0	-10.5
Lot 1 DP116038	6.2	-9.0	-8.4			6.1	-9.1	-8.5
290 Hanlan St	6.2	-4.4	-3.9			6.1	-4.5	-4.0
40 Hanlan St	6.2	-3.3	-2.8			6.1	-3.4	-2.9
500 Hanlan St	7.2	-3.2	-2.7			7.0	-3.4	-2.9
42 Fountains Rd	7.2	-6.3	-5.8			7.0	-6.5	-6.0
38 Fountains Rd	7.0	-5.6	-5.1			6.8	-5.8	-5.3
34 Fountains Rd	6.6	-2.7	-2.2			6.4	-2.9	-2.4
23 Fountains Rd	6.6	0.0	0.5			6.4	-0.2	0.3
23 Fountains Rd	5.8	-0.9	-0.4			5.7	-1.0	-0.5
2 Pandala Rd	6.1	-0.7	-0.2			6.0	-0.8	-0.3
Lot B DP393508		Purchased					Purchased	
29 Hanlan St	5.2	-5.5	-5.0			5.1	-5.6	-5.1
2/6 Hanlan St	5.1	-1.8	0.7			5.0	-1.9	0.6
2/1 Hanlan St	5.1	-0.9	-0.4			5.0	-1.0	-0.5
Number of houses flooded		0	3				0	2

Address	50% AEP Flood: Flood Level (m)	Depth: Floor (m)	Depth: Property (m)	Velocity (m/s)	Hazard	Flood Level (m)	Depth: Floor (m)	Depth: Property (m)	Velocity (m/s)	Hazard
Number of houses flooded		0	0				0	0		

Note: 1) Where inundation depths are negative they refer to freeboard above the flood level.

STAGE DAMAGE CURVES

Inundation Depth	Direct damage to House	Direct damage to Property	Timber Warehouse
0.00	$0	$0	$0
0.05	$4 000	$100	
0.10	$8 000	$250	
0.15	$10 000	$500	
0.20	$12 000	$1 000	
0.25	$13 500	$1 500	
0.30	$15 000	$2 000	
0.35	$16 500	$3 000	
0.40	$18 000	$4 000	
0.50	$23 000	$6 000	
0.60	$26 000	$8 000	$440 000
0.70	$30 000	$10 000	
0.80	$33 000	$12 000	
0.90	$36 000	$14 000	
1.00	$40 000	$16 000	
1.10	$42 500	$18 000	
1.20	$45 000	$20 000	
1.30	$48 000	$21 400	
1.40	$52 000	$22 800	
1.50	$55 000	$24 000	
1.75	$65 000	$25 500	
2.00	$77 500	$27 000	
2.25	$95 000	$28 500	
2.50	$120 000	$30 000	
2.75	$130 000	$30 000	
3.00	$130 000	$30 000	$625 000
4.00	$130 000	$30 000	



DAMAGES CAUSED BY FLOOD EVENTS

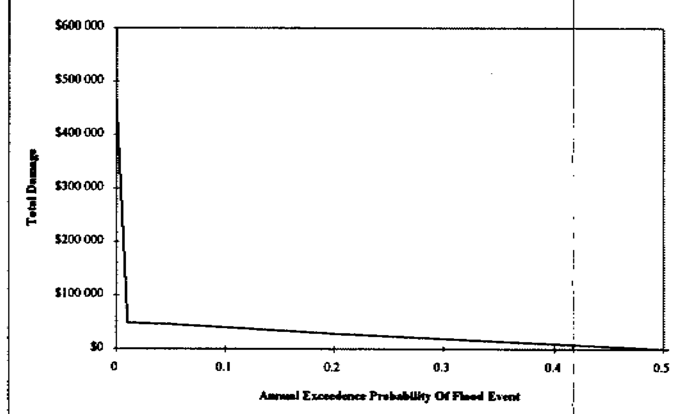
EVENT: Recurrence Interval (years)	AEP	TANGIBLE DAMAGES: Residential Damage: Direct Building Damage	Direct Property Damage	Total Direct Damage	Indirect Residential	Industrial Damage: Direct Building Damage	Direct Property Damage	Total Direct Damage	Indirect Industrial	Infrastructur Damage	Total Tangible Damages	INTANGIBLE DAMAGES: Residential Properties Flooded	Total Intangible Damages	TOTAL DAMAGES
1	1	$0	$0	$0	$0					$0	$0	0	$0	$0
2	0.5	$0	$0	$0	$0					$0	$0	0	$0	$0
5	0.2	$0	$10 000	$10 000	$3 000					$5 000	$18 000	0	$10 000	$28 000
20	0.05	$0	$16 000	$16 000	$5 000					$8 000	$29 000	0	$16 000	$45 000
100	0.01	$0	$17 000	$17 000	$5 000					$9 000	$31 000	0	$17 000	$48 000
PMF	0	$63 000	$100 000	$163 000	$49 000					$82 000	$294 000	4	$163 000	$457 000

INDIRECT AND INTANGIBLE

Tangible	
Residential indirect as % of direct	30%
Industrial indirect as % of direct	50%
Infrastructure as % of total direct	50%
Intangible	
Social Damage	
Residential as % of direct	100%
Industrial as % of direct	50%
Enviromental	N/A
Actual damage as % of potential	100%

* The Annual Average Damage has been calculated as the area under the Damages vs AEP graph. The area between the 0 and 0.01 AEP (PMF and 100yr ARI) events has been calculated using Simpson rule while the rest have been calculated by trapezoids.

DAMAGES vs AEP



AVERAGE ANNUAL DAMAGE*

For Events of	Damage
2yr to 5yr ARI	$4 000
5yr to 20yr ARI	$5 000
20yr to 100yr ARI	$2 000
100yr ARI to PMF	$3 000
(It was estimated that an event of 2yr ARI magnitude or greater is required to cause damage)	
Total Average Annual Damage	
Potential	$14 000
Actual	$14 000
Present Worth of Damage	
Term = 20yrs, Interest = 7%pa	$150 000
Term = 20yrs, Interest = 4%pa	$190 000
Term = 20yrs, Interest = 10%pa	$120 000
Term = 50yrs, Interest = 7%pa	$190 000

Appendix D

BENEFIT-COST ANALYSIS

Appendix D
BENEFIT-COST ANALYSIS

Table D.1 presents the benefit-cost ratios determined for the combined recommended options. A 50 year design life with an annual interest rate of 7% is recommended as the adopted criteria for calculation of the benefit cost ratio. The combined capital cost of all recommended options is $5,597,400.

Table D.1 Benefit/cost analysis for proposed works (combined)

i	N	Present Value of Damages for Existing Conditions	Present Value of Damages after Proposed Works	Present Value of Benefit	B/C
	20	630,000	190,000	440,000	0.08
5%	50	990,000	300,000	690,000	0.12
	100	1,130,000	340,000	790,00	0.14
	20	490,000	150,000	340,000	0.06
7%	**50**	**630,000**	**190,00**	**440,000**	**0.08**
	100	660,000	200,000	460,000	0.08
	20	390,000	120,000	270,000	0.05
10%	50	460,000	140,000	320,000	0.06
	100	460,000	140,000	320,000	0.06

The following formulae were used for this analysis:

$AAD = \Sigma\ AEP * d(AEP)$

$PV = AAD*(1-(1+i))/ I$

$B/C = (PVex - PVfin)/C$ and;

i = annual interest rate
N = number of years in design life
B/C = benefit cost ratio
AEP = annual exceedence probability of flood
d(AEP) = cost of flood damages for a particular AEP
PVex = present value of damages for existing conditions
PVfin = present value of damages after completion of proposed works
AAD = average annual damage cost
C = capital cost of works.

End of Report