# A REPORT ON DEVELOPMENT OF MACQUARIE RIVULET AS A REFERENCE CATCHMENT FOR THE ILLAWARRA

Prepared By:

Water Research Foundation of Australia
Illawarra Regional Committee
Stormwater Subcommittee
Editor : E H Rigby - December 1996

TODAY'S RESEARCH
TOMORROW'S PRACTICE

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# GLOSSARY

Where the following abbreviated or technical terms occur in this report, they have the following meaning:

## ABBREVIATIONS

| | | |
|---|---|---|
| AEP | - | Annual Exceedance Probability; The probability of a rainfall or flood event of given magnitude being equalled or exceeded in any one year. |
| AHD | - | Australian Height Datum: National reference datum for level |
| ARI | - | Average Recurrence Interval; The expected or average interval of time between exceedances of a rainfall or flood event of given magnitude. |
| ARR | - | Australian Rainfall and Runoff; National Code of Practice for Drainage published by Institution of Engineers, Australia, 1987. |
| FPDM | - | Flood Plain Development Manual; Guidelines for Development in Flood Plains published by N.S.W. State Government, 1986. |
| FSL | - | Flood Surface Level |
| ha | - | Hectare. (Area = 10,000 $m^2$) |
| IFD | - | Intensity - Frequency - Duration<br>Rainfall parameters used to describe rainfall at a particular location. |
| km | - | Kilometre. (Distance = 1,000m) |
| m | - | Metre. |
| $m^2$ | - | Square Metre. |
| ha | - | Hectare (Area =10,000 m2) |
| $m^3$ | - | Cubic Metre. |
| m/sec | - | Metres/Second ( Velocity) |
| $m^3$/sec | - | Cubic Metre per Second. |
| NWC | - | Natural Water Course;<br>A small creek or channel in its natural condition. |
| PMF | - | Probable Maximum Flood;<br>Flood calculated to be the maximum physically possible. |
| PMP | - | Probable Maximum Precipitation;<br>Rainfall calculated to be the maximum physically possible. |
| RCP | - | Reinforced Concrete Pipe |
| sec | - | Second. |
| yr | - | Year. |

## TECHNICAL TERMS

| | | |
|---|---|---|
| Alluvium | - | Material eroded, transported and deposited by streams. |
| Antecedent | - | Pre-existing (conditions e.g. wetness of soils). |
| Areal | - | Variation over an area of a particular parameter. |
| Catchment | - | Area draining into a particular creek system, typically bounded by higher ground around its perimeter. |
| Cover | - | Type and distribution of vegetation on catchment. |
| Critical Flow | - | Water flowing at a Froude No. of one. |
| Culvert | - | An enclosed conduit (typically pipe or box) that conveys stormwater below ground. |
| Discharge | - | The flow rate of water. |
| Escarpment | - | A cliff or steep slope, of some extent, generally separating two level or gently sloping areas. |
| Flood | - | A relatively high stream flow which overtops the stream banks. |
| Floodstorages | - | Those parts of the flood plain that are important for the storage of floodwaters during the passage of a flood. |
| Floodways | - | Those areas where a significant volume of water flows during floods. They are often aligned with obvious naturally defined channels and are areas which, if partly blocked, would cause a significant redistribution of flow. |
| Flood Fringes | - | Those parts of the flood plain left after floodways and flood storages have been abstracted. |
| Froude No. | - | A measure of flow instability - below a value of one, flow is tranquil and smooth, above one flow tends to be rough and undulating (as in rapids). |
| Geotechnical | - | Relating to Engineering and the materials of the earth crust. |
| Gradient | - | Slope or rate of fall of land/pipe/stream. |
| Gully | - | Narrow ravine, small valley. |
| Headwall | - | Wall constructed around inlet or outlet of a culvert. |
| Hydraulic | - | A term given to the study of water flow, as relates to the evaluation of flow depths, levels and velocities. |
| Hydrology | - | A term given to the study of the rainfall and runoff process. |
| Hydrograph | - | A graph of flood flow against time. |
| Hyetograph | - | A graph of rainfall intensity against time. |
| Isohyets | - | Lines joining points of equal rainfall on a plan. |
| Manning's n | - | A measure of channel or pipe roughness. |
| Oreographic | - | Pertaining to changes in relief, mountains. |
| Orthophoto | - | Aerial photograph with contours, boundaries or grids added. |
| Pluviograph | - | An instrument which records rain collected as a function of time. |
| Runoff | - | Water running off a catchment during a storm. |
| Scour | - | Rapid erosion of soil in the banks or bed of a creek, typically occurring in areas of high flow velocities and turbulence. |
| Siltation | - | The filling or raising up of the bed of a watercourse or channel by deposited silt. |
| Spurs | - | Secondary ridges typically occurring at right angles to a main ridge line, formed by stream erosion of the slopes of the main ridge. |
| Stratigraphy | - | The sequence of layers in which soils/rocks have been deposited. |
| Surcharge | - | Flow unable to enter a culvert or exiting from a pit as a result of inadequate capacity. |
| Topography | - | The natural surface features of a region. |
| Urbanisation | - | The change in land usage from a natural to developed state. |
| Watercourse | - | A small stream or creek. |

# PRECIS

In 1983 a subcommittee of the Illawarra Regional Committee of the Water Research Foundation was formed to collect, correlate and distribute hydrologic data of relevance to the Illawarra region.

Over the part thirteen years this subcommittee has provided a much needed forum for communication between professionals practicing in the hydrology field in the region.

The subcommittee was disbanded earlier this year following a decision to disband its parent committee, the Illawarra Regional Committee of the Water Research Foundation of Australia.

Whilst the subcommittee did not fulfil all of the several short and long terms goals set in 1983, it has organised several workshops and through its members undertaken a range of valuable studies.

This Report and associated Compendium of Data draws together as much of the data collected and analysis prepared by the subcommittee as is available at this time, in the belief that this material will be of value to Hydrologists and Engineers undertaking similar studies in the region.

The Report provides an overview of available catchment and event data, precis previous studies, and presents the results of a range of analyses of catchment hydrology and floodplain hydraulics undertaken by members of the subcommttee.

The Report concludes with an appraisal of the data and analyses performed and provides recommendations as to model parameters considered appropriate to the catchment and region.

The Compendium of Data contains data collected by the subcommittee relating to the hydrology of Macquarie Rivulet, upon which the various analysis described in the Report were based.

Given the considerable benefits to the community and all participating in this Subcommittee, it is, in conclusion, recommended that a similar subcommittee be reconstituted under an appropriate professional body, so that the work of the subcommittee might continue.

# DEVELOPMENT OF MACQUARIE RIVULET AS A REFERENCE CATCHMENT FOR THE ILLAWARRA

## 1. INTRODUCTION

### 1.1 BACKGROUND

In 1983 a subcommittee of the Illawarra Regional Committee of the Water Research Foundation of Australia was formed, to collect, correlate and distribute hydrologic data of relevance to the region.

The long term objectives of this subcommittee were :

a) *The promotion of communication between professional practising in the stormwater management field in the Illawarra.*

b) *The establishment of an accessible data base of filtered hydrologic and hydraulic data relevant to the Illawarra Region.*

c) *The promotion of research relevant to regional problems in stormwater management.*

d) *The review and development of guidelines relevant to practise in the field of stormwater management in the Illawarra.*

The short term objectives were :

a) *To prepare an inventory of present hydrologic/hydraulic data available within the region.*

b) *The establishment by consensus of minimum standards for the local validation/calibration of hydrologic/hydraulic models prior to their use in the Illawarra.*

*c)* *The establishment by consensus of parameters appropriate to the application of a select range of validated/calibrated models in the region.*

*d)* *The establishment by consensus of minimum standards for documentation of the usage of and results derived from the application of hydrologic/hydraulic models in the region.*

Further details of the philosophy behind foundation of this subcommittee and its goals are described by Rigby (1984).

Over the past thirteen years this subcommittee has met regularly, providing a much needed forum for discussion and communication between professionals practicing in the hydrology field in the Illawarra.

This subcommittee was disbanded earlier this year, following the decision to disband its parent committee, the Illawarra Regional Committee of the Water Research Foundation of Australia.

In pursuing the various goals of the subcommittee, Macquarie Rivulet was selected as a reference catchment for the region and a considerable body of data was accumulated by the subcommittee on this catchment.

Once basic data had been assembled, a series of hydrologic modelling exercises were undertaken by the committee members exploring ;

- Variability and Uncertainty in Modelled Design Discharges
- Variability and Uncertainty in Modelled Historic Event Discharges

The results of this work has been reported by Boyd et al (1989).

This earlier work was further developed in a series of flood studies by Forbes Rigby (1990 - 1996).

Whilst the subcommittee has now been disbanded, without achieving all of the goals set in 1983, it was felt that such work as had been completed could and would prove of value to the profession if collated and published.

The parent committee was approached and kindly agreed to provide the funds necessary for this work to be undertaken.

This work draws together as much of the data and analysis, as is available at this time , into a Report and supporting Compendium of Data.

The first document, (this report) reviews available data and earlier studies of flooding in the catchment, and documents the work of the subcommittee and others in modelling the hydrology of flood discharges in Macquarie Rivulet and the hydraulics of flood flows in the lower reaches of Macquarie Rivulet.

A second document subtitled, 'A Compendium of Data' containing data relating to the hydrology of Macquarie Rivulet and forming the basis of the hydrologic and hydraulic modelling described in this report, has been assembled as a companion document.

It is hoped that the material contained in this Report and associated 'Compendium of Data', will assist Hydrologists and Engineers preparing drainage studies in the region.

## 1.2 LIMITATIONS

This report does not unfortunately present a single coherent view of the underlying data, hydrology or hydraulics of flood flows in Macquarie Rivulet. Over the thirteen years of activity of the subcommittee there has been considerable improvement in the quality of data available and models to simulate the hydrologic and hydraulic processes.

In consequence, both the data and the work of the subcommittee has evolved with time reflecting these changes.

The material presented in this report, is presented in the context of work undertaken at the time, by the subcommittee. Earlier analyses have not been updated, in this report, to reflect current data or practice. Care is therefore needed in extracting data or comparing results between earlier and later analyses.

In addition, since reliable data for only a single flood event in Macquarie Rivulet was available at the time of preparation of this report, this particular event was not used for model calibration purposes. All results from the hydrologic modelling are based on regionally derived values for model parameters and local experience in fitting models to recorded data in nearby catchments. All results from the hydraulic modelling are based on subjective assessment of bed friction and eddy loss parameters following guidelines presented by Chow (1959), Arcement & Schneider (1984), Hicks & Mason (1991), Lee & Froelich (1989) and the ECGL of Brigham Young University (1994).

The single flood event for which data was available, was applied in a validation role to assess the reasonableness of chosen parameters.

# 2. CATCHMENT DATA

## 2.1 DESCRIPTION

The 105 $km^2$ catchment of Macquarie Rivulet combines the three main subcatchments of Macquarie Rivulet and its tributaries, Frazers Creek and Marshal Mount Creek. All three sub-catchments are predominantly rural with some urban development in the lower reaches of Frazers Creek and Macquarie Rivulet, around Albion Park.

An outline of key features of the catchment is provided below. A more detailed description of the catchment is provided in the following Compendium of Data.

## 2.2 CLIMATE

Annual rainfall in the catchment varies from 1100 mm in the lower reaches around Lake Illawarra, to 1600 mm at the escarpment. Both design rainfall and historic storms generally exhibit significant intensity gradients, with the higher intensities occurring closer to the escarpment.

## 2.3 PHYSIOGRAPHY

Macquarie Rivulet has a stream length of 22.5 km, with total fall from head waters to outlet at Lake Illawarra of 680 metres. The catchment is confined to the east by the Tasman Sea and to the west by the Illawarra coastal escarpment. For the majority of its length, the stream meanders along a relatively flat river valley with the lower reaches combining on a broad flat flood plain, above the Princes Highway prior to discharging into Lake Illawarra.

## 2.4 GEOLOGY

The stratigraphy of the catchment generally comprises Narrabeen Group sandstones and siltstones overlying the Illawarra Coal Measures. Below the 100 m contour, residual soils and clays are encountered, while deposits of alluvium, sands and silts occur below the 4 m contour.

## 2.5 VEGETATION

The escarpment and foothills are heavily wooded with some of the more inaccessible areas in a relatively natural condition. A distinct gradation in species is evident moving down from the escarpment face to the valley floor.

## 2.6 LANDUSE

Much of the flatter land within the catchment has been cleared for pastoral use. Land around the Albion Park township is in the process of ongoing urban development. Other significant land uses within the catchment include industrial and commercial properties, road and rail transport corridors and the aerodrome at Albion Park

## 2.7 MAPPING

The catchment area is covered by 1:100.000 and 1:25.000 and partially by 1:10,000 topographic mapping. 1:4,000 black and white orthophoto mapping has also been completed in the eastern half of the catchment.

## 2.8 AERIAL PHOTOGRAPHY

The Lands Department and B.H.P. Engineering - Land Technologies Division have flown the coast line and escarpment at regular intervals over the last two decades providing comprehensive stereo pair and oblique photography of the coastal strip. Prints are readily available from the respective organisations.

## 2.9 GROUND SURVEY

Survey of portions of Macquarie Rivulet and its tributaries have been undertaken in support of flood studies by a number of organisations including the Water Resources Commission, Wargon Chapman and Associates Pty Ltd, Forbes Rigby Pty Ltd, and Kinhill Engineers.

## 2.10 GROUND PHOTOGRAPHY

Selected photographs of Macquarie Rivulet are provided in the Compendium of Data.

## 2.11 RAINFALL GAUGING

Continuously read gauges were installed by the Public Works Department at Glover Hill, Calderwood, Upper Calderwood, North Macquarie and Yellow Rock in the mid eighties.

The Bureau of Meteorology has available daily or monthly rainfall records for several stations within and adjacent to the Macquarie Rivulet catchment.

## 2.12 STREAM GAUGING

The Water Resources Commission (now Department of Land and Water Conservation) has maintained a continuous flood stage recorder in Macquarie Rivulet near Sunnybank since 1949. The Public Works Department has maintained both a continuous and maximum height recorder near the Princes Highway bridge since 1988.

## 2.13 LAKE ILLAWARRA GAUGING

NSW Public Works operates continuous water level recorders in Lake Illawarra at Koonawarra and at the Lake's entrance. These stations have recently been fitted with water quality recording equipment.

# 3. EVENT DATA

## 3.1 FLOODING GENERALLY

The Macquarie Rivulet floodplain has over the years been regularly inundated by floodwaters, often resulting in roads into the Albion Park township becoming impassable to traffic. On some occasions the aerodrome has been flooded. The Albion Park town centre has experienced repeated flooding, often affecting low lying buildings near the Tongarra Road and Terry Street intersection.

An outline of key data available in respect to flooding within the catchment is provided below. Full details of available event data is provided in the following Compendium of Data.

## 3.2 HISTORIC RAINFALL DATA

Pluviometers were installed in the catchment in the 1980's. During most of the major events recorded since installation, one or more of the pluviometers has failed to operate, however during the June 1991 event all four pluviometers functioned throughout the event.

Currently pluviometers are located at Upper Calderwood, Clover Hill, Yellow Rock, and North Macquarie.

## 3.3 HISTORIC FLOOD LEVELS

Long term records for stream flood levels are available for the Sunnybank gauge, while the Princes Highway gauge provides a record of recent stream flood levels. With the exception of the June 1991 flood, there are few other surveyed flood levels in the catchment for historic events. Following the June 1991 event, flood debris marks were surveyed between Albion Park and Lake Illawarra. Surveyed flood debris levels from the June 1991 event are reproduced in the Compendium of Data.

Recent significant gauged flood heights include:

- **June 1991** - Peak stage at Princes Hwy gauge 3.65 m AHD.
  Peak stage at Sunnybank gauge 3.8 m above gauge datum.
- **April 1988** - Peak stage at Princes Hwy gauge 3.13 m AHD.
- **August 1986** - Peak stage at Princes Hwy gauge 2.95 m AHD.
- **December 1985** - Peak stage at Princes Hwy gauge 2.4 m AHD.
- **February 1984** - Peak stage at Sunnybank gauge 4.15 m above gauge datum.

# 4. PREVIOUS STUDIES

## 4.1 WATER RESOURCES COMMISSION

***Albion Park - Flood Study Report (1985)***

This flood study was prepared by the Water Resources Commission in 1986 in order to improve upon the accuracy of previous floodplain mapping and to quantify the degree and costs of flooding in the Albion Park township. The study also delineated the floodway and flood fringe areas for development control.

Design discharges in Macquarie Rivulet were determined from a flood frequency analysis of the Albion Park (Sunnybank) stream gauge. This was supplemented with modelling using the RSWM model to determine discharges in the tributaries. Estimated 100 year ARI discharges included:

- Sunnybank gauge 915 $m^3/s$.
- Calderwood Bridge 1290 $m^3/s$
- Frazers Ck at Tongarra Rd 285 $m^3/s$

Flood levels and velocities were modelled with HEC 2 using surveyed cross sections and flows as noted above.

With respect to flooding, the report indicated that:

> *"Inundation of the commercial centre of the township occurs with a flood above a 1 in 10 years recurrence interval"*

The study found that Albion Park incurred annual flood damage costs of $70,000 in 1985 dollars.

Background data provided in the report includes:

- An annual series of the highest gauged flows at Sunnybank from 1949 to 1984.

- Floodplain and channel cross sections, surveyed from the Albion Park aerodrome to the upstream ends of the Albion Park township. The survey included Macquarie Rivulet and Frazer Ck and its tributaries in the vicinity of Albion Park.

## 4.2 STATE RAIL AUTHORITY

***Report on Investigation for New Railway Underbridge Over Macquarie Rivulet at Albion Park 101.169 km (Illawarra Line) (1980)***

This report was prepared by Wargon Chapman and Associates Pty Ltd for the State Rail Authority in 1980. The purpose of the investigation was to determine the required bridge geometry to replace an existing timber bridge over Macquarie Rivulet.

Design flowrates were estimated using both the Cordery-Webb unit hydrograph method and the Pilgrim McDermott Rational Method. The 100 year flowrate at the railway bridge was estimated to be 1700 m3/s.

Flood levels at the bridge were calculated using a backwater analysis. It was found that the new bridge should have an opening width of at least 120 metres.

Additional data provided in the report includes:

- Surveyed cross sections of Macquarie Rivulet from downstream of the Princes Highway to Lake Illawarra outlet.
- Historic flood level at the bridge for the 1935 flood - 4.75 m AHD (exact location unclear)

## 4.3 FORBES RIGBY PTY LTD

### 4.3.1 A Report on the Impact of Flooding on the Development of Land at Macquarie Rivulet, Yallah (1990)

This study was prepared in 1990 to accompany a Development Application for a subdivision at Yallah, on the banks of Lake Illawarra and Macquarie Rivulet. The purpose of the study was to determine design flood levels at the location of the development site.

Design flowrates were determined using the PSxRM model. RORB and WBNM models were also created as check models. The hydraulics of flows in Macquarie Rivulet and on the floodplain were modelled using a one-dimensional backwater model, WSP1. The 100 year ARI flowrate at the outlet of Macquarie Rivulet was estimated to be 1800 $m^3/s$, while the 100 year ARI flood levels were found to vary from RL 2.0m AHD at Lake Illawarra to RL 5.1m AHD immediately downstream of the Princes Highway Bridge.

The study found that flood categories across the proposed development site varied from "Flood Free" to "High Hazard" floodway

Additional data provided in the report includes surveyed cross sections of Macquarie Rivulet from the Princes Highway to Lake Illawarra, hydrologic model input and computed flood levels in the lower reaches of Macquarie Rivulet.

#### 4.3.2 A Supplementary Report on the Impact of Development of Land Adjacent to Macquarie Rivulet on Flooding in Macquarie Rivulet (1991)

Following the 1990 study, a more detailed study of the lower reaches of Macquarie Rivulet was undertaken to better define the likely impact of the proposed development on flooding in Macquarie Rivulet. As a result of complex flood flow patterns expected in the lower reaches of Macquarie Rivulet, it was considered necessary to use a two dimensional model to supersede the original WSP1, one dimensional model.

The finite element model, FESWMS-2DH was used to model the floodplain hydraulics. Various site filling configurations were modelled to determine appropriate earthworks for "nil adverse impact" on flooding.

The report concluded that it was possible to fill the site, in part with compensatory excavation on the floodplain, without impacting upon flood levels in the designated flood event.

The report provides computed flood profiles and velocity vectors in the lower reaches, on the floodplain and in Macquarie Rivulet, between the Princes Highway and Lake Illawarra. Other useful information included a detail survey of levels on the northern bank of the lower floodplain, below the Princes Highway.

### 4.3.3 A Review of Flooding in the Lower Reaches of Macquarie Rivulet and the Potential for Cross Flows from Macquarie Rivulet into Albion Creek (1993)

The objective of this report, was to assess the degree to which flood flows could divert from Macquarie Rivulet into the Albion Creek catchment, in a design 1% AEP event. This study was necessary to determine the potential flood hazard at a new subdivision adjacent to Albion Creek.

Design flowrates were obtained using the PSxRM model now modified to explicitly reflect floodplain storage on the upper and lower floodplains, while floodplain hydraulics were modelled using a two dimensional model, FESWMS-2DH.

The report concluded that in a 100 year ARI flood:

*"Crossflow from Macquarie Rivulet into the Albion Creek system would occur,*

*(a) Along low lying land at the rear of lots backing onto the Illawarra rail line.*

& *(b) Through a depression in the natural ridge line separating the two catchments to the north of the Albion Park eastwest runway."*

### 4.3.4 A Review of Flooding in the Lower Reaches of Macquarie Rivulet and the Impact of Development on Flooding (1994)

This report examined the potential impact of filling to be placed on the floodplain downstream of the railbridge, on flood levels in Macquarie Rivulet. This was the third study in a series commissioned to permit Council approval of final detailed earthworks designs for this development.

The model PSxRM was used as the primary hydrologic model while comparisons were made with discharges predicted by members of the Water Research Foundation, Illawarra Subcommittee using RAFTS, RORB and WBNM. All models were in reasonable agreement. The hydraulics of flows on the lower floodplain were modelled using RMA2, a two dimensional finite element model.

Recorded rainfall and gauged flood levels for the June 1991 flood event enabled partial validation of the hydrologic and hydraulic models

The study concluded that :

> *"the development as proposed will not increase the level of flooding upstream or downstream of the site"*

Additional useful data included in the report includes:

- Predicted discharges and flood levels for the 1991 flood.
- Summary of recorded information for the 1991 flood
- Design flood level and velocity contours in the lower reaches of Macquarie Rivulet.

### 4.3.5 A Review of Flooding at the Corner of Terry St and Tongarra Rd Albion Park, NSW (1995).

This study was undertaken to refine previously estimated flood levels in Albion Park, for the purpose of setting development floor levels at the corner of Terry St and Tongarra Rd.

Flowrates were estimated using the PSxRM model prepared for the earlier Forbes Rigby Pty Ltd studies. The floodplain hydraulics were modelled using a two dimensional finite element model, RMA2. The RMA2 model, originally prepared for earlier studies was extended to include the 'upper' floodplain and Albion Park township.

The previously determined (DWR, 1986) 100 year ARI flood level of RL 9.2 m AHD at the intersection of Terry St and Tongarra Rd, was found to be high. A flood level of 7.0 m AHD was calculated as a result of backwater inundation from Macquarie Rivulet, while flooding from local catchments upstream of the intersection were found to result in a flood level of 7.5 m AHD at the site. The adopted 100 year flood level at the intersection was 7.5 m AHD.

The report provides design flood surface levels and velocities, from the Princes Highway to the Albion Park township, and surveyed spot levels of the Terry St/Tongarra Road intersection.

## 4.4 KINHILL ENGINEERS PTY LTD

### *Extension to Albion Park Flood Study (1993)*

The objective of this study was to refine the existing flood study and determine flood levels in Albion Park for input to the Albion Park Local Environmental Plan. It was necessary to review the existing Water Resources Commission Flood Study and extend the previous flood modelling to include tributaries draining new developments in Albion Park.

Design flows were determined using the RAFTS model. The impact of proposed urbanisation in the catchment was incorporated into the RAFTS model. The PSxRM model, established by Forbes Rigby (1993) was used as a check model Comparisons with results from other modellers were also made. The previous flood frequency analysis (DWR, 1986) was updated to include records to 1992 and the results compared with the RAFTS model. Discharges predicted by the RAFTS model were significantly (up to 30%) lower than those determined by the extended flood frequency analysis.

Hydraulic calculations were performed using HEC 2. The existing creek survey was supplemented with 17 additional sections (from photogrammetry) in Yellow Rock Creek, Hazelton Creek and Fraser Ck and its tributaries.

The report provides design flood profiles in the tributaries of Macquarie Rivulet at Albion Park. The effect of urbanising the Cooback Ck catchment was found to be negligible further downstream and construction of a detention basin in this catchment was found to be unwarranted.

## 4.5 WATER RESEARCH FOUNDATION (Illawarra Group)

### 4.5.1 Data Collection and Analysis

In 1983 a Subcommittee of the Water Research Foundation - Illawarra Group was formed to promote communication amongst professionals practicing in the flood mitigation and drainage fields and to collect and disseminate information of relevance in those fields.

The goals and objectives of the subcommittee are described by Rigby (1984).

In pursuing these goals, the subcommittee initially focused on the collection of relevant data for a 'Reference Catchment' for the region. Since Macquarie Rivulet was the only catchment with any length of record, in the area, it was the unanimous choice for the initial catchment to be developed by the Subcommittee.

This initial data collection phase took a great deal longer than anticipated, but resulted in a highly useable body of hydrologic data on the catchment and events that had occurred in the catchment in recent years. Much of this data is reproduced in the following Compendium of Data.

Once data covering the basic catchment physiography had been assembled, the subcommittee began a series of exercises to explore the variation between models and modellers, that typically occurs on an ungauged catchment.

In general it was found that, on an ungauged catchment, there was about as much variation (of the order of ± 20%) between modellers (using the same model) as there was between models (constructed by the same modeller) when applied in design mode.

In event mode there was generally a similar variation between models and modellers but the individual models exhibited some noticeable phase shifts in respect to hydrograph peaks and variation in respect to the degree of attenuation of rapidly varying rainfall, in the resulting hydrograph.

Simulated hydrographs, prepared by various modellers, for the June '91 event (at SunnyBank and the Princes Highway), without calibration, are reproduced in Appendices 1.1 and 1.2.

In the following phase of the subcommittees investigation into the hydrology of the catchment, a series of estimates were made by members, using different models, of peak discharge for a range of nominated ARI's, to see how well the models could predict the discharges, at Sunnybank, obtained from actual ranked streamflow records. In general, all models produced similar discharge/ARI gradients when plotted on log probability paper (with a spread of actual discharges for a given ARI) but all were highly skewed with respect to the ranked streamflows.

Whilst various explanations were canvassed, no explanation was agreed, although concerns were expressed by most of the subcommittee as to the reliability of the SunnyBank rating curve and likely impact on the ranked streamflows.

This second phase of the subcommittee's activities is reported in greater detail by Boyd et al (1989).

### 4.5.2 Albion Park Stream Gauge Hydraulic Analysis - Rating Curve Derivation

As reported by Boyd et al (1989), investigation of the Macquarie Rivulet system by the Stormwater Subcommittee of the Water Research Foundation, lead to conjecture that the rating curve developed for the Albion Park stream gauge on Macquarie Rivulet may have overestimated stream flowrates for given stage heights. Each of the hydrologic modellers in the study estimated 100 year ARI flowrates significantly (up to 50%) lower than those estimated using a flood frequency analysis based upon the gauge rating curve and flood stage records.

Comparison of peak flows based upon hydrologic modelling (WBNM and PSXRM - refer WRF 1996) for the June 1991 flood event, for which reliable rainfall data was available, and peak gauged flows based upon the measured flood height and the assumed rating curve, again suggested that the rating curve was significantly overestimating flowrates.

The Albion Park gauge has been at its present position on Macquarie Rivulet since 1978, having been relocated progressively upstream twice since its initial installation in 1949. The gauge is now about 1.1 km upstream of its original location.

At each location, a rating curve had been developed at the gauged cross section based upon a combination of current measurements and hydraulic analysis.

Whilst the former gauge locations included relatively reliable weirs, the present gauge is located at an unmodified creek cross section.

The DWR has made current measurements for the present gauge for maximum flows of less than a 1 year ARI. Extrapolation of the rating curve up to events of 100 year ARI was achieved by the application of Mannings formula with an assumed bed gradient and channel roughness.

In 1994 Forbes Rigby undertook a more rigorous backwater analysis with HEC2 (US Army Corps of Engineers) using a survey of Macquarie Rivulet for about 1 km upstream and downstream of the gauge prepared by members of the Stormwater Subcommittee. However the results of this analysis agreed closely with the more approximate DWR analysis based upon Mannings formula and hence the suspected overestimation of gauged flows remained unexplained.

In pursuing this anomaly, a closer inspection of the aerial photography and a site visit revealed that low flows are ponded for a distance of about 30 m downstream of the gauge, indicating that the stream bed is level or may actually rise for a short distance downstream of the gauge. For the 1994 HEC 2 analysis, the spacing between the cross section at the gauge and the nearest section downstream was 120 metres and hence the small rise in the creek bed was not incorporated in the modelling. In lieu of extra cross sectional survey, an additional section was inserted into the HEC 2 model, 30 metres downstream of the gauge with the bed level assumed equal to that of the gauge section bed level (as indicated by the ponded water). The HEC 2 model was then rerun and a new rating curve prepared.

Incorporation of the flat stream bed downstream of the gauge resulted in a marked (30 percent) decrease in the predicted stream discharge for a given gauge water level. The resulting rating curve, (reproduced in Appendix 4.1), was then found to agree well with predicted flows based upon the hydrologic modelling lending weight to concerns as to the accuracy of the present rating curve.

Additional detail survey, incorporating stream cross sections from approximately 30 metres downstream of the gauge to at least 200 metres downstream of the gauge should be undertaken, to enable further HEC 2 modelling, to confirm the above assumptions and establish a more reliable rating curve.

In the interim, it is recommended that the amended curve of Figure 4.1 be used to convert flood stage to discharge at the SunnyBank gauge.

### 4.5.3 Princes Highway Stream Gauge - Rating Curve Derivation

Since a hydraulic model (FESWMS - 2DH) had been constructed for the lower floodplain incorporating the reach containing the Princes Highway Gauge, it was resolved to prepare a interim rating curve for the gauge based on model simulation.

This work was undertaken by Forbes Rigby resulting in the curve reproduced in Appendix 4.2

In the course of running the 2D model for the required spread of discharges, it became apparent that model instability occurred around the 250 to 450 $m^3$/sec discharge level. In investigating the regime of flooding in this discharge range it became apparent that instability coincided with the development of spillover from Macquarie Rivulet into Haywards Bay and continued until the depth of water spilling over into Haywards Bay was sufficient to reinstate subcritical flows in the area of the breach.

Since FESWMS (and later attempts with RMA2) could not be manoeuvred into a stable solution in this range, this range of the curve was interpolated from adjacent data. In addition, attempts to extend the 2D model below about 200 $m^3$/sec resulted in such major changes to the active elemental layout that a stable solution again could not be achieved. This low flow area of the curve was therefore constructed with a 1D model (HEC2). The same (1D) model was used to explore the impact of changes in lake level on the rating curve - the discharge envelope below 200 $m^3$/sec contained in Figure 4.2, covering lake levels ranging from 1m to 2m AHD.

# 5. CATCHMENT HYDROLOGY

## 5.1 MODEL SELECTION

A number of hydrologic methods are available for the determination of maximum flows corresponding to a selected level of probability.

The most direct and reliable method where stream flow data are available is `Flood Frequency' analysis of stream flow records.

In the absence of a reliable stream flow record, catchment modelling, covering a range of procedures from the rational method to advanced computer models. The more advanced models provide stormwater runoff hydrographs in addition to peak flow estimates. In addition, these models enable the impact of various land uses on runoff volumes and flowrates to be assessed.

There are 47 years of flood stage records for Sunnybank, at the approximate centroid of the catchment. There are also relatively recent records of flood stage below the Princes Highway Bridge.

Following a Flood Frequency approach, the stream discharge for a range of ranked events can be estimated for Sunnybank from the available flood stage and rating data. These results can, in turn, be used to determine, by extrapolation, the equivalent stream discharge and flood surface level further downstream, at another site. This is the methodology used in the Albion Park flood study prepared by the Water Resources Commission (1986).

As a result of progressive changes to the stream cross section at the Sunnybank gauging station and localised backwater influences which were not considered in the rating curve derivation, it is probable that the rating curve used to convert flood stage to stream flowrate at Sunnybank is in error in significant flood events. In a study conducted by Boyd et al (in 1989), flow predictions from six independent rainfall runoff models were compared against a flood frequency analysis using streamflow records from the Sunnybank gauge. All six models predicted significantly lower flowrates than that of the streamflow data frequency analysis.

Whilst other explanations are possible, the uniformity of the difference between modelled and stream flow data does cast some doubt on the accuracy of the present rating curve, for this station.

Further flow measurements at higher discharges or hydraulic modelling is considered necessary to improve the accuracy of the Sunnybank rating curve. Some refinement of the rating curve for this gauge has been attempted by the Water Research Foundation Subcommittee as discussed in section 4.5 of this report.

Given the significant impact of dynamic storage on the lower floodplain, on peak flows, (downstream of the Sunnybank gauge), problems with the Sunnybank gauge rating curve and the development and ready availability of advanced modelling tools, the flood frequency approach was not considered further in this study.

Catchment modelling was the selected method of hydrologic analysis for this study. The primary model used in the analysis was the Penn State Extended Runoff Model (PSxRM),(Rigby and Watts,1983).

The Watershed Bounded Network Model (WBNM),(Boyd et al 1995) was applied in a support role to provide a check on the reasonableness of the predicted flowrates.

## 5.2 MODEL APPLICATION

The Macquarie Rivulet catchment was subdivided into 49 sub catchments for input to WBNM and into 33 subareas for input to PSxRM as shown in Appendices 2.1 and 2.2 respectively.

As is apparent from the isohyets of annual rainfall (Appendix (3)) and charts of A.R.R. '87 - Volume 2, rainfall gradients are quite significant in the Macquarie Rivulet Catchment.

In examination of rainfall causing "major" flooding events in the Illawarra by Foreman & Rigby (1990), it was concluded that longer duration (6 to 24 hour) storms are mostly responsible for "major" flooding even on quite small catchments (a few hectares). This would appear to be due to the inclusion of intense short duration rainfall within longer duration storms, such that early lead up rainfall totally saturates the catchment prior to the intense burst, maximising runoff from the catchment. This trend is also evident in discharges from the Macquarie Rivulet

Catchment, wherein peak discharges from ranked stream flow records occur in storms with durations well in excess of the response time of the catchment. The significance of embedded intense bursts within a design storm, on peak discharges, is explored further by Rigby & Bannigan (1996).

A.R.R. '87 charts were used to determine IFD data and storm temporal patterns for three `design rainfall' stations, within the catchment. These stations are located at the approximate centroid of the western, central and eastern sections of the catchment (Refer Figure 2.12.1 of the Compendium of Data for location). IFD data for each design rainfall station is reproduced in Appendix 2.9 to 2.11 inclusive.

In accordance with current practice, it has been assumed that the design 1% AEP flood event will be produced by the design 1% AEP storm event, given average antecedent catchment conditions.

Selection of model parameters, in the following analysis, is based on work by:

Boyd, et al (1989)
Cordery (1974)
Rigby and Watts (1983)

The calibration/fit parameters selected for the WBNM and PSxRM models are listed in Table 5.2.1.

| PARAMETER | VALUE | | | ACRONYM COMMENT |
|---|---|---|---|---|
| **WBNM V2** | | | | |
| Initial loss (Pervious surface) (Historic) | 15 mm | | | Regionally Derived Value |
| Initial loss (Pervious surface) (Design) | 0 mm | | | Reflecting 'burst' in storm |
| Initial loss (Impervious surface) | 1 mm | | | Built into model |
| Continuing loss (Pervious surface) | 2.5mm/hr | | | Cordery (1974) |
| C (Lag Parameter) | 1.29 | | | Regional Default |
| Stream Routing factor | 0.6 | | | Model Default |
| **PSxRM V8** | | | | |
| Soil Basic Curve Number | 85 | | | (CN @ AMC=2) |
| Paved Surface Curve Number | 99 | | | (CN) |
| Design Burst Duration | <=1hr | | =>6hrs | Burst Duration |
| Soil Antecedent Moisture Condition | 3.0 | 2.5 | 2.0 | (AMC) |
| Soil Adjusted Curve Number | 97 | 91 | 85 | (CN @ AMC) |
| Soil Initial Abstraction | 0.0S | 0.05S | 0.1S | (IA)(S Storage mm) |
| Soil Surface Detention | 0.0mm (Nil) | | | (-) |
| Soil Surface Retardance | 0.200 | | | (n) |
| Paved Surface Retardance | 0.040 | | | (n) |
| Overbank Flow Velocity Ratio | 1.0 | | | (Major System Only) |
| Baseflow Coefficient | 0.0m$^3$/sec/ha | | | (NO base flow) |

**ADOPTED HYDROLOGIC MODEL PARAMETERS**

**TABLE 5.2.1**

In design mode, an allowance was made for lead up rain, prior to the design burst, by setting the initial loss to zero mm in WBNM and by raising the AMC to 3 (CN = 97) in PSxRM. No other allowance was made for the impact of embedded bursts on calculated design discharges.

The attenuation provided by dynamic flood storage on the lower flood plains has been explicitly included in each of the models. 'Synthetic' basins with a Height-Discharge-Storage relationship equal to that of the floodplain have been introduced in subareas 20, 25, 30, 31, 32 & 33 for PSxRM and at nodes 19, 35, 41, 44, 47 & 49 for WBNM.

In both the WBNM and PSxRM models, travel time through each flooded sub area and time of travel from the centroid of each subarea to the subarea outlet the hydrograph travel times have been reduced in flooded sub areas to reflect the expected high flood wave velocities through drowned subareas. This adjustment is made automatically in WBNM when routing the flood through a basin subarea, whilst in PSxRM the reduced travel time must be set by the model user.

## 5.3 EVENT OF JUNE 11TH, 1991

Discharges were also modelled for the storm occurring on the 7, 8, 9, 10 and 11 June 1991. Whilst attempts to model earlier storms had not been successful (due to failure of one or more of the pluviographs during these storms and problems with high spatial and temporal variability in rainfall), the June '91 event was well documented with all four gauges functioning throughout the three day storm. In addition, the degree of spatial and temporal variability of rainfall within the catchment was not as great as in some of the earlier storms, increasing the level of confidence in the ability of the four gauges to represent rainfall across the full catchment.

This storm was initially modelled by several researchers (part of the local Water Research Foundation Illawarra Subcommittee) with a view to examining the variability of predicted discharges between users and models. Notwithstanding the different models adopted, both peak discharge and hydrograph shape were in good agreement. A summary of this work is set out in table 5.3.1 below and graphed in Appendices 1.1 and 1.2. Further details are provided in a paper by Boyd et al (1989).

| USER : MODEL | DISCHARGE THROUGH RAIL BRIDGE |
|---|---|
| USER A : RAFTS | 550 $m^3$/sec @ 10 a.m. on 11 June 1991 |
| USER B : PSxRM | 575 $m^3$/sec @ 12 midday on 11 June 1991 |
| USER C : WBNM | 630 $m^3$/sec @ 11 a.m. on 11 June 1991 |
| USER D : RORB | 550 $m^3$/sec @ 10 a.m. on 11 June 1994 |

**PRELIMINARY PEAK DISCHARGES : WRF SUBCOMMITTEE**
**MACQUARIE RIVULET EVENT OF JUNE 1991**

**TABLE 5.3.1**

As the full duration of a real event is often difficult to include in a model without loss of resolution, it is not uncommon for the most intense burst only to be modelled (provided it extends sufficiently in time to fully mobilise runoff from the whole catchment).

To explore the reasonableness of such an approach, the June 91 event was also modelled as a partial storm burst over a 48 hour period using both WBNM & PSxRM.

It was found that for WBNM, simple inclusion of zero initial loss was sufficient for the 'partial' storm to rapidly merge into the full storm hydrograph. With PSxRM it was found that the speed of convergence could be improved by both inclusion of zero initial loss and raising the AMC to 3 (CN = 97).

This work was subsequently extended and updated by Forbes Rigby (1993), producing peak discharges as set out below in table 5.3.2.

| LOCATION | PSxRM | WBNM |
|---|---|---|
| Frazers Creek @ Tongarra Rd | 90 | 80 |
| Macquarie Rivulet @ Calderwood Rd | 420 | 370 |
| Marshal Mount @ Grey Meadows | 120 | 90 |
| Macquarie Rivulet @ Rail Bridge | 575 | 516 |

**PREDICTED PEAK FLOW (m3/sec)**
**EVENT OF 11 JUNE 1991**

**TABLE 5.3.2**

## 5.4 DESIGN 1% AEP EVENT

Discharges were initially computed for the catchment in its present condition, for the 1% AEP (100 year ARI) design burst spectrum to ascertain the 'critical' burst duration.

These analyses confirm that 1% peak discharge is not particularly sensitive to design burst duration, being predicted with acceptable accuracy by bursts of 2 to 12 hour duration. A six hour burst duration was adopted as the 'critical design' burst duration for modelling the design 1% AEP event in PSxRM and 9 hours in WBNM.

Peak discharges predicted by the two Models at several key locations within the catchment, in the 1% AEP event, are listed in Table 5.4.1

| LOCATION | PSxRM | WBNM |
|---|---|---|
| Frazers Creek @ Tongarra Rd | 200 | 200 |
| Macquarie Rivulet @ Calderwood Rd | 1170 | 1060 |
| Marshal Mount @ Grey Meadows | 190 | 200 |
| Macquarie Rivulet @ Rail Bridge | 1200 | 1215 |

**PREDICTED 1% AEP PEAK FLOWS (m3/sec)**

**TABLE 5.4.1**

With respect to the reliability of the above predictions, it should be noted that any error in or change in the value of the following key parameters will directly vary peak flows predicted by the models.

(a) Rainfall
(b) Losses
(c) Surface Runoff
(d) Channel Routing
(e) Storage Effects

An examination of catchment topography above Sunnybank suggests that channel attenuation above Sunnybank would be minimal. Below Sunnybank, however, and on the flood plain between Albion Park and the Princes Highway in particular, substantial flood plain storage is present in most significant events. This dynamic storage has been indirectly simulated in each model as a number of synthetic (retarding) basins with storage-discharge relationships equal to that of the floodplain.

In consequence of the degree to which this catchment has been investigated by various researchers, and the general agreement in predicted peak discharges achieved, it is reasonable to conclude that the preceding peak flows may be adopted with some confidence.

# 6. FLOODPLAIN HYDRAULICS

## 6.1 MODEL SELECTION

Evaluation of the response of the Macquarie Rivulet system to floodplain flows across the upper and lower floodplains is complex, involving consideration of temporally and spatially distributed inflows, in conjunction with (uncoupled) temporally varying outlet conditions at Lake Illawarra.

Hydraulic models are available to model both one dimensional (vertically averaged flow assumed perpendicular to a model cross section and two dimensional (vertically averaged flow unrestrained horizontal direction) flow conditions.

Given the complex flow fields across each floodplain, it was considered that a two dimensional model would be required to adequately simulate flood flows in the Macquarie Rivulet system. The two dimensional finite element based model (RMA2) developed by the US Army, was chosen for the most recent studies by Forbes Rigby in this area (earlier studies by Forbes Rigby had been based on FESWMS-2DH).

RMA2 is a finite element hydrodynamic numerical model. It computes water-surface elevations and horizontal velocity components for subcritical, free-surface flow in two dimensional flow fields.

Code for the model was initially developed by Norton, King and Orlob (1973), of Water Resources Engineers, for the Walla District, Corps of Engineers, and delivered in 1973. Subsequent enhancements have been made by King and Norton, of Resources Management Associates (RMA), and by the WES Hydraulics Laboratory, culminating in the current version of the code (4.20). Personnel in the Estuaries and Waterways divisions of the WES developed the data input module, wet-dry and marsh porosity enhancements, parameter revision within a time step, and storm passages.

RMA2 is a general purpose model designed for far-field problems in which vertical accelerations are negligible and velocity vectors generally point in the same direction over the entire depth of the water column at any instant of time. It expects a vertically homogeneous fluid with a free surface.

Given the short travel time through the `upper flood plain', relative to the duration of peak flooding - and inclusion of storage attenuation effects in the hydrologic model, a steady state solution was adopted in the hydraulic model.

## 6.2 MODEL APPLICATION

It was necessary to split the Macquarie Rivulet floodplain into two discreet modelled areas referred to as the lower and upper floodplains. This division was required due to limitations in the number of elements permissible in the preprocessor module (SMS).

The lower floodplain model covers the area between Lake Illawarra and the Princes Highway. The upper floodplain model extends from the Princes Highway, upstream to the Albion Park township.

A series of sections across Macquarie Rivulet and Frazers Creek were surveyed and have been included in the earlier report prepared by the Water Resources Commission (1986).

A detail survey of the `lower flood plain', creek waterway, associated bridges and adjacent bays was undertaken by D Allen - Surveyor in 1990, in support of earlier studies of flooding in this area (Forbes Rigby (1990)(1991)).

Additional survey of the `upper' flood plain, and creek adjacent to Croom Road and the runway of Albion Park aerodrome was undertaken by Shellharbour Council in 1992 in support of an examination of potential cross flows from Macquarie Rivulet to Albion Creek (Forbes Rigby (1993)).

In conjunction with 1:4000 contoured orthophoto mapping this data was ingested into the pre-processor (SMS) contoured and checked before being input to the hydraulic model (RMA2).

Particular care was taken to ensure that the shallow depressions and raised areas on the flood plain were correctly represented in the model. Additional elements were created in areas where flows were expected to vary rapidly (viz at constrictions in the flow net).

Bed friction (Mannings 'n') and eddy viscosity were specified as :

(a) In the Creek Waterway

n = 0.020

E = 10,000 pascal-sec

(b) On the Flood Plain

n = 0.035

E = 5,000 pascal-sec

The finite element layouts for the two models are reproduced in Appendices 3.1 & 3.2.

The RMA2 model was run for both the historic June 1991 event and 100 year ARI design event. For the 1991 event a water level of 1.8 m AHD was used as the boundary condition at Lake Illawarra, based upon the maximum recorded levels at Berkeley Boat Harbour for this event. For the 100 year ARI event, a boundary condition of 2 m AHD was assumed. (Equal to the estimated 1% AEP lake level - It is noted that more recent work by Lawson & Treloar (1993) has increased the 1% AEP lake level to RL 2.2m AHD)

Whilst it is unlikely that the lake would be at its peak coincident with peak flooding in Macquarie Rivulet - flooding above the Rail Bridge is minimally affected by lake level (in the 1.0 to 2.5 m range) hence a simple (and conservative in the outfall reach) assumption of coincidence has been made in present modelling.

## 6.3 VALIDATION EVENT OF JUNE 11TH, 1991

Using predicted discharges for this event (575 $m^3$/sec peak through the road and rail bridges) and the lake at RL 1.8 m AHD, the hydraulics of flood flows through the lower flood plain were simulated with the model RMA2. In summary:

- Agreement between modelled and recorded levels was very good;
- At the PWD gauge the peak flood level recorded was 3.65m AHD; and
- At the same location the model predicted flooding at 3.70m AHD.

On the upper floodplain, since attenuation from dynamic storage on the floodplain had already been incorporated into the hydrologic model, equivalent (averaged) flows were input to the steady state hydraulic model as set out in Figure 6.3.1.

Agreement between the model and recorded levels was not as good on the upper floodplain as on the lower floodplain, with significant (greater than one metre) differences in the uppermost modelled reach of Macquarie Rivulet.

The predicted level of the main water body (to the north of the village) was in reasonable agreement with recorded levels although several debris levels recorded were clearly not indicative of the flood at its peak.

In general the model layout of the upper flood plain is in need of adjustment to better suit the edges of the June 91 flood, and waterway losses appear to be in need of an increase to better replicate recorded levels in the upper reaches.

To an extent this lack of fit arises as a consequence of the simple single value treatment of bed friction losses in RMA2. Earlier modelling by FESWMS-2DA using a ramped loss model produced much better agreement but was discarded in favour of RMA2 when the advanced SMS (FASTTABS) interface for RMA2 became available.

At greater flow depths (as in the 1% AEP event) the need for increased losses in RMA2 to improve the fit should not be as pronounced.

The present RMA2 model of the upper floodplain is in need of refinement to better simulate the recorded flood data and flood edge geometry prior to any further study of flooding on the upper floodplain.

Contours of the flood surface as modelled by RMA2 for the lower floodplain are reproduced in Appendix 3.5 and for the upper floodplain in Appendix 3.6.

## 6.4 DESIGN 1% AEP EVENT BELOW PRINCES HIGHWAY

The hydraulics of `design' flood flows in the reach below the highway were simulated by the model using the predicted peak discharge for the design 1% AEP event through the rail bridge of 1200 $m^3$/sec.

Adopting a flood level of 2 m AHD at Lake Illawarra, this model run predicted a flood level upstream of the Princes Highway road bridge of RL 5.0 m AHD.

Contours of the flood surface predicted by RMA2 for this event are reproduced in Appendix 3.7. Flood velocities are presented in Appendix 3.9 and Flood Hazard Levels in Appendix 3.11.

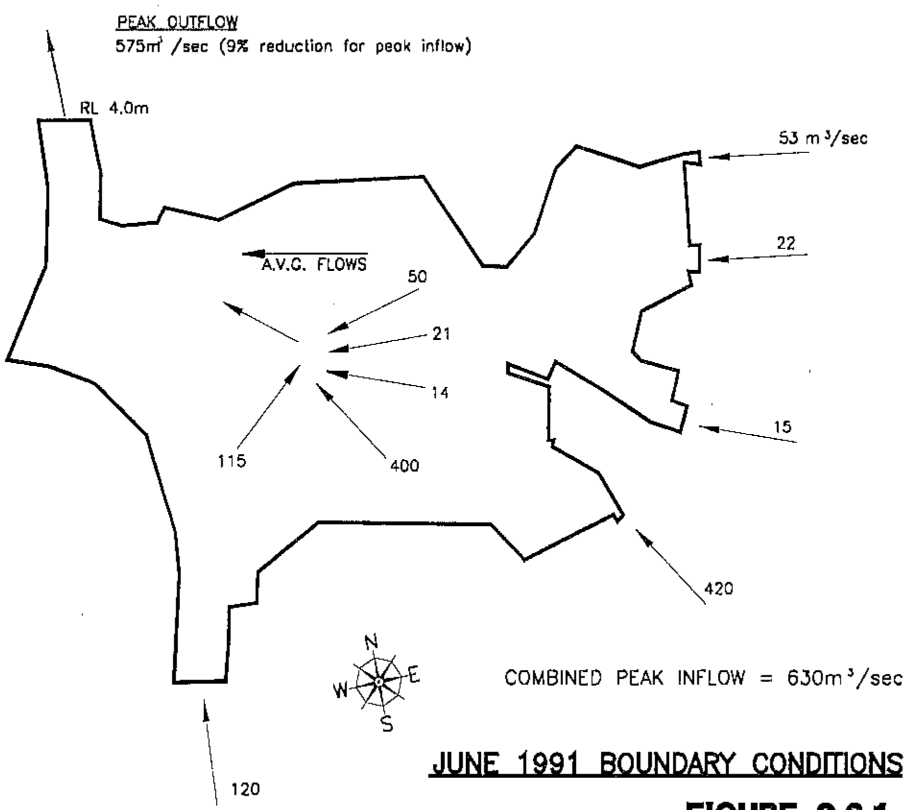
## 6.5 DESIGN 1% AEP EVENT ABOVE THE PRINCES HIGHWAY

Commencing with a starting RL of 5.0 m AHD above the road bridge, the hydraulics of `design' flood flows through the `upper flood plain' were simulated by the model using predicted discharges for the design 1% AEP event for each of the tributary arms and outlet.

Since attenuation from dynamic storage on the floodplain had already been incorporated into the hydrologic model, equivalent (averaged) flows were input to the steady state hydraulic model as set out in Figure 6.5.1.

Contours of the flood surface predicted by RMA2 for this event are reproduced in Appendix 3.8. Flood Velocities are presented in Appendix 3.10 and Flood Hazard Levels in Appendix 3.12.

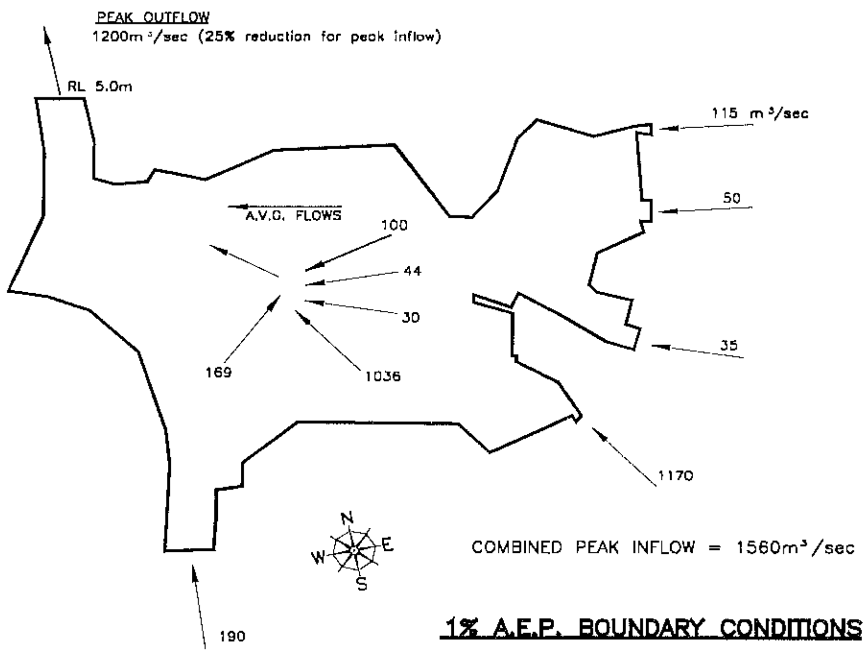
Given the underestimation of flood levels in the upper most reach of Macquarie Rivulet in the June 91 simulation it is likely that the Design 1% model also under predicts levels in this upper reach. Further refinement of the model of the upper floodplain is necessary before predicted flood levels in the uppermost reach can be accepted with any confidence.




COMBINED PEAK INFLOW = 630m³/sec

**JUNE 1991 BOUNDARY CONDITIONS**

**FIGURE 6.3.1**




COMBINED PEAK INFLOW = 1560m³/sec

**1% A.E.P. BOUNDARY CONDITIONS**

**FIGURE 6.4.1**

**MODEL BOUNDARY CONDITIONS UPPER FLOOD PLAIN**

# 7. CONCLUSIONS

## 7.1 GENERALLY

- Development of a reference catchment in sufficient detail to be a reliable base for model calibration and validation is a very lengthy process, particularly where reliable event data, for several events, is not already on record. It is the subcommittees experience that development of a reliable reference catchment dataset is a task to be measured in decades, not years.

- It is equally the subcommittees conclusion that <u>all</u> data should be considered in error until such time as its reasonableness can be demonstrated by comparison with other means of estimating its value, preferably by several different methods. Whilst this presumption will necessarily delay progress significantly, it has been the subcommittees experience that to not question data is to risk even greater delays.

## 7.2 CATCHMENT DATA

- Whilst a considerable body of data has been collected, there is an urgent need for more event data to support the single (June 1991) even used for validation of models to date

- Given ongoing filling operations on the northern bank of the lower floodplain, there is a need to obtain final landform levels in this area so that future event modelling can reflect these changes. Should a significant event occur prior to finalisation of these works, an interim resurvey will be required to establish a model reflecting the geometry of the floodplain at the time of the event.

- The rating curve derived for the Princes Highway gauge is appropriate to conditions prior to filling on the northern bank of the low floodplain. It does not reflect present conditions and will need to be rebuilt to reflect conditions appropriate to future events. There is an urgent need for flow gauging to validate the rating curve which is solely based on model simulation at this time.

- The rating curve derived for the Sunnybank gauge is in urgent need of review. Present hydrologic and hydraulic modelling suggests that the present curve overestimates discharge for a given gauge height up to 30%, particularly at higher discharges.

  Flow gauging at higher (10 to 2% AEP) level discharges is most desirable to validate any review of the present curve.

  Whilst it is difficult to now review the relationships derived for earlier sites, it would be most helpful if the previous sites rating curves (and ranked discharges) could also be critically reviewed. As the only site in the region with any length of record, the Sunnybank gauge plays a most important role in establishing basic hydrologic characteristics of the region such as yield, volumetric runoff coefficients and runoff coefficients for models such as the rational probabilistic model.

## 7.3 CATCHMENT HYDROLOGY

- In the Illawarra Region high temporal and spatial variability in recorded rainfall across catchments requires a <u>very</u> dense pluviograph network to confidentially capture a real event. Use of a single pluviograph record to simulate a recorded event on any catchment in the Illawarra could result in a substantially different rainfall distribution from that experienced by the catchment. Where a pluviograph record from an adjoining catchment is translated into the study catchment, any similarity between actual and translated events is likely to be purely coincidental, particularly for the more frequently occurring (lower intensity) events.

  The present four pluviographs in the Macquarie Rivulet catchment are demonstrably the <u>minimum</u> required to adequately define most real rainfall events.

- In constructing a hydrologic model of catchments similar to Macquarie Rivulet, where significant overbank floodplain storage is present, floodplain storage should be directly modelled either by :

  a) inclusion in the hydrological model as a dynamic storage with attenuated flows subsequently input to a steady state hydraulic model or,

b) inputting full hydrographs from a hydrologic model that does not explicitly include floodplain storage into a dynamic hydraulic model.

Significant storage in the above context is defined as overbank storage causing more than ten percent attenuation in peak discharge when explicitly included in the model. In Macquarie Rivulet omission of explicit modelling of the floodplain storages increases peak catchment discharge from 1200 m/sec to 1600 $m^3$/sec at the rail bridge, (a 33% impact). Whilst it is possible to vary the lag parameters of models such as RORB & WBNM to simulate floodplain attenuation, doing so greatly reduces the transportability of the model to nearby catchments where floodplain storage may be significantly different.

## 7.4 CATCHMENT HYDRAULICS

- Where it is proposed to construct a 2D model of the floodplain to model a wide range of discharges, it is crucial that this be known at the time the model is created, so that the edges of the flood can be smoothly represented at each step in the range of discharges to be modelled. In addition, if within bank discharges are to be included in the range, it is necessary to provide considerable additional detail in the element structure describing the within bank waterway.

  Since both the FESWMS-2DH and RMA2 models of Macquarie Rivulet were initially constructed to permit modelling of the 1% AEP flood event they do not perform well as flows diminish, exposing irregular edges around the active mesh and poor representation of the actual within bank waterway once flows are restricted to the channel.

  The present models can not therefore reliably simulate flood flows approaching the within bank capacity of the main channel and should not be used for this purpose.

- With support for FEXWMS-2DH having been included in SMS, there is now good reason to consider returning to FESWMS-2DH as the hydraulic model for the upper and lower floodplains.

  In particular FESWMS-2DH permits supercritical flows to occur in the solution domain (overcoming problems with flows from Macquarie Rivulet into Haywards Bay that cause instability in RMA2) and a ramped loss model, more representative of the conditions existing on the floodplain as floodwaters rise from depths less than the roughness height of vegetation to several times the height of vegetation on the floodplain.

# 8. RECOMMENDATIONS

## 8.1 CATCHMENT DATA

- Every effort should be made to accumulate flow gauging data for the new gauge at the Princes Highway and to extend the flow gauging dataset at Sunnybank to incorporate higher discharges.

- Additional stream survey should be undertaken in the vicinity of the Sunnybank gauge to permit the present HEC-2 based rating curve for the gauge presented in this report to be affirmed or updated. The present HEC-2 based rating curse should be used as the rating curve for this station until such time as the model is updated or flow gauging at higher discharges is available to replace the present model.

- There should be no reduction in the number of rainfall and stream gauges in the catchment. Four rainfall gauges and two stream gauges are the minimum required to adequately define an event in this catchment.

- Additional event data should be collected as it occurs, to augment the single event for which reliable data is available at this time.

- The datum of all flow depth indicators on roads within the catchment should be established on AHD.

## 8.2 CATCHMENT HYDROLOGY

- Given the ongoing development and enhanced capabilities of the model WBNM, this model (WBNM) should replace PSxRM as the primary hydrologic model in any future development of Macquarie Rivulet as a reference catchment.

- The significance of embedded design rainfall burst within longer duration design rainfall, in modifying peak discharges of a given AEP should be investigated further.

- The marked skew between ranked streamflows and modelled discharges should be investigated further to establish the cause and recommendations prepared as to changes in the use of models considered necessary to permit design models to better represent the recorded peak flow distribution.

- All models should be progressively calibrated/validated against new event data as data becomes available.

## 8.3 FLOODPLAIN HYDRAULICS

- The present RMA2 based models of the upper and lower floodplain should be transferred back to FESWMS-2DH and merged into a single model in any future hydraulic model of flows in these reaches.

- In the FESWMS-2DH model, the layout of elements should be adjusted to permit smoother edges to develop around the active mesh as flows decrease below the 1% AEP flood level and the upper floodplain waterway should be refined to better represent the geometry of the within bank section.

- The present fill emplacement on the northern bank of the lower floodplain should be surveyed and incorporated into the model once complete. Should a significant event occur prior to completion of this work an interim survey and model reconstruction will be required to simulate flooding at that time.

# 9. ACKNOWLEDGMENTS

This report documents the efforts of the Stormwater Subcommittee of the Illawarra Group of the Water Research Foundation, over a period of thirteen years, from late 1983 to 1996.

Over this time notable input was provided by many organisations and individuals.

In particular, the following organisations and individuals have played a key role in this Subcommittees activities, since its inception :

| | |
|---|---|
| Forbes Rigby Pty Ltd | Mr E Rigby & Mr V Watts |
| Public Works Department NSW | Mr J Malone, Mr G Kearney, Mr G Clarke |
| Roads & Traffic Authority | Mr N Burke |
| Shoalhaven City Council | Mr J Downey |
| State Emergency Services | Mr C Johnston |
| University of Wollongong | Messrs M Boyd & S Sivakumar |
| Wollongong City Council | Mr I Foreman, Mr P Silveri, Mr R V Drie |

The considerable effort of all involved in making this material available is acknowledged with the thanks of the Subcommittee Chairman on behalf of both the Stormwater Subcommittee and parent Illawarra Group of the Water Research Foundation of Australia.

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1. INTERMODEL COMPARISONS

2. CATCHMENT HYDROLOGY

3. FLOODPLAIN HYDRAULICS

4. RATING CURVES

5. PAPERS PUBLISHED

Note : Refer 'Compendium of Data' for catchment & event data

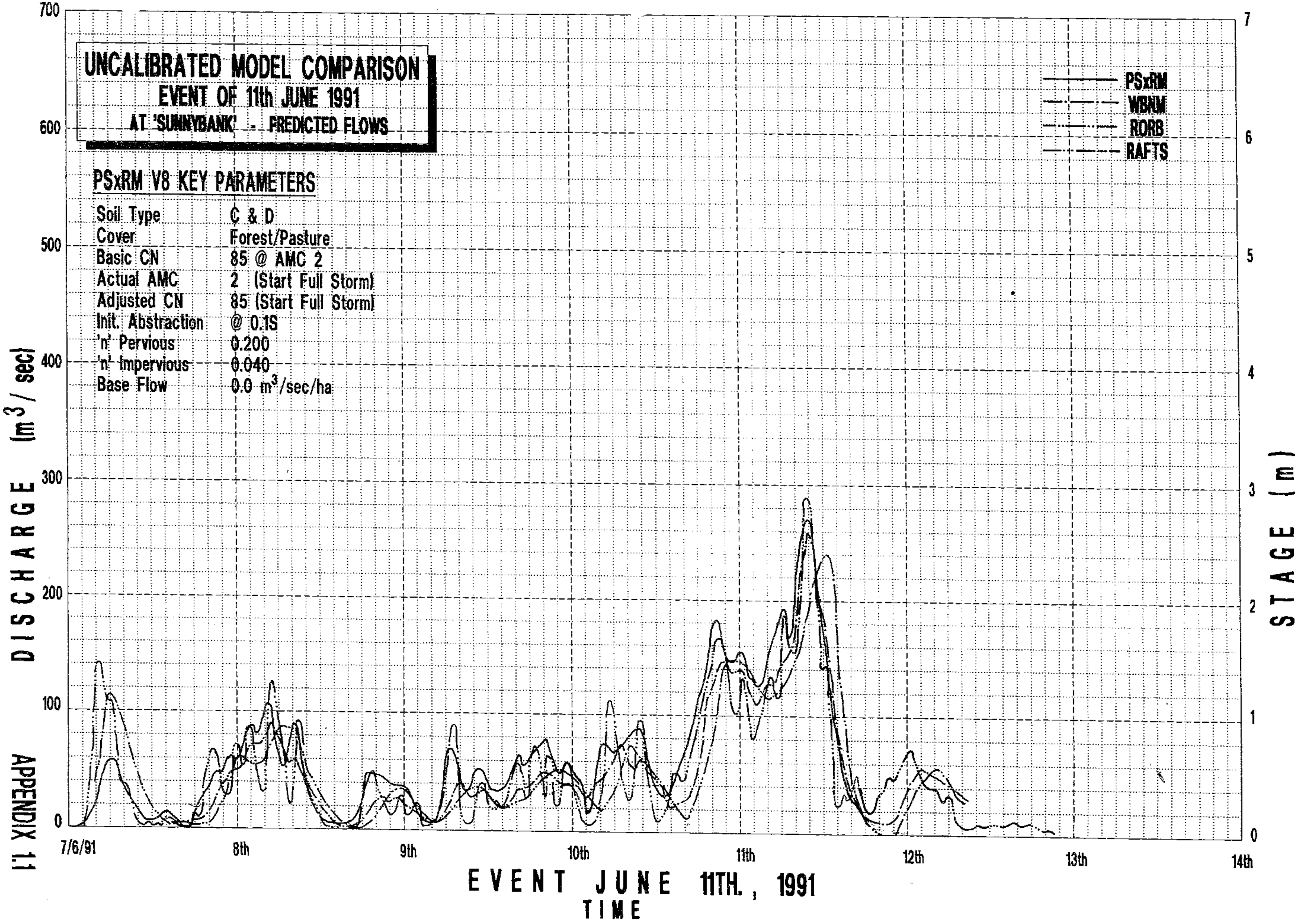
# APPENDICES

APPENDIX 1

1.1 Event of June '91 (SunnyBank Gauge Site)

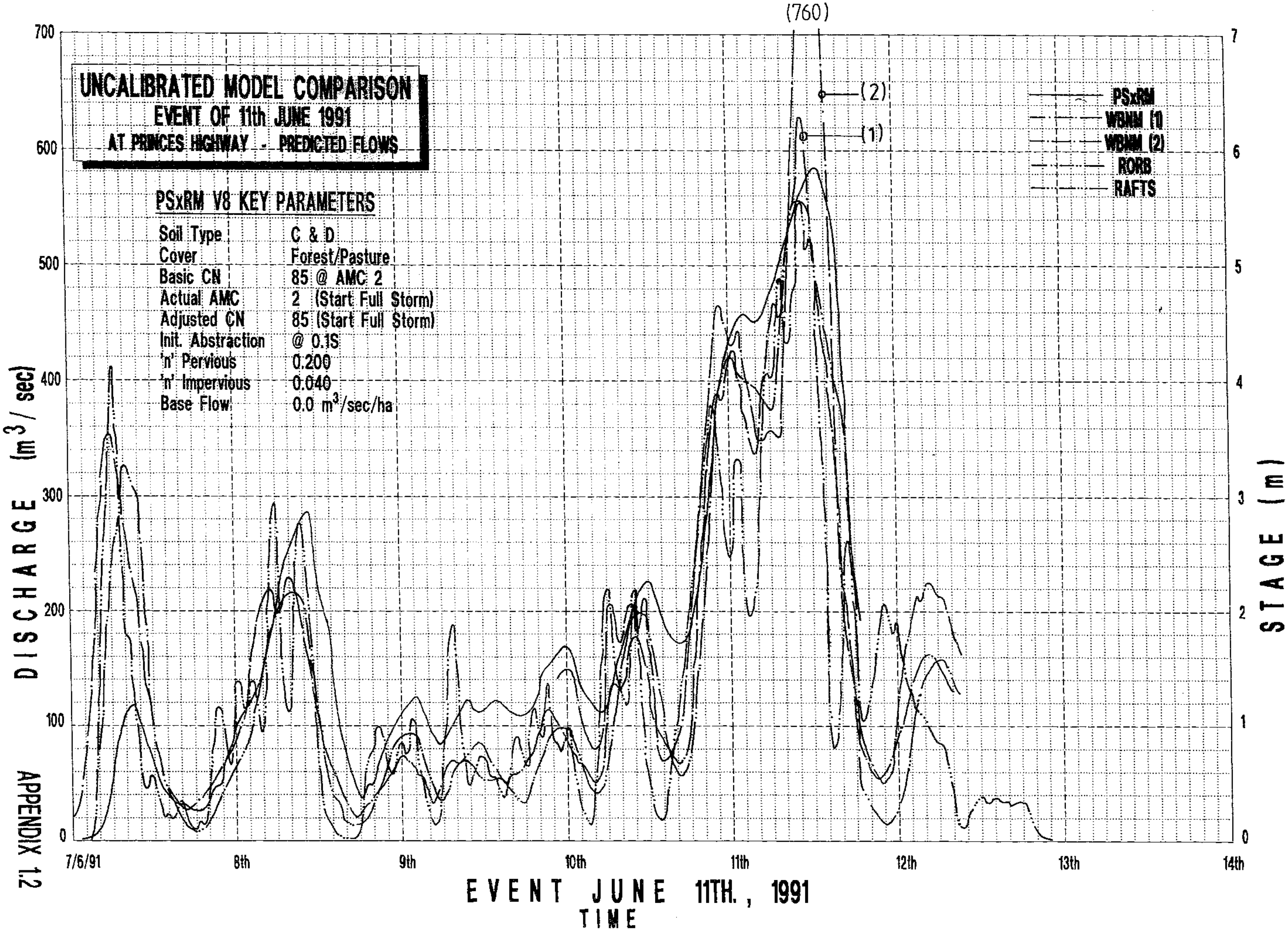
1.2 Event of June '91 (Highway Gauge Site)

# INTERMODEL COMPARISONS



UNCALIBRATED MODEL COMPARISON
EVENT OF 11th JUNE 1991
AT 'SUNNYBANK' - PREDICTED FLOWS
PSxRM V8 KEY PARAMETERS
Soil Type C & D
Cover Forest/Pasture
Basic CN 85 @ AMC 2
Actual AMC 2 (Start Full Storm)
Adjusted CN 85 (Start Full Storm)
Init. Abstraction @ 0.1S
'n' Pervious 0.200
'n' Impervious 0.040
Base Flow 0.0 m³/sec/ha
PSxRM
WBNM
RORB
RAFTS
DISCHARGE (m³/ sec)
STAGE (m)
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
7
7/6/91
8th
9th
10th
11th
12th
13th
14th
EVENT JUNE 11TH., 1991
TIME


APPENDIX 1.1


UNCALIBRATED MODEL COMPARISON
EVENT OF 11th JUNE 1991
AT PRINCES HIGHWAY - PREDICTED FLOWS
PSxRM V8 KEY PARAMETERS
Soil Type C & D
Cover Forest/Pasture
Basic CN 85 @ AMC 2
Actual AMC 2 (Start Full Storm)
Adjusted CN 85 (Start Full Storm)
Init. Abstraction @ 0.1S
'n' Pervious 0.200
'n' Impervious 0.040
Base Flow 0.0 m3/sec/ha
PSxRM
WBNM (1)
WBNM (2)
RORB
RAFTS
(760)
(2)
(1)
DISCHARGE (m3/ sec)
STAGE (m)
7/6/91
8th
9th
10th
11th
12th
13th
14th
EVENT JUNE 11TH., 1991
TIME

APPENDIX 1.2

# APPENDIX 2


2.1 WBNM Model Subdivision

2.2 PSxRM Model Subdivision

2.3 WBNM Output - Event of June '91

2.4 PSxRM Output - Event of June '91

2.5 WBNM Output - Design 1% AEP Event

2.6 PSxRM Output - Design 1% AEP Event

2.7 PSxRM - Hydrograph June '91 @ SunnyBank

2.8 PSxRM - Hydrograph June '91 @ Highway

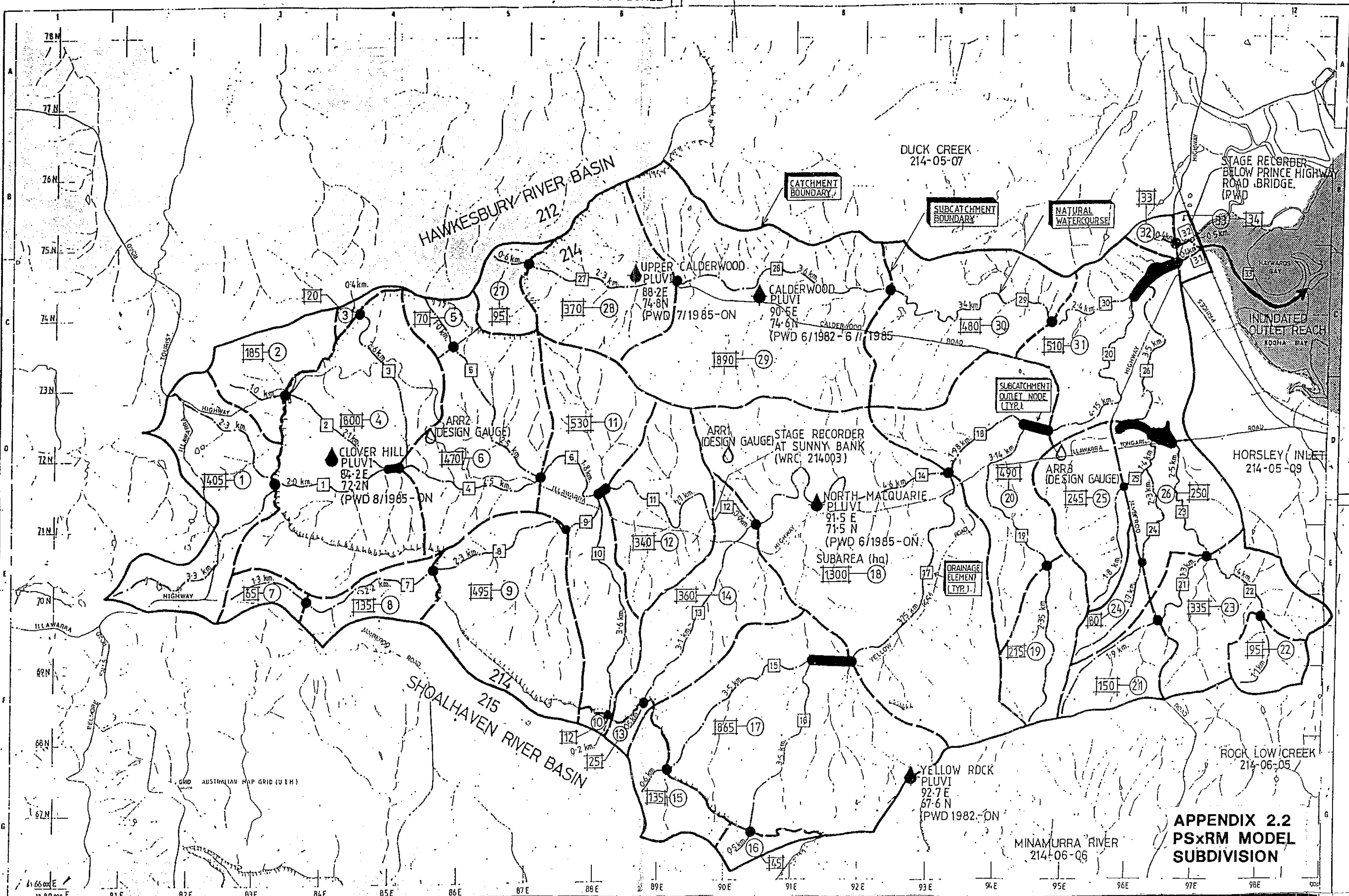
2.9 IFD Plot - Design Gauge ARR2 (Western)

2.10 IFD Plot - Design Gauge ARR1 (Central)

2.11 IFD Plot - Design Gauge ARR3 (Eastern)


# CATCHMENT HYDROLOGY

DO NOT SCALE | IF IN DOUBT ASK




**APPENDIX 2.2**
**PSxRM MODEL SUBDIVISION**

| REV | DATE | BY | APP. | DETAILS |
|---|---|---|---|---|
| | | | | |

| DRAWING STATUS | | |
|---|---|---|
| DESIGN BY | E.H.RIGBY | 00/00/88 |
| DRAWN BY | A.JOSEPH | 00/06/88 |
| DRAFTING CHECK | | |
| DESIGN CHECK | | |
| FINAL APPROVAL | | |

**PRELIMINARY**

SCALE: (on A1 Original) 1:25,000

DATUM: AHD


**FORBES RIGBY PTY LTD**
CONSULTING ENGINEERS & PLANNERS
278 Keira Street, P.O. Box 5125, Wollongong, NSW 2500
Ph:(042) 28 4133 Fax: (042) 28 6811 ACN 003-936-981




PROJECT TITLE: MACQUARIE RIVULET REFERENCE CATCHMENT
Wollongong Coastal Basin 214-05-08

DRAWING TITLE: PSxRM SUBDIVISION

| File Reference No. | Drawing No. | REV |
|---|---|---|
| 83093-2 | 7002 | 0 |

```
===========================================================================
#
#                 W  B  N  M      Version 2.10 October 1995
#                      S U M M A R Y   D U M P   F I L E
#
===========================================================================
#                    Input Data File Used for this RUN: U:\1983\83093-2\WBNM\M9106.TXT
#                    Input Data File Last Edited on: 18/12/1996
#                                                At: 17:8:58
#
#                    The META FILE was CREATED    on: 18/12/1996
#                                                At: 17:8:58
#
#       Data Dumped on Wednesday, 18/12/1996  At: 17:8:58:45
#   Run Title: Reference catchment for WRF : November 1995
#   Catchment Title: MACRQUARIE RIVULET
#   *
#   June 1991 Storm event
#   DYNAMIC STORAGE ADDED
#   *
#   File: m9106
#
===========================================================================
#
#   To MEET QA requirements please fill out the following;
#
#   This Run was Performed By:..T. ANGER..........
#
#                     Signed:..[signature]..........      Date: 18/12/96
#
#     This Run was CHECKED By:.....E. RIGBY..
#
#                     Signed:.....[signature]....      Date: 18/12/96
#
===========================================================================
#
#              E V E N T   No.  1
#
#     RESULTS at the Catchment Outlet for Storm Event No.  1
#  Recorded Storm Event of Recorded storm June 1991
#     Routing Period for this Event is 15.0Mins
#     Recorded Event Date: 09/06/91 Time: 1400.00
#
#     LOSS PARAMETERS USED IN THIS RUN
#     Loss Model Used for this Event is :  LRG
#     Initial Loss for Impervious Surfaces Set to 1.0mm
#     Initial Loss for Pervious Surfaces Set to 15.0mm
#     Continueing Loss  Rate for Pervious Surfaces Set to 2.5mm
#     Number of Gauges Used in this EVENT 4.0
#                          IMPFACTOR = 0.10
#     Total Catchment area being Analysed              := 105.600 km^2
#     Average Rainfall Depth over the Catchment        := 490.187 mm
#     Average Excess Rainfall Depth over the Catchment := 374.391 mm
--------------------------------------------------------------------------
#     Calculated Runoff Depth of area being Analysed   := 361.382 mm
#     Recorded Runoff Depth of area being Analysed     :=   0.000 mm
#        Note: If Excess Rainfall > Recorded Runoff then it is
#              recommended that larger rainfall losses are used.
#     Original Routing Period Specified                := 15.0 mins
#     Final adjusted Routing Period                    := 15.0 mins
#
+++++++++++++++++++++++ TOTAL CATCHMENT ++++++++++++++++++++++
#
#    CALCULATED PEAK Discharge at the CATCHMENT OUTLET :=   518.487 m^3/s
#    RECORDED PEAK Discharge at the CATCHMENT OUTLET   :=     0.000 m^3/s
#    CALCULATED TIME to PEAK at the CATCHMENT OUTLET   := 2805.000 mins
#    RECORDED TIME to PEAK at the CATCHMENT OUTLET     := 0.000 mins
===========================================================================
#
#
#    Tabulated SUMMARY of VOLUMES in thousands of m3
```

| Sub-Catch Number | Diverted From | From U/S Sub-Catch | RainFall Excess | Diverted To D/S | Curr.S/C Outflow | Balance Balance |
|---|---|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 748.270 | 0.00 | 747.18 | 1.080 |
| 2 | 0.00 | 0.00 | 1004.090 | 0.00 | 1002.53 | 1.560 |
| 3 | 0.00 | 1749.71 | 1830.440 | 0.00 | 3570.92 | 9.240 |
| 4 | 0.00 | 0.00 | 1521.070 | 0.00 | 1517.29 | 3.780 |
| 5 | 0.00 | 0.00 | 1035.830 | 0.00 | 1034.20 | 1.630 |
| 6 | 0.00 | 6122.40 | 844.770 | 0.00 | 6958.96 | 8.220 |
| 7 | 0.00 | 0.00 | 1393.990 | 0.00 | 1390.32 | 3.670 |
| 8 | 0.00 | 8349.28 | 291.490 | 0.00 | 8635.41 | 5.360 |
| 9 | 0.00 | 0.00 | 834.620 | 0.00 | 833.48 | 1.140 |
| 10 | 0.00 | 833.48 | 2827.870 | 0.00 | 3642.27 | 19.070 |
| 11 | 0.00 | 0.00 | 859.200 | 0.00 | 857.75 | 1.450 |

**APPENDIX 2.3**
**WBNM OUTPUT -**
**EVENT OF JUNE '91**

| | | | | | | |
|---|---|---|---|---|---|---|
| 12 | 0.00 | 13135.43 | 1241.600 | 0.00 | 14350.15 | 26.880 |
| 13 | 0.00 | 14350.15 | 3674.500 | 0.00 | 17925.53 | 99.120 |
| 14 | 0.00 | 0.00 | 3638.920 | 0.00 | 3613.41 | 25.510 |
| 15 | 0.00 | 3613.41 | 2183.910 | 0.00 | 5770.48 | 26.840 |
| 16 | 0.00 | 23696.01 | 512.990 | 0.00 | 24171.03 | 37.970 |
| 17 | 0.00 | 0.00 | 743.240 | 0.00 | 742.21 | 1.040 |
| 18 | 0.00 | 742.21 | 855.040 | 0.00 | 1595.10 | 2.150 |
| 19 | 0.00 | 25766.14 | 0.000 | 0.00 | 25704.96 | 61.180 |
| 20 | 0.00 | 25704.96 | 375.930 | 0.00 | 26040.44 | 40.450 |
| 21 | 0.00 | 0.00 | 375.100 | 0.00 | 374.86 | 0.250 |
| 22 | 0.00 | 374.86 | 161.490 | 0.00 | 536.12 | 0.230 |
| 23 | 0.00 | 26576.56 | 144.590 | 0.00 | 26697.10 | 24.060 |
| 24 | 0.00 | 0.00 | 521.810 | 0.00 | 521.30 | 0.510 |
| 25 | 0.00 | 521.30 | 635.270 | 0.00 | 1155.45 | 1.130 |
| 26 | 0.00 | 0.00 | 888.430 | 0.00 | 886.98 | 1.450 |
| 27 | 0.00 | 2042.43 | 460.070 | 0.00 | 2500.79 | 1.700 |
| 28 | 0.00 | 0.00 | 280.000 | 0.00 | 279.84 | 0.160 |
| 29 | 0.00 | 279.84 | 271.540 | 0.00 | 551.16 | 0.220 |
| 30 | 0.00 | 0.00 | 466.420 | 0.00 | 466.18 | 0.240 |
| 31 | 0.00 | 466.18 | 94.190 | 0.00 | 560.28 | 0.090 |
| 32 | 0.00 | 1111.44 | 0.000 | 0.00 | 1111.44 | 0.000 |
| 33 | 0.00 | 0.00 | 457.900 | 0.00 | 457.70 | 0.210 |
| 34 | 0.00 | 457.70 | 72.240 | 0.00 | 529.83 | 0.100 |
| 35 | 0.00 | 4142.06 | 0.000 | 0.00 | 4141.66 | 0.400 |
| 36 | 0.00 | 4141.66 | 646.250 | 0.00 | 4784.51 | 3.410 |
| 37 | 0.00 | 4784.51 | 57.790 | 0.00 | 4841.52 | 0.780 |
| 38 | 0.00 | 0.00 | 1783.590 | 0.00 | 1777.58 | 6.010 |
| 39 | 0.00 | 1777.58 | 3308.060 | 0.00 | 5053.19 | 32.450 |
| 40 | 0.00 | 5053.19 | 1710.690 | 0.00 | 6736.24 | 27.640 |
| 41 | 0.00 | 6736.24 | 0.000 | 0.00 | 6528.39 | 207.850 |
| 42 | 0.00 | 6528.39 | 288.110 | 0.00 | 6789.29 | 27.210 |
| 43 | 0.00 | 6789.29 | 250.800 | 0.00 | 7013.53 | 26.560 |
| 44 | 0.00 | 38552.15 | 0.000 | 0.00 | 38005.08 | 547.070 |
| 45 | 0.00 | 38005.08 | 67.410 | 0.00 | 38033.50 | 38.980 |
| 46 | 0.00 | 0.00 | 118.640 | 0.00 | 118.54 | 0.100 |
| 47 | 0.00 | 118.54 | 0.000 | 0.00 | 100.47 | 18.080 |
| 48 | 0.00 | 100.47 | 57.560 | 0.00 | 157.29 | 0.730 |
| 49 | 0.00 | 38190.79 | 0.000 | 0.00 | 38161.91 | 28.870 |

#
# Tabulated SUMMARY of PEAK DISCHARGES in m^3/s

| Sub-Catch Number | Channel U/S End | Channel D/S End | plus Local Inflow | After Diversion | Maximum Water Reached (m) |
|---|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 16.05 | 16.05 | 0.00 |
| 2 | 0.00 | 0.00 | 21.05 | 21.05 | 0.00 |
| 3 | 37.10 | 30.39 | 66.00 | 66.00 | 0.00 |
| 4 | 0.00 | 0.00 | 30.84 | 30.84 | 0.00 |
| 5 | 0.00 | 0.00 | 21.66 | 21.66 | 0.00 |
| 6 | 118.49 | 107.49 | 122.99 | 122.99 | 0.00 |
| 7 | 0.00 | 0.00 | 28.48 | 28.48 | 0.00 |
| 8 | 151.48 | 146.55 | 151.03 | 151.03 | 0.00 |
| 9 | 0.00 | 0.00 | 17.76 | 17.76 | 0.00 |
| 10 | 17.76 | 13.73 | 68.02 | 68.02 | 0.00 |
| 11 | 0.00 | 0.00 | 18.29 | 18.29 | 0.00 |
| 12 | 234.61 | 218.65 | 238.92 | 238.92 | 0.00 |
| 13 | 238.92 | 223.85 | 271.38 | 271.38 | 0.00 |
| 14 | 0.00 | 0.00 | 65.43 | 65.43 | 0.00 |
| 15 | 65.43 | 60.76 | 92.86 | 92.86 | 0.00 |
| 16 | 352.66 | 350.28 | 359.51 | 359.51 | 0.00 |
| 17 | 0.00 | 0.00 | 15.06 | 15.06 | 0.00 |
| 18 | 15.06 | 13.99 | 29.87 | 29.87 | 0.00 |
| 19 | 382.68 | 368.91 | 368.91 | 368.91 | 0.57 |
| 20 | 368.91 | 368.36 | 373.63 | 373.63 | 0.00 |
| 21 | 0.00 | 0.00 | 9.53 | 9.53 | 0.00 |
| 22 | 9.53 | 8.72 | 13.00 | 13.00 | 0.00 |
| 23 | 381.45 | 381.36 | 383.29 | 383.29 | 0.00 |
| 24 | 0.00 | 0.00 | 10.76 | 10.76 | 0.00 |
| 25 | 10.76 | 10.09 | 22.90 | 22.90 | 0.00 |
| 26 | 0.00 | 0.00 | 17.79 | 17.79 | 0.00 |
| 27 | 40.69 | 39.34 | 46.26 | 46.26 | 0.00 |
| 28 | 0.00 | 0.00 | 5.91 | 5.91 | 0.00 |
| 29 | 5.91 | 5.71 | 11.64 | 11.64 | 0.00 |
| 30 | 0.00 | 0.00 | 11.75 | 11.75 | 0.00 |
| 31 | 11.75 | 11.23 | 13.83 | 13.83 | 0.00 |
| 32 | 25.47 | 25.47 | 25.47 | 25.47 | 0.00 |
| 33 | 0.00 | 0.00 | 11.57 | 11.57 | 0.00 |
| 34 | 11.57 | 11.17 | 13.22 | 13.22 | 0.00 |
| 35 | 79.06 | 76.84 | 76.84 | 76.84 | 0.34 |
| 36 | 76.84 | 73.65 | 84.90 | 84.90 | 0.00 |
| 37 | 84.90 | 85.03 | 85.89 | 85.89 | 0.00 |
| 38 | 0.00 | 0.00 | 35.80 | 35.80 | 0.00 |
| 39 | 35.80 | 28.95 | 91.31 | 91.31 | 0.00 |
| 40 | 91.31 | 82.21 | 114.04 | 114.04 | 0.00 |
| 41 | 114.04 | 92.33 | 92.33 | 92.33 | 0.62 |
| 42 | 92.33 | 92.16 | 93.80 | 93.80 | 0.00 |

| | | | | | |
|---|---|---|---|---|---|
| 43 | 93.80 | 93.53 | 95.27 | 95.27 | 0.00 |
| 44 | 541.33 | 516.52 | 516.52 | 516.52 | 0.54 |
| 45 | 516.52 | 516.56 | 516.87 | 516.87 | 0.00 |
| 46 | 0.00 | 0.00 | 2.94 | 2.94 | 0.00 |
| 47 | 2.94 | 1.38 | 1.38 | 1.38 | 0.55 |
| 48 | 1.38 | 1.38 | 2.80 | 2.80 | 0.00 |
| 49 | 518.51 | 518.49 | 518.49 | 518.49 | 0.55 |

#
# Tabulated SUMMARY of PEAK TIMES in Minutes

| Sub-Catch Number | Channel U/S End | Channel D/S End | plus Local Inflow | After Diversion |
|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 2 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 3 | 2760.00 | 2775.00 | 2760.00 | 2760.00 |
| 4 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 5 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 6 | 2760.00 | 2775.00 | 2760.00 | 2760.00 |
| 7 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 8 | 2760.00 | 2775.00 | 2775.00 | 2775.00 |
| 9 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 10 | 2760.00 | 2775.00 | 2760.00 | 2760.00 |
| 11 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 12 | 2760.00 | 2775.00 | 2775.00 | 2775.00 |
| 13 | 2775.00 | 2805.00 | 2700.00 | 2700.00 |
| 14 | 0.00 | 0.00 | 2460.00 | 2460.00 |
| 15 | 2460.00 | 2520.00 | 2460.00 | 2460.00 |
| 16 | 2700.00 | 2700.00 | 2700.00 | 2700.00 |
| 17 | 0.00 | 0.00 | 2460.00 | 2460.00 |
| 18 | 2460.00 | 2475.00 | 2400.00 | 2400.00 |
| 19 | 2700.00 | 2730.00 | 2730.00 | 2730.00 |
| 20 | 2730.00 | 2745.00 | 2745.00 | 2745.00 |
| 21 | 0.00 | 0.00 | 2400.00 | 2400.00 |
| 22 | 2400.00 | 2415.00 | 2400.00 | 2400.00 |
| 23 | 2745.00 | 2745.00 | 2745.00 | 2745.00 |
| 24 | 0.00 | 0.00 | 2460.00 | 2460.00 |
| 25 | 2460.00 | 2475.00 | 2460.00 | 2460.00 |
| 26 | 0.00 | 0.00 | 2460.00 | 2460.00 |
| 27 | 2460.00 | 2475.00 | 2460.00 | 2460.00 |
| 28 | 0.00 | 0.00 | 2460.00 | 2460.00 |
| 29 | 2460.00 | 2460.00 | 2400.00 | 2400.00 |
| 30 | 0.00 | 0.00 | 2400.00 | 2400.00 |
| 31 | 2400.00 | 2400.00 | 2400.00 | 2400.00 |
| 32 | 2400.00 | 2400.00 | 2400.00 | 2400.00 |
| 33 | 0.00 | 0.00 | 2400.00 | 2400.00 |
| 34 | 2400.00 | 2400.00 | 2400.00 | 2400.00 |
| 35 | 2400.00 | 2415.00 | 2415.00 | 2415.00 |
| 36 | 2415.00 | 2445.00 | 2445.00 | 2445.00 |
| 37 | 2445.00 | 2445.00 | 2445.00 | 2445.00 |
| 38 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 39 | 2760.00 | 2775.00 | 2760.00 | 2760.00 |
| 40 | 2760.00 | 2775.00 | 2760.00 | 2760.00 |
| 41 | 2760.00 | 2805.00 | 2805.00 | 2805.00 |
| 42 | 2805.00 | 2820.00 | 2820.00 | 2820.00 |
| 43 | 2820.00 | 2820.00 | 2760.00 | 2760.00 |
| 44 | 2745.00 | 2805.00 | 2805.00 | 2805.00 |
| 45 | 2805.00 | 2805.00 | 2805.00 | 2805.00 |
| 46 | 0.00 | 0.00 | 2760.00 | 2760.00 |
| 47 | 2760.00 | 2790.00 | 2790.00 | 2790.00 |
| 48 | 2790.00 | 2790.00 | 2760.00 | 2760.00 |
| 49 | 2805.00 | 2805.00 | 2805.00 | 2805.00 |

#
# Tabulated SUMMARY of IMPERVIOUS and PERVIOUS Area RUNOFF

| Sub-Catch | I M P E R V I O U S | | P E R V I O U S | |
|---|---|---|---|---|
| Number | Volume | Peak | Volume | Peak |
| 1 | 0.00 | 0.00 | 747.18 | 16.05 |
| 2 | 0.00 | 0.00 | 1002.53 | 21.05 |
| 3 | 0.00 | 0.00 | 1825.22 | 36.57 |
| 4 | 0.00 | 0.00 | 1517.29 | 30.84 |
| 5 | 0.00 | 0.00 | 1034.20 | 21.66 |
| 6 | 0.00 | 0.00 | 843.62 | 17.95 |
| 7 | 0.00 | 0.00 | 1390.32 | 28.48 |
| 8 | 0.00 | 0.00 | 291.18 | 6.75 |
| 9 | 0.00 | 0.00 | 833.48 | 17.76 |
| 10 | 0.00 | 0.00 | 2813.73 | 54.75 |
| 11 | 0.00 | 0.00 | 857.75 | 18.29 |
| 12 | 0.00 | 0.00 | 1238.21 | 25.69 |
| 13 | 0.00 | 0.00 | 3650.78 | 69.69 |
| 14 | 0.00 | 0.00 | 3613.41 | 65.43 |
| 15 | 0.00 | 0.00 | 2174.97 | 44.41 |
| 16 | 0.00 | 0.00 | 512.54 | 12.59 |
| 17 | 0.00 | 0.00 | 742.21 | 15.06 |
| 18 | 55.69 | 1.34 | 798.28 | 18.60 |
| 19 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 375.68 | 9.54 |

| | | | | |
|---|---|---|---|---|
| 21 | 0.00 | 0.00 | 374.86 | 9.53 |
| 22 | 0.00 | 0.00 | 161.43 | 4.42 |
| 23 | 0.00 | 0.00 | 144.53 | 3.98 |
| 24 | 0.00 | 0.00 | 521.30 | 10.76 |
| 25 | 0.00 | 0.00 | 634.61 | 12.96 |
| 26 | 0.00 | 0.00 | 886.98 | 17.79 |
| 27 | 0.00 | 0.00 | 459.70 | 11.43 |
| 28 | 0.00 | 0.00 | 279.84 | 5.91 |
| 29 | 0.00 | 0.00 | 271.39 | 7.12 |
| 30 | 115.99 | 2.78 | 350.19 | 8.96 |
| 31 | 23.38 | 0.56 | 70.79 | 2.03 |
| 32 | 0.00 | 0.00 | 0.00 | 0.00 |
| 33 | 140.02 | 3.36 | 317.67 | 8.21 |
| 34 | 4.69 | 0.11 | 67.53 | 1.94 |
| 35 | 0.00 | 0.00 | 0.00 | 0.00 |
| 36 | 0.00 | 0.00 | 645.54 | 15.44 |
| 37 | 0.00 | 0.00 | 57.78 | 1.67 |
| 38 | 0.00 | 0.00 | 1777.58 | 35.80 |
| 39 | 0.00 | 0.00 | 3287.83 | 63.32 |
| 40 | 0.00 | 0.00 | 1704.72 | 34.53 |
| 41 | 0.00 | 0.00 | 0.00 | 0.00 |
| 42 | 0.00 | 0.00 | 287.94 | 7.51 |
| 43 | 0.00 | 0.00 | 250.56 | 5.90 |
| 44 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45 | 8.58 | 0.21 | 58.80 | 1.69 |
| 46 | 0.00 | 0.00 | 118.54 | 2.94 |
| 47 | 0.00 | 0.00 | 0.00 | 0.00 |
| 48 | 0.00 | 0.00 | 57.51 | 1.48 |
| 49 | 0.00 | 0.00 | 0.00 | 0.00 |

END OF W B N M Ver 2.10 - S U M M A R Y D U M P F I L E

Data Dumped on Wednesday, 18/12/1996 Completed At: 17:8:59:22

Reference catchment for WRF : November 1995
MACRQUARIE RIVULET
*
June 1991 Storm event
DYNAMIC STORAGE ADDED
*
File: m9106

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 1.29 | | | | | | | | | | | |
| 1 | OL | 0 | 0 | 0 | 175 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 2 | OL | 0 | 0 | 0 | 230 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 3 | WC | 1 | 2 | 0 | 415 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 4 | OL | 0 | 0 | 0 | 345 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 5 | OL | 0 | 0 | 0 | 240 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 6 | WC | 3 | 4 | 5 | 200 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 7 | OL | 0 | 0 | 0 | 345 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 8 | WC | 6 | 7 | 0 | 75 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 9 | OL | 0 | 0 | 0 | 195 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 10 | WC | 9 | 0 | 0 | 740 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 11 | OL | 0 | 0 | 0 | 225 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 12 | WC | 8 | 10 | 11 | 340 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 13 | WC | 12 | 0 | 0 | 1045 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 14 | OL | 0 | 0 | 0 | 1055 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 15 | WC | 14 | 0 | 0 | 635 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 16 | WC | 13 | 15 | 0 | 145 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 17 | OL | 0 | 0 | 0 | 215 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 18 | WC | 17 | 0 | 0 | 240 | 5.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 19 | S1 | 16 | 18 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 20 | WC | 19 | 0 | 0 | 105 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 21 | OL | 0 | 0 | 0 | 105 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 22 | WC | 21 | 0 | 0 | 45 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 23 | WC | 20 | 22 | 0 | 40 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 24 | OL | 0 | 0 | 0 | 150 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 25 | WC | 24 | 0 | 0 | 180 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 26 | OL | 0 | 0 | 0 | 250 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 27 | WC | 25 | 26 | 0 | 130 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 28 | OL | 0 | 0 | 0 | 80 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 29 | WC | 28 | 0 | 0 | 77 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 30 | OL | 0 | 0 | 0 | 125 | 20.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 31 | WC | 30 | 0 | 0 | 25 | 20.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 32 | DU | 29 | 31 | 0 | .0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 33 | OL | 0 | 0 | 0 | 120 | 25.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 34 | WC | 33 | 0 | 0 | 20 | 5.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 35 | S1 | 27 | 32 | 34 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 36 | WC | 35 | 0 | 0 | 180 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 37 | WC | 36 | 0 | 0 | 16 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 38 | OL | 0 | 0 | 0 | 465 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 39 | WC | 38 | 0 | 0 | 890 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 40 | WC | 39 | 0 | 0 | 480 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 41 | S1 | 40 | 0 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 42 | WC | 41 | 0 | 0 | 80 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 43 | WC | 42 | 0 | 0 | 70 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 44 | S1 | 23 | 37 | 43 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 45 | WC | 44 | 0 | 0 | 18 | 10.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 46 | OL | 0 | 0 | 0 | 33 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 47 | S1 | 46 | 0 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 48 | WC | 47 | 0 | 0 | 16 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 49 | S1 | 45 | 48 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |

Sub-area Co-ordinates

| | | | | |
|---|---|---|---|---|
| 1 | 282200 | 1170400 | 283400 | 1171600 |
| 2 | 282500 | 1172100 | 283400 | 1171600 |
| 3 | 284200 | 1171200 | 285100 | 1171900 |
| 4 | 283700 | 1173100 | 285100 | 1171900 |
| 5 | 285200 | 1173200 | 285100 | 1171900 |
| 6 | 286000 | 1171600 | 287200 | 1171700 |
| 7 | 286600 | 1172900 | 287200 | 1171700 |
| 8 | 287600 | 1171700 | 288100 | 1171500 |
| 9 | 284000 | 1170000 | 285600 | 1170400 |
| 10 | 287500 | 1169700 | 288100 | 1171500 |
| 11 | 288200 | 1172600 | 288100 | 1171500 |
| 12 | 289000 | 1171200 | 289800 | 1171200 |
| 13 | 290800 | 1170700 | 293300 | 1171800 |
| 14 | 290700 | 1168100 | 291900 | 1169100 |
| 15 | 292900 | 1169800 | 293300 | 1171800 |
| 16 | 293400 | 1172300 | 294800 | 1172400 |
| 17 | 294800 | 1169400 | 294800 | 1170500 |
| 18 | 294300 | 1171100 | 294800 | 1172400 |
| 19 | 294800 | 1172400 | 294800 | 1172400 |
| 20 | 295600 | 1173100 | 296000 | 1174200 |
| 21 | 294000 | 1173100 | 294900 | 1173100 |
| 22 | 295300 | 1173400 | 296000 | 1174200 |
| 23 | 296100 | 1174200 | 297000 | 1174800 |
| 24 | 296000 | 1169000 | 296500 | 1169600 |
| 25 | 297100 | 1169700 | 297300 | 1170600 |
| 26 | 298200 | 1169700 | 297300 | 1170600 |

```
27   297200   1171200   296200   1172300
28   295900   1169700   296300   1170500
29   296500   1171100   296500   1172200
30   295600   1170800   296000   1171500
31   296100   1171700   296500   1172200
32   296500   1172200   296500   1172200
33   295100   1171700   295700   1172300
34   296000   1172200   296200   1172300
35   296200   1172300   296200   1172300
36   296500   1173300   296300   1173900
37   296300   1174100   296700   1174800
38   288000   1174500   289200   1174500
39   290300   1174100   292400   1174400
40   293200   1173900   294800   1174000
41   294800   1174000   294800   1174000
42   295000   1173800   295500   1174100
43   295800   1174600   296700   1174800
44   296700   1174800   296700   1174800
45   296900   1174800   297000   1175000
46   296500   1175100   296700   1175200
47   296700   1175200   296700   1175200
48   296800   1175200   297000   1175000
49   297000   1175000   297000   1175000
Rating Tables
-1
Stream Details
3    R  0.6   -1   -1  -1
6    R  0.6   -1   -1  -1
8    R  0.6   -1   -1  -1
10   R  0.6   -1   -1  -1
12   R  0.6   -1   -1  -1
13   R  0.6   -1   -1  -1
15   R  0.6   -1   -1  -1
16   R  0.6   -1   -1  -1
18   R  0.6   -1   -1  -1
20   R  0.6   -1   -1  -1
22   R  0.6   -1   -1  -1
23   R  0.6   -1   -1  -1
25   R  0.6   -1   -1  -1
27   R  0.6   -1   -1  -1
29   R  0.6   -1   -1  -1
31   R  0.6   -1   -1  -1
34   R  0.6   -1   -1  -1
36   R  0.6   -1   -1  -1
37   R  0.6   -1   -1  -1
39   R  0.6   -1   -1  -1
40   R  0.6   -1   -1  -1
42   R  0.6   -1   -1  -1
43   R  0.6   -1   -1  -1
45   R  0.6   -1   -1  -1
48   R  0.6   -1   -1  -1
Basin Details
6
19
Storage in Macquarie Riv. u/s of Albion Park
1.0      1.0
4
0.00      0.0     0.0
1.00    650.0  1500.0
2.00   1300.0  3000.0
3.00   1950.0  4500.0
0.00
35
Storage in Frazers Ck. u/s of Tongarra
1.0      1.0
4
0.00      0.0     0.0
1.00    225.0   150.0
2.00    450.0   300.0
3.00    675.0   450.0
0.00
41
Storage in Marshall Mount Ck. u/s of Grey Meadows
1.0      1.0
4
0.00      0.0     0.0
1.00    150.0  1500.0
2.00    300.0  3000.0
3.00    450.0  4500.0
0.00
44
Storage in Macquarie Riv. u/s Princes Hway
1.0      1.0
4
```

```
0.00      0.0      0.0
1.00    950.0   5000.0
2.00   1900.0  10000.0
3.00   2850.0  15000.0
0.00
47
Storage @ Yallah u/s Princes Hway
1.0     1.0
4
0.00      0.0      0.0
1.00      2.5     75.0
2.00      5.0    150.0
3.00      7.5    300.0
0.00
49
Storage in Macquarie Riv. d/s Princes Hway
1.0     1.0
4
0.00      0.0      0.0
1.00    950.0    250.0
2.00   1900.0    500.0
3.00   2850.0    750.0
0.00
Rainfall Storm Details
1
Recorded storm June 1991
REC
15
09/06/91
1400
LRG
15.0     2.5
4
50     60
PWD CLOVER HILL PLUVI
284200  1172200
3.5  9.5  10  2.5  13
4  13  1.5  5.5  10.5
5.5  4.5  0.5  2.5  11
18  9  5.5  4  16
8  4  3.5  2  5.5
8.5  5.5  10.5  15.5  17.5
21.5  19.5  18  12.5  20.5
10.5  12  16  16.5  13
24  17.5  23  36.5  33.5
14  20.5  1.5  4.5  2
PWD NORTH MACQUARIE PLUVI
291500  1171500
0.5  7  4  2  5.5
8.5  10.5  3  6  3
0.5  1.5  0.0  0.5  6
10.5  11.5  3.5  4.5  9
8  3  2.5  3  1.5
7.5  3.5  12  14  15
12.5  23  10  9  27.5
18.5  9  8  17  40
19.5  13  17.5  20  27.5
17.5  6.5  0.0  0.5  0.0
PWD YELLOW ROCK PLUVI
292700  1167600
0.5  7  5  0.5  5.5
1  6.5  1  4.5  2
0.5  4.5  0.0  0.0  4.5
11.5  10.5  6.5  7.5  17
9.5  3.5  3  3.5  1
7  3  9.5  13  10.5
16  19.5  12.5  8.5  18.5
22.5  13  5.5  15.5  28
28.5  20.5  21  11.5  15.5
15  10  0.0  0.5  0.0
PWD UPPER CALDERWOOD PLUVI
288200  1174800
1.5  6.5  5  1  7
8.5  12  2.5  1.5  5
3  0.5  0.0  1  9.5
13  6  4  3  21
5  4.5  2.5  4  3
6.5  5  12  17  21
17  23  15.5  13  24.5
9  14  13.5  15  10
29  13.5  21  35  9.5
39  4.5  0.0  1.5  3.5
CALC
Recorded Hydrographs
```

```
*****************************************
*                                       *
*             P S x R M                 *
*                                       *
*    Penn State Extended Runoff Model   *
*                                       *
*      Metric DOS/UNIX Version V8.04    *
*                                       *
*              May   1992               *
*                                       *
*****************************************
```

Macquarie Rivulet Reference Catchment - Ref : 81093

Storm of 7/6/91 - Rainfall Data from 9/6/91 2pm to 11/6/91 4pm

Lower floodplain storeages included in model as special storeages

SCS CN for pervious surface increased to AMC 3 level in recognition

of the fact that significant earlier rain not modelled.

15/06/1992

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**APPENDIX 2.4**
**PSxRM OUTPUT -**
**EVENT OF JUNE '91**

## I N P U T   D A T A   E C H O

GENERAL WATERSHED AND RUN DATA

No of Subareas = 33     No of Basins = 6     No of Obs Hydrog = 0

No of Raingauges, recording = 4  nonrecording = 0

Time Interv, min; Routing 4.0  Printing %120.0  Rainfall 60.0  Total = 4800.0

Resid Inf Time = 720 min   4 Raingauges used in Weighting, with Exp 2.0

Standard (default) Parameters :

| Mannings n | | Dep Storage | | SCS -- CN | | IA | STCGTI | CTS Ratio |
|---|---|---|---|---|---|---|---|---|
| Imperv | Perv | Imperv | Perv | Imperv | Perv | | min | |
| .040 | .200 | 0.00 | 0.00 | 99.0 | 97.0 | .10 | 0.0 | 1.00 |

Baseflow Coefficient = 0.0000 m3/s/ha

Hydrographs will be listed for Subareas:
12 20 25 26 30 31 32 33

Basins are located on Subareas:
20 26 30 31 32 33

SUBAREA PROPERTIES AND DIMENSIONS

| ID No | Area ha | Length m | Slope m /m | Manning's n Imp | Manning's n Perv | Imperv Fract | SCS-CN Imp | SCS-CN Perv | IA | Coordinates E | Coordinates N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 405.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 82.3 | 71.5 |
| 2 | 185.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 83.1 | 73.4 |
| 3 | 20.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 84.3 | 74.2 |
| 4 | 800.0 | 1000. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 84.4 | 72.1 |
| 5 | 70.0 | 600. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 85.7 | 74.0 |
| 6 | 470.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 86.2 | 72.3 |
| 7 | 65.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 83.1 | 70.2 |
| 8 | 135.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 84.7 | 70.1 |
| 9 | 495.0 | 300. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 86.8 | 70.0 |
| 10 | 12.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 88.0 | 68.3 |
| 11 | 530.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 87.8 | 71.3 |
| 12 | 340.0 | 300. | .150 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 88.9 | 71.3 |
| 13 | 25.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 84.5 | 68.3 |
| 14 | 360.0 | 200. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 89.7 | 69.8 |
| 15 | 135.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 89.1 | 67.1 |
| 16 | 45.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 90.5 | 66.5 |
| 17 | 865.0 | 500. | .150 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 90.9 | 69.4 |
| 18 | 1300.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 91.5 | 71.5 |
| 19 | 215.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 94.8 | 69.4 |
| 20 | 490.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 94.0 | 71.5 |
| 21 | 150.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 96.0 | 69.0 |
| 22 | 95.0 | 300. | .150 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 98.1 | 69.1 |
| 23 | 335.0 | 500. | .050 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 97.2 | 70.0 |
| 24 | 80.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 96.0 | 70.0 |
| 25 | 245.0 | 700. | .040 | .040 | .200 | .10 | 99.0 | 97.0 | .10 | 95.5 | 71.4 |
| 26 | 250.0 | 500. | .020 | .040 | .200 | .05 | 99.0 | 97.0 | .10 | 96.6 | 71.4 |
| 27 | 95.0 | 300. | .100 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 86.5 | 74.5 |
| 28 | 370.0 | 300. | .200 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 88.6 | 74.7 |
| 29 | 890.0 | 500. | .150 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 90.4 | 74.4 |
| 30 | 480.0 | 500. | .030 | .040 | .200 | 0.00 | 99.0 | 97.0 | .10 | 93.5 | 74.0 |
| 31 | 510.0 | 300. | .010 | .040 | .200 | .10 | 99.0 | 97.0 | .10 | 95.8 | 73.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | 33.0 | 300. | .030 | .040 | .200 | .05 | 99.0 | 97.0 | .10 | 96.8 | 75.0 |
| 33 | 34.0 | 300. | .030 | .040 | .200 | .10 | 99.0 | 97.0 | .10 | 96.3 | 75.1 |

| I.D. No. | Depr.Storage Imp. | Perv. | CGtoInlet TT(min) | Drainage Elements Within Subarea | | | Outgoing Elements Cap,m3/s | TT,min | CTS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 10.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 2 | 0.000 | 0.000 | 3.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 3 | 0.000 | 0.000 | 1.00 | 0 | 0 | 0 | 0.0 | 10.0 | 1.0 |
| 4 | 0.000 | 0.000 | 8.00 | 1 | 2 | 3 | 0.0 | 10.0 | 1.0 |
| 5 | 0.000 | 0.000 | 2.00 | 0 | 0 | 0 | 0.0 | 10.0 | 1.0 |
| 6 | 0.000 | 0.000 | 6.00 | 4 | 5 | 0 | 0.0 | 10.0 | 1.0 |
| 7 | 0.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 17.5 | 1.0 |
| 8 | 0.000 | 0.000 | 10.00 | 7 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 9 | 0.000 | 0.000 | 8.00 | 8 | 0 | 0 | 0.0 | 6.0 | 1.0 |
| 10 | 0.000 | 0.000 | 1.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 11 | 0.000 | 0.000 | 8.00 | 6 | 9 | 10 | 0.0 | 16.0 | 1.0 |
| 12 | 0.000 | 0.000 | 6.00 | 11 | 0 | 0 | 0.0 | 6.0 | 1.0 |
| 13 | 0.000 | 0.000 | 3.00 | 0 | 0 | 0 | 0.0 | 12.0 | 1.0 |
| 14 | 0.000 | 0.000 | 10.00 | 12 | 13 | 0 | 0.0 | 27.0 | 1.0 |
| 15 | 0.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 16 | 0.000 | 0.000 | 2.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 17 | 0.000 | 0.000 | 8.00 | 15 | 16 | 0 | 0.0 | 22.0 | 1.0 |
| 18 | 0.000 | 0.000 | 12.00 | 14 | 17 | 0 | 0.0 | 12.0 | 1.0 |
| 19 | 0.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 19.0 | 1.0 |
| 20 | 0.000 | 0.000 | 10.00 | 18 | 19 | 0 | 0.0 | 33.0 | 1.0 |
| 21 | 0.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 22 | 0.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 23 | 0.000 | 0.000 | 6.00 | 21 | 22 | 0 | 0.0 | 21.0 | 1.0 |
| 24 | 0.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 25 | 0.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 26 | 0.000 | 0.000 | 8.00 | 23 | 24 | 25 | 0.0 | 28.0 | 1.0 |
| 27 | 0.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 28 | 0.000 | 0.000 | 6.00 | 27 | 0 | 0 | 0.0 | 27.0 | 1.0 |
| 29 | 0.000 | 0.000 | 12.00 | 28 | 0 | 0 | 0.0 | 27.0 | 1.0 |
| 30 | 0.000 | 0.000 | 15.00 | 29 | 0 | 0 | 0.0 | 19.0 | 1.0 |
| 31 | 0.000 | 0.000 | 15.00 | 20 | 26 | 30 | 0.0 | 3.0 | 1.0 |
| 32 | 0.000 | 0.000 | 2.00 | 0 | 0 | 0 | 0.0 | 3.0 | 1.0 |
| 33 | 0.000 | 0.000 | 1.00 | 31 | 32 | 0 | 0.0 | 100.0 | 1.0 |

BASIN DATA

MCQRIV ABOVE ALBION PARK

Basin No 1 in Area No 20 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 1500.0 | 650.0 |
| 2.0 | 3000.0 | 1300.0 |
| 3.0 | 4500.0 | 1950.0 |

FRAZERS ABOVE TONGARRA

Basin No 2 in Area No 26 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 150.0 | 225.0 |
| 2.0 | 300.0 | 450.0 |
| 3.0 | 450.0 | 675.0 |

MARSHAL ABOVE GREY MEADOWS

Basin No 3 in Area No 30 of Type 2 with 0.0 m3/s Bypass

| Elevation | Storage | Outflow |
|---|---|---|

| m | m3E3 | m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 1500.0 | 150.0 |
| 2.0 | 3000.0 | 300.0 |
| 3.0 | 4500.0 | 450.0 |

MACRIV ABOVE PRINCES HWAY
Basin No 4 in Area No 31 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 5000.0 | 950.0 |
| 2.0 | 10000.0 | 1900.0 |
| 3.0 | 15000.0 | 2850.0 |

YALLAH ABOVE PRINCES HWAY
Basin No 5 in Area No 32 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 75.0 | 2.5 |
| 2.0 | 150.0 | 5.0 |
| 3.0 | 300.0 | 7.5 |

MACRIV BETWEEN BRIDGES
Basin No 6 in Area No 33 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 250.0 | 950.0 |
| 2.0 | 500.0 | 1900.0 |
| 3.0 | 750.0 | 2850.0 |

RAINFALL DATA

Recording Raingauges

Raingauge No 1 CLOVER HILL, Coordinates = 84.20 East 72.20 North
Total rain = 567.00 mm , Starting Time and Centroid = 0.0 %1797.3 min

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3.50 | 9.50 | 10.00 | 2.50 | 13.00 | 4.00 | 13.00 | 1.50 | 5.50 | 10.50 |
| 5.50 | 4.50 | .50 | 2.50 | 11.00 | 18.00 | 9.00 | 5.50 | 4.00 | 16.00 |
| 8.00 | 4.00 | 3.50 | 2.00 | 5.50 | 8.50 | 5.50 | 10.50 | 15.50 | 17.50 |
| 21.50 | 19.50 | 18.00 | 12.50 | 20.50 | 10.50 | 12.00 | 16.00 | 16.50 | 13.00 |
| 24.00 | 17.50 | 23.00 | 36.50 | 33.50 | 14.00 | 20.50 | 1.50 | 4.50 | 2.00 |

Raingauge No 2 NORTH MACQUARIE, Coordinates = 91.50 East 71.50 North
Total rain = 464.00 mm , Starting Time and Centroid = 0.0 %1861.6 min

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .50 | 7.00 | 4.00 | 2.00 | 5.50 | 8.50 | 10.50 | 3.00 | 6.00 | 3.00 |
| .50 | 1.50 | 0.00 | .50 | 6.00 | 10.50 | 11.50 | 3.50 | 4.50 | 9.00 |
| 8.00 | 3.00 | 2.50 | 3.00 | 1.50 | 7.50 | 3.50 | 12.00 | 14.00 | 15.00 |
| 12.50 | 23.00 | 10.00 | 9.00 | 27.50 | 18.50 | 9.00 | 8.00 | 17.00 | 40.00 |
| 19.50 | 13.00 | 17.50 | 20.00 | 27.50 | 17.50 | 6.50 | 0.00 | .50 | 0.00 |

Raingauge No 3 YELLOW ROCK, Coordinates = 92.70 East 67.60 North
Total rain = 441.50 mm , Starting Time and Centroid = 0.0 %1866.8 min

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .50 | 7.00 | 5.00 | .50 | 5.50 | 1.00 | 6.50 | 1.00 | 4.50 | 2.00 |
| .50 | 4.50 | 0.00 | 0.00 | 4.50 | 11.50 | 10.50 | 6.50 | 7.50 | 17.00 |
| 9.50 | 3.50 | 3.00 | 3.50 | 1.00 | 7.00 | 3.00 | 9.50 | 13.00 | 10.50 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 16.00 | 19.50 | 12.50 | 8.50 | 18.50 | 22.50 | 13.00 | 5.50 | 15.50 | 28.00 |
| 28.50 | 20.50 | 21.00 | 11.50 | 15.50 | 15.00 | 10.00 | 0.00 | .50 | 0.00 |

Raingauge No 4 UPPER CALDERWOOD, Coordinates = 88.20 East 74.80 North
Total rain = 503.00 mm , Starting Time and Centroid = 0.0 %1858.4 min

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1.50 | 6.50 | 5.00 | 1.00 | 7.00 | 8.50 | 12.00 | 2.50 | 1.50 | 5.00 |
| 3.00 | .50 | 0.00 | 1.00 | 9.50 | 13.00 | 6.00 | 4.00 | 3.00 | 21.00 |
| 5.00 | 4.50 | 2.50 | 4.00 | 3.00 | 6.50 | 5.00 | 12.00 | 17.00 | 21.00 |
| 17.00 | 23.00 | 15.50 | 13.00 | 24.50 | 9.00 | 14.00 | 13.50 | 15.00 | 10.00 |
| 29.00 | 13.50 | 21.00 | 35.00 | 9.50 | 39.00 | 4.50 | 0.00 | 1.50 | 3.50 |

Weighting Factors

| Subarea | Nearest Gauges and Weighting Factors | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .854 | 4 | .077 | 2 | .041 | 3 | .028 |
| 2 | 1 | .868 | 4 | .082 | 2 | .031 | 3 | .018 |
| 3 | 1 | .735 | 4 | .189 | 2 | .050 | 3 | .026 |
| 4 | 1 | .996 | 4 | .002 | 2 | .001 | 3 | .001 |
| 5 | 1 | .501 | 4 | .399 | 2 | .069 | 3 | .031 |
| 6 | 1 | .628 | 4 | .246 | 2 | .088 | 3 | .039 |
| 7 | 1 | .810 | 4 | .089 | 2 | .058 | 3 | .043 |
| 8 | 1 | .770 | 4 | .104 | 2 | .074 | 3 | .051 |
| 9 | 1 | .449 | 2 | .214 | 4 | .208 | 3 | .128 |
| 10 | 2 | .304 | 3 | .303 | 1 | .231 | 4 | .162 |
| 11 | 4 | .319 | 2 | .288 | 1 | .288 | 3 | .105 |
| 12 | 2 | .483 | 4 | .258 | 1 | .143 | 3 | .117 |
| 13 | 1 | .569 | 4 | .156 | 2 | .147 | 3 | .129 |
| 14 | 2 | .544 | 3 | .241 | 4 | .122 | 1 | .093 |
| 15 | 3 | .498 | 2 | .262 | 1 | .131 | 4 | .109 |
| 16 | 3 | .715 | 2 | .166 | 1 | .060 | 4 | .058 |
| 17 | 2 | .511 | 3 | .376 | 4 | .067 | 1 | .046 |
| 18 | 2 | 1.000 | 3 | 0.000 | 4 | 0.000 | 1 | 0.000 |
| 19 | 3 | .599 | 2 | .300 | 4 | .063 | 1 | .038 |
| 20 | 2 | .635 | 3 | .235 | 4 | .089 | 1 | .041 |
| 21 | 3 | .586 | 2 | .284 | 4 | .080 | 1 | .050 |
| 22 | 3 | .492 | 2 | .313 | 4 | .118 | 1 | .076 |
| 23 | 3 | .465 | 2 | .349 | 4 | .116 | 1 | .070 |
| 24 | 3 | .487 | 2 | .360 | 4 | .097 | 1 | .056 |
| 25 | 2 | .478 | 3 | .344 | 4 | .118 | 1 | .060 |
| 26 | 2 | .423 | 3 | .371 | 4 | .134 | 1 | .071 |
| 27 | 4 | .712 | 1 | .201 | 2 | .062 | 3 | .025 |
| 28 | 4 | .982 | 2 | .009 | 1 | .007 | 3 | .002 |
| 29 | 4 | .577 | 2 | .300 | 1 | .067 | 3 | .056 |
| 30 | 2 | .582 | 4 | .208 | 3 | .143 | 1 | .067 |
| 31 | 2 | .482 | 3 | .239 | 4 | .195 | 1 | .084 |
| 32 | 2 | .425 | 3 | .240 | 4 | .232 | 1 | .103 |
| 33 | 2 | .435 | 4 | .238 | 3 | .226 | 1 | .101 |

# H Y D R O G R A P H   O U T P U T

Hydrograph Output for Subarea 12

Storm Total = 486.18 mm, Centroid at %1852.2 min, Subarea = 340 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Inflow | Type 0 W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 8.103 | 4.391 | 1.5 | | | 0.0 | 2.9 | |
| 240.0 | 14.495 | 5.579 | 2.1 | | | 0.0 | 34.2 | |
| 360.0 | 29.513 | 6.732 | 7.1 | | | 0.0 | 61.9 | |
| 480.0 | 43.344 | 7.187 | 4.5 | | | 0.0 | 57.4 | |
| 600.0 | 52.390 | 7.374 | 3.5 | | | 0.0 | 59.9 | |
| 720.0 | 54.451 | 7.447 | 1.5 | | | 0.0 | 47.4 | |
| 840.0 | 55.394 | 7.514 | .7 | | | 0.0 | 26.9 | |
| 960.0 | 73.067 | 7.730 | 9.0 | | | 0.0 | 95.6 | |
| 1080.0 | 88.295 | 7.852 | 5.0 | | | 0.0 | 77.8 | |
| 1200.0 | 102.684 | 7.936 | 7.9 | | | 0.0 | 96.9 | |
| 1320.0 | 113.826 | 7.988 | 4.1 | | | 0.0 | 68.3 | |
| 1440.0 | 119.519 | 8.011 | 2.9 | | | 0.0 | 40.4 | |
| 1560.0 | 129.089 | 8.045 | 5.8 | | | 0.0 | 52.8 | |
| 1680.0 | 146.063 | 8.095 | 10.5 | | | 0.0 | 78.9 | |
| 1800.0 | 176.344 | 8.161 | 14.5 | | | 0.0 | 139.7 | |
| 1920.0 | 213.367 | 8.217 | 20.9 | | | 0.0 | 184.4 | |
| 2040.0 | 234.497 | 8.241 | 10.3 | | | 0.0 | 149.4 | |
| 2160.0 | 281.404 | 8.282 | 18.3 | | | 0.0 | 140.7 | |
| 2280.0 | 299.776 | 8.295 | 8.8 | | | 0.0 | 129.9 | |
| 2400.0 | 359.675 | 8.328 | 36.5 | | | 0.0 | 159.5 | |
| 2520.0 | 393.588 | 8.342 | 14.0 | | | 0.0 | 166.4 | |
| 2640.0 | 433.579 | 8.356 | 20.1 | | | 0.0 | 259.2 | |
| 2760.0 | 479.263 | 8.369 | 17.4 | | | 0.0 | 229.0 | |
| 2880.0 | 485.655 | 8.371 | 2.3 | | | 0.0 | 105.7 | |
| 3000.0 | 486.144 | 8.371 | .6 | | | 0.0 | 46.0 | |
| 3120.0 | 486.144 | 8.371 | .2 | | | 0.0 | 16.9 | |
| 3240.0 | 486.144 | 8.371 | .1 | | | 0.0 | 6.4 | |
| 3360.0 | 486.144 | 8.371 | .1 | | | 0.0 | 3.0 | |
| 3480.0 | 486.144 | 8.371 | .0 | | | 0.0 | 1.7 | |
| 3600.0 | 486.144 | 8.371 | .0 | | | 0.0 | 1.1 | |
| 3720.0 | 486.144 | 8.371 | .0 | | | 0.0 | .8 | |
| 3840.0 | 486.144 | 8.371 | .0 | | | 0.0 | .5 | |
| 3960.0 | 486.144 | 8.371 | .0 | | | 0.0 | .4 | |
| 4080.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .3 | |
| 4200.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .2 | |
| 4320.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .2 | |
| 4440.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .2 | |
| 4560.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .1 | |
| 4680.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .1 | |
| 4800.0 | 486.144 | 8.371 | 0.0 | | | 0.0 | .1 | |

Runoff Depth = 478.6 mm , Runoff Peak = 38.0 m3/s at 2396.0 min
Runoff Volume = 1627.3 m3E3

Hydrograph Output for Subarea 20

Storm Total = 466.43 mm, Centroid at %1859.9 min, Subarea = 490 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | Basin Type 2 W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 6.601 | 3.965 | .7 | 2.6 | 0.0 | 0.0 | 2.6 | |
| 240.0 | 13.303 | 5.423 | 2.3 | 39.5 | .0 | 0.0 | 24.1 | |
| 360.0 | 26.505 | 6.592 | 7.6 | 97.2 | .1 | 0.0 | 78.1 | |
| 480.0 | 40.812 | 7.133 | 7.5 | 106.6 | .2 | 0.0 | 107.2 | |
| 600.0 | 49.859 | 7.336 | 5.8 | 98.9 | .2 | 0.0 | 101.8 | |
| 720.0 | 52.071 | 7.417 | 2.7 | 73.7 | .1 | 0.0 | 82.9 | |
| 840.0 | 52.708 | 7.483 | 1.2 | 44.5 | .1 | 0.0 | 53.9 | |
| 960.0 | 67.953 | 7.694 | 9.4 | 132.9 | .1 | 0.0 | 96.3 | |
| 1080.0 | 83.970 | 7.838 | 8.6 | 143.6 | .2 | 0.0 | 147.4 | |
| 1200.0 | 96.803 | 7.921 | 9.8 | 165.4 | .2 | 0.0 | 156.1 | |
| 1320.0 | 108.665 | 7.981 | 7.1 | 132.1 | .2 | 0.0 | 147.2 | |
| 1440.0 | 114.194 | 8.006 | 4.5 | 85.7 | .2 | 0.0 | 100.5 | |
| 1560.0 | 122.638 | 8.039 | 6.5 | 94.4 | .1 | 0.0 | 87.8 | |
| 1680.0 | 137.616 | 8.088 | 11.6 | 146.4 | .2 | 0.0 | 127.5 | |
| 1800.0 | 166.365 | 8.158 | 19.3 | 243.2 | .3 | 0.0 | 209.5 | |
| 1920.0 | 200.979 | 8.217 | 27.2 | 348.2 | .5 | 0.0 | 314.6 | |
| 2040.0 | 221.955 | 8.244 | 14.2 | 273.5 | .5 | 0.0 | 310.0 | |
| 2160.0 | 266.922 | 8.288 | 27.2 | 321.5 | .5 | 0.0 | 294.8 | |
| 2280.0 | 285.418 | 8.302 | 12.9 | 238.7 | .4 | 0.0 | 276.9 | |
| 2400.0 | 338.427 | 8.334 | 46.1 | 430.4 | .5 | 0.0 | 347.2 | |
| 2520.0 | 374.716 | 8.351 | 21.7 | 344.8 | .6 | 0.0 | 396.5 | |
| 2640.0 | 411.473 | 8.365 | 26.2 | 404.6 | .6 | 0.0 | 369.9 | |
| 2760.0 | 457.044 | 8.379 | 27.1 | 418.7 | .6 | 0.0 | 420.8 | |
| 2880.0 | 465.923 | 8.382 | 6.2 | 211.7 | .4 | 0.0 | 292.1 | |
| 3000.0 | 466.426 | 8.382 | 1.9 | 88.1 | .2 | 0.0 | 118.8 | |
| 3120.0 | 466.426 | 8.382 | .8 | 35.2 | .1 | 0.0 | 49.1 | |
| 3240.0 | 466.426 | 8.382 | .4 | 14.0 | .0 | 0.0 | 19.2 | |
| 3360.0 | 466.426 | 8.382 | .3 | 6.3 | .0 | 0.0 | 8.1 | |
| 3480.0 | 466.426 | 8.382 | .2 | 3.4 | 0.0 | 0.0 | 4.1 | |
| 3600.0 | 466.426 | 8.382 | .1 | 2.1 | 0.0 | 0.0 | 2.4 | |
| 3720.0 | 466.426 | 8.382 | .1 | 1.4 | 0.0 | 0.0 | 1.6 | |
| 3840.0 | 466.426 | 8.382 | .1 | 1.0 | 0.0 | 0.0 | 1.1 | |
| 3960.0 | 466.426 | 8.382 | .0 | .8 | 0.0 | 0.0 | .8 | |
| 4080.0 | 466.426 | 8.382 | .0 | .6 | 0.0 | 0.0 | .6 | |
| 4200.0 | 466.426 | 8.382 | .0 | .5 | 0.0 | 0.0 | .5 | |
| 4320.0 | 466.426 | 8.382 | .0 | .4 | 0.0 | 0.0 | .4 | |
| 4440.0 | 466.426 | 8.382 | .0 | .3 | 0.0 | 0.0 | .3 | |
| 4560.0 | 466.426 | 8.382 | .0 | .3 | 0.0 | 0.0 | .3 | |
| 4680.0 | 466.426 | 8.382 | .0 | .2 | 0.0 | 0.0 | .2 | |
| 4800.0 | 466.426 | 8.382 | .0 | .2 | 0.0 | 0.0 | .2 | |

Runoff Depth = 458.7 mm , Runoff Peak = 48.0 m3/s at 2408.0 min
Runoff Volume = 2247.8 m3E3

Hydrograph Output for Subarea 25

Storm Total = 467.02 mm, Centroid at %1859.2 min, Subarea = 245 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type Inflow | Q W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 7.079 | 3.898 | .3 | | | 0.0 | .3 | |
| 240.0 | 13.454 | 5.126 | .9 | | | 0.0 | .9 | |
| 360.0 | 27.109 | 6.207 | 3.0 | | | 0.0 | 3.0 | |
| 480.0 | 41.065 | 6.678 | 3.6 | | | 0.0 | 3.6 | |
| 600.0 | 50.124 | 6.862 | 3.0 | | | 0.0 | 3.0 | |
| 720.0 | 52.238 | 6.934 | 1.6 | | | 0.0 | 1.6 | |
| 840.0 | 52.808 | 6.995 | .9 | | | 0.0 | .9 | |
| 960.0 | 68.744 | 7.192 | 4.0 | | | 0.0 | 4.0 | |
| 1080.0 | 84.312 | 7.318 | 4.2 | | | 0.0 | 4.2 | |
| 1200.0 | 97.530 | 7.395 | 4.8 | | | 0.0 | 4.8 | |
| 1320.0 | 109.005 | 7.448 | 3.8 | | | 0.0 | 3.8 | |
| 1440.0 | 114.540 | 7.470 | 2.5 | | | 0.0 | 2.5 | |
| 1560.0 | 123.297 | 7.501 | 3.2 | | | 0.0 | 3.2 | |
| 1680.0 | 138.596 | 7.546 | 5.2 | | | 0.0 | 5.2 | |
| 1800.0 | 167.583 | 7.610 | 8.9 | | | 0.0 | 8.9 | |
| 1920.0 | 202.777 | 7.663 | 12.7 | | | 0.0 | 12.7 | |
| 2040.0 | 222.840 | 7.687 | 7.6 | | | 0.0 | 7.6 | |
| 2160.0 | 268.502 | 7.727 | 13.3 | | | 0.0 | 13.3 | |
| 2280.0 | 286.317 | 7.739 | 7.2 | | | 0.0 | 7.2 | |
| 2400.0 | 341.541 | 7.769 | 20.6 | | | 0.0 | 20.6 | |
| 2520.0 | 376.065 | 7.784 | 11.7 | | | 0.0 | 11.7 | |
| 2640.0 | 413.339 | 7.797 | 13.0 | | | 0.0 | 13.0 | |
| 2760.0 | 458.800 | 7.810 | 13.8 | | | 0.0 | 13.8 | |
| 2880.0 | 466.516 | 7.812 | 4.3 | | | 0.0 | 4.3 | |
| 3000.0 | 467.019 | 7.812 | 1.7 | | | 0.0 | 1.7 | |
| 3120.0 | 467.019 | 7.812 | .8 | | | 0.0 | .8 | |
| 3240.0 | 467.019 | 7.812 | .5 | | | 0.0 | .5 | |
| 3360.0 | 467.019 | 7.812 | .3 | | | 0.0 | .3 | |
| 3480.0 | 467.019 | 7.812 | .2 | | | 0.0 | .2 | |
| 3600.0 | 467.019 | 7.812 | .1 | | | 0.0 | .1 | |
| 3720.0 | 467.019 | 7.812 | .1 | | | 0.0 | .1 | |
| 3840.0 | 467.019 | 7.812 | .1 | | | 0.0 | .1 | |
| 3960.0 | 467.019 | 7.812 | .1 | | | 0.0 | .1 | |
| 4080.0 | 467.019 | 7.812 | .1 | | | 0.0 | .1 | |
| 4200.0 | 467.019 | 7.812 | .0 | | | 0.0 | .1 | |
| 4320.0 | 467.019 | 7.812 | .0 | | | 0.0 | .0 | |
| 4440.0 | 467.019 | 7.812 | .0 | | | 0.0 | .0 | |
| 4560.0 | 467.019 | 7.812 | .0 | | | 0.0 | .0 | |
| 4680.0 | 467.019 | 7.812 | .0 | | | 0.0 | .0 | |
| 4800.0 | 467.019 | 7.812 | .0 | | | 0.0 | .0 | |

Runoff Depth = 459.4 mm , Runoff Peak = 21.1 m3/s at 2404.0 min
Runoff Volume = 1125.6 m3E3

Hydrograph Output for Subarea 26

Storm Total = 468.22 mm, Centroid at %1858.5 min, Subarea = 250 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 7.097 | 4.011 | .3 | 2.2 | 0.0 | 0.0 | 2.2 | |
| 240.0 | 13.488 | 5.291 | .8 | 4.1 | .0 | 0.0 | 3.5 | |
| 360.0 | 27.178 | 6.421 | 3.0 | 9.4 | .0 | 0.0 | 9.1 | |
| 480.0 | 41.171 | 6.913 | 3.6 | 11.7 | .1 | 0.0 | 11.6 | |
| 600.0 | 50.253 | 7.106 | 3.1 | 11.2 | .1 | 0.0 | 11.3 | |
| 720.0 | 52.372 | 7.181 | 1.7 | 8.9 | .0 | 0.0 | 9.2 | |
| 840.0 | 52.944 | 7.244 | .9 | 4.4 | .0 | 0.0 | 5.0 | |
| 960.0 | 68.921 | 7.451 | 4.0 | 19.9 | .1 | 0.0 | 17.1 | |
| 1080.0 | 84.528 | 7.582 | 4.4 | 22.9 | .1 | 0.0 | 24.4 | |
| 1200.0 | 97.781 | 7.663 | 4.8 | 34.0 | .1 | 0.0 | 31.3 | |
| 1320.0 | 109.285 | 7.718 | 3.9 | 22.3 | .1 | 0.0 | 26.0 | |
| 1440.0 | 114.835 | 7.741 | 2.6 | 13.6 | .1 | 0.0 | 12.4 | |
| 1560.0 | 123.614 | 7.774 | 3.2 | 15.4 | .1 | 0.0 | 15.9 | |
| 1680.0 | 138.952 | 7.821 | 5.2 | 23.3 | .1 | 0.0 | 21.7 | |
| 1800.0 | 168.014 | 7.887 | 9.1 | 37.0 | .2 | 0.0 | 36.0 | |
| 1920.0 | 203.299 | 7.944 | 12.9 | 57.5 | .2 | 0.0 | 55.0 | |
| 2040.0 | 223.413 | 7.968 | 7.9 | 38.5 | .2 | 0.0 | 43.1 | |
| 2160.0 | 269.193 | 8.010 | 13.6 | 62.9 | .2 | 0.0 | 55.9 | |
| 2280.0 | 287.054 | 8.023 | 7.5 | 36.0 | .2 | 0.0 | 45.0 | |
| 2400.0 | 342.419 | 8.055 | 20.7 | 82.0 | .3 | 0.0 | 68.6 | |
| 2520.0 | 377.031 | 8.070 | 12.1 | 67.7 | .4 | 0.0 | 79.2 | |
| 2640.0 | 414.401 | 8.083 | 13.2 | 56.1 | .2 | 0.0 | 50.0 | |
| 2760.0 | 459.979 | 8.097 | 14.2 | 56.6 | .3 | 0.0 | 60.7 | |
| 2880.0 | 467.715 | 8.099 | 4.6 | 21.8 | .1 | 0.0 | 24.4 | |
| 3000.0 | 468.220 | 8.099 | 1.8 | 7.4 | .0 | 0.0 | 7.9 | |
| 3120.0 | 468.220 | 8.099 | .9 | 3.2 | .0 | 0.0 | 3.5 | |
| 3240.0 | 468.220 | 8.099 | .5 | 1.7 | 0.0 | 0.0 | 1.7 | |
| 3360.0 | 468.220 | 8.099 | .3 | 1.0 | 0.0 | 0.0 | 1.1 | |
| 3480.0 | 468.220 | 8.099 | .2 | .7 | 0.0 | 0.0 | .7 | |
| 3600.0 | 468.220 | 8.099 | .2 | .5 | 0.0 | 0.0 | .5 | |
| 3720.0 | 468.220 | 8.099 | .1 | .4 | 0.0 | 0.0 | .3 | |
| 3840.0 | 468.220 | 8.099 | .1 | .3 | 0.0 | 0.0 | .3 | |
| 3960.0 | 468.220 | 8.099 | .1 | .2 | 0.0 | 0.0 | .2 | |
| 4080.0 | 468.220 | 8.099 | .1 | .2 | 0.0 | 0.0 | .2 | |
| 4200.0 | 468.220 | 8.099 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4320.0 | 468.220 | 8.099 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4440.0 | 468.220 | 8.099 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4560.0 | 468.220 | 8.099 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4680.0 | 468.220 | 8.099 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4800.0 | 468.220 | 8.099 | .0 | .1 | 0.0 | 0.0 | .1 | |

Runoff Depth = 460.3 mm , Runoff Peak = 21.3 m3/s at 2404.0 min
Runoff Volume = 1150.8 m3E3

Hydrograph Output for Subarea 30

Storm Total = 475.72 mm, Centroid at %1857.4 min, Subarea = 480 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 6.254 | 3.848 | .3 | .6 | 0.0 | 0.0 | .6 | |
| 240.0 | 13.431 | 5.437 | 1.7 | 7.5 | .0 | 0.0 | 2.0 | |
| 360.0 | 26.452 | 6.585 | 5.9 | 25.2 | .1 | 0.0 | 9.6 | |
| 480.0 | 41.421 | 7.144 | 7.6 | 28.2 | .1 | 0.0 | 18.7 | |
| 600.0 | 50.648 | 7.346 | 6.2 | 22.2 | .1 | 0.0 | 22.1 | |
| 720.0 | 53.006 | 7.426 | 3.3 | 12.6 | .1 | 0.0 | 19.6 | |
| 840.0 | 53.724 | 7.491 | 1.7 | 6.5 | .1 | 0.0 | 14.3 | |
| 960.0 | 68.591 | 7.693 | 7.5 | 36.5 | .1 | 0.0 | 18.1 | |
| 1080.0 | 85.405 | 7.840 | 9.0 | 33.7 | .2 | 0.0 | 27.1 | |
| 1200.0 | 98.118 | 7.920 | 9.3 | 56.6 | .2 | 0.0 | 36.6 | |
| 1320.0 | 110.627 | 7.982 | 7.8 | 39.2 | .3 | 0.0 | 42.6 | |
| 1440.0 | 116.265 | 8.006 | 5.1 | 22.0 | .2 | 0.0 | 36.3 | |
| 1560.0 | 124.570 | 8.038 | 6.0 | 23.8 | .2 | 0.0 | 29.2 | |
| 1680.0 | 139.539 | 8.085 | 9.9 | 41.1 | .2 | 0.0 | 30.9 | |
| 1800.0 | 168.657 | 8.154 | 17.9 | 80.4 | .3 | 0.0 | 46.7 | |
| 1920.0 | 203.413 | 8.212 | 24.8 | 103.1 | .5 | 0.0 | 70.6 | |
| 2040.0 | 225.764 | 8.240 | 15.5 | 75.9 | .5 | 0.0 | 80.6 | |
| 2160.0 | 270.979 | 8.283 | 27.0 | 75.0 | .5 | 0.0 | 77.9 | |
| 2280.0 | 290.561 | 8.297 | 14.5 | 63.3 | .5 | 0.0 | 73.2 | |
| 2400.0 | 342.440 | 8.328 | 39.5 | 84.0 | .5 | 0.0 | 73.5 | |
| 2520.0 | 381.298 | 8.346 | 24.0 | 79.2 | .5 | 0.0 | 77.8 | |
| 2640.0 | 418.310 | 8.359 | 25.6 | 127.6 | .6 | 0.0 | 91.4 | |
| 2760.0 | 464.960 | 8.374 | 28.2 | 152.0 | .8 | 0.0 | 117.0 | |
| 2880.0 | 475.212 | 8.376 | 9.0 | 55.8 | .7 | 0.0 | 110.1 | |
| 3000.0 | 475.725 | 8.376 | 3.2 | 16.9 | .5 | 0.0 | 71.0 | |
| 3120.0 | 475.725 | 8.376 | 1.5 | 6.9 | .3 | 0.0 | 39.7 | |
| 3240.0 | 475.725 | 8.376 | .8 | 2.8 | .1 | 0.0 | 21.2 | |
| 3360.0 | 475.725 | 8.376 | .5 | 1.4 | .1 | 0.0 | 11.1 | |
| 3480.0 | 475.725 | 8.376 | .3 | .8 | .0 | 0.0 | 5.8 | |
| 3600.0 | 475.725 | 8.376 | .2 | .6 | .0 | 0.0 | 3.1 | |
| 3720.0 | 475.725 | 8.376 | .2 | .4 | .0 | 0.0 | 1.7 | |
| 3840.0 | 475.725 | 8.376 | .1 | .3 | 0.0 | 0.0 | 1.0 | |
| 3960.0 | 475.725 | 8.376 | .1 | .2 | 0.0 | 0.0 | .6 | |
| 4080.0 | 475.725 | 8.376 | .1 | .2 | 0.0 | 0.0 | .4 | |
| 4200.0 | 475.725 | 8.376 | .1 | .1 | 0.0 | 0.0 | .3 | |
| 4320.0 | 475.725 | 8.376 | .1 | .1 | 0.0 | 0.0 | .2 | |
| 4440.0 | 475.725 | 8.376 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4560.0 | 475.725 | 8.376 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4680.0 | 475.725 | 8.376 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 4800.0 | 475.725 | 8.376 | .0 | .1 | 0.0 | 0.0 | .1 | |

Runoff Depth = 467.7 mm , Runoff Peak = 42.8 m3/s at 2412.0 min
Runoff Volume = 2245.1 m3E3

Hydrograph Output for Subarea 31

Storm Total = 474.86 mm, Centroid at %1856.8 min, Subarea = 510 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 6.243 | 3.651 | .6 | 5.0 | 0.0 | 0.0 | 5.0 | |
| 240.0 | 13.407 | 5.116 | 2.0 | 25.1 | .0 | 0.0 | 10.2 | |
| 360.0 | 26.404 | 6.169 | 6.6 | 85.9 | .0 | 0.0 | 47.0 | |
| 480.0 | 41.345 | 6.681 | 8.0 | 135.4 | .1 | 0.0 | 98.8 | |
| 600.0 | 50.556 | 6.866 | 6.5 | 142.8 | .1 | 0.0 | 131.5 | |
| 720.0 | 52.910 | 6.939 | 3.4 | 121.2 | .1 | 0.0 | 131.9 | |
| 840.0 | 53.626 | 6.999 | 1.8 | 84.7 | .1 | 0.0 | 108.4 | |
| 960.0 | 68.466 | 7.183 | 8.3 | 124.8 | .1 | 0.0 | 105.5 | |
| 1080.0 | 85.250 | 7.318 | 9.4 | 191.1 | .2 | 0.0 | 148.1 | |
| 1200.0 | 97.940 | 7.391 | 10.0 | 228.4 | .2 | 0.0 | 198.2 | |
| 1320.0 | 110.425 | 7.448 | 8.1 | 226.6 | .2 | 0.0 | 222.1 | |
| 1440.0 | 116.054 | 7.469 | 5.3 | 171.5 | .2 | 0.0 | 203.4 | |
| 1560.0 | 124.344 | 7.498 | 6.5 | 143.1 | .2 | 0.0 | 165.9 | |
| 1680.0 | 139.285 | 7.542 | 10.8 | 178.4 | .2 | 0.0 | 161.7 | |
| 1800.0 | 168.350 | 7.605 | 19.1 | 282.9 | .2 | 0.0 | 217.7 | |
| 1920.0 | 203.043 | 7.658 | 26.7 | 429.7 | .3 | 0.0 | 330.4 | |
| 2040.0 | 225.353 | 7.683 | 16.2 | 452.4 | .4 | 0.0 | 420.3 | |
| 2160.0 | 270.486 | 7.722 | 28.5 | 458.7 | .5 | 0.0 | 449.0 | |
| 2280.0 | 290.033 | 7.735 | 15.2 | 418.5 | .5 | 0.0 | 440.5 | |
| 2400.0 | 341.817 | 7.763 | 42.8 | 507.2 | .5 | 0.0 | 458.7 | |
| 2520.0 | 380.604 | 7.779 | 25.1 | 561.9 | .5 | 0.0 | 520.4 | |
| 2640.0 | 417.548 | 7.792 | 27.3 | 550.5 | .6 | 0.0 | 549.5 | |
| 2760.0 | 464.113 | 7.805 | 29.6 | 607.6 | .6 | 0.0 | 573.5 | |
| 2880.0 | 474.347 | 7.808 | 9.1 | 480.6 | .6 | 0.0 | 549.6 | |
| 3000.0 | 474.859 | 7.808 | 3.2 | 258.6 | .4 | 0.0 | 403.3 | |
| 3120.0 | 474.859 | 7.808 | 1.5 | 119.0 | .2 | 0.0 | 228.9 | |
| 3240.0 | 474.859 | 7.808 | .8 | 54.5 | .1 | 0.0 | 113.4 | |
| 3360.0 | 474.859 | 7.808 | .5 | 25.7 | .1 | 0.0 | 53.8 | |
| 3480.0 | 474.859 | 7.808 | .4 | 13.0 | .0 | 0.0 | 25.8 | |
| 3600.0 | 474.859 | 7.808 | .3 | 7.2 | .0 | 0.0 | 13.0 | |
| 3720.0 | 474.859 | 7.808 | .2 | 4.3 | 0.0 | 0.0 | 7.1 | |
| 3840.0 | 474.859 | 7.808 | .1 | 2.8 | 0.0 | 0.0 | 4.2 | |
| 3960.0 | 474.859 | 7.808 | .1 | 1.9 | 0.0 | 0.0 | 2.7 | |
| 4080.0 | 474.859 | 7.808 | .1 | 1.4 | 0.0 | 0.0 | 1.9 | |
| 4200.0 | 474.859 | 7.808 | .1 | 1.0 | 0.0 | 0.0 | 1.3 | |
| 4320.0 | 474.859 | 7.808 | .1 | .8 | 0.0 | 0.0 | 1.0 | |
| 4440.0 | 474.859 | 7.808 | .1 | .6 | 0.0 | 0.0 | .8 | |
| 4560.0 | 474.859 | 7.808 | .0 | .5 | 0.0 | 0.0 | .6 | |
| 4680.0 | 474.859 | 7.808 | .0 | .4 | 0.0 | 0.0 | .5 | |
| 4800.0 | 474.859 | 7.808 | .0 | .4 | 0.0 | 0.0 | .4 | |

Runoff Depth = 467.4 mm , Runoff Peak = 46.2 m3/s at 2412.0 min
Runoff Volume = 2383.8 m3E3

Eydrograph Output for Subarea 32

Storm Total = 478.26 mm, Centroid at %1855.5 min, Subarea = 33 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 7.971 | 4.244 | .1 | .1 | 0.0 | 0.0 | .1 | |
| 240.0 | 14.258 | 5.389 | .2 | .2 | 0.0 | 0.0 | .0 | |
| 360.0 | 29.032 | 6.503 | .6 | .6 | .0 | 0.0 | .1 | |
| 480.0 | 42.638 | 6.944 | .5 | .5 | .1 | 0.0 | .2 | |
| 600.0 | 51.536 | 7.125 | .4 | .4 | .1 | 0.0 | .2 | |
| 720.0 | 53.564 | 7.197 | .2 | .2 | .1 | 0.0 | .2 | |
| 840.0 | 54.491 | 7.262 | .1 | .1 | .1 | 0.0 | .2 | |
| 960.0 | 71.876 | 7.471 | .7 | .7 | .1 | 0.0 | .3 | |
| 1080.0 | 86.856 | 7.590 | .5 | .5 | .1 | 0.0 | .3 | |
| 1200.0 | 101.011 | 7.672 | .7 | .7 | .2 | 0.0 | .4 | |
| 1320.0 | 111.972 | 7.722 | .5 | .5 | .2 | 0.0 | .4 | |
| 1440.0 | 117.572 | 7.744 | .3 | .3 | .2 | 0.0 | .4 | |
| 1560.0 | 126.986 | 7.777 | .5 | .5 | .2 | 0.0 | .4 | |
| 1680.0 | 143.684 | 7.825 | .9 | .9 | .2 | 0.0 | .5 | |
| 1800.0 | 173.472 | 7.890 | 1.3 | 1.3 | .2 | 0.0 | .6 | |
| 1920.0 | 209.891 | 7.944 | 1.9 | 1.9 | .3 | 0.0 | .8 | |
| 2040.0 | 230.677 | 7.968 | 1.0 | 1.0 | .4 | 0.0 | 1.0 | |
| 2160.0 | 276.819 | 8.008 | 1.8 | 1.8 | .4 | 0.0 | 1.1 | |
| 2280.0 | 294.891 | 8.020 | .9 | .9 | .4 | 0.0 | 1.1 | |
| 2400.0 | 353.814 | 8.052 | 3.2 | 3.2 | .5 | 0.0 | 1.3 | |
| 2520.0 | 387.176 | 8.066 | 1.5 | 1.5 | .6 | 0.0 | 1.5 | |
| 2640.0 | 426.515 | 8.079 | 1.9 | 1.9 | .6 | 0.0 | 1.6 | |
| 2760.0 | 471.455 | 8.092 | 1.8 | 1.8 | .6 | 0.0 | 1.6 | |
| 2880.0 | 477.742 | 8.093 | .4 | .4 | .6 | 0.0 | 1.5 | |
| 3000.0 | 478.223 | 8.094 | .1 | .1 | .5 | 0.0 | 1.2 | |
| 3120.0 | 478.223 | 8.094 | .1 | .1 | .4 | 0.0 | 1.0 | |
| 3240.0 | 478.223 | 8.094 | .0 | .0 | .3 | 0.0 | .8 | |
| 3360.0 | 478.223 | 8.094 | .0 | .0 | .2 | 0.0 | .6 | |
| 3480.0 | 478.223 | 8.094 | .0 | .0 | .2 | 0.0 | .5 | |
| 3600.0 | 478.223 | 8.094 | 0.0 | 0.0 | .2 | 0.0 | .4 | |
| 3720.0 | 478.223 | 8.094 | 0.0 | 0.0 | .1 | 0.0 | .3 | |
| 3840.0 | 478.223 | 8.094 | 0.0 | 0.0 | .1 | 0.0 | .2 | |
| 3960.0 | 478.223 | 8.094 | 0.0 | 0.0 | .1 | 0.0 | .2 | |
| 4080.0 | 478.223 | 8.094 | 0.0 | 0.0 | .1 | 0.0 | .2 | |
| 4200.0 | 478.223 | 8.094 | 0.0 | 0.0 | .0 | 0.0 | .1 | |
| 4320.0 | 478.223 | 8.094 | 0.0 | 0.0 | .0 | 0.0 | .1 | |
| 4440.0 | 478.223 | 8.094 | 0.0 | 0.0 | .0 | 0.0 | .1 | |
| 4560.0 | 478.223 | 8.094 | 0.0 | 0.0 | .0 | 0.0 | .1 | |
| 4680.0 | 478.223 | 8.094 | 0.0 | 0.0 | .0 | 0.0 | .0 | |
| 4800.0 | 478.223 | 8.094 | 0.0 | 0.0 | .0 | 0.0 | .0 | |

Runoff Depth = 470.8 mm , Runoff Peak = 3.3 m3/s at 2396.0 min
Runoff Volume = 155.4 m3E3

Hydrograph Output for Subarea 33

Storm Total = 478.61 mm, Centroid at %1855.5 min, Subarea = 34 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | Basin Type 2 W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 120.0 | 7.977 | 4.127 | .1 | .4 | 0.0 | 0.0 | .4 | |
| 240.0 | 14.269 | 5.224 | .2 | 10.3 | .0 | 0.0 | 9.6 | |
| 360.0 | 29.054 | 6.289 | .6 | 46.8 | .0 | 0.0 | 44.9 | |
| 480.0 | 42.669 | 6.710 | .5 | 98.1 | .1 | 0.0 | 96.3 | |
| 600.0 | 51.575 | 6.883 | .4 | 131.3 | .1 | 0.0 | 130.7 | |
| 720.0 | 53.603 | 6.951 | .2 | 132.3 | .1 | 0.0 | 132.8 | |
| 840.0 | 54.531 | 7.013 | .1 | 109.3 | .1 | 0.0 | 110.4 | |
| 960.0 | 71.929 | 7.213 | .7 | 106.5 | .1 | 0.0 | 105.7 | |
| 1080.0 | 86.920 | 7.326 | .6 | 148.0 | .2 | 0.0 | 145.8 | |
| 1200.0 | 101.086 | 7.404 | .7 | 198.1 | .2 | 0.0 | 196.5 | |
| 1320.0 | 112.054 | 7.451 | .5 | 222.4 | .2 | 0.0 | 222.1 | |
| 1440.0 | 117.659 | 7.472 | .3 | 204.6 | .2 | 0.0 | 206.0 | |
| 1560.0 | 127.080 | 7.504 | .5 | 167.8 | .2 | 0.0 | 169.0 | |
| 1680.0 | 143.790 | 7.550 | .9 | 163.2 | .2 | 0.0 | 162.4 | |
| 1800.0 | 173.600 | 7.611 | 1.4 | 218.3 | .2 | 0.0 | 215.2 | |
| 1920.0 | 210.046 | 7.663 | 2.0 | 330.3 | .3 | 0.0 | 325.4 | |
| 2040.0 | 230.848 | 7.686 | 1.1 | 420.1 | .4 | 0.0 | 418.3 | |
| 2160.0 | 277.025 | 7.724 | 1.8 | 451.1 | .5 | 0.0 | 450.6 | |
| 2280.0 | 295.110 | 7.736 | .9 | 442.8 | .5 | 0.0 | 443.8 | |
| 2400.0 | 354.077 | 7.766 | 3.4 | 462.9 | .5 | 0.0 | 460.7 | |
| 2520.0 | 387.463 | 7.779 | 1.5 | 521.9 | .5 | 0.0 | 519.8 | |
| 2640.0 | 426.832 | 7.792 | 1.9 | 552.3 | .6 | 0.0 | 552.0 | |
| 2760.0 | 471.805 | 7.804 | 1.8 | 576.4 | .6 | 0.0 | 575.0 | |
| 2880.0 | 478.097 | 7.806 | .4 | 552.1 | .6 | 0.0 | 554.9 | |
| 3000.0 | 478.578 | 7.806 | .1 | 408.3 | .4 | 0.0 | 415.6 | |
| 3120.0 | 478.578 | 7.806 | .1 | 234.3 | .3 | 0.0 | 239.9 | |
| 3240.0 | 478.578 | 7.806 | .0 | 117.1 | .1 | 0.0 | 120.3 | |
| 3360.0 | 478.578 | 7.806 | .0 | 55.9 | .1 | 0.0 | 57.3 | |
| 3480.0 | 478.578 | 7.806 | .0 | 27.0 | .0 | 0.0 | 27.8 | |
| 3600.0 | 478.578 | 7.806 | 0.0 | 13.8 | .0 | 0.0 | 14.0 | |
| 3720.0 | 478.578 | 7.806 | 0.0 | 7.6 | 0.0 | 0.0 | 7.8 | |
| 3840.0 | 478.578 | 7.806 | 0.0 | 4.6 | 0.0 | 0.0 | 4.6 | |
| 3960.0 | 478.578 | 7.806 | 0.0 | 2.9 | 0.0 | 0.0 | 3.0 | |
| 4080.0 | 478.578 | 7.806 | 0.0 | 2.0 | 0.0 | 0.0 | 2.0 | |
| 4200.0 | 478.578 | 7.806 | 0.0 | 1.5 | 0.0 | 0.0 | 1.5 | |
| 4320.0 | 478.578 | 7.806 | 0.0 | 1.1 | 0.0 | 0.0 | 1.1 | |
| 4440.0 | 478.578 | 7.806 | 0.0 | .9 | 0.0 | 0.0 | .9 | |
| 4560.0 | 478.578 | 7.806 | 0.0 | .7 | 0.0 | 0.0 | .7 | |
| 4680.0 | 478.578 | 7.806 | 0.0 | .6 | 0.0 | 0.0 | .6 | |
| 4800.0 | 478.578 | 7.806 | 0.0 | .5 | 0.0 | 0.0 | .4 | |

Runoff Depth = 471.4 mm , Runoff Peak = 3.4 m3/s at 2396.0 min
Runoff Volume = 160.3 m3E3

O U T F L O W   S U M M A R Y

| Subarea No | Peak Runoff m3/s | Time of peak,min | Runoff Volume m3E3 | Peak Outflow m3/s | Time of peak,min |
|---|---|---|---|---|---|
| 1 | 37.4 | 2664.0 | 2214.5 | 37.4 | 2664.0 |
| 2 | 17.1 | 2656.0 | 1015.2 | 17.1 | 2656.0 |
| 3 | 1.9 | 2656.0 | 107.8 | 1.9 | 2656.0 |
| 4 | 74.2 | 2708.0 | 4472.6 | 122.4 | 2640.0 |
| 5 | 6.1 | 2732.0 | 366.0 | 6.1 | 2732.0 |
| 6 | 43.0 | 2672.0 | 2490.7 | 162.2 | 2640.0 |
| 7 | 6.3 | 2656.0 | 352.7 | 6.3 | 2656.0 |
| 8 | 12.3 | 2668.0 | 727.3 | 16.9 | 2640.0 |
| 9 | 44.6 | 2684.0 | 2515.0 | 52.7 | 2640.0 |
| 10 | 1.4 | 2388.0 | 57.6 | 1.4 | 2388.0 |
| 11 | 52.5 | 2752.0 | 2628.2 | 251.8 | 2640.0 |
| 12 | 38.0 | 2396.0 | 1627.3 | 259.2 | 2640.0 |
| 13 | 2.3 | 2672.0 | 129.6 | 2.3 | 2672.0 |
| 14 | 40.3 | 2404.0 | 1675.3 | 276.8 | 2640.0 |
| 15 | 11.1 | 2452.0 | 624.6 | 11.1 | 2452.0 |
| 16 | 3.6 | 2456.0 | 201.8 | 3.6 | 2456.0 |
| 17 | 86.7 | 2408.0 | 3937.9 | 96.1 | 2400.0 |
| 18 | 126.6 | 2412.0 | 5931.8 | 387.7 | 2400.0 |
| 19 | 17.4 | 2460.0 | 965.5 | 17.4 | 2460.0 |
| 20 | 48.0 | 2408.0 | 2247.8 | 420.8 | 2760.0 |
| 21 | 12.2 | 2460.0 | 676.9 | 12.2 | 2460.0 |
| 22 | 7.9 | 2456.0 | 434.7 | 7.9 | 2456.0 |
| 23 | 26.7 | 2460.0 | 1531.6 | 40.8 | 2400.0 |
| 24 | 6.5 | 2460.0 | 363.8 | 6.5 | 2460.0 |
| 25 | 21.1 | 2404.0 | 1125.6 | 21.1 | 2404.0 |
| 26 | 21.3 | 2404.0 | 1150.8 | 79.2 | 2520.0 |
| 27 | 9.7 | 2752.0 | 478.9 | 9.7 | 2752.0 |
| 28 | 38.4 | 2764.0 | 1832.8 | 45.9 | 2760.0 |
| 29 | 84.5 | 2768.0 | 4311.6 | 126.5 | 2760.0 |
| 30 | 42.8 | 2412.0 | 2245.1 | 117.0 | 2760.0 |
| 31 | 46.2 | 2412.0 | 2383.8 | 573.5 | 2760.0 |
| 32 | 3.3 | 2396.0 | 155.4 | 1.6 | 2760.0 |
| 33 | 3.4 | 2396.0 | 160.3 | 575.0 | 2760.0 |

Surcharge Flow Occurs in Subareas
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Surcharge Above 0 Percent of Drainage Element Capacity Occurs in Subareas
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

```
 NHL  NA  NRES  NRG  NNRG  NPRT  NOBS  NPFP  NWG  EXW  IPCS
   5  33    6    4     0     8     0     0    4  2.0     0
Macquarie Rivulet Reference Catchment - Ref : 81093
Storm of 7/6/91 - Rainfall Data from 9/6/91 2pm to 11/6/91 4pm
Lower floodplain storeages included in model as special storeages
SCS CN for pervious surface incresed to AMC 3 level in recognition
of the fact that significant earlier rain not modelled.
    TR      PRI       DT      DTR     TRI
  4800.0   120.0    4.00     60.0   720.0
 STDN1  STDN2  STCN1  STCN2  STDIA  STDS1  STDS2  STCTS   STCGI  CBF
 0.040  0.200   99.0   97.0  0.100  0.000  0.000  1.00    0.0 0.0000
Rain Gauge Data ID  NPT   STR   XRG    YRG   Raingauge Name
   1                50    0.0   84.20  72.20 CLOVER HILL
 3.5  9.5  10  2.5  13
 4  13  1.5  5.5  10.5
 5.5  4.5  0.5  2.5  11
 18  9  5.5  4  16
 8  4  3.5  2  5.5
 8.5  5.5  10.5  15.5  17.5
 21.5  19.5  18  12.5  20.5
 10.5  12  16  16.5  13
 24  17.5  23  36.5  33.5
 14  20.5  1.5  4.5  2
 2                  50    0.0   91.50  71.50 NORTH MACQUARIE
 0.5  7  4  2  5.5
 8.5  10.5  3  6  3
 0.5  1.5  0.0  0.5  6
 10.5  11.5  3.5  4.5  9
 8  3  2.5  3  1.5
 7.5  3.5  12  14  15
 12.5  23  10  9  27.5
 18.5  9  8  17  40
 19.5  13  17.5  20  27.5
 17.5  6.5  0.0  0.5  0.0
 3                  50    0.0   92.70  67.60 YELLOW ROCK
 0.5  7  5  0.5  5.5
 1  6.5  1  4.5  2
 0.5  4.5  0.0  0.0  4.5
 11.5  10.5  6.5  7.5  17
 9.5  3.5  3  3.5  1
 7  3  9.5  13  10.5
 16  19.5  12.5  8.5  18.5
 22.5  13  5.5  15.5  28
 28.5  20.5  21  11.5  15.5
 15  10  0.0  0.5  0.0
 4                  50    0.0   88.2   74.8 UPPER CALDERWOOD
 1.5  6.5  5  1  7
 8.5  12  2.5  1.5  5
 3  0.5  0.0  1  9.5
 13  6  4  3  21
 5  4.5  2.5  4  3
 6.5  5  12  17  21
 17  23  15.5  13  24.5
 9  14  13.5  15  10
 29  13.5  21  35  9.5
 39  4.5  0.0  1.5  3.5
```

Subareas for Hydrograph Output
12 20 25 26 30
31 32 33
Subareas with Basins
20 26 30 31 32
33

| Subarea ID | Area(ha) | Length(m) | Slope | Imp.Fr. | X-Coord | Y-Coord |
|---|---|---|---|---|---|---|
| 1 | 405.00 | 500.0 | 0.100 | 0.00 | 82.30 | 71.50 |
| 2 | 185.00 | 500.0 | 0.100 | 0.00 | 83.10 | 73.40 |
| 3 | 20.00 | 200.0 | 0.100 | 0.00 | 84.30 | 74.20 |
| 4 | 800.00 | 1000.0 | 0.200 | 0.00 | 84.40 | 72.10 |
| 5 | 70.00 | 600.0 | 0.100 | 0.00 | 85.70 | 74.00 |
| 6 | 470.00 | 500.0 | 0.200 | 0.00 | 86.20 | 72.30 |
| 7 | 65.00 | 200.0 | 0.100 | 0.00 | 83.10 | 70.20 |
| 8 | 135.00 | 500.0 | 0.100 | 0.00 | 84.70 | 70.10 |
| 9 | 495.00 | 300.0 | 0.200 | 0.00 | 86.80 | 70.00 |
| 10 | 12.00 | 200.0 | 0.100 | 0.00 | 88.00 | 68.30 |
| 11 | 530.00 | 500.0 | 0.200 | 0.00 | 87.80 | 71.30 |
| 12 | 340.00 | 300.0 | 0.150 | 0.00 | 88.90 | 71.30 |
| 13 | 25.00 | 200.0 | 0.100 | 0.00 | 84.50 | 68.30 |
| 14 | 360.00 | 200.0 | 0.200 | 0.00 | 89.70 | 69.80 |
| 15 | 135.00 | 500.0 | 0.100 | 0.00 | 89.10 | 67.10 |
| 16 | 45.00 | 500.0 | 0.100 | 0.00 | 90.50 | 66.50 |
| 17 | 865.00 | 500.0 | 0.150 | 0.00 | 90.90 | 69.40 |
| 18 | 1300.00 | 500.0 | 0.100 | 0.00 | 91.50 | 71.50 |
| 19 | 215.00 | 500.0 | 0.200 | 0.00 | 94.80 | 69.40 |
| 20 | 490.00 | 500.0 | 0.100 | 0.00 | 94.00 | 71.50 |
| 21 | 150.00 | 500.0 | 0.200 | 0.00 | 96.00 | 69.00 |
| 22 | 95.00 | 300.0 | 0.150 | 0.00 | 98.10 | 69.10 |
| 23 | 335.00 | 500.0 | 0.050 | 0.00 | 97.20 | 70.00 |
| 24 | 80.00 | 500.0 | 0.100 | 0.00 | 96.00 | 70.00 |
| 25 | 245.00 | 700.0 | 0.040 | 0.10 | 95.50 | 71.40 |
| 26 | 250.00 | 500.0 | 0.020 | 0.05 | 96.60 | 71.40 |
| 27 | 95.00 | 300.0 | 0.100 | 0.00 | 86.50 | 74.50 |
| 28 | 370.00 | 300.0 | 0.200 | 0.00 | 88.60 | 74.70 |
| 29 | 890.00 | 500.0 | 0.150 | 0.00 | 90.40 | 74.40 |
| 30 | 480.00 | 500.0 | 0.030 | 0.00 | 93.50 | 74.00 |
| 31 | 510.00 | 300.0 | 0.010 | 0.10 | 95.80 | 73.80 |
| 32 | 33.00 | 300.0 | 0.030 | 0.05 | 96.80 | 75.00 |
| 33 | 34.00 | 300.0 | 0.030 | 0.10 | 96.30 | 75.10 |

| Parameters | N1 | N2 | CN1 | CN2 | IA | DEP1 | DEP2 | CTS | CGTI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 2 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 3.0 |
| 3 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 1.0 |
| 4 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 5 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 2.0 |
| 6 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 7 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 8 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 9 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 10 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 1.0 |
| 11 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 12 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 13 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 3.0 |
| 14 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 15 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 16 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 2.0 |
| 17 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 18 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 12.0 |
| 19 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 20 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 21 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 22 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 23 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 24 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 25 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 26 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 27 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 28 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 29 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 12.0 |
| 30 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 15.0 |
| 31 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 15.0 |
| 32 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 2.0 |
| 33 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 1.0 |

| DRAINAGE ELEM. DATA | KP | CAP | PT | NAP(1) | NAP(2) | NAP(3) |
|---|---|---|---|---|---|---|
| 1 | 0 | 0.0 | 8.0 | 0 | 0 | 0 |
| 2 | 0 | 0.0 | 8.0 | 0 | 0 | 0 |
| 3 | 0 | 0.0 | 10.0 | 0 | 0 | 0 |
| 4 | 3 | 0.0 | 10.0 | 1 | 2 | 3 |
| 5 | 0 | 0.0 | 10.0 | 0 | 0 | 0 |
| 6 | 2 | 0.0 | 10.0 | 4 | 5 | 0 |
| 7 | 0 | 0.0 | 17.5 | 0 | 0 | 0 |
| 8 | 1 | 0.0 | 9.0 | 7 | 0 | 0 |
| 9 | 1 | 0.0 | 6.0 | 8 | 0 | 0 |
| 10 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 11 | 3 | 0.0 | 16.0 | 6 | 9 | 10 |
| 12 | 1 | 0.0 | 6.0 | 11 | 0 | 0 |
| 13 | 0 | 0.0 | 12.0 | 0 | 0 | 0 |
| 14 | 2 | 0.0 | 27.0 | 12 | 13 | 0 |
| 15 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 16 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 17 | 2 | 0.0 | 22.0 | 15 | 16 | 0 |
| 18 | 2 | 0.0 | 12.0 | 14 | 17 | 0 |
| 19 | 0 | 0.0 | 19.0 | 0 | 0 | 0 |
| 20 | 2 | 0.0 | 33.0 | 18 | 19 | 0 |
| 21 | 0 | 0.0 | 8.0 | 0 | 0 | 0 |
| 22 | 0 | 0.0 | 9.0 | 0 | 0 | 0 |
| 23 | 2 | 0.0 | 21.0 | 21 | 22 | 0 |
| 24 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 25 | 0 | 0.0 | 8.0 | 0 | 0 | 0 |
| 26 | 3 | 0.0 | 28.0 | 23 | 24 | 25 |
| 27 | 0 | 0.0 | 9.0 | 0 | 0 | 0 |
| 28 | 1 | 0.0 | 27.0 | 27 | 0 | 0 |
| 29 | 1 | 0.0 | 27.0 | 28 | 0 | 0 |
| 30 | 1 | 0.0 | 19.0 | 29 | 0 | 0 |
| 31 | 3 | 0.0 | 3.0 | 20 | 26 | 30 |
| 32 | 0 | 0.0 | 3.0 | 0 | 0 | 0 |
| 33 | 2 | 0.0 | 99.99 | 31 | 32 | 0 |

| Basin Data | IRES | NSQ | IRT | QBYP | STI | NAME |
|---|---|---|---|---|---|---|
| | 20 | 4 | 2 | 0.0 | 0.0 | MCQRIV ABOVE ALBION PARK |

Elevation (m)

| | | | |
|---|---|---|---|
| 0.0 | 1.0 | 2.0 | 3.0 |

```
 Storeage    (m3E3)
       0.0   1500    3000    4500
 Outflow     (m3/sec)
       0.0   650     1300    1950
                 26       4       2         0.0       0.0    FRAZERS ABOVE TONGARRA
 Elevation   (m)
       0.0    1.0     2.0     3.0
 Storeage    (m3E3)
       0.0    150     300     450
 Outflow     (m3/sec)
       0.0    225     450     675
                 30       4       2         0.0       0.0    MARSHAL ABOVE GREY MEADOWS
 Elevation   (m)
       0.0    1.0     2.0     3.0
 Storeage    (m3E3)
       0.0   1500    3000    4500
 Outflow     (m3/sec)
       0.0    150     300     450
                 31       4       2         0.0       0.0    MACRIV ABOVE PRINCES HWAY
 Elevation   (m)
       0.0    1.0     2.0     3.0
 Storeage    (m3E3)
       0.0   5000   10000   15000
 Outflow     (m3/sec)
       0.0    950    1900    2850
                 32       4       2         0.0       0      YALLAH ABOVE PRINCES HWAY
 Elevation   (m)
       0.0    1.0     2.0     3.0
 Storeage    (m3E3)
       0.0     75     150     300
 Outflow     (m3/sec)
       0.0    2.5     5.0     7.5
                 33       4       2         0.0       0.0    MACRIV BETWEEN BRIDGES
 Elevation   (m)
       0.0    1.0     2.0     3.0
 Storeage    (m3E3)
       0.0    250     500     750
 Outflow     (m3/sec)
       0.0    950    1900    2850
End of Input
```

```
===========================================================================
#
#                  W  B  N  M      Version 2.10 October 1995
#                      S U M M A R Y  D U M P  F I L E
#
===========================================================================
#                    Input Data File Used for this RUN: U:\1983\83093-2\WBNM\M100YR9H.TXT
#                    Input Data File Last Edited on: 18/12/1996
#                                                At: 17:2:30
#
#                    The META FILE was CREATED    on: 18/12/1996
#                                                At: 17:2:30
#
#       Data Dumped on Wednesday, 18/12/1996  At: 17:2:30:84
#   Run Title: Reference catchment for WRF : November 1995
#   Catchment Title: MACRQUARIE RIVULET
#   *
#   100Yr ARI 9HR DESIGN STORM EVENT
#   DYNAMIC STORAGE ADDED
#   *
#   File: 100YR
#
===========================================================================
#
#   To MEET QA requirements please fill out the following;
#
#   This Run was Performed By:..T. ANGER...
#
#                       Signed:...............         Date: 18/12/96
#
#     This Run was CHECKED By:.....E. RIGBY..
#
#                       Signed:...............         Date: 18/12/96
#
===========================================================================
#
#              E V E N T   No.  1
#
#      RESULTS at the Catchment Outlet for Storm Event No.  1
#   DESIGN Storm Event: design 100 year 540 minute
#      Routing Period for this Event is 15.0Mins
#
#      LOSS PARAMETERS USED IN THIS RUN
#      Loss Model Used for this Event is :  LRG
#      Initial Loss for Impervious Surfaces Set to 1.0mm
#      Initial Loss for Pervious Surfaces Set to 0.0mm
#      Continueing Loss  Rate for Pervious Surfaces Set to 2.5mm
#      Number of Gauges Used in this EVENT 3.0
#      DESIGN STORM EVENT of ARI = 100Yrs
#      Storm Burst Duration 540mins
#                            ARF = 0.96
#      For Embedded Storm Event Duration is 540.00
#      For Embedded Storm FACTOR = 0.00
#                            IMPFACTOR = 0.10
#      Total Catchment area being Analysed             := 105.600 km^2
#      Average Rainfall Depth over the Catchment       := 325.686 mm
#      Average Excess Rainfall Depth over the Catchment := 303.338 mm
---------------------------------------------------------------------------
#      Calculated Runoff Depth of area being Analysed   := 303.622 mm
#      Recorded Runoff Depth of area being Analysed     :=  0.000 mm
#         Note: If Excess Rainfall > Recorded Runoff then it is
#               recommended that larger rainfall losses are used.
#      Original Routing Period Specified               := 15.0 mins
#      Final adjusted Routing Period                   := 15.0 mins
#
+++++++++++++++++++++++ TOTAL CATCHMENT +++++++++++++++++++++++
#
#    CALCULATED PEAK Discharge at the CATCHMENT OUTLET :=  1215.700 m^3/s
#    RECORDED PEAK Discharge at the CATCHMENT OUTLET   :=      0.000 m^3/s
#    CALCULATED TIME to PEAK at the CATCHMENT OUTLET   := 480.000 mins
#    RECORDED TIME to PEAK at the CATCHMENT OUTLET     := 0.000 mins
===========================================================================
#
#
#    Tabulated SUMMARY of VOLUMES in thousands of m3
Sub-Catch  Diverted  From U/S    RainFall   Diverted  Curr.S/C  Balance
 Number      From    Sub-Catch    Excess     To D/S   Outflow   Balance
    1        0.00       0.00      538.940     0.00    539.33   -0.390
    2        0.00       0.00      705.750     0.00    706.26   -0.510
    3        0.00    1245.59     1267.120     0.00   2513.40   -0.690
    4        0.00       0.00     1054.020     0.00   1054.65   -0.630
```

**APPENDIX 2.5**
**WBNM OUTPUT -**
**DESIGN 1% AEP EVENT**

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 0.00 | 0.00 | 729.050 | 0.00 | 729.56 | -0.500 |
| 6 | 0.00 | 4297.61 | 607.900 | 0.00 | 4906.31 | -0.800 |
| 7 | 0.00 | 0.00 | 1058.030 | 0.00 | 1058.66 | -0.640 |
| 8 | 0.00 | 5964.97 | 241.680 | 0.00 | 6207.35 | -0.700 |
| 9 | 0.00 | 0.00 | 600.200 | 0.00 | 600.69 | -0.490 |
| 10 | 0.00 | 600.69 | 2377.500 | 0.00 | 2979.82 | -1.640 |
| 11 | 0.00 | 0.00 | 751.110 | 0.00 | 751.67 | -0.560 |
| 12 | 0.00 | 9938.85 | 1179.940 | 0.00 | 11119.78 | -0.990 |
| 13 | 0.00 | 11119.78 | 3574.340 | 0.00 | 14696.26 | -2.140 |
| 14 | 0.00 | 0.00 | 3342.680 | 0.00 | 3344.01 | -1.330 |
| 15 | 0.00 | 3344.01 | 1840.820 | 0.00 | 5186.63 | -1.800 |
| 16 | 0.00 | 19882.90 | 380.400 | 0.00 | 20263.22 | 0.080 |
| 17 | 0.00 | 0.00 | 570.640 | 0.00 | 571.03 | -0.390 |
| 18 | 0.00 | 571.03 | 600.470 | 0.00 | 1171.94 | -0.430 |
| 19 | 0.00 | 21435.17 | 0.000 | 0.00 | 21435.01 | 0.160 |
| 20 | 0.00 | 21435.01 | 259.260 | 0.00 | 21694.95 | -0.670 |
| 21 | 0.00 | 0.00 | 266.830 | 0.00 | 267.01 | -0.180 |
| 22 | 0.00 | 267.01 | 112.050 | 0.00 | 379.15 | -0.090 |
| 23 | 0.00 | 22074.10 | 102.970 | 0.00 | 22178.77 | -1.700 |
| 24 | 0.00 | 0.00 | 398.140 | 0.00 | 398.43 | -0.300 |
| 25 | 0.00 | 398.43 | 470.570 | 0.00 | 869.43 | -0.430 |
| 26 | 0.00 | 0.00 | 662.680 | 0.00 | 663.08 | -0.400 |
| 27 | 0.00 | 1532.51 | 330.680 | 0.00 | 1863.52 | -0.330 |
| 28 | 0.00 | 0.00 | 207.300 | 0.00 | 207.46 | -0.160 |
| 29 | 0.00 | 207.46 | 192.940 | 0.00 | 400.54 | -0.140 |
| 30 | 0.00 | 0.00 | 316.050 | 0.00 | 316.22 | -0.170 |
| 31 | 0.00 | 316.22 | 62.570 | 0.00 | 378.81 | -0.020 |
| 32 | 0.00 | 779.34 | 0.000 | 0.00 | 779.34 | 0.000 |
| 33 | 0.00 | 0.00 | 296.370 | 0.00 | 296.52 | -0.150 |
| 34 | 0.00 | 296.52 | 49.220 | 0.00 | 345.78 | -0.030 |
| 35 | 0.00 | 2988.64 | 0.000 | 0.00 | 2988.64 | 0.000 |
| 36 | 0.00 | 2988.64 | 453.800 | 0.00 | 3443.35 | -0.910 |
| 37 | 0.00 | 3443.35 | 41.120 | 0.00 | 3484.54 | -0.080 |
| 38 | 0.00 | 0.00 | 1500.030 | 0.00 | 1500.68 | -0.650 |
| 39 | 0.00 | 1500.68 | 2983.730 | 0.00 | 4486.00 | -1.590 |
| 40 | 0.00 | 4486.00 | 1342.050 | 0.00 | 5829.09 | -1.040 |
| 41 | 0.00 | 5829.09 | 0.000 | 0.00 | 5828.89 | 0.210 |
| 42 | 0.00 | 5828.89 | 203.010 | 0.00 | 6034.79 | -2.900 |
| 43 | 0.00 | 6034.79 | 182.640 | 0.00 | 6220.18 | -2.740 |
| 44 | 0.00 | 31883.47 | 0.000 | 0.00 | 31882.90 | 0.570 |
| 45 | 0.00 | 31882.90 | 47.820 | 0.00 | 31932.60 | -1.890 |
| 46 | 0.00 | 0.00 | 87.510 | 0.00 | 87.55 | -0.040 |
| 47 | 0.00 | 87.55 | 0.000 | 0.00 | 87.31 | 0.240 |
| 48 | 0.00 | 87.31 | 42.580 | 0.00 | 129.93 | -0.030 |
| 49 | 0.00 | 32062.55 | 0.000 | 0.00 | 32062.51 | 0.050 |

#

# Tabulated SUMMARY of PEAK DISCHARGES in m^3/s

| Sub-Catch Number | Channel U/S End | Channel D/S End | plus Local Inflow | After Diversion | Maximum Water Reached (m) |
|---|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 39.93 | 39.93 | 0.00 |
| 2 | 0.00 | 0.00 | 51.26 | 51.26 | 0.00 |
| 3 | 91.19 | 79.78 | 164.62 | 164.62 | 0.00 |
| 4 | 0.00 | 0.00 | 73.96 | 73.96 | 0.00 |
| 5 | 0.00 | 0.00 | 52.77 | 52.77 | 0.00 |
| 6 | 291.35 | 275.40 | 314.78 | 314.78 | 0.00 |
| 7 | 0.00 | 0.00 | 74.24 | 74.24 | 0.00 |
| 8 | 389.03 | 382.61 | 396.96 | 396.96 | 0.00 |
| 9 | 0.00 | 0.00 | 44.14 | 44.14 | 0.00 |
| 10 | 44.14 | 34.31 | 186.46 | 186.46 | 0.00 |
| 11 | 0.00 | 0.00 | 54.71 | 54.71 | 0.00 |
| 12 | 632.48 | 598.63 | 670.20 | 670.20 | 0.00 |
| 13 | 670.20 | 610.38 | 783.78 | 783.78 | 0.00 |
| 14 | 0.00 | 0.00 | 207.22 | 207.22 | 0.00 |
| 15 | 207.22 | 181.10 | 288.73 | 288.73 | 0.00 |
| 16 | 1060.40 | 1054.13 | 1071.39 | 1071.39 | 0.00 |
| 17 | 0.00 | 0.00 | 41.61 | 41.61 | 0.00 |
| 18 | 41.61 | 37.14 | 79.79 | 79.79 | 0.00 |
| 19 | 1131.56 | 1057.52 | 1057.52 | 1057.52 | 1.63 |
| 20 | 1057.52 | 1051.88 | 1059.75 | 1059.75 | 0.00 |
| 21 | 0.00 | 0.00 | 20.40 | 20.40 | 0.00 |
| 22 | 20.40 | 20.20 | 29.03 | 29.03 | 0.00 |
| 23 | 1073.08 | 1072.51 | 1074.98 | 1074.98 | 0.00 |
| 24 | 0.00 | 0.00 | 29.80 | 29.80 | 0.00 |
| 25 | 29.80 | 26.91 | 61.50 | 61.50 | 0.00 |
| 26 | 0.00 | 0.00 | 47.73 | 47.73 | 0.00 |
| 27 | 109.23 | 102.75 | 127.42 | 127.42 | 0.00 |
| 28 | 0.00 | 0.00 | 16.43 | 16.43 | 0.00 |
| 29 | 16.43 | 15.54 | 30.51 | 30.51 | 0.00 |
| 30 | 0.00 | 0.00 | 25.72 | 25.72 | 0.00 |
| 31 | 25.72 | 24.80 | 29.85 | 29.85 | 0.00 |
| 32 | 59.61 | 59.61 | 59.61 | 59.61 | 0.00 |

| | | | | | |
|---|---|---|---|---|---|
| 33 | 0.00 | 0.00 | 24.67 | 24.67 | 0.00 |
| 34 | 24.67 | 23.65 | 27.70 | 27.70 | 0.00 |
| 35 | 213.24 | 204.60 | 204.60 | 204.60 | 0.91 |
| 36 | 204.60 | 196.02 | 223.99 | 223.99 | 0.00 |
| 37 | 223.99 | 222.68 | 224.85 | 224.85 | 0.00 |
| 38 | 0.00 | 0.00 | 102.37 | 102.37 | 0.00 |
| 39 | 102.37 | 82.52 | 265.26 | 265.26 | 0.00 |
| 40 | 265.26 | 243.10 | 319.72 | 319.72 | 0.00 |
| 41 | 319.72 | 203.37 | 203.37 | 203.37 | 1.36 |
| 42 | 203.37 | 202.89 | 206.26 | 206.26 | 0.00 |
| 43 | 206.26 | 206.15 | 209.08 | 209.08 | 0.00 |
| 44 | 1436.80 | 1214.27 | 1214.27 | 1214.27 | 1.28 |
| 45 | 1214.27 | 1214.08 | 1214.70 | 1214.70 | 0.00 |
| 46 | 0.00 | 0.00 | 7.71 | 7.71 | 0.00 |
| 47 | 7.71 | 1.90 | 1.90 | 1.90 | 0.76 |
| 48 | 1.90 | 1.90 | 5.10 | 5.10 | 0.00 |
| 49 | 1217.13 | 1215.70 | 1215.70 | 1215.70 | 1.28 |

#
# Tabulated SUMMARY of PEAK TIMES in Minutes

| Sub-Catch Number | Channel U/S End | Channel D/S End | plus Local Inflow | After Diversion |
|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 330.00 | 330.00 |
| 2 | 0.00 | 0.00 | 330.00 | 330.00 |
| 3 | 330.00 | 345.00 | 330.00 | 330.00 |
| 4 | 0.00 | 0.00 | 330.00 | 330.00 |
| 5 | 0.00 | 0.00 | 330.00 | 330.00 |
| 6 | 330.00 | 345.00 | 330.00 | 330.00 |
| 7 | 0.00 | 0.00 | 330.00 | 330.00 |
| 8 | 330.00 | 345.00 | 345.00 | 345.00 |
| 9 | 0.00 | 0.00 | 330.00 | 330.00 |
| 10 | 330.00 | 360.00 | 330.00 | 330.00 |
| 11 | 0.00 | 0.00 | 330.00 | 330.00 |
| 12 | 330.00 | 345.00 | 345.00 | 345.00 |
| 13 | 345.00 | 375.00 | 375.00 | 375.00 |
| 14 | 0.00 | 0.00 | 330.00 | 330.00 |
| 15 | 330.00 | 360.00 | 330.00 | 330.00 |
| 16 | 360.00 | 375.00 | 375.00 | 375.00 |
| 17 | 0.00 | 0.00 | 330.00 | 330.00 |
| 18 | 330.00 | 345.00 | 330.00 | 330.00 |
| 19 | 375.00 | 405.00 | 405.00 | 405.00 |
| 20 | 405.00 | 420.00 | 405.00 | 405.00 |
| 21 | 0.00 | 0.00 | 330.00 | 330.00 |
| 22 | 330.00 | 330.00 | 330.00 | 330.00 |
| 23 | 405.00 | 420.00 | 420.00 | 420.00 |
| 24 | 0.00 | 0.00 | 330.00 | 330.00 |
| 25 | 330.00 | 345.00 | 330.00 | 330.00 |
| 26 | 0.00 | 0.00 | 330.00 | 330.00 |
| 27 | 330.00 | 345.00 | 330.00 | 330.00 |
| 28 | 0.00 | 0.00 | 300.00 | 300.00 |
| 29 | 300.00 | 330.00 | 330.00 | 330.00 |
| 30 | 0.00 | 0.00 | 300.00 | 300.00 |
| 31 | 300.00 | 315.00 | 315.00 | 315.00 |
| 32 | 315.00 | 315.00 | 315.00 | 315.00 |
| 33 | 0.00 | 0.00 | 300.00 | 300.00 |
| 34 | 300.00 | 315.00 | 315.00 | 315.00 |
| 35 | 330.00 | 330.00 | 330.00 | 330.00 |
| 36 | 330.00 | 360.00 | 345.00 | 345.00 |
| 37 | 345.00 | 345.00 | 345.00 | 345.00 |
| 38 | 0.00 | 0.00 | 330.00 | 330.00 |
| 39 | 330.00 | 360.00 | 330.00 | 330.00 |
| 40 | 330.00 | 360.00 | 345.00 | 345.00 |
| 41 | 345.00 | 450.00 | 450.00 | 450.00 |
| 42 | 450.00 | 465.00 | 450.00 | 450.00 |
| 43 | 450.00 | 465.00 | 465.00 | 465.00 |
| 44 | 405.00 | 480.00 | 480.00 | 480.00 |
| 45 | 480.00 | 480.00 | 480.00 | 480.00 |
| 46 | 0.00 | 0.00 | 300.00 | 300.00 |
| 47 | 300.00 | 420.00 | 420.00 | 420.00 |
| 48 | 420.00 | 435.00 | 300.00 | 300.00 |
| 49 | 480.00 | 480.00 | 480.00 | 480.00 |

#
# Tabulated SUMMARY of IMPERVIOUS and PERVIOUS Area RUNOFF

| Sub-Catch | I M P E R V I O U S | | P E R V I O U S | |
|---|---|---|---|---|
| Number | Volume | Peak | Volume | Peak |
| 1 | 0.00 | 0.00 | 539.33 | 39.93 |
| 2 | 0.00 | 0.00 | 706.26 | 51.26 |
| 3 | 0.00 | 0.00 | 1267.75 | 87.34 |
| 4 | 0.00 | 0.00 | 1054.65 | 73.96 |
| 5 | 0.00 | 0.00 | 729.56 | 52.77 |
| 6 | 0.00 | 0.00 | 608.39 | 44.62 |
| 7 | 0.00 | 0.00 | 1058.66 | 74.24 |

| | | | | |
|---|---|---|---|---|
| 8 | 0.00 | 0.00 | 241.86 | 19.48 |
| 9 | 0.00 | 0.00 | 600.69 | 44.14 |
| 10 | 0.00 | 0.00 | 2378.97 | 154.30 |
| 11 | 0.00 | 0.00 | 751.67 | 54.71 |
| 12 | 0.00 | 0.00 | 1180.74 | 83.15 |
| 13 | 0.00 | 0.00 | 3575.90 | 222.81 |
| 14 | 0.00 | 0.00 | 3344.01 | 207.22 |
| 15 | 0.00 | 0.00 | 1842.06 | 121.13 |
| 16 | 0.00 | 0.00 | 380.69 | 28.53 |
| 17 | 0.00 | 0.00 | 571.03 | 41.61 |
| 18 | 32.47 | 3.19 | 568.35 | 41.21 |
| 19 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 259.43 | 19.83 |
| 21 | 0.00 | 0.00 | 267.01 | 20.40 |
| 22 | 0.00 | 0.00 | 112.11 | 9.52 |
| 23 | 0.00 | 0.00 | 103.04 | 8.88 |
| 24 | 0.00 | 0.00 | 398.43 | 29.80 |
| 25 | 0.00 | 0.00 | 470.94 | 34.78 |
| 26 | 0.00 | 0.00 | 663.08 | 47.73 |
| 27 | 0.00 | 0.00 | 330.90 | 24.98 |
| 28 | 0.00 | 0.00 | 207.46 | 16.43 |
| 29 | 0.00 | 0.00 | 193.06 | 15.35 |
| 30 | 67.51 | 6.63 | 248.71 | 19.09 |
| 31 | 13.37 | 1.31 | 49.21 | 4.56 |
| 32 | 0.00 | 0.00 | 0.00 | 0.00 |
| 33 | 78.93 | 7.75 | 217.59 | 16.92 |
| 34 | 2.67 | 0.26 | 46.57 | 4.33 |
| 35 | 0.00 | 0.00 | 0.00 | 0.00 |
| 36 | 0.00 | 0.00 | 454.15 | 33.54 |
| 37 | 0.00 | 0.00 | 41.13 | 3.88 |
| 38 | 0.00 | 0.00 | 1500.68 | 102.37 |
| 39 | 0.00 | 0.00 | 2985.31 | 189.69 |
| 40 | 0.00 | 0.00 | 1342.48 | 90.88 |
| 41 | 0.00 | 0.00 | 0.00 | 0.00 |
| 42 | 0.00 | 0.00 | 203.16 | 16.08 |
| 43 | 0.00 | 0.00 | 182.77 | 14.73 |
| 44 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45 | 5.13 | 0.50 | 42.70 | 4.03 |
| 46 | 0.00 | 0.00 | 87.55 | 7.71 |
| 47 | 0.00 | 0.00 | 0.00 | 0.00 |
| 48 | 0.00 | 0.00 | 42.59 | 4.02 |
| 49 | 0.00 | 0.00 | 0.00 | 0.00 |

END OF W B N M Ver 2.10 - S U M M A R Y D U M P F I L E
Data Dumped on Wednesday, 18/12/1996 Completed At: 17:2:31:44

Reference catchment for WRF : November 1995
MACRQUARIE RIVULET
*
100Yr ARI 9HR DESIGN STORM EVENT
DYNAMIC STORAGE ADDED
*
File: 100YR
49 1.29

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | OL | 0 | 0 | 0 | 175 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 2 | OL | 0 | 0 | 0 | 230 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 3 | WC | 1 | 2 | 0 | 415 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 4 | OL | 0 | 0 | 0 | 345 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 5 | OL | 0 | 0 | 0 | 240 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 6 | WC | 3 | 4 | 5 | 200 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 7 | OL | 0 | 0 | 0 | 345 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 8 | WC | 6 | 7 | 0 | 75 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 9 | OL | 0 | 0 | 0 | 195 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 10 | WC | 9 | 0 | 0 | 740 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 11 | OL | 0 | 0 | 0 | 225 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 12 | WC | 8 | 10 | 11 | 340 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 13 | WC | 12 | 0 | 0 | 1045 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 14 | OL | 0 | 0 | 0 | 1055 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 15 | WC | 14 | 0 | 0 | 635 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 16 | WC | 13 | 15 | 0 | 145 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 17 | OL | 0 | 0 | 0 | 215 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 18 | WC | 17 | 0 | 0 | 240 | 5.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 19 | S1 | 16 | 18 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 20 | WC | 19 | 0 | 0 | 105 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 21 | OL | 0 | 0 | 0 | 105 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 22 | WC | 21 | 0 | 0 | 45 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 23 | WC | 20 | 22 | 0 | 40 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 24 | OL | 0 | 0 | 0 | 150 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 25 | WC | 24 | 0 | 0 | 180 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 26 | OL | 0 | 0 | 0 | 250 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 27 | WC | 25 | 26 | 0 | 130 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 28 | OL | 0 | 0 | 0 | 80 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 29 | WC | 28 | 0 | 0 | 77 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 30 | OL | 0 | 0 | 0 | 125 | 20.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 31 | WC | 30 | 0 | 0 | 25 | 20.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 32 | DU | 29 | 31 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 33 | OL | 0 | 0 | 0 | 120 | 25.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 34 | WC | 33 | 0 | 0 | 20 | 5.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 35 | S1 | 27 | 32 | 34 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 36 | WC | 35 | 0 | 0 | 180 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 37 | WC | 36 | 0 | 0 | 16 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 38 | OL | 0 | 0 | 0 | 465 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 39 | WC | 38 | 0 | 0 | 890 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 40 | WC | 39 | 0 | 0 | 480 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 41 | S1 | 40 | 0 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 42 | WC | 41 | 0 | 0 | 80 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 43 | WC | 42 | 0 | 0 | 70 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 44 | S1 | 23 | 37 | 43 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 45 | WC | 44 | 0 | 0 | 18 | 10.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 46 | OL | 0 | 0 | 0 | 33 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 47 | S1 | 46 | 0 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 48 | WC | 47 | 0 | 0 | 16 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |
| 49 | S1 | 45 | 48 | 0 | 0 | 0.0 | -1 | -1 | -1 | -1 | -1 | -1 |

Sub-area Co-ordinates

| | | | | |
|---|---|---|---|---|
| 1 | 282200 | 1170400 | 283400 | 1171600 |
| 2 | 282500 | 1172100 | 283400 | 1171600 |
| 3 | 284200 | 1171200 | 285100 | 1171900 |
| 4 | 283700 | 1173100 | 285100 | 1171900 |
| 5 | 285200 | 1173200 | 285100 | 1171900 |
| 6 | 286000 | 1171600 | 287200 | 1171700 |
| 7 | 286600 | 1172900 | 287200 | 1171700 |
| 8 | 287600 | 1171700 | 288100 | 1171500 |
| 9 | 284000 | 1170000 | 285600 | 1170400 |
| 10 | 287500 | 1169700 | 288100 | 1171500 |
| 11 | 288200 | 1172600 | 288100 | 1171500 |
| 12 | 289000 | 1171200 | 289800 | 1171200 |
| 13 | 290800 | 1170700 | 293300 | 1171800 |
| 14 | 290700 | 1168100 | 291900 | 1169100 |
| 15 | 292900 | 1169800 | 293300 | 1171800 |
| 16 | 293400 | 1172300 | 294800 | 1172400 |
| 17 | 294800 | 1169400 | 294800 | 1170500 |
| 18 | 294300 | 1171100 | 294800 | 1172400 |
| 19 | 294800 | 1172400 | 294800 | 1172400 |
| 20 | 295600 | 1173100 | 296000 | 1174200 |
| 21 | 294000 | 1173100 | 294900 | 1173100 |
| 22 | 295300 | 1173400 | 296000 | 1174200 |
| 23 | 296100 | 1174200 | 297000 | 1174800 |
| 24 | 296000 | 1169000 | 296500 | 1169600 |
| 25 | 297100 | 1169700 | 297300 | 1170600 |
| 26 | 298200 | 1169700 | 297300 | 1170600 |

```
27   297200   1171200   296200   1172300
28   295900   1169700   296300   1170500
29   296500   1171100   296500   1172200
30   295600   1170800   296000   1171500
31   296100   1171700   296500   1172200
32   296500   1172200   296500   1172200
33   295100   1171700   295700   1172300
34   296000   1172200   296200   1172300
35   296200   1172300   296200   1172300
36   296500   1173300   296300   1173900
37   296300   1174100   296700   1174800
38   288000   1174500   289200   1174500
39   290300   1174100   292400   1174400
40   293200   1173900   294800   1174000
41   294800   1174000   294800   1174000
42   295000   1173800   295500   1174100
43   295800   1174600   296700   1174800
44   296700   1174800   296700   1174800
45   296900   1174800   297000   1175000
46   296500   1175100   296700   1175200
47   296700   1175200   296700   1175200
48   296800   1175200   297000   1175000
49   297000   1175000   297000   1175000
Rating Tables
-1
Stream Details
3    R  0.6   -1   -1  -1
6    R  0.6   -1   -1  -1
8    R  0.6   -1   -1  -1
10   R  0.6   -1   -1  -1
12   R  0.6   -1   -1  -1
13   R  0.6   -1   -1  -1
15   R  0.6   -1   -1  -1
16   R  0.6   -1   -1  -1
18   R  0.6   -1   -1  -1
20   R  0.6   -1   -1  -1
22   R  0.6   -1   -1  -1
23   R  0.6   -1   -1  -1
25   R  0.6   -1   -1  -1
27   R  0.6   -1   -1  -1
29   R  0.6   -1   -1  -1
31   R  0.6   -1   -1  -1
34   R  0.6   -1   -1  -1
36   R  0.6   -1   -1  -1
37   R  0.6   -1   -1  -1
39   R  0.6   -1   -1  -1
40   R  0.6   -1   -1  -1
42   R  0.6   -1   -1  -1
43   R  0.6   -1   -1  -1
45   R  0.6   -1   -1  -1
48   R  0.6   -1   -1  -1
Basin Details
6
19
Storage in Macquarie Riv. u/s of Albion Park
1.0      1.0
4
0.00      0.0      0.0
1.00    650.0   1500.0
2.00   1300.0   3000.0
3.00   1950.0   4500.0
0.00
35
Storage in Frazers Ck. u/s of Tongarra
1.0      1.0
4
0.00      0.0      0.0
1.00    225.0    150.0
2.00    450.0    300.0
3.00    675.0    450.0
0.00
41
Storage in Marshall Mount Ck. u/s of Grey Meadows
1.0      1.0
4
0.00      0.0      0.0
1.00    150.0   1500.0
2.00    300.0   3000.0
3.00    450.0   4500.0
0.00
44
Storage in Macquarie Riv. u/s Princes Hway
1.0      1.0
4
```

```
0.00      0.0      0.0
1.00    950.0   5000.0
2.00   1900.0  10000.0
3.00   2850.0  15000.0
0.00
47
Storage @ Yallah u/s Princes Hway
1.0      1.0
4
0.00      0.0      0.0
1.00      2.5     75.0
2.00      5.0    150.0
3.00      7.5    300.0
0.00
49
Storage in Macquarie Riv. d/s Princes Hway
1.0      1.0
4
0.00      0.0      0.0
1.00    950.0    250.0
2.00   1900.0    500.0
3.00   2850.0    750.0
0.00
Rainfall Storm Details
1
design 100 year 540 minute
DES
15
LRG
0.0      2.5
3
100      540      -1
MACQUARIE_ARR#1
MACQUARIE_ARR#2
MACQUARIE_ARR#3
CALC
Recorded Hydrographs
-1
```

```
****************************************
*                                      *
*            P  S x R  M               *
*                                      *
*   Penn State Extended Runoff Model   *
*                                      *
*     Metric DOS/UNIX Version V8.04    *
*                                      *
*            May   1992                *
*                                      *
****************************************
```

Macquarie Rivulet Reference Catchment - Ref : 81093

Design Storm of 100Yr RI and 6 Hour Duration to ARR 87

Attenuation thru flooded reaches in Subs 20 26 30 31 32 33

modelled by * decreasing average overland flowpath lengths in each

* decreasing travel and CGTI times in each

* addition of special storeages in each

28/08/1992

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. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**APPENDIX 2.6**
**PSxRM OUTPUT -**
**DESIGN 1% AEP EVENT**

INPUT DATA ECHO

GENERAL WATERSHED AND RUN DATA

No of Subareas = 33 No of Basins = 6 No of Obs Hydrog = 0

No of Raingauges, recording = 3 nonrecording = 0

Time Interv, min; Routing 1.0 Printing 30.0 Rainfall 30.0 Total = 900.0

Resid Inf Time = 720 min 3 Raingauges used in Weighting, with Exp 2.0

Standard (default) Parameters :

| Mannings n | | Dep Storage | | SCS -- CN | | IA | STCGTI | CTS Ratio |
|---|---|---|---|---|---|---|---|---|
| Imperv | Perv | Imperv | Perv | Imperv | Perv | | min | |
| .040 | .200 | 1.00 | 0.00 | 99.0 | 85.0 | .10 | 0.0 | 1.00 |

Baseflow Coefficient = 0.0000 m3/s/ha

Hydrographs will be listed for Subareas:
12 20 25 26 30 31 32 33

Basins are located on Subareas:
20 26 30 31 32 33

SUBAREA PROPERTIES AND DIMENSIONS

| ID No | Area ha | Length m | Slope m /m | Manning's n Imp | Manning's n Perv | Imperv Fract | SCS-CN Imp | SCS-CN Perv | IA | Coordinates E | Coordinates N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 405.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 82.3 | 71.5 |
| 2 | 185.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 83.1 | 73.4 |
| 3 | 20.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 84.3 | 74.2 |
| 4 | 800.0 | 1000. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 84.4 | 72.1 |
| 5 | 70.0 | 600. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 85.7 | 74.0 |
| 6 | 470.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 86.2 | 72.3 |
| 7 | 65.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 83.1 | 70.2 |
| 8 | 135.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 84.7 | 70.1 |
| 9 | 495.0 | 300. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 86.8 | 70.0 |
| 10 | 12.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 88.0 | 68.3 |
| 11 | 530.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 87.8 | 71.3 |
| 12 | 340.0 | 300. | .150 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 88.9 | 71.3 |
| 13 | 25.0 | 200. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 84.5 | 68.3 |
| 14 | 360.0 | 200. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 89.7 | 69.8 |
| 15 | 135.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 89.1 | 67.1 |
| 16 | 45.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 90.5 | 66.5 |
| 17 | 865.0 | 500. | .150 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 90.9 | 69.4 |
| 18 | 1300.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 91.5 | 71.5 |
| 19 | 215.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 94.8 | 69.4 |
| 20 | 490.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 94.0 | 71.5 |
| 21 | 150.0 | 500. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 96.0 | 69.0 |
| 22 | 95.0 | 300. | .150 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 98.1 | 69.1 |
| 23 | 335.0 | 500. | .050 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 97.2 | 70.0 |
| 24 | 80.0 | 500. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 96.0 | 70.0 |
| 25 | 245.0 | 700. | .040 | .040 | .200 | .10 | 99.0 | 85.0 | .10 | 95.5 | 71.4 |
| 26 | 250.0 | 500. | .020 | .040 | .200 | .05 | 99.0 | 85.0 | .10 | 96.6 | 71.4 |
| 27 | 95.0 | 300. | .100 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 86.5 | 74.5 |
| 28 | 370.0 | 300. | .200 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 88.6 | 74.7 |
| 29 | 890.0 | 500. | .150 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 90.4 | 74.4 |
| 30 | 480.0 | 500. | .030 | .040 | .200 | 0.00 | 99.0 | 85.0 | .10 | 93.5 | 74.0 |
| 31 | 510.0 | 300. | .010 | .040 | .200 | .10 | 99.0 | 85.0 | .10 | 95.8 | 73.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | 33.0 | 300. | .030 | .040 | .200 | .05 | 99.0 | 85.0 | .10 | 96.8 | 75.0 |
| 33 | 34.0 | 300. | .030 | .040 | .200 | .10 | 99.0 | 85.0 | .10 | 96.3 | 75.1 |

| I.D. No. | Depr.Storage Imp. | Perv. | CGtoInlet TT(min) | Drainage Elements Within Subarea | | | Outgoing Elements Cap,m3/s | TT,min | CTS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.000 | 0.000 | 10.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 2 | 1.000 | 0.000 | 3.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 3 | 1.000 | 0.000 | 1.00 | 0 | 0 | 0 | 0.0 | 10.0 | 1.0 |
| 4 | 1.000 | 0.000 | 8.00 | 1 | 2 | 3 | 0.0 | 10.0 | 1.0 |
| 5 | 1.000 | 0.000 | 2.00 | 0 | 0 | 0 | 0.0 | 10.0 | 1.0 |
| 6 | 1.000 | 0.000 | 6.00 | 4 | 5 | 0 | 0.0 | 10.0 | 1.0 |
| 7 | 1.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 17.5 | 1.0 |
| 8 | 1.000 | 0.000 | 10.00 | 7 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 9 | 1.000 | 0.000 | 8.00 | 8 | 0 | 0 | 0.0 | 6.0 | 1.0 |
| 10 | 1.000 | 0.000 | 1.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 11 | 1.000 | 0.000 | 8.00 | 6 | 9 | 10 | 0.0 | 16.0 | 1.0 |
| 12 | 1.000 | 0.000 | 6.00 | 11 | 0 | 0 | 0.0 | 6.0 | 1.0 |
| 13 | 1.000 | 0.000 | 3.00 | 0 | 0 | 0 | 0.0 | 12.0 | 1.0 |
| 14 | 1.000 | 0.000 | 10.00 | 12 | 13 | 0 | 0.0 | 27.0 | 1.0 |
| 15 | 1.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 16 | 1.000 | 0.000 | 2.00 | 0 | 0 | 0 | 0.0 | 14.0 | 1.0 |
| 17 | 1.000 | 0.000 | 8.00 | 15 | 16 | 0 | 0.0 | 22.0 | 1.0 |
| 18 | 1.000 | 0.000 | 12.00 | 14 | 17 | 0 | 0.0 | 12.0 | 1.0 |
| 19 | 1.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 19.0 | 1.0 |
| 20 | 1.000 | 0.000 | 7.50 | 18 | 19 | 0 | 0.0 | 16.0 | 1.0 |
| 21 | 1.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 8.0 | 1.0 |
| 22 | 1.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 23 | 1.000 | 0.000 | 6.00 | 21 | 22 | 0 | 0.0 | 16.0 | 1.0 |
| 24 | 1.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 11.0 | 1.0 |
| 25 | 1.000 | 0.000 | 6.00 | 0 | 0 | 0 | 0.0 | 6.0 | 1.0 |
| 26 | 1.000 | 0.000 | 6.00 | 23 | 24 | 25 | 0.0 | 14.0 | 1.0 |
| 27 | 1.000 | 0.000 | 4.00 | 0 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 28 | 1.000 | 0.000 | 6.00 | 27 | 0 | 0 | 0.0 | 27.0 | 1.0 |
| 29 | 1.000 | 0.000 | 12.00 | 28 | 0 | 0 | 0.0 | 20.0 | 1.0 |
| 30 | 1.000 | 0.000 | 7.50 | 29 | 0 | 0 | 0.0 | 9.0 | 1.0 |
| 31 | 1.000 | 0.000 | 7.50 | 20 | 26 | 30 | 0.0 | 1.5 | 1.0 |
| 32 | 1.000 | 0.000 | 1.00 | 0 | 0 | 0 | 0.0 | 1.5 | 1.0 |
| 33 | 1.000 | 0.000 | .50 | 31 | 32 | 0 | 0.0 | 100.0 | 1.0 |

BASIN DATA

MCQRIV ABOVE ALBION PARK
Basin No 1 in Area No 20 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 1500.0 | 650.0 |
| 2.0 | 3000.0 | 1300.0 |
| 3.0 | 4500.0 | 1950.0 |

FRAZERS ABOVE TONGARRA
Basin No 2 in Area No 26 of Type 2 with 0.0 m3/s Bypass

| Elevation m | Storage m3E3 | Outflow m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 150.0 | 225.0 |
| 2.0 | 300.0 | 450.0 |
| 3.0 | 450.0 | 675.0 |

MARSHAL ABOVE GREY MEADOWS
Basin No 3 in Area No 30 of Type 2 with 0.0 m3/s Bypass

Elevation Storage Outflow

| m | m3E3 | m3/s |
|---|---|---|
| 0.0 | 0.0 | 0.0 |
| 1.0 | 1500.0 | 150.0 |
| 2.0 | 3000.0 | 300.0 |
| 3.0 | 4500.0 | 450.0 |

MACRIV ABOVE PRINCES HWAY
Basin No 4 in Area No 31 of Type 2 with 0.0 m3/s Bypass

| Elevation | Storage | Outflow |
|---|---|---|
| m | m3E3 | m3/s |
| 0.0 | 0.0 | 0.0 |
| 1.0 | 5000.0 | 950.0 |
| 2.0 | 10000.0 | 1900.0 |
| 3.0 | 15000.0 | 2850.0 |

YALLAH ABOVE PRINCES HWAY
Basin No 5 in Area No 32 of Type 2 with 0.0 m3/s Bypass

| Elevation | Storage | Outflow |
|---|---|---|
| m | m3E3 | m3/s |
| 0.0 | 0.0 | 0.0 |
| 1.0 | 75.0 | 2.5 |
| 2.0 | 150.0 | 5.0 |
| 3.0 | 300.0 | 7.5 |

MACRIV BETWEEN BRIDGES
Basin No 6 in Area No 33 of Type 2 with 0.0 m3/s Bypass

| Elevation | Storage | Outflow |
|---|---|---|
| m | m3E3 | m3/s |
| 0.0 | 0.0 | 0.0 |
| 1.0 | 250.0 | 950.0 |
| 2.0 | 500.0 | 1900.0 |
| 3.0 | 750.0 | 2850.0 |

RAINFALL DATA

Recording Raingauges

Raingauge No 1 ARR1, Coordinates = 90.00 East 72.00 North
Total rain = 322.32 mm , Starting Time and Centroid = 0.0 147.1 min

13.22 25.79 35.46 75.10 49.31 26.11 22.56 22.56 16.44 19.66
9.99 6.12

Raingauge No 2 ARR2, Coordinates = 85.59 East 72.30 North
Total rain = 294.00 mm , Starting Time and Centroid = 0.0 147.1 min

12.05 23.52 32.34 68.50 44.98 23.81 20.58 20.58 14.99 17.93
9.11 5.59

Raingauge No 3 ARR3, Coordinates = 94.94 East 72.05 North
Total rain = 238.02 mm , Starting Time and Centroid = 0.0 147.1 min

9.76 19.04 26.18 55.46 36.42 19.28 16.66 16.66 12.14 14.52
7.38 4.52

Weighting Factors

| Subarea | Nearest Gauges and Weighting Factors | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | .791 | 1 | .152 | 3 | .057 |
| 2 | 2 | .832 | 1 | .124 | 3 | .043 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | 2 | .843 | 1 | .119 | 3 | .038 |
| 4 | 2 | .944 | 1 | .044 | 3 | .012 |
| 5 | 2 | .861 | 1 | .111 | 3 | .028 |
| 6 | 2 | .970 | 1 | .025 | 3 | .005 |
| 7 | 2 | .780 | 1 | .163 | 3 | .058 |
| 8 | 2 | .813 | 1 | .145 | 3 | .042 |
| 9 | 2 | .637 | 1 | .302 | 3 | .061 |
| 10 | 1 | .477 | 2 | .387 | 3 | .136 |
| 11 | 1 | .498 | 2 | .451 | 3 | .051 |
| 12 | 1 | .842 | 2 | .120 | 3 | .039 |
| 13 | 2 | .653 | 1 | .256 | 3 | .091 |
| 14 | 1 | .733 | 2 | .156 | 3 | .111 |
| 15 | 1 | .487 | 2 | .307 | 3 | .206 |
| 16 | 1 | .469 | 3 | .283 | 2 | .248 |
| 17 | 1 | .653 | 3 | .212 | 2 | .135 |
| 18 | 1 | .784 | 3 | .161 | 2 | .055 |
| 19 | 3 | .762 | 1 | .180 | 2 | .058 |
| 20 | 3 | .918 | 1 | .067 | 2 | .015 |
| 21 | 3 | .758 | 1 | .176 | 2 | .066 |
| 22 | 3 | .733 | 1 | .185 | 2 | .082 |
| 23 | 3 | .811 | 1 | .135 | 2 | .054 |
| 24 | 3 | .847 | 1 | .113 | 2 | .040 |
| 25 | 3 | .969 | 1 | .023 | 2 | .007 |
| 26 | 3 | .910 | 1 | .066 | 2 | .024 |
| 27 | 2 | .725 | 1 | .222 | 3 | .053 |
| 28 | 1 | .549 | 2 | .343 | 3 | .108 |
| 29 | 1 | .694 | 3 | .157 | 2 | .149 |
| 30 | 3 | .689 | 1 | .249 | 2 | .062 |
| 31 | 3 | .878 | 1 | .091 | 2 | .031 |
| 32 | 3 | .762 | 1 | .168 | 2 | .070 |
| 33 | 3 | .759 | 1 | .172 | 2 | .069 |

H Y D R O G R A P H   O U T P U T

Hydrograph Output for Subarea 12

Storm Total = 315.67 mm, Centroid at 147.1 min, Subarea = 340 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 0 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 10.354 | 9.619 | .1 | | | 0.0 | .3 | |
| 60.0 | 33.146 | 21.742 | 9.4 | | | 0.0 | 23.9 | |
| 90.0 | 65.976 | 30.072 | 37.4 | | | 0.0 | 128.7 | |
| 120.0 | 131.763 | 37.169 | 109.7 | | | 0.0 | 455.8 | |
| 150.0 | 185.112 | 39.901 | 92.6 | | | 0.0 | 731.6 | |
| 180.0 | 215.227 | 40.946 | 56.5 | | | 0.0 | 739.8 | |
| 210.0 | 238.019 | 41.587 | 44.2 | | | 0.0 | 607.0 | |
| 240.0 | 260.116 | 42.116 | 41.5 | | | 0.0 | 493.8 | |
| 270.0 | 277.415 | 42.479 | 33.4 | | | 0.0 | 413.4 | |
| 300.0 | 296.040 | 42.828 | 34.7 | | | 0.0 | 367.7 | |
| 330.0 | 307.720 | 43.028 | 24.0 | | | 0.0 | 317.4 | |
| 360.0 | 314.475 | 43.137 | 15.9 | | | 0.0 | 248.5 | |
| 390.0 | 315.675 | 43.210 | 7.3 | | | 0.0 | 170.6 | |
| 420.0 | 315.675 | 43.274 | 3.6 | | | 0.0 | 104.7 | |
| 450.0 | 315.675 | 43.336 | 2.1 | | | 0.0 | 62.2 | |
| 480.0 | 315.675 | 43.395 | 1.3 | | | 0.0 | 38.4 | |
| 510.0 | 315.675 | 43.451 | .9 | | | 0.0 | 25.4 | |
| 540.0 | 315.675 | 43.506 | .6 | | | 0.0 | 17.8 | |
| 570.0 | 315.675 | 43.558 | .4 | | | 0.0 | 12.9 | |
| 600.0 | 315.675 | 43.608 | .3 | | | 0.0 | 9.7 | |
| 630.0 | 315.675 | 43.656 | .2 | | | 0.0 | 7.5 | |
| 660.0 | 315.675 | 43.701 | .2 | | | 0.0 | 5.9 | |
| 690.0 | 315.675 | 43.746 | .1 | | | 0.0 | 4.7 | |
| 720.0 | 315.675 | 43.788 | .1 | | | 0.0 | 3.8 | |
| 750.0 | 315.675 | 43.828 | .1 | | | 0.0 | 3.1 | |
| 780.0 | 315.675 | 43.867 | .1 | | | 0.0 | 2.5 | |
| 810.0 | 315.675 | 43.905 | .1 | | | 0.0 | 2.1 | |
| 840.0 | 315.675 | 43.941 | .0 | | | 0.0 | 1.8 | |
| 870.0 | 315.675 | 43.975 | .0 | | | 0.0 | 1.5 | |
| 900.0 | 315.675 | 44.008 | .0 | | | 0.0 | 1.3 | |

Runoff Depth = 271.9 mm , Runoff Peak = 117.6 m3/s at 126.0 min
Runoff Volume = 924.6 m3E3

Hydrograph Output for Subarea 20

Storm Total = 244.52 mm, Centroid at 147.1 min, Subarea = 490 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 7.686 | 7.445 | .0 | .1 | 0.0 | 0.0 | .1 | |
| 60.0 | 25.023 | 18.412 | 3.2 | 15.3 | 0.0 | 0.0 | 4.3 | |
| 90.0 | 50.208 | 26.860 | 20.7 | 123.0 | .1 | 0.0 | 40.7 | |
| 120.0 | 100.164 | 34.622 | 82.6 | 518.2 | .3 | 0.0 | 197.9 | |
| 150.0 | 142.140 | 37.877 | 96.1 | 1057.6 | .8 | 0.0 | 529.2 | |
| 180.0 | 166.054 | 39.145 | 70.1 | 1330.8 | 1.4 | 0.0 | 902.7 | |
| 210.0 | 183.798 | 39.913 | 54.5 | 1283.5 | 1.7 | 0.0 | 1129.8 | |
| 240.0 | 200.914 | 40.547 | 48.6 | 1114.0 | 1.8 | 0.0 | 1168.5 | |
| 270.0 | 214.469 | 40.989 | 40.5 | 935.6 | 1.7 | 0.0 | 1087.8 | |
| 300.0 | 228.814 | 41.408 | 39.3 | 799.1 | 1.5 | 0.0 | 964.0 | |
| 330.0 | 238.106 | 41.656 | 30.5 | 691.0 | 1.3 | 0.0 | 841.0 | |
| 360.0 | 243.436 | 41.799 | 21.8 | 573.5 | 1.1 | 0.0 | 723.8 | |
| 390.0 | 244.520 | 41.920 | 12.8 | 435.9 | .9 | 0.0 | 600.8 | |
| 420.0 | 244.520 | 42.037 | 7.6 | 300.6 | .7 | 0.0 | 470.2 | |
| 450.0 | 244.520 | 42.149 | 5.0 | 191.5 | .5 | 0.0 | 344.3 | |
| 480.0 | 244.520 | 42.257 | 3.4 | 118.0 | .4 | 0.0 | 237.9 | |
| 510.0 | 244.520 | 42.360 | 2.4 | 73.5 | .2 | 0.0 | 158.1 | |
| 540.0 | 244.520 | 42.459 | 1.8 | 48.0 | .2 | 0.0 | 103.4 | |
| 570.0 | 244.520 | 42.554 | 1.4 | 33.1 | .1 | 0.0 | 68.1 | |
| 600.0 | 244.520 | 42.645 | 1.0 | 24.0 | .1 | 0.0 | 45.9 | |
| 630.0 | 244.520 | 42.732 | .8 | 17.9 | .0 | 0.0 | 31.9 | |
| 660.0 | 244.520 | 42.816 | .7 | 13.8 | .0 | 0.0 | 22.9 | |
| 690.0 | 244.520 | 42.896 | .5 | 10.8 | .0 | 0.0 | 16.9 | |
| 720.0 | 244.520 | 42.973 | .4 | 8.6 | .0 | 0.0 | 12.8 | |
| 750.0 | 244.520 | 43.047 | .3 | 6.9 | .0 | 0.0 | 10.0 | |
| 780.0 | 244.520 | 43.118 | .3 | 5.6 | .0 | 0.0 | 7.9 | |
| 810.0 | 244.520 | 43.185 | .2 | 4.6 | 0.0 | 0.0 | 6.3 | |
| 840.0 | 244.520 | 43.251 | .2 | 3.8 | 0.0 | 0.0 | 5.2 | |
| 870.0 | 244.520 | 43.313 | .2 | 3.2 | 0.0 | 0.0 | 4.2 | |
| 900.0 | 244.520 | 43.373 | .1 | 2.7 | 0.0 | 0.0 | 3.5 | |

Runoff Depth = 200.7 mm , Runoff Peak = 97.8 m3/s at 128.0 min
Runoff Volume = 983.2 m3E3

Hydrograph Output for Subarea 25

Storm Total = 240.39 mm, Centroid at 147.1 min, Subarea = 245 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 0 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 7.885 | 7.062 | .2 | | | 0.0 | .2 | |
| 60.0 | 25.241 | 16.920 | 2.3 | | | 0.0 | 2.3 | |
| 90.0 | 50.241 | 24.458 | 8.1 | | | 0.0 | 8.1 | |
| 120.0 | 100.338 | 31.465 | 30.0 | | | 0.0 | 30.0 | |
| 150.0 | 140.964 | 34.321 | 39.2 | | | 0.0 | 39.2 | |
| 180.0 | 163.897 | 35.436 | 33.2 | | | 0.0 | 33.2 | |
| 210.0 | 181.253 | 36.128 | 27.9 | | | 0.0 | 27.9 | |
| 240.0 | 198.081 | 36.703 | 25.2 | | | 0.0 | 25.2 | |
| 270.0 | 211.254 | 37.099 | 21.5 | | | 0.0 | 21.5 | |
| 300.0 | 225.437 | 37.482 | 20.4 | | | 0.0 | 20.4 | |
| 330.0 | 234.331 | 37.703 | 16.5 | | | 0.0 | 16.5 | |
| 360.0 | 239.475 | 37.832 | 12.6 | | | 0.0 | 12.6 | |
| 390.0 | 240.389 | 37.945 | 8.4 | | | 0.0 | 8.4 | |
| 420.0 | 240.389 | 38.054 | 5.7 | | | 0.0 | 5.7 | |
| 450.0 | 240.389 | 38.158 | 4.1 | | | 0.0 | 4.1 | |
| 480.0 | 240.389 | 38.258 | 3.1 | | | 0.0 | 3.1 | |
| 510.0 | 240.389 | 38.354 | 2.3 | | | 0.0 | 2.3 | |
| 540.0 | 240.389 | 38.446 | 1.8 | | | 0.0 | 1.8 | |
| 570.0 | 240.389 | 38.534 | 1.5 | | | 0.0 | 1.5 | |
| 600.0 | 240.389 | 38.618 | 1.2 | | | 0.0 | 1.2 | |
| 630.0 | 240.389 | 38.699 | 1.0 | | | 0.0 | 1.0 | |
| 660.0 | 240.389 | 38.777 | .8 | | | 0.0 | .8 | |
| 690.0 | 240.389 | 38.852 | .7 | | | 0.0 | .7 | |
| 720.0 | 240.389 | 38.923 | .6 | | | 0.0 | .6 | |
| 750.0 | 240.389 | 38.992 | .5 | | | 0.0 | .5 | |
| 780.0 | 240.389 | 39.058 | .4 | | | 0.0 | .4 | |
| 810.0 | 240.389 | 39.121 | .4 | | | 0.0 | .4 | |
| 840.0 | 240.389 | 39.181 | .3 | | | 0.0 | .3 | |
| 870.0 | 240.389 | 39.239 | .3 | | | 0.0 | .3 | |
| 900.0 | 240.389 | 39.295 | .2 | | | 0.0 | .2 | |

Runoff Depth = 198.2 mm , Runoff Peak = 40.2 m3/s at 156.0 min
Runoff Volume = 485.7 m3E3

Hydrograph Output for Subarea 26

Storm Total = 244.90 mm, Centroid at 147.1 min, Subarea = 250 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 8.033 | 7.462 | .1 | .9 | 0.0 | 0.0 | .9 | |
| 60.0 | 25.715 | 17.931 | 1.6 | 5.9 | .0 | 0.0 | 3.4 | |
| 90.0 | 51.184 | 25.889 | 7.2 | 30.7 | .1 | 0.0 | 20.6 | |
| 120.0 | 102.222 | 33.244 | 29.3 | 123.8 | .4 | 0.0 | 85.7 | |
| 150.0 | 143.610 | 36.229 | 40.1 | 199.5 | .8 | 0.0 | 173.0 | |
| 180.0 | 166.973 | 37.394 | 34.6 | 186.9 | .9 | 0.0 | 196.2 | |
| 210.0 | 184.656 | 38.115 | 29.2 | 147.7 | .7 | 0.0 | 163.0 | |
| 240.0 | 201.799 | 38.715 | 26.3 | 125.3 | .6 | 0.0 | 132.6 | |
| 270.0 | 215.219 | 39.128 | 22.5 | 108.0 | .5 | 0.0 | 114.3 | |
| 300.0 | 229.669 | 39.527 | 21.3 | 98.4 | .5 | 0.0 | 101.6 | |
| 330.0 | 238.730 | 39.756 | 17.4 | 84.3 | .4 | 0.0 | 89.8 | |
| 360.0 | 243.971 | 39.889 | 13.3 | 64.5 | .3 | 0.0 | 72.1 | |
| 390.0 | 244.902 | 40.004 | 9.0 | 43.5 | .2 | 0.0 | 51.3 | |
| 420.0 | 244.902 | 40.115 | 6.1 | 27.5 | .1 | 0.0 | 33.2 | |
| 450.0 | 244.902 | 40.221 | 4.4 | 18.1 | .1 | 0.0 | 21.3 | |
| 480.0 | 244.902 | 40.323 | 3.3 | 12.7 | .1 | 0.0 | 14.5 | |
| 510.0 | 244.902 | 40.421 | 2.5 | 9.3 | .0 | 0.0 | 10.5 | |
| 540.0 | 244.902 | 40.514 | 2.0 | 7.1 | .0 | 0.0 | 7.9 | |
| 570.0 | 244.902 | 40.604 | 1.6 | 5.5 | .0 | 0.0 | 6.1 | |
| 600.0 | 244.902 | 40.690 | 1.3 | 4.4 | .0 | 0.0 | 4.8 | |
| 630.0 | 244.902 | 40.773 | 1.1 | 3.5 | .0 | 0.0 | 3.8 | |
| 660.0 | 244.902 | 40.852 | .9 | 2.9 | .0 | 0.0 | 3.1 | |
| 690.0 | 244.902 | 40.928 | .8 | 2.4 | .0 | 0.0 | 2.6 | |
| 720.0 | 244.902 | 41.001 | .6 | 2.0 | 0.0 | 0.0 | 2.1 | |
| 750.0 | 244.902 | 41.071 | .5 | 1.7 | 0.0 | 0.0 | 1.8 | |
| 780.0 | 244.902 | 41.138 | .5 | 1.4 | 0.0 | 0.0 | 1.5 | |
| 810.0 | 244.902 | 41.202 | .4 | 1.2 | 0.0 | 0.0 | 1.3 | |
| 840.0 | 244.902 | 41.264 | .4 | 1.0 | 0.0 | 0.0 | 1.1 | |
| 870.0 | 244.902 | 41.323 | .3 | .9 | 0.0 | 0.0 | .9 | |
| 900.0 | 244.902 | 41.380 | .3 | .8 | 0.0 | 0.0 | .8 | |

Runoff Depth = 200.5 mm , Runoff Peak = 41.3 m3/s at 156.0 min
Runoff Volume = 501.3 m3E3

Hydrograph Output for Subarea 30

Storm Total = 262.49 mm, Centroid at 147.1 min, Subarea = 480 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 8.251 | 7.925 | .0 | .0 | 0.0 | 0.0 | .0 | |
| 60.0 | 26.861 | 19.237 | 2.3 | 5.8 | 0.0 | 0.0 | .5 | |
| 90.0 | 53.897 | 27.709 | 15.2 | 46.9 | .0 | 0.0 | 4.8 | |
| 120.0 | 107.523 | 35.313 | 65.7 | 202.4 | .2 | 0.0 | 24.6 | |
| 150.0 | 152.583 | 38.453 | 89.9 | 389.4 | .5 | 0.0 | 69.4 | |
| 180.0 | 178.254 | 39.669 | 74.7 | 418.2 | .8 | 0.0 | 124.7 | |
| 210.0 | 197.302 | 40.403 | 60.9 | 315.0 | 1.1 | 0.0 | 164.7 | |
| 240.0 | 215.676 | 41.008 | 54.1 | 241.3 | 1.2 | 0.0 | 183.4 | |
| 270.0 | 230.226 | 41.429 | 45.9 | 205.7 | 1.3 | 0.0 | 190.1 | |
| 300.0 | 245.625 | 41.827 | 43.3 | 184.1 | 1.3 | 0.0 | 190.9 | |
| 330.0 | 255.600 | 42.064 | 35.1 | 161.1 | 1.3 | 0.0 | 187.8 | |
| 360.0 | 261.322 | 42.192 | 26.5 | 128.6 | 1.2 | 0.0 | 180.7 | |
| 390.0 | 262.486 | 42.298 | 17.3 | 86.1 | 1.1 | 0.0 | 168.6 | |
| 420.0 | 262.486 | 42.400 | 11.5 | 51.4 | 1.0 | 0.0 | 152.1 | |
| 450.0 | 262.486 | 42.497 | 8.0 | 29.0 | .9 | 0.0 | 133.6 | |
| 480.0 | 262.486 | 42.590 | 5.9 | 18.0 | .8 | 0.0 | 115.4 | |
| 510.0 | 262.486 | 42.680 | 4.4 | 12.2 | .7 | 0.0 | 98.8 | |
| 540.0 | 262.486 | 42.766 | 3.4 | 8.8 | .6 | 0.0 | 84.2 | |
| 570.0 | 262.486 | 42.848 | 2.7 | 6.5 | .5 | 0.0 | 71.6 | |
| 600.0 | 262.486 | 42.927 | 2.2 | 5.0 | .4 | 0.0 | 60.7 | |
| 630.0 | 262.486 | 43.003 | 1.8 | 3.9 | .3 | 0.0 | 51.4 | |
| 660.0 | 262.486 | 43.075 | 1.5 | 3.1 | .3 | 0.0 | 43.5 | |
| 690.0 | 262.486 | 43.145 | 1.2 | 2.5 | .2 | 0.0 | 36.8 | |
| 720.0 | 262.486 | 43.212 | 1.0 | 2.1 | .2 | 0.0 | 31.1 | |
| 750.0 | 262.486 | 43.276 | .9 | 1.7 | .2 | 0.0 | 26.2 | |
| 780.0 | 262.486 | 43.337 | .8 | 1.4 | .1 | 0.0 | 22.2 | |
| 810.0 | 262.486 | 43.396 | .6 | 1.2 | .1 | 0.0 | 18.7 | |
| 840.0 | 262.486 | 43.453 | .6 | 1.0 | .1 | 0.0 | 15.8 | |
| 870.0 | 262.486 | 43.507 | .5 | .9 | .1 | 0.0 | 13.3 | |
| 900.0 | 262.486 | 43.559 | .4 | .7 | .1 | 0.0 | 11.3 | |

Runoff Depth = 216.7 mm , Runoff Peak = 92.0 m3/s at 157.0 min
Runoff Volume = 1040.1 m3E3

Hydrograph Output for Subarea 31

Storm Total = 247.41 mm, Centroid at 147.1 min, Subarea = 510 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 7.777 | 6.977 | .5 | 3.9 | 0.0 | 0.0 | 3.9 | |
| 60.0 | 25.318 | 16.949 | 5.3 | 10.0 | 0.0 | 0.0 | 1.5 | |
| 90.0 | 50.801 | 24.576 | 19.0 | 56.3 | .0 | 0.0 | 10.7 | |
| 120.0 | 101.346 | 31.551 | 69.6 | 257.6 | .1 | 0.0 | 53.5 | |
| 150.0 | 143.818 | 34.468 | 89.2 | 630.0 | .2 | 0.0 | 167.6 | |
| 180.0 | 168.014 | 35.604 | 73.1 | 1070.1 | .4 | 0.0 | 367.0 | |
| 210.0 | 185.968 | 36.291 | 60.0 | 1399.9 | .7 | 0.0 | 620.8 | |
| 240.0 | 203.286 | 36.858 | 53.8 | 1526.2 | .9 | 0.0 | 867.0 | |
| 270.0 | 217.001 | 37.253 | 45.6 | 1487.3 | 1.1 | 0.0 | 1054.0 | |
| 300.0 | 231.516 | 37.627 | 43.3 | 1371.5 | 1.2 | 0.0 | 1163.7 | |
| 330.0 | 240.917 | 37.850 | 34.8 | 1225.5 | 1.3 | 0.0 | 1203.1 | |
| 360.0 | 246.311 | 37.976 | 26.1 | 1075.7 | 1.3 | 0.0 | 1187.8 | |
| 390.0 | 247.408 | 38.083 | 17.0 | 916.6 | 1.2 | 0.0 | 1131.7 | |
| 420.0 | 247.408 | 38.186 | 11.2 | 749.7 | 1.1 | 0.0 | 1044.5 | |
| 450.0 | 247.408 | 38.285 | 7.9 | 585.3 | 1.0 | 0.0 | 934.3 | |
| 480.0 | 247.408 | 38.379 | 5.8 | 439.0 | .9 | 0.0 | 810.9 | |
| 510.0 | 247.408 | 38.470 | 4.3 | 321.2 | .7 | 0.0 | 685.0 | |
| 540.0 | 247.408 | 38.557 | 3.4 | 233.6 | .6 | 0.0 | 565.8 | |
| 570.0 | 247.408 | 38.641 | 2.7 | 171.9 | .5 | 0.0 | 459.7 | |
| 600.0 | 247.408 | 38.721 | 2.1 | 129.2 | .4 | 0.0 | 369.3 | |
| 630.0 | 247.408 | 38.798 | 1.7 | 99.6 | .3 | 0.0 | 294.8 | |
| 660.0 | 247.408 | 38.871 | 1.4 | 78.4 | .2 | 0.0 | 234.6 | |
| 690.0 | 247.408 | 38.942 | 1.2 | 62.9 | .2 | 0.0 | 186.7 | |
| 720.0 | 247.408 | 39.010 | 1.0 | 51.1 | .2 | 0.0 | 148.8 | |
| 750.0 | 247.408 | 39.075 | .9 | 42.0 | .1 | 0.0 | 118.9 | |
| 780.0 | 247.408 | 39.137 | .7 | 34.8 | .1 | 0.0 | 95.4 | |
| 810.0 | 247.408 | 39.197 | .6 | 28.9 | .1 | 0.0 | 76.8 | |
| 840.0 | 247.408 | 39.255 | .6 | 24.2 | .1 | 0.0 | 62.1 | |
| 870.0 | 247.408 | 39.310 | .5 | 20.3 | .1 | 0.0 | 50.5 | |
| 900.0 | 247.408 | 39.363 | .4 | 17.1 | .0 | 0.0 | 41.2 | |

Runoff Depth = 205.8 mm , Runoff Peak = 91.2 m3/s at 157.0 min
Runoff Volume = 1049.6 m3E3

Hydrograph Output for Subarea 32

Storm Total = 256.07 mm, Centroid at 147.1 min, Subarea = 33 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 10.149 | 9.108 | .0 | .0 | 0.0 | 0.0 | .0 | |
| 60.0 | 30.302 | 19.786 | .5 | .5 | 0.0 | 0.0 | .0 | |
| 90.0 | 58.214 | 27.356 | 1.9 | 1.9 | .0 | 0.0 | .1 | |
| 120.0 | 116.830 | 34.466 | 6.8 | 6.8 | .1 | 0.0 | .3 | |
| 150.0 | 156.692 | 36.905 | 6.8 | 6.8 | .3 | 0.0 | .7 | |
| 180.0 | 178.049 | 37.849 | 4.7 | 4.7 | .4 | 0.0 | 1.0 | |
| 210.0 | 196.068 | 38.513 | 3.7 | 3.7 | .5 | 0.0 | 1.2 | |
| 240.0 | 213.993 | 39.081 | 3.4 | 3.4 | .5 | 0.0 | 1.3 | |
| 270.0 | 227.215 | 39.452 | 2.8 | 2.8 | .6 | 0.0 | 1.4 | |
| 300.0 | 242.750 | 39.842 | 2.8 | 2.8 | .6 | 0.0 | 1.5 | |
| 330.0 | 250.945 | 40.032 | 2.1 | 2.1 | .6 | 0.0 | 1.6 | |
| 360.0 | 255.913 | 40.144 | 1.5 | 1.5 | .6 | 0.0 | 1.6 | |
| 390.0 | 256.075 | 40.248 | .8 | .8 | .6 | 0.0 | 1.6 | |
| 420.0 | 256.075 | 40.349 | .5 | .5 | .6 | 0.0 | 1.5 | |
| 450.0 | 256.075 | 40.446 | .3 | .3 | .6 | 0.0 | 1.4 | |
| 480.0 | 256.075 | 40.538 | .2 | .2 | .5 | 0.0 | 1.4 | |
| 510.0 | 256.075 | 40.627 | .2 | .2 | .5 | 0.0 | 1.3 | |
| 540.0 | 256.075 | 40.712 | .1 | .1 | .5 | 0.0 | 1.2 | |
| 570.0 | 256.075 | 40.794 | .1 | .1 | .5 | 0.0 | 1.2 | |
| 600.0 | 256.075 | 40.872 | .1 | .1 | .4 | 0.0 | 1.1 | |
| 630.0 | 256.075 | 40.947 | .1 | .1 | .4 | 0.0 | 1.0 | |
| 660.0 | 256.075 | 41.020 | .0 | .0 | .4 | 0.0 | 1.0 | |
| 690.0 | 256.075 | 41.089 | .0 | .0 | .4 | 0.0 | .9 | |
| 720.0 | 256.075 | 41.155 | .0 | .0 | .4 | 0.0 | .9 | |
| 750.0 | 256.075 | 41.219 | .0 | .0 | .3 | 0.0 | .8 | |
| 780.0 | 256.075 | 41.280 | .0 | .0 | .3 | 0.0 | .8 | |
| 810.0 | 256.075 | 41.338 | .0 | .0 | .3 | 0.0 | .7 | |
| 840.0 | 256.075 | 41.394 | .0 | .0 | .3 | 0.0 | .7 | |
| 870.0 | 256.075 | 41.448 | .0 | .0 | .3 | 0.0 | .7 | |
| 900.0 | 256.075 | 41.500 | .0 | .0 | .2 | 0.0 | .6 | |

Runoff Depth = 213.9 mm , Runoff Peak = 7.0 m3/s at 122.0 min
Runoff Volume = 70.6 m3E3

Hydrograph Output for Subarea 33

Storm Total = 256.36 mm, Centroid at 147.1 min, Subarea = 34 ha

| Time min | Precip mm | Infilt mm | Runoff m3/s | Basin Type 2 Inflow | W.S.El. | Pipe Q m3/s | Surch m3/s | Obs Q m3/s |
|---|---|---|---|---|---|---|---|---|
| 30.0 | 10.511 | 8.995 | .1 | .4 | 0.0 | 0.0 | .4 | |
| 60.0 | 31.020 | 19.128 | .7 | 2.3 | 0.0 | 0.0 | 1.8 | |
| 90.0 | 59.220 | 26.233 | 2.2 | 12.6 | .0 | 0.0 | 10.5 | |
| 120.0 | 118.953 | 32.939 | 7.4 | 59.0 | .1 | 0.0 | 49.6 | |
| 150.0 | 158.177 | 35.167 | 7.1 | 169.6 | .2 | 0.0 | 149.7 | |
| 180.0 | 178.943 | 36.027 | 4.8 | 362.9 | .3 | 0.0 | 330.0 | |
| 210.0 | 196.888 | 36.650 | 3.8 | 613.1 | .6 | 0.0 | 574.5 | |
| 240.0 | 214.834 | 37.185 | 3.5 | 859.5 | .9 | 0.0 | 824.9 | |
| 270.0 | 227.909 | 37.530 | 2.8 | 1048.9 | 1.1 | 0.0 | 1025.0 | |
| 300.0 | 243.547 | 37.900 | 2.9 | 1162.6 | 1.2 | 0.0 | 1150.0 | |
| 330.0 | 251.494 | 38.074 | 2.1 | 1204.8 | 1.3 | 0.0 | 1202.2 | |
| 360.0 | 256.365 | 38.177 | 1.5 | 1191.6 | 1.3 | 0.0 | 1196.0 | |
| 390.0 | 256.365 | 38.276 | .8 | 1136.9 | 1.2 | 0.0 | 1146.8 | |
| 420.0 | 256.365 | 38.371 | .5 | 1050.8 | 1.1 | 0.0 | 1064.8 | |
| 450.0 | 256.365 | 38.462 | .3 | 941.6 | 1.0 | 0.0 | 958.6 | |
| 480.0 | 256.365 | 38.550 | .2 | 818.7 | .9 | 0.0 | 837.1 | |
| 510.0 | 256.365 | 38.633 | .2 | 692.7 | .7 | 0.0 | 711.1 | |
| 540.0 | 256.365 | 38.714 | .1 | 573.1 | .6 | 0.0 | 590.1 | |
| 570.0 | 256.365 | 38.791 | .1 | 466.3 | .5 | 0.0 | 481.1 | |
| 600.0 | 256.365 | 38.865 | .1 | 375.0 | .4 | 0.0 | 387.5 | |
| 630.0 | 256.365 | 38.936 | .1 | 299.6 | .3 | 0.0 | 309.8 | |
| 660.0 | 256.365 | 39.004 | .0 | 238.7 | .3 | 0.0 | 246.9 | |
| 690.0 | 256.365 | 39.069 | .0 | 190.1 | .2 | 0.0 | 196.6 | |
| 720.0 | 256.365 | 39.132 | .0 | 151.6 | .2 | 0.0 | 156.7 | |
| 750.0 | 256.365 | 39.192 | .0 | 121.3 | .1 | 0.0 | 125.3 | |
| 780.0 | 256.365 | 39.250 | .0 | 97.4 | .1 | 0.0 | 100.6 | |
| 810.0 | 256.365 | 39.305 | .0 | 78.5 | .1 | 0.0 | 81.0 | |
| 840.0 | 256.365 | 39.358 | .0 | 63.6 | .1 | 0.0 | 65.6 | |
| 870.0 | 256.365 | 39.409 | .0 | 51.7 | .1 | 0.0 | 53.3 | |
| 900.0 | 256.365 | 39.457 | .0 | 42.3 | .0 | 0.0 | 43.5 | |

Runoff Depth = 216.2 mm , Runoff Peak = 7.4 m3/s at 121.0 min
Runoff Volume = 73.5 m3E3

O U T F L O W   S U M M A R Y

| Subarea No | Peak Runoff m3/s | Time of peak,min | Runoff Volume m3E3 | Peak Outflow m3/s | Time of peak,min |
|---|---|---|---|---|---|
| 1 | 107.6 | 131.0 | 1015.4 | 107.6 | 131.0 |
| 2 | 49.2 | 124.0 | 463.7 | 49.2 | 124.0 |
| 3 | 6.5 | 121.0 | 50.4 | 6.5 | 121.0 |
| 4 | 188.9 | 158.0 | 1994.3 | 336.3 | 150.0 |
| 5 | 17.4 | 123.0 | 175.5 | 17.4 | 123.0 |
| 6 | 137.6 | 127.0 | 1177.5 | 447.6 | 150.0 |
| 7 | 21.3 | 124.0 | 163.8 | 21.3 | 124.0 |
| 8 | 36.0 | 131.0 | 339.2 | 52.5 | 150.0 |
| 9 | 163.4 | 128.0 | 1265.4 | 181.4 | 120.0 |
| 10 | 4.0 | 121.0 | 30.8 | 4.0 | 121.0 |
| 11 | 162.9 | 129.0 | 1384.5 | 732.1 | 150.0 |
| 12 | 117.6 | 126.0 | 924.6 | 739.8 | 180.0 |
| 13 | 8.2 | 123.0 | 63.2 | 8.2 | 123.0 |
| 14 | 128.9 | 130.0 | 954.6 | 799.3 | 180.0 |
| 15 | 36.1 | 125.0 | 339.9 | 36.1 | 125.0 |
| 16 | 11.7 | 123.0 | 111.2 | 11.7 | 123.0 |
| 17 | 251.1 | 129.0 | 2218.7 | 268.2 | 150.0 |
| 18 | 366.1 | 133.0 | 3413.9 | 1276.9 | 180.0 |
| 19 | 51.9 | 127.0 | 457.8 | 51.9 | 127.0 |
| 20 | 97.8 | 128.0 | 983.2 | 1168.5 | 240.0 |
| 21 | 36.2 | 127.0 | 319.6 | 36.2 | 127.0 |
| 22 | 25.3 | 124.0 | 204.3 | 25.3 | 124.0 |
| 23 | 64.8 | 156.0 | 695.7 | 118.0 | 150.0 |
| 24 | 16.5 | 127.0 | 164.7 | 16.5 | 127.0 |
| 25 | 40.2 | 156.0 | 485.7 | 40.2 | 156.0 |
| 26 | 41.3 | 156.0 | 501.3 | 196.2 | 180.0 |
| 27 | 29.3 | 124.0 | 240.9 | 29.3 | 124.0 |
| 28 | 124.4 | 126.0 | 962.0 | 138.8 | 120.0 |
| 29 | 263.4 | 133.0 | 2319.9 | 374.0 | 150.0 |
| 30 | 92.0 | 157.0 | 1040.1 | 190.9 | 300.0 |
| 31 | 91.2 | 157.0 | 1049.6 | 1203.1 | 330.0 |
| 32 | 7.0 | 122.0 | 70.6 | 1.6 | 360.0 |
| 33 | 7.4 | 121.0 | 73.5 | 1202.2 | 330.0 |

Surcharge Flow Occurs in Subareas
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 2

Surcharge Above 0 Percent of Drainage Element Capacity Occurs in Subareas
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 2

| NHL | NA | NRES | NRG | NNRG | NPRT | NOBS | NPFP | NWG | EXW | IPCS |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 33 | 6 | 0 | 3 | 8 | 0 | 0 | 3 | 2.0 | 0 |

Macquarie Rivulet Reference Catchment - Ref : 81093
Design Storm of 100Yr RI and 6 Hour Duration to ARR 87
Attenuation thru flooded reaches in Subs 20 26 30 31 32 33
modelled by * decreasing average overland flowpath lengths in each
* decreasing travel and CGTI times in each
* addition of special storeages in each

| TR(min) | PRI(min) | DT(min) | DTR(min) | TRI(min) |
|---|---|---|---|---|
| 900.0 | 30.0 | 1.00 | 30.0 | 720.0 |

| STDN1 | STDN2 | STCN1 | STCN2 | STDIA | STDS1 | STDS2 | STCTS | STCGI | CBF |
|---|---|---|---|---|---|---|---|---|---|
| 0.040 | 0.200 | 99.0 | 85.0 | 0.100 | 1.000 | 0.000 | 1.00 | 0.0 | 0.0000 |

ARR basic design storm data

| ZONE | ARI | DURA(hrs) |
|---|---|---|
| 1 | 100 | 6 |

ARR design gauge data

| ID | I(mm/hr) | XRG | YRG | NAME |
|---|---|---|---|---|
| 1 | 53.72 | 90.00 | 72.00 | ARR1 |
| 2 | 49.00 | 85.59 | 72.30 | ARR2 |
| 3 | 39.67 | 94.94 | 72.05 | ARR3 |

Subareas for Hydrograph Output
12 20 25 26 30
31 32 33
Subareas with Basins
20 26 30 31 32
33

| Subarea ID | Area(ha) | Length(m) | Slope | Imp.Fr. | X-Coord | Y-Coord |
|---|---|---|---|---|---|---|
| 1 | 405.00 | 500.0 | 0.100 | 0.00 | 82.30 | 71.50 |
| 2 | 185.00 | 500.0 | 0.100 | 0.00 | 83.10 | 73.40 |
| 3 | 20.00 | 200.0 | 0.100 | 0.00 | 84.30 | 74.20 |
| 4 | 800.00 | 1000.0 | 0.200 | 0.00 | 84.40 | 72.10 |
| 5 | 70.00 | 600.0 | 0.100 | 0.00 | 85.70 | 74.00 |
| 6 | 470.00 | 500.0 | 0.200 | 0.00 | 86.20 | 72.30 |
| 7 | 65.00 | 200.0 | 0.100 | 0.00 | 83.10 | 70.20 |
| 8 | 135.00 | 500.0 | 0.100 | 0.00 | 84.70 | 70.10 |
| 9 | 495.00 | 300.0 | 0.200 | 0.00 | 86.80 | 70.00 |
| 10 | 12.00 | 200.0 | 0.100 | 0.00 | 88.00 | 68.30 |
| 11 | 530.00 | 500.0 | 0.200 | 0.00 | 87.80 | 71.30 |
| 12 | 340.00 | 300.0 | 0.150 | 0.00 | 88.90 | 71.30 |
| 13 | 25.00 | 200.0 | 0.100 | 0.00 | 84.50 | 68.30 |
| 14 | 360.00 | 200.0 | 0.200 | 0.00 | 89.70 | 69.80 |
| 15 | 135.00 | 500.0 | 0.100 | 0.00 | 89.10 | 67.10 |
| 16 | 45.00 | 500.0 | 0.100 | 0.00 | 90.50 | 66.50 |
| 17 | 865.00 | 500.0 | 0.150 | 0.00 | 90.90 | 69.40 |
| 18 | 1300.00 | 500.0 | 0.100 | 0.00 | 91.50 | 71.50 |
| 19 | 215.00 | 500.0 | 0.200 | 0.00 | 94.80 | 69.40 |
| 20 | 490.00 | 500.0 | 0.100 | 0.00 | 94.00 | 71.50 |
| 21 | 150.00 | 500.0 | 0.200 | 0.00 | 96.00 | 69.00 |
| 22 | 95.00 | 300.0 | 0.150 | 0.00 | 98.10 | 69.10 |
| 23 | 335.00 | 500.0 | 0.050 | 0.00 | 97.20 | 70.00 |
| 24 | 80.00 | 500.0 | 0.100 | 0.00 | 96.00 | 70.00 |
| 25 | 245.00 | 700.0 | 0.040 | 0.10 | 95.50 | 71.40 |
| 26 | 250.00 | 500.0 | 0.020 | 0.05 | 96.60 | 71.40 |
| 27 | 95.00 | 300.0 | 0.100 | 0.00 | 86.50 | 74.50 |
| 28 | 370.00 | 300.0 | 0.200 | 0.00 | 88.60 | 74.70 |
| 29 | 890.00 | 500.0 | 0.150 | 0.00 | 90.40 | 74.40 |
| 30 | 480.00 | 500.0 | 0.030 | 0.00 | 93.50 | 74.00 |
| 31 | 510.00 | 300.0 | 0.010 | 0.10 | 95.80 | 73.80 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | 33.00 | 300.0 | 0.030 | 0.05 | 96.80 | 75.00 |
| 33 | 34.00 | 300.0 | 0.030 | 0.10 | 96.30 | 75.10 |

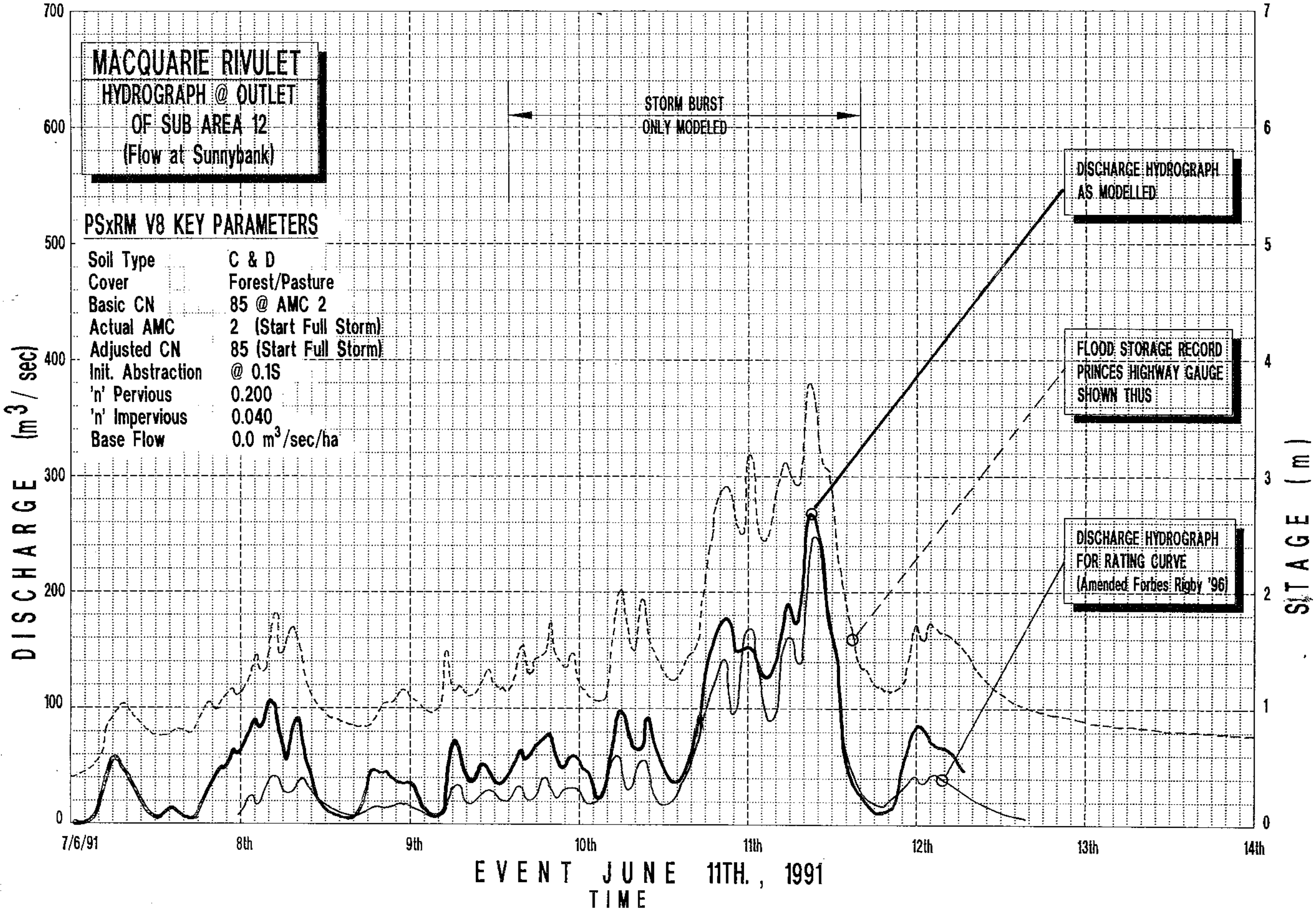
| Parameters | N1 | N2 | CN1 | CN2 | IA | DEP1 | DEP2 | CTS | CGTI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 2 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 3.0 |
| 3 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 1.0 |
| 4 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 5 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 2.0 |
| 6 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 7 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 8 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 9 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 10 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 1.0 |
| 11 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 12 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 13 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 3.0 |
| 14 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 10.0 |
| 15 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 16 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 2.0 |
| 17 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 8.0 |
| 18 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 12.0 |
| 19 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 20 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 7.5 |
| 21 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 22 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 23 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 24 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 25 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 26 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 27 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 4.0 |
| 28 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 6.0 |
| 29 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 12.0 |
| 30 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 7.5 |
| 31 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 7.5 |
| 32 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 1.0 |
| 33 | -1.000 | -1.000 | -1.0 | -1.0 | -1.0 | -1.00 | -1.00 | -1.00 | 0.5 |

| DRAINAGE ELEM. DATA | KP | CAP | PT | NAP(1) | NAP(2) | NAP(3) |
|---|---|---|---|---|---|---|
| 1 | 0 | 0.0 | 8.0 | 0 | 0 | 0 |
| 2 | 0 | 0.0 | 8.0 | 0 | 0 | 0 |
| 3 | 0 | 0.0 | 10.0 | 0 | 0 | 0 |
| 4 | 3 | 0.0 | 10.0 | 1 | 2 | 3 |
| 5 | 0 | 0.0 | 10.0 | 0 | 0 | 0 |
| 6 | 2 | 0.0 | 10.0 | 4 | 5 | 0 |
| 7 | 0 | 0.0 | 17.5 | 0 | 0 | 0 |
| 8 | 1 | 0.0 | 9.0 | 7 | 0 | 0 |
| 9 | 1 | 0.0 | 6.0 | 8 | 0 | 0 |
| 10 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 11 | 3 | 0.0 | 16.0 | 6 | 9 | 10 |
| 12 | 1 | 0.0 | 6.0 | 11 | 0 | 0 |
| 13 | 0 | 0.0 | 12.0 | 0 | 0 | 0 |
| 14 | 2 | 0.0 | 27.0 | 12 | 13 | 0 |
| 15 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 16 | 0 | 0.0 | 14.0 | 0 | 0 | 0 |
| 17 | 2 | 0.0 | 22.0 | 15 | 16 | 0 |
| 18 | 2 | 0.0 | 12.0 | 14 | 17 | 0 |
| 19 | 0 | 0.0 | 19.0 | 0 | 0 | 0 |

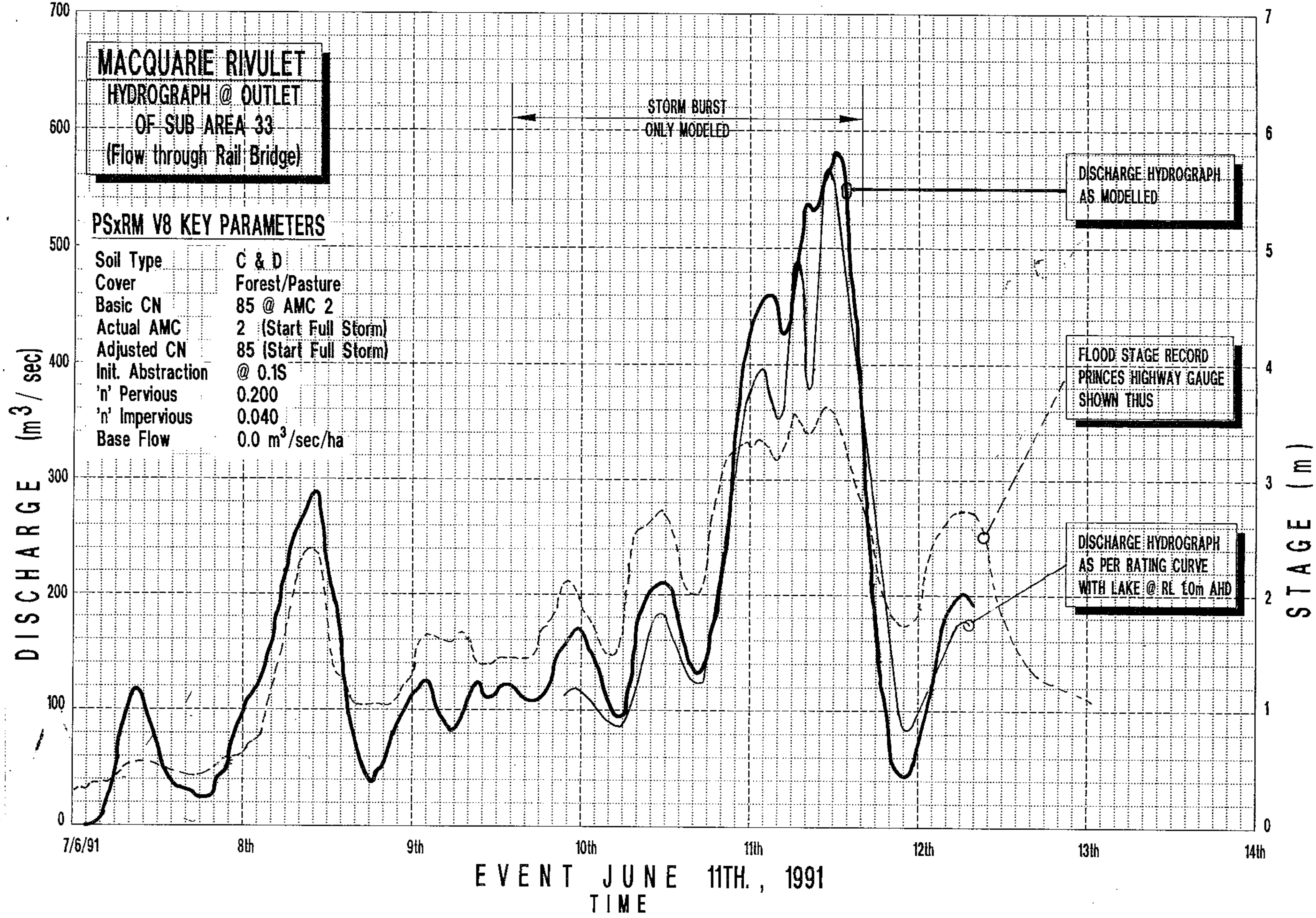
```
     20                        2     0.0    16.0    18     19     0
     21                        0     0.0     8.0     0      0     0
     22                        0     0.0     9.0     0      0     0
     23                        2     0.0    16.0    21     22     0
     24                        0     0.0    11.0     0      0     0
     25                        0     0.0     6.0     0      0     0
     26                        3     0.0    14.0    23     24    25
     27                        0     0.0     9.0     0      0     0
     28                        1     0.0    27.0    27      0     0
     29                        1     0.0    20.0    28      0     0
     30                        1     0.0     9.0    29      0     0
     31                        3     0.0     1.5    20     26    30
     32                        0     0.0     1.5     0      0     0
     33                        2     0.0    99.99   31     32     0
 Basin Data      IRES      NSQ     IRT      QBYP      STI    NAME
                  20        4       2        0.0      0.0    MCQRIV ABOVE ALBION PARK
 Elevation   (m)
      0.0     1.0     2.0     3.0
 Storeage    (m3E3)
      0.0     1500    3000    4500
 Outflow     (m3/sec)
      0.0     650     1300    1950
                  26        4       2        0.0      0.0    FRAZERS ABOVE TONGARRA
 Elevation   (m)
      0.0     1.0     2.0     3.0
 Storeage    (m3E3)
      0.0     150     300     450
 Outflow     (m3/sec)
      0.0     225     450     675
                  30        4       2        0.0      0.0    MARSHAL ABOVE GREY MEADO
 Elevation   (m)
      0.0     1.0     2.0     3.0
 Storeage    (m3E3)
      0.0     1500    3000    4500
 Outflow     (m3/sec)
      0.0     150     300     450
                  31        4       2        0.0      0.0    MACRIV ABOVE PRINCES HWAY
 Elevation   (m)
      0.0     1.0     2.0     3.0
 Storeage    (m3E3)
      0.0     5000   10000   15000
 Outflow     (m3/sec)
      0.0     950     1900    2850
                  32        4       2        0.0      0      YALLAH ABOVE PRINCES HWAY
 Elevation   (m)
      0.0     1.0     2.0     3.0
 Storeage    (m3E3)
      0.0     75      150     300
 Outflow     (m3/sec)
      0.0     2.5     5.0     7.5
                  33        4       2        0.0      0.0    MACRIV BETWEEN BRIDGES
 Elevation   (m)
      0.0     1.0     2.0     3.0
 Storeage    (m3E3)
      0.0     250     500     750
 Outflow     (m3/sec)
```

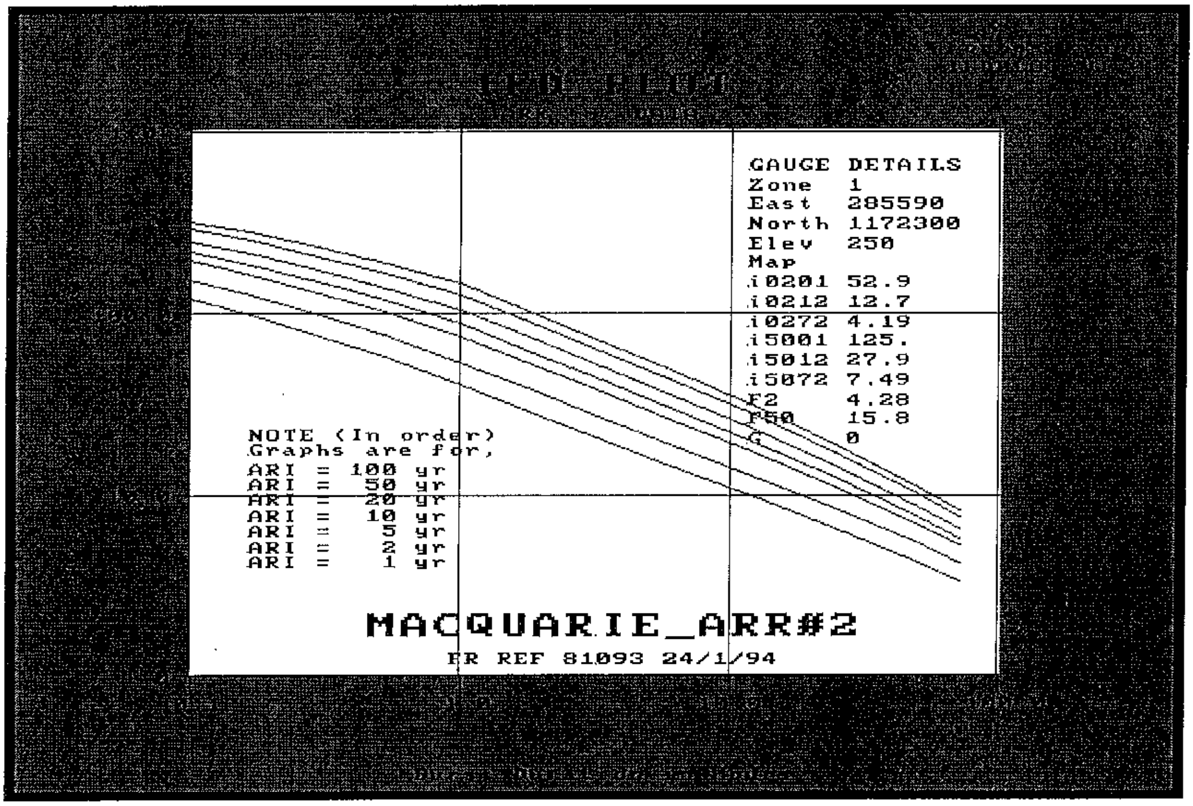


```
      0.0     950     1900    2850
 End of Input
```

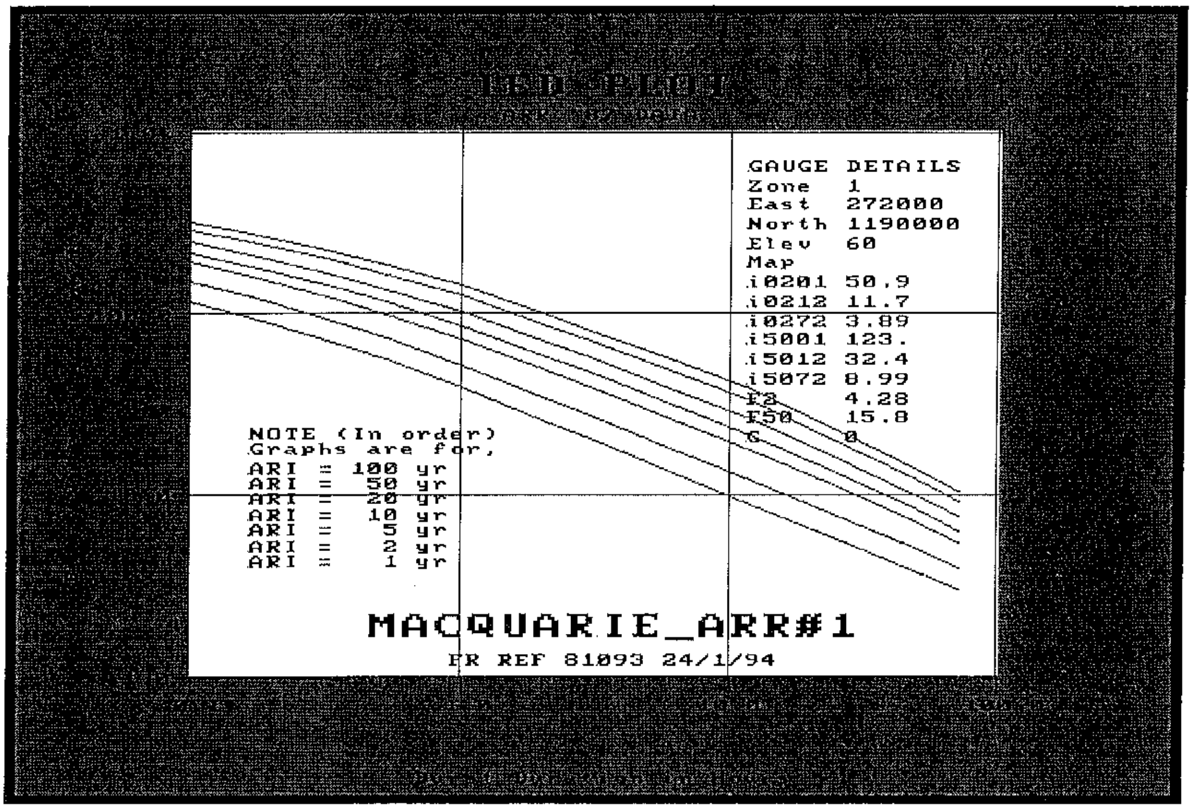


MACQUARIE RIVULET
HYDROGRAPH @ OUTLET
OF SUB AREA 12
(Flow at Sunnybank)
PSxRM V8 KEY PARAMETERS
Soil Type C & D
Cover Forest/Pasture
Basic CN 85 @ AMC 2
Actual AMC 2 (Start Full Storm)
Adjusted CN 85 (Start Full Storm)
Init. Abstraction @ 0.1S
'n' Pervious 0.200
'n' Impervious 0.040
Base Flow 0.0 m3/sec/ha
STORM BURST
ONLY MODELED
DISCHARGE HYDROGRAPH
AS MODELLED
FLOOD STORAGE RECORD
PRINCES HIGHWAY GAUGE
SHOWN THUS
DISCHARGE HYDROGRAPH
FOR RATING CURVE
(Amended Forbes Rigby '96)
DISCHARGE (m3/sec)
0
100
200
300
400
500
600
700
STAGE (m)
0
1
2
3
4
5
6
7
7/6/91
8th
9th
10th
11th
12th
13th
14th
EVENT JUNE 11TH., 1991
TIME

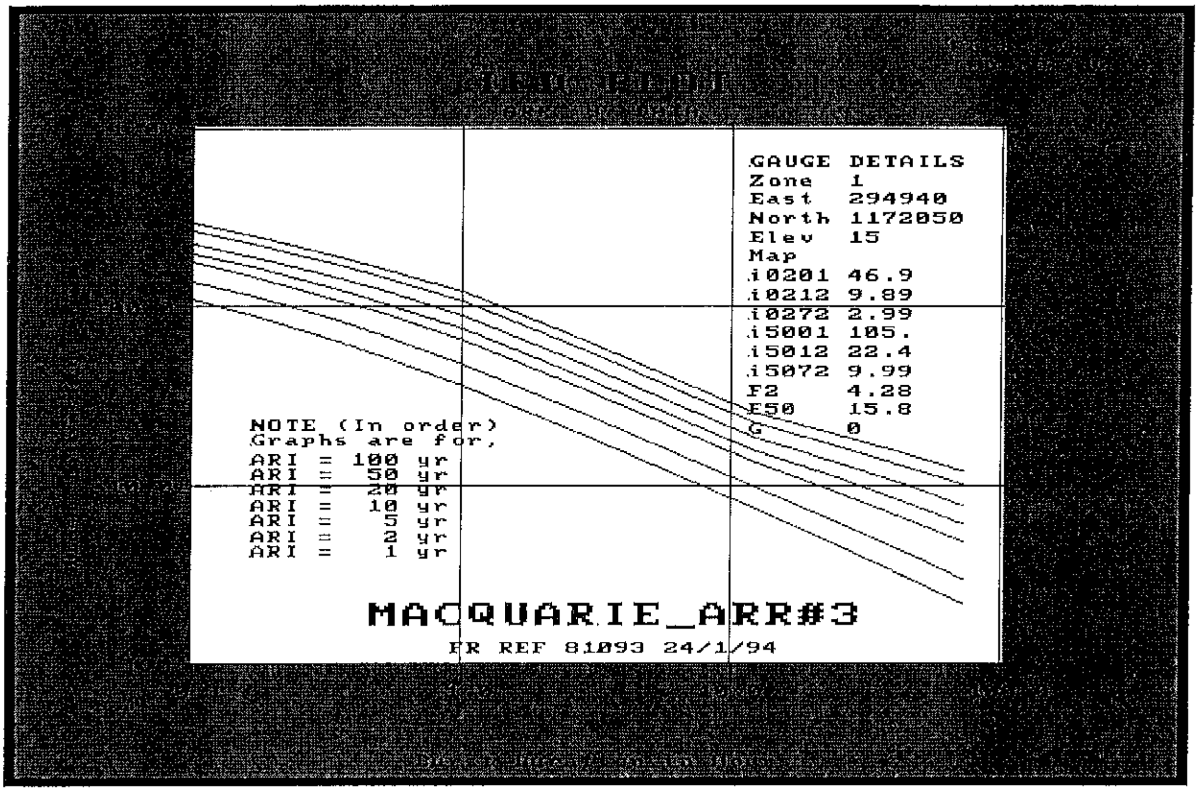

MACQUARIE RIVULET
HYDROGRAPH @ OUTLET
OF SUB AREA 33
(Flow through Rail Bridge)
PSxRM V8 KEY PARAMETERS
Soil Type C & D
Cover Forest/Pasture
Basic CN 85 @ AMC 2
Actual AMC 2 (Start Full Storm)
Adjusted CN 85 (Start Full Storm)
Init. Abstraction @ 0.1S
'n' Pervious 0.200
'n' Impervious 0.040
Base Flow 0.0 m3/sec/ha
STORM BURST
ONLY MODELED
DISCHARGE HYDROGRAPH
AS MODELLED
FLOOD STAGE RECORD
PRINCES HIGHWAY GAUGE
SHOWN THUS
DISCHARGE HYDROGRAPH
AS PER RATING CURVE
WITH LAKE @ RL 1.0m AHD
DISCHARGE (m3/ sec)
0
100
200
300
400
500
600
700
STAGE (m)
0
1
2
3
4
5
6
7
7/6/91
8th
9th
10th
11th
12th
13th
14th
EVENT JUNE 11TH., 1991
TIME




APPENDIX 2.9
IFD PLOT - DESIGN GAUGE
ARR #2 (WESTERN)




APPENDIX 2.10
IFD PLOT - DESIGN GAUGE
ARR #1 (CENTRAL)




APPENDIX 2.11
IFD PLOT - DESIGN GAUGE
ARR #3 (EASTERN)

APPENDIX 3


3.1 Model Layout - Lower Floodplain

3.2 Model Layout - Upper Floodplain

3.3 Model Topography - Lower

3.4 Model Topography - Upper

3.5 Modelled Flood Surface - June '91, Lower

3.6 Modelled Flood Surface - June '91, Upper

3.7 Modelled Flood Surface - 1% AEP, Lower

3.8 Modelled Flood Surface - 1% AEP, Upper

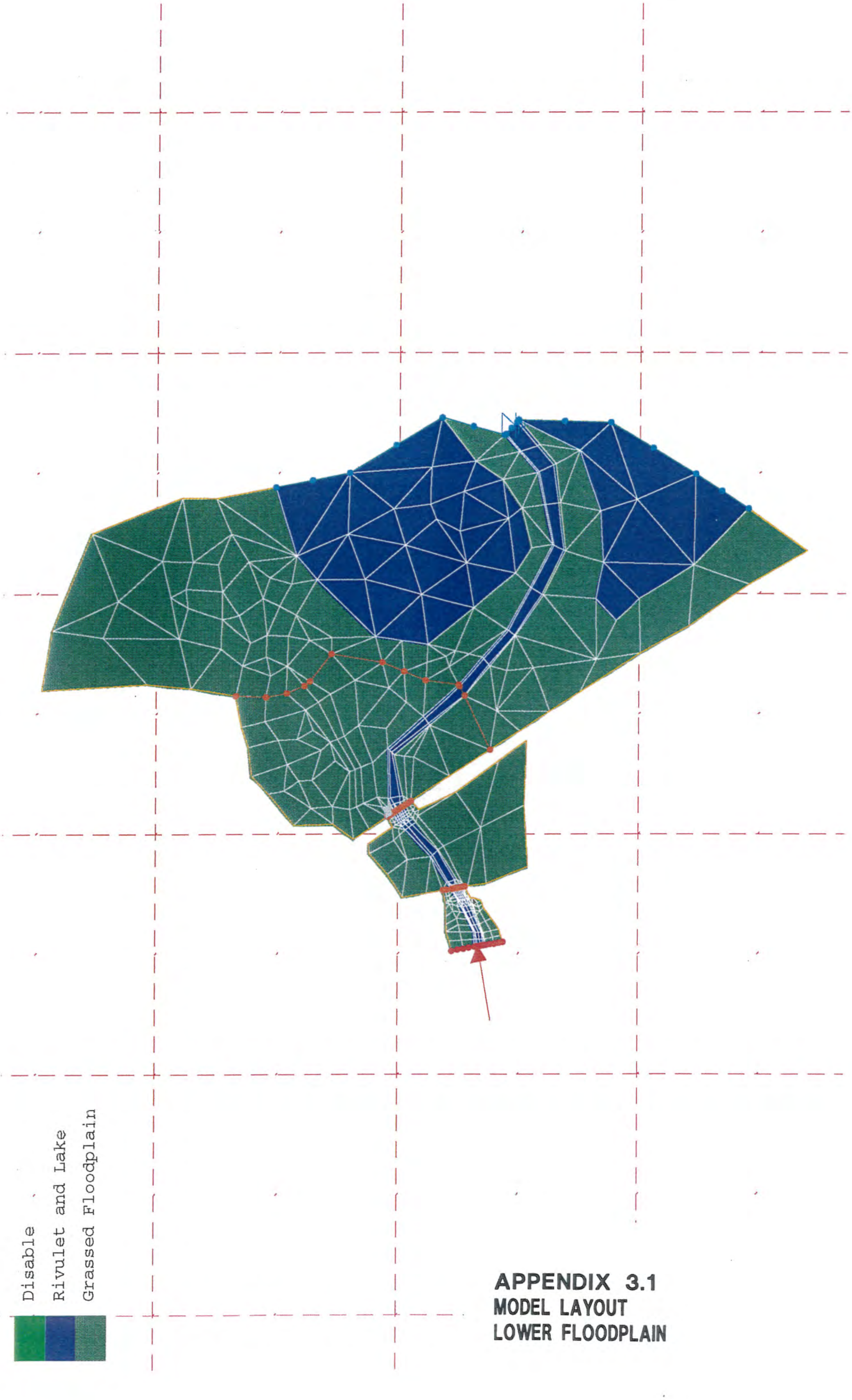
3.9 Modelled Flood Velocities - 1% AEP, Lower

3.10 Modelled Flood Velocities - 1% AEP, Upper

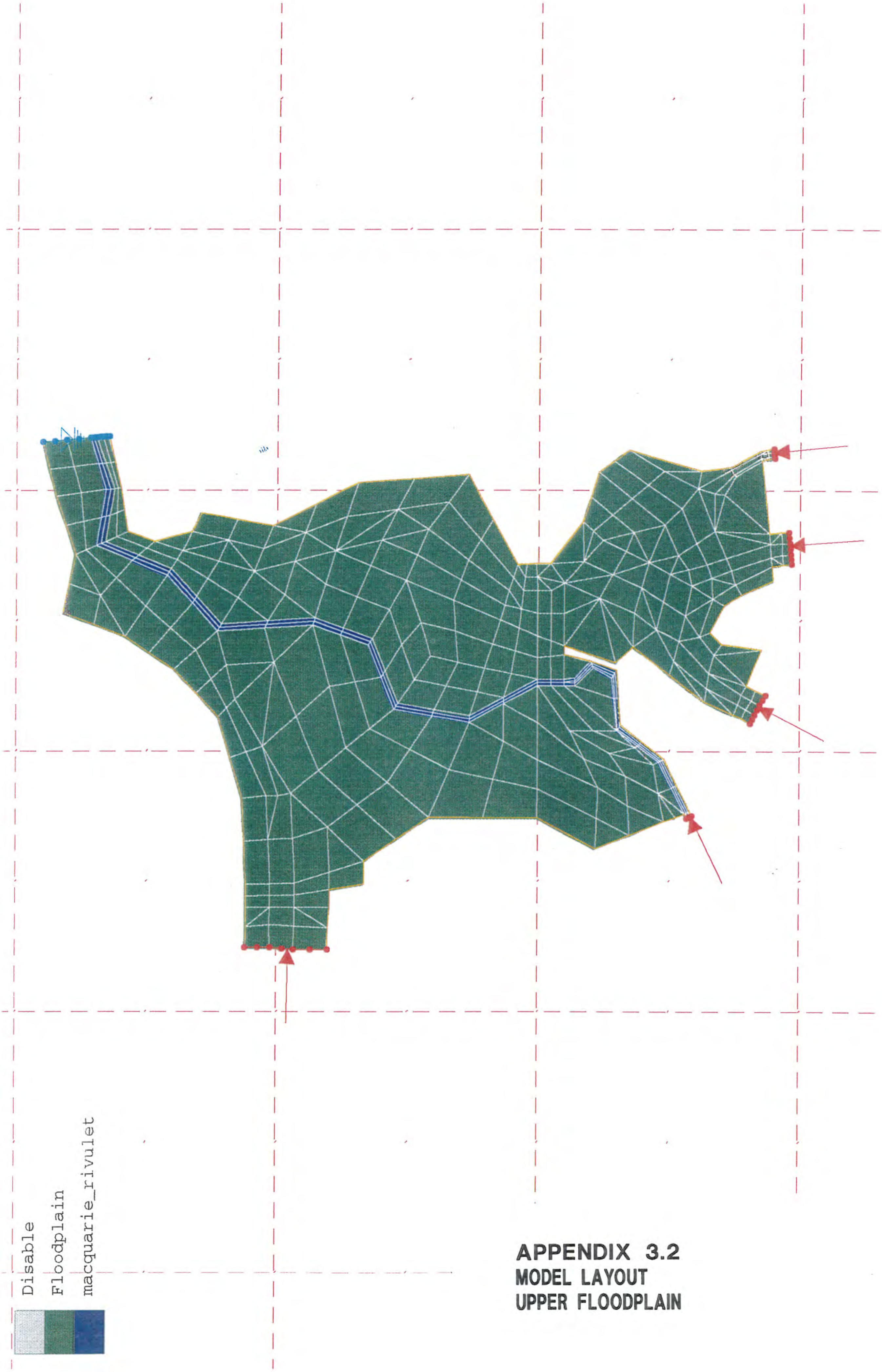
3.11 Modelled Flood Hazard Levels - 1% AEP, Lower

3.12 Modelled Flood Hazard Levels - 1% AEP, Upper

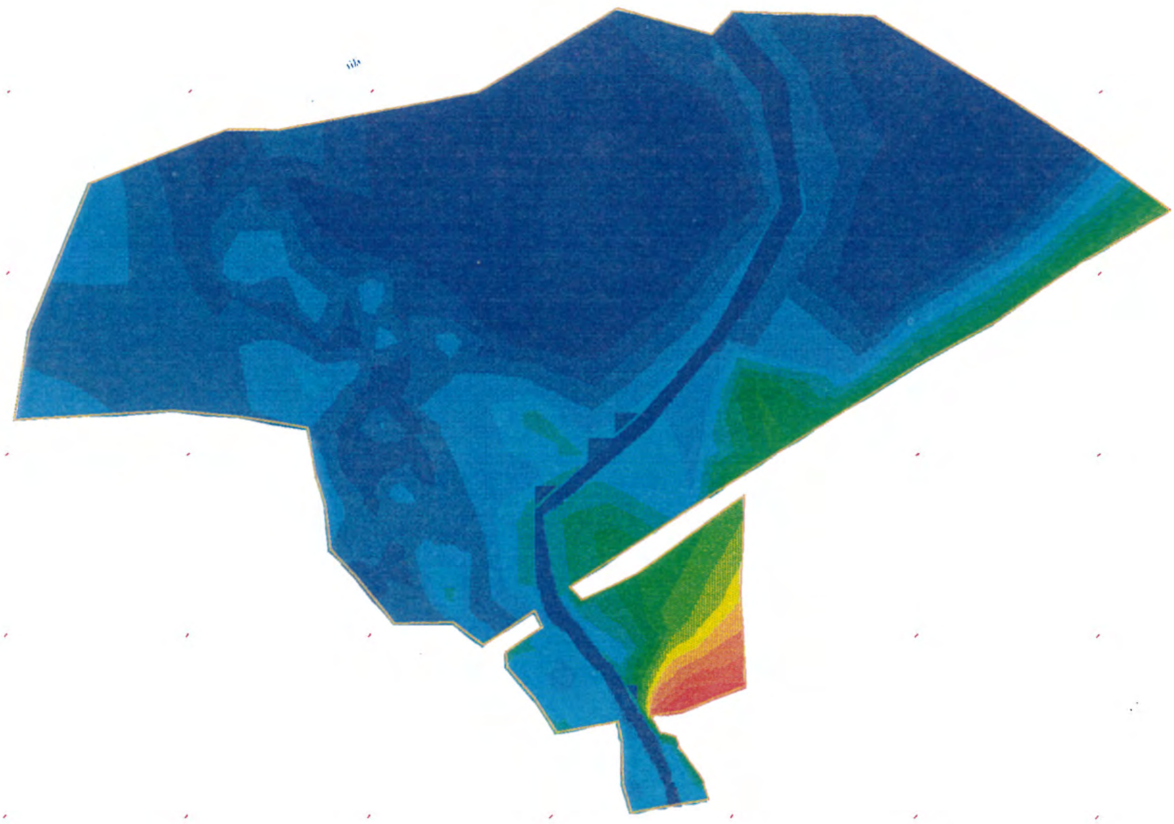

# FLOODPLAIN HYDRAULICS

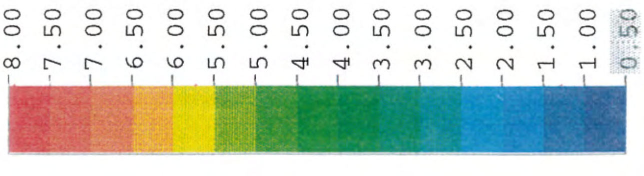



**APPENDIX 3.1**
**MODEL LAYOUT**
**LOWER FLOODPLAIN**

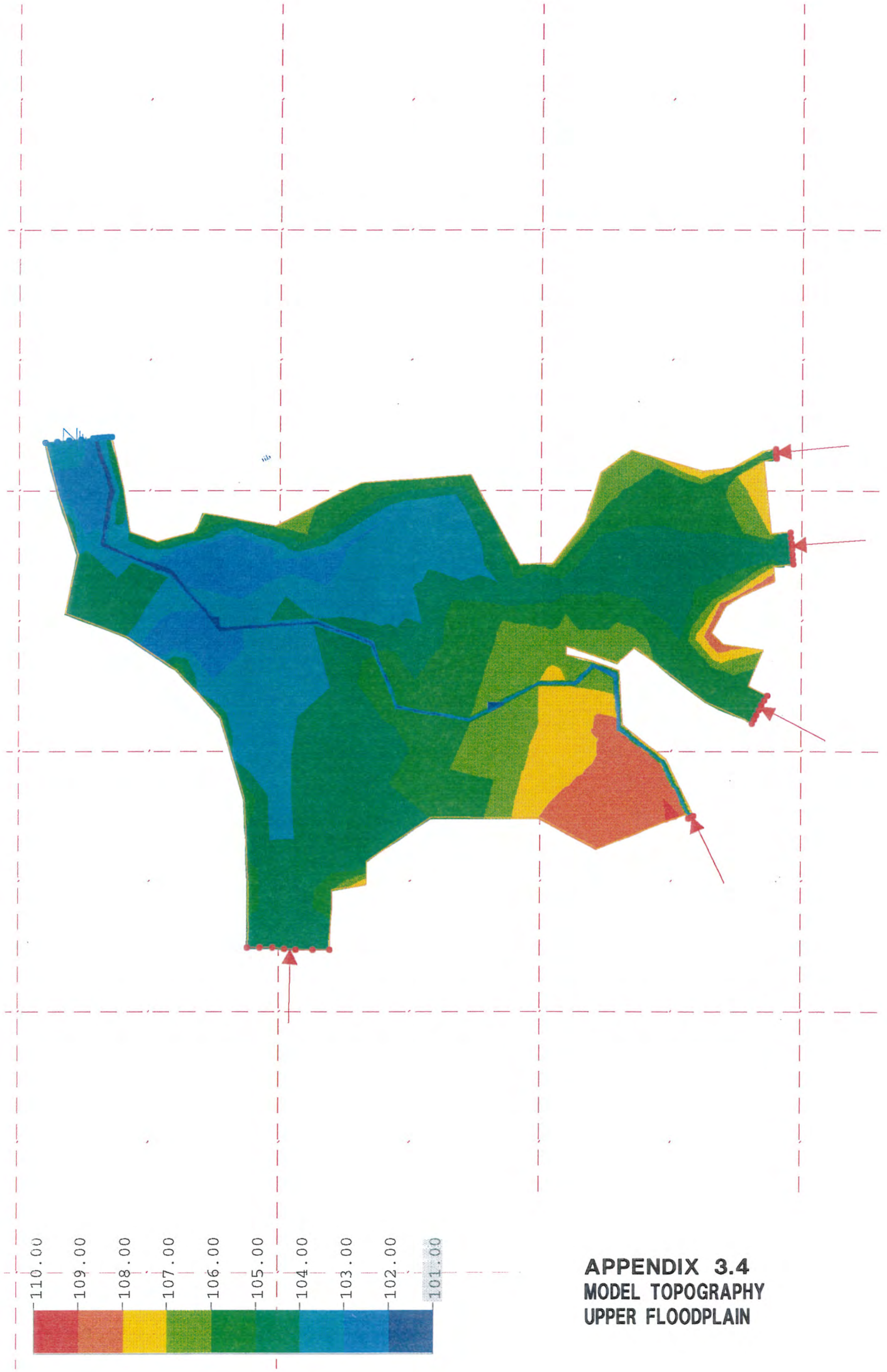



**APPENDIX 3.2**
**MODEL LAYOUT**
**UPPER FLOODPLAIN**

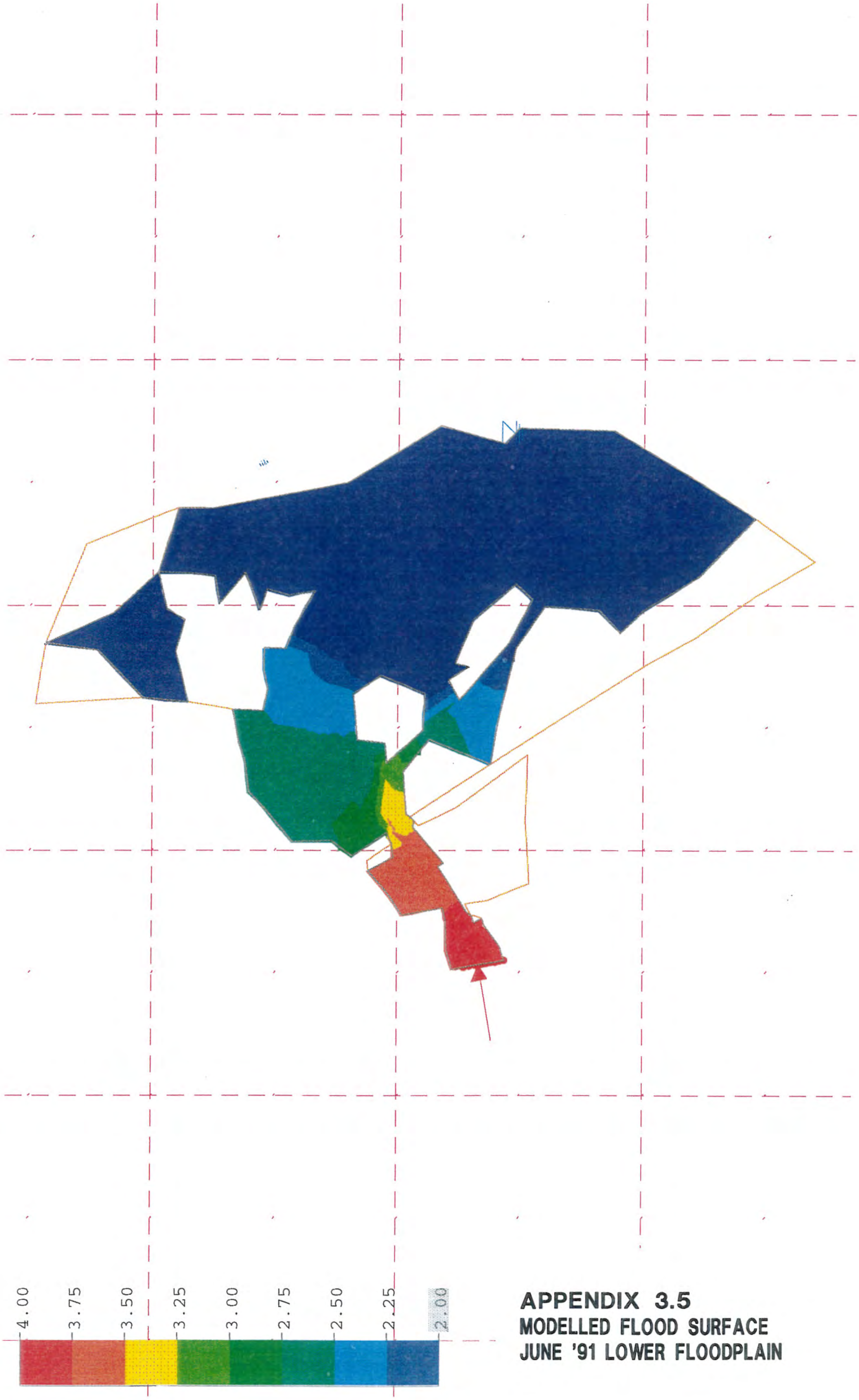




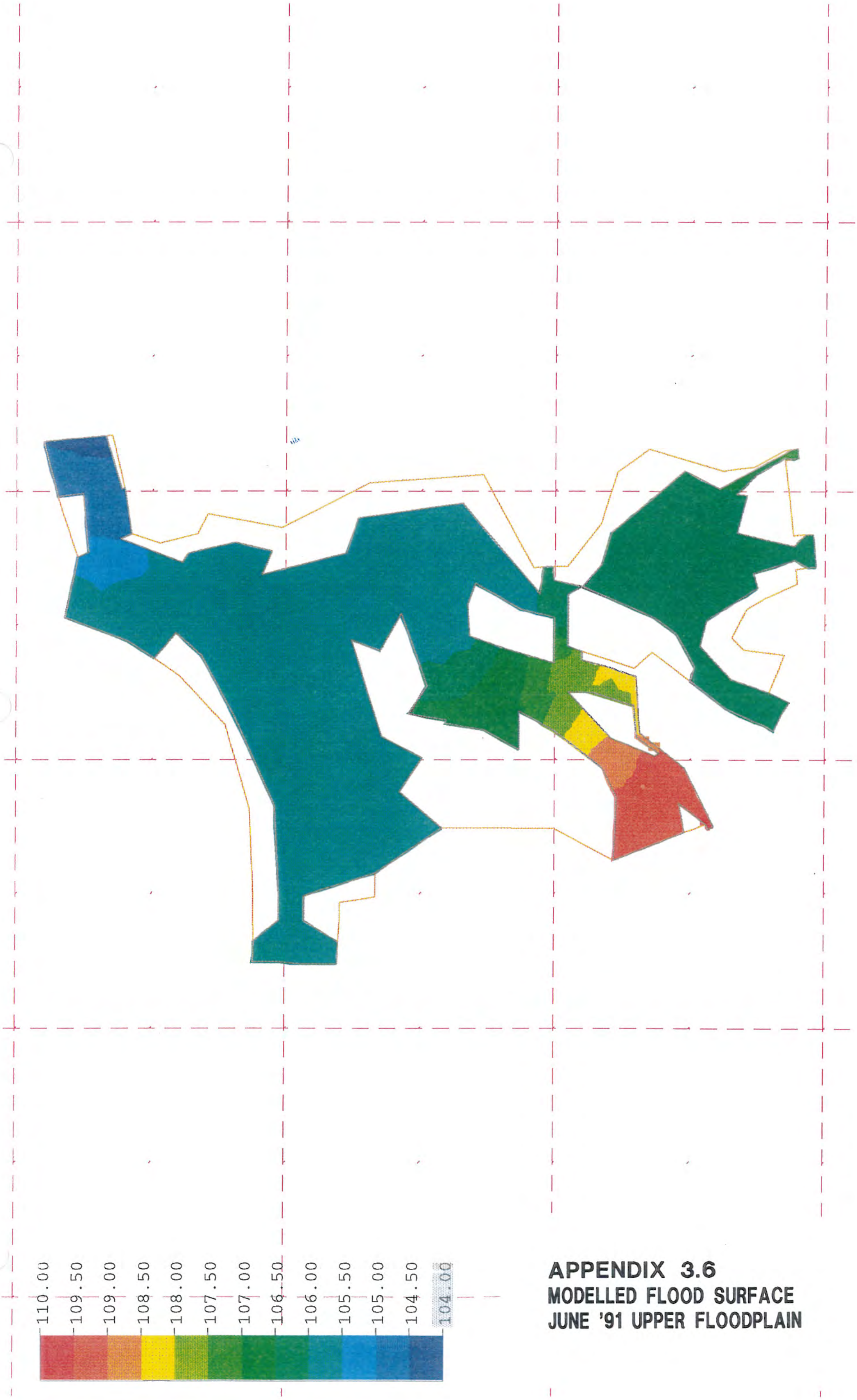

**APPENDIX 3.3**
**MODEL TOPOGRAPHY**
**LOWER FLOODPLAIN**



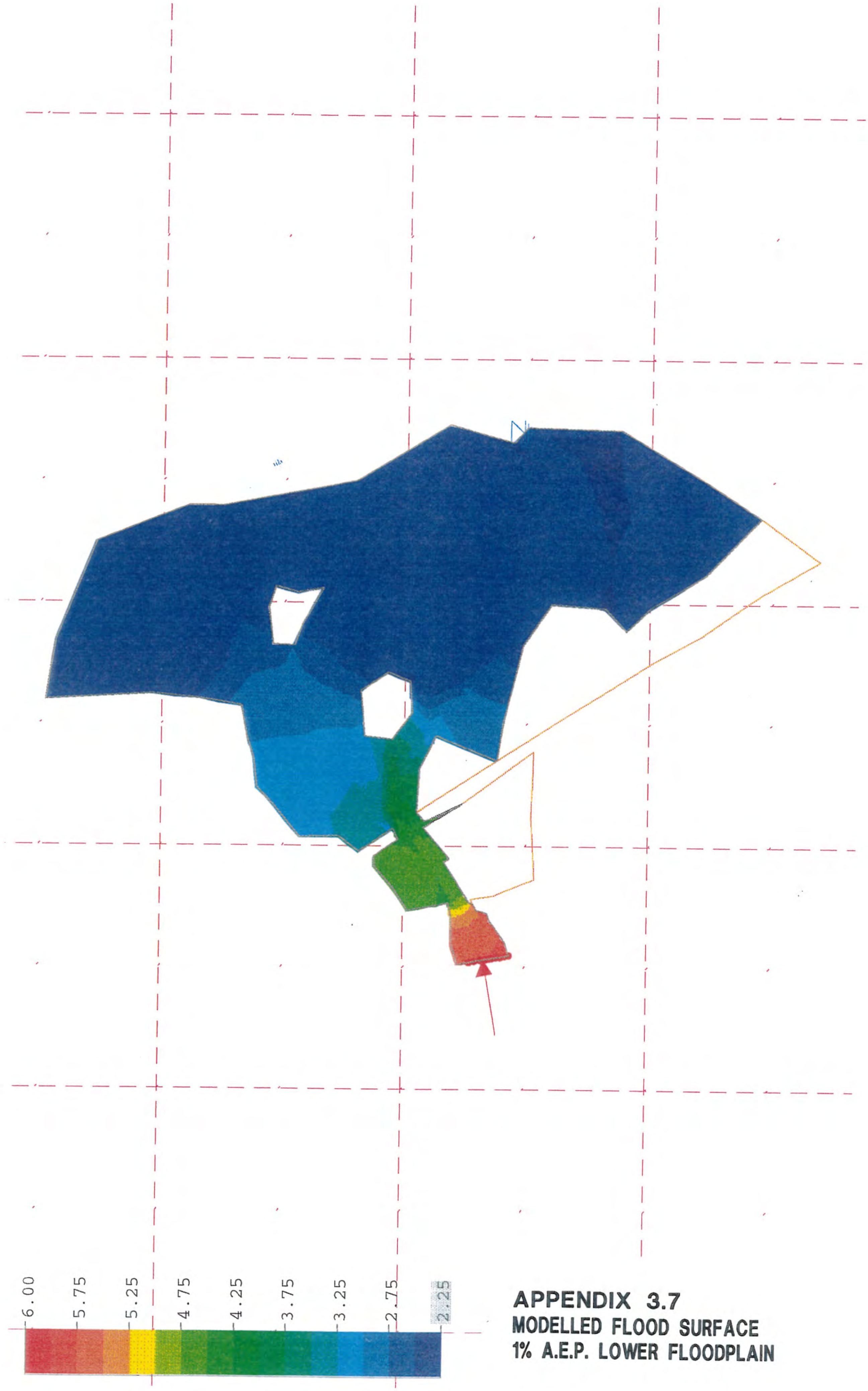

**APPENDIX 3.4**
**MODEL TOPOGRAPHY**
**UPPER FLOODPLAIN**



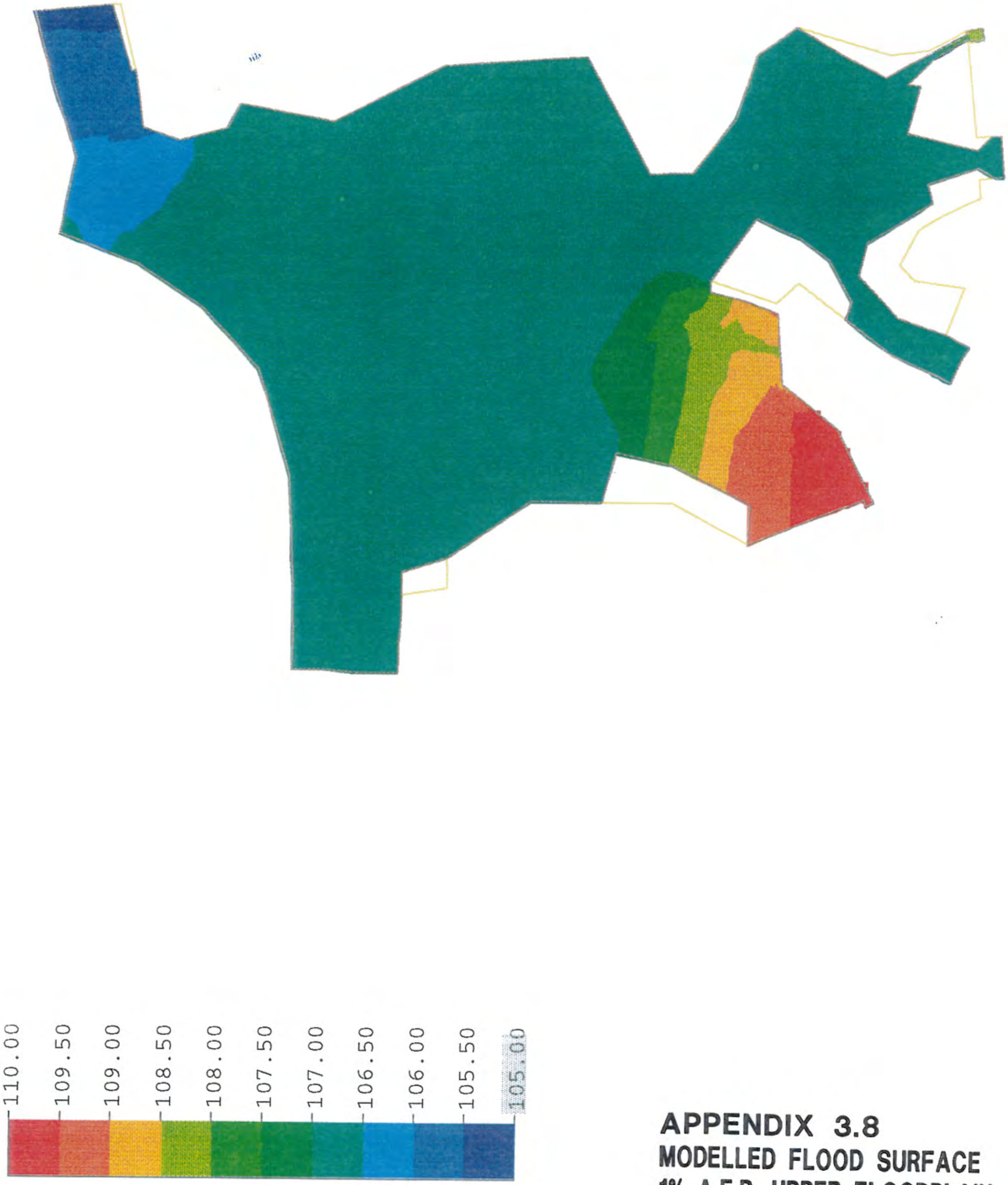

**APPENDIX 3.5**
**MODELLED FLOOD SURFACE**
**JUNE '91 LOWER FLOODPLAIN**



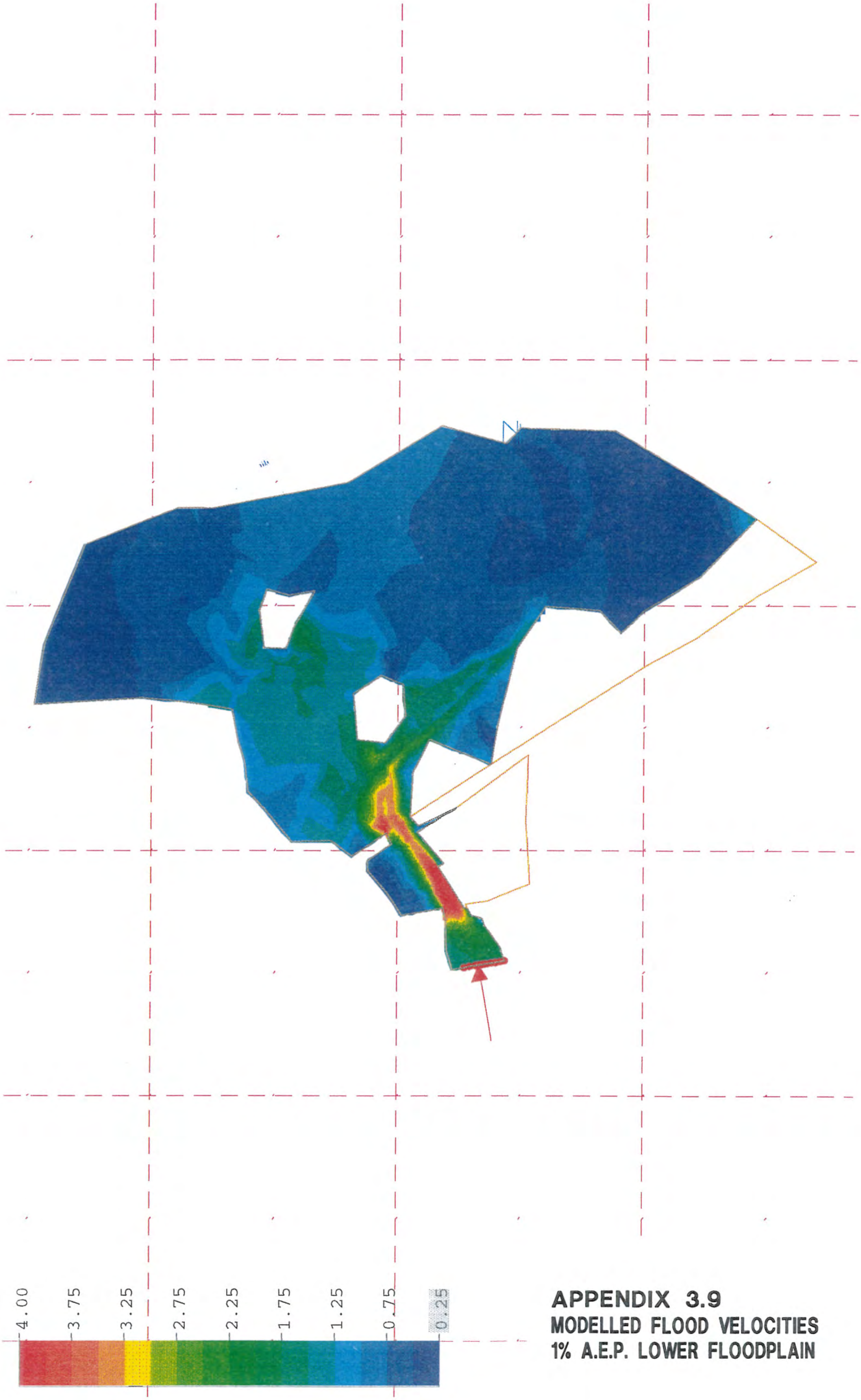

**APPENDIX 3.6**
**MODELLED FLOOD SURFACE**
**JUNE '91 UPPER FLOODPLAIN**



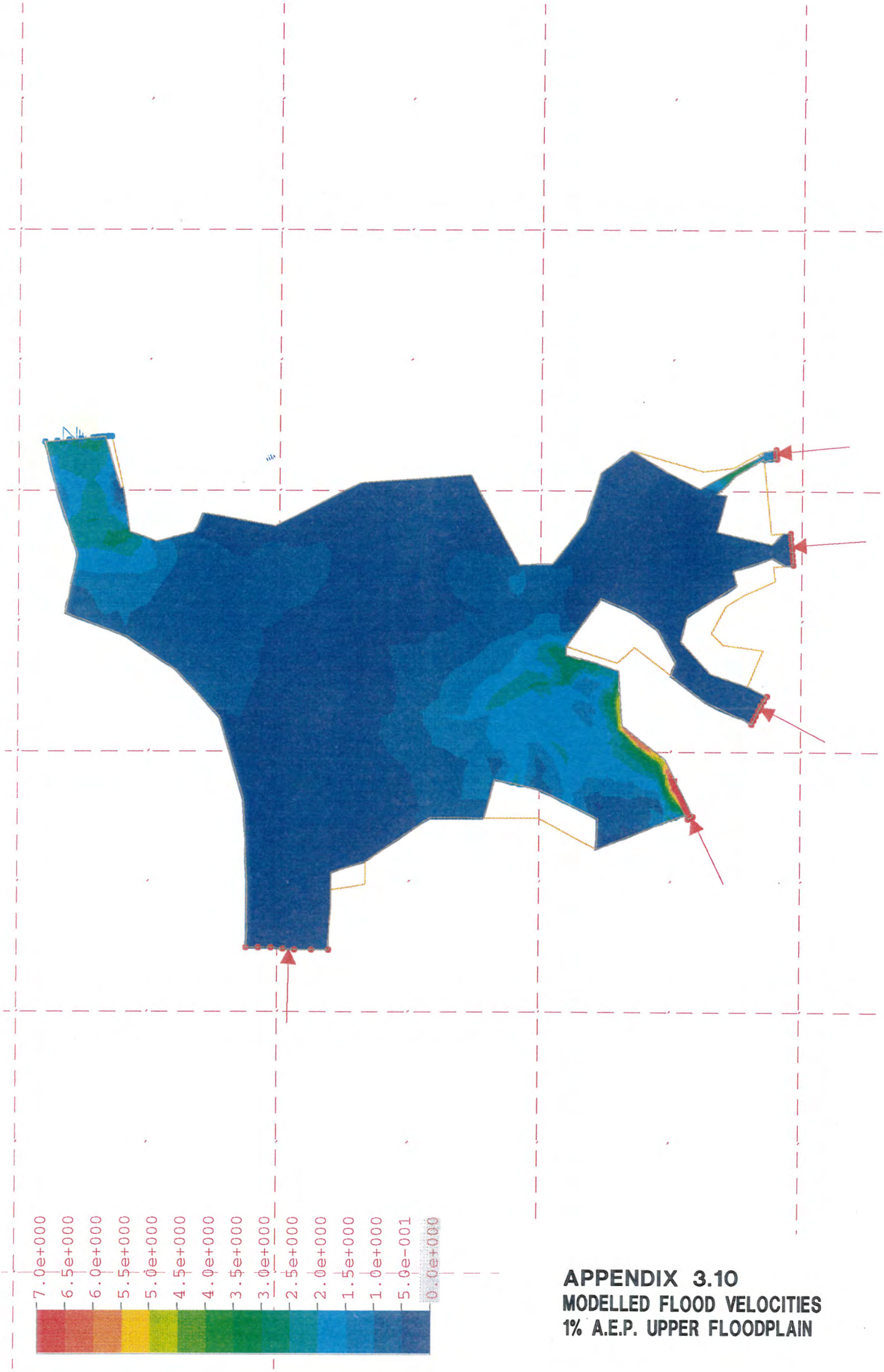

**APPENDIX 3.7**
**MODELLED FLOOD SURFACE**
**1% A.E.P. LOWER FLOODPLAIN**



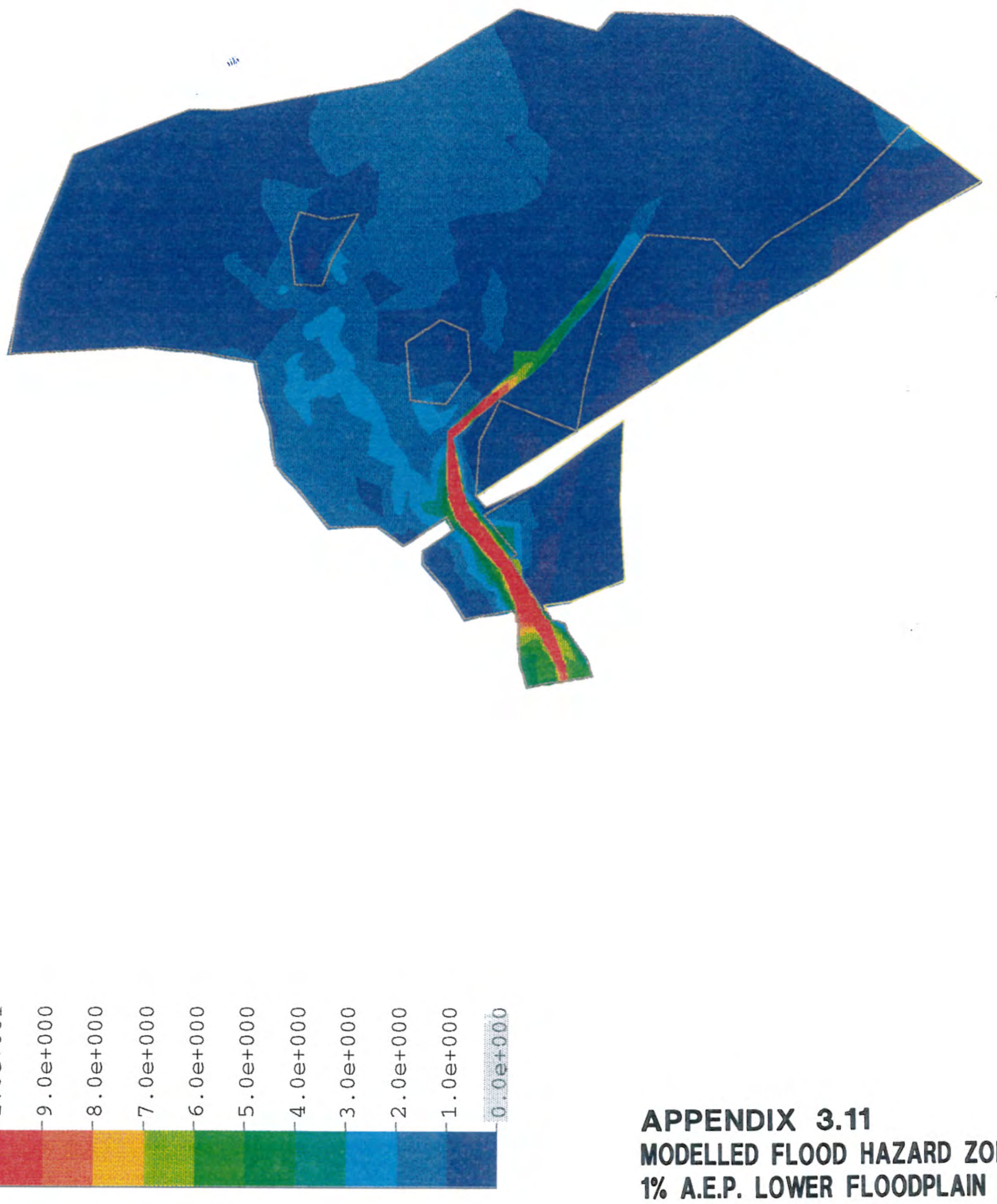

**APPENDIX 3.8**
**MODELLED FLOOD SURFACE**
**1% A.E.P. UPPER FLOODPLAIN**



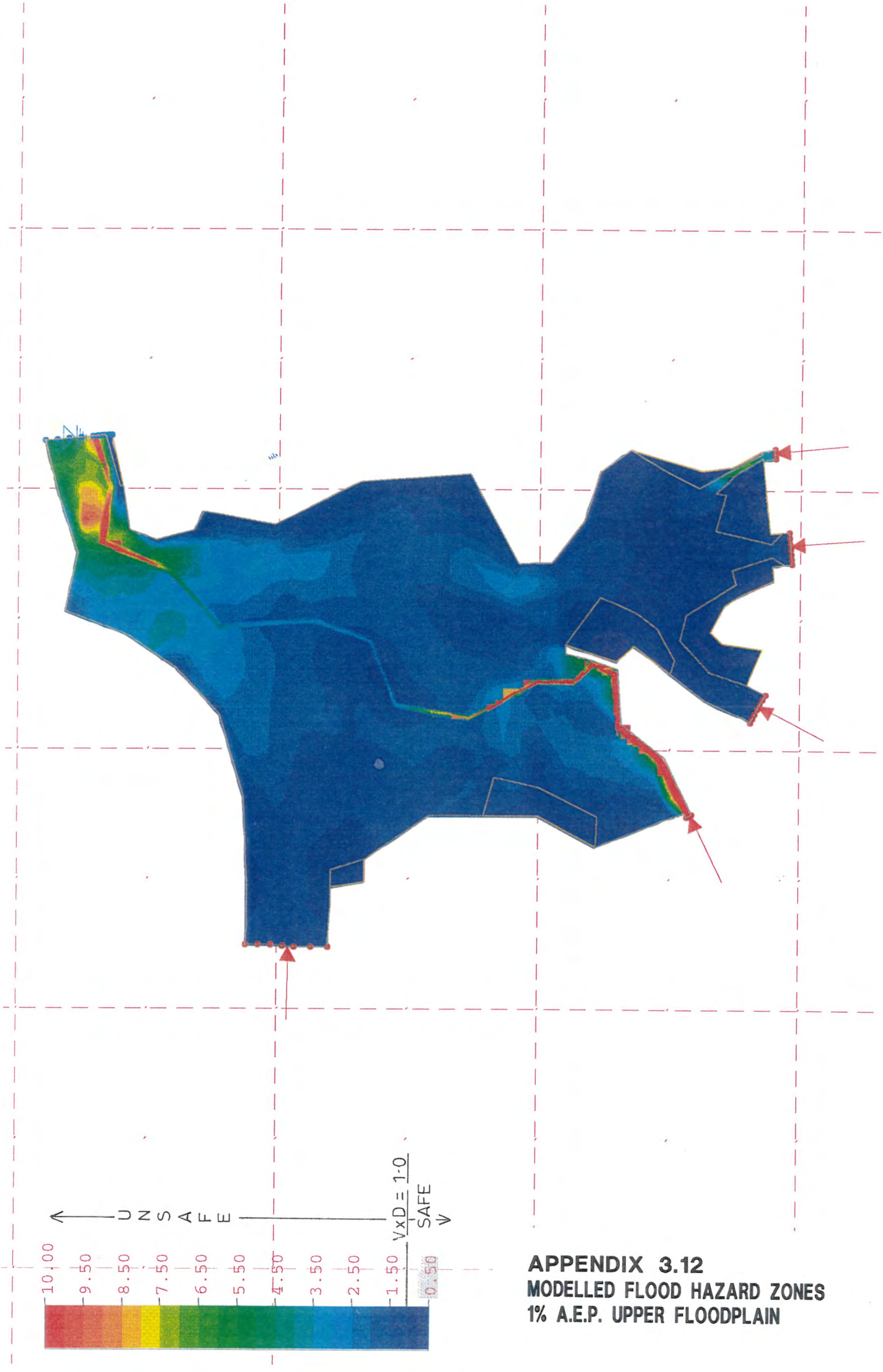

**APPENDIX 3.9**
**MODELLED FLOOD VELOCITIES**
**1% A.E.P. LOWER FLOODPLAIN**




**APPENDIX 3.10**
**MODELLED FLOOD VELOCITIES**
**1% A.E.P. UPPER FLOODPLAIN**




**APPENDIX 3.11**
**MODELLED FLOOD HAZARD ZONES**
**1% A.E.P. LOWER FLOODPLAIN**



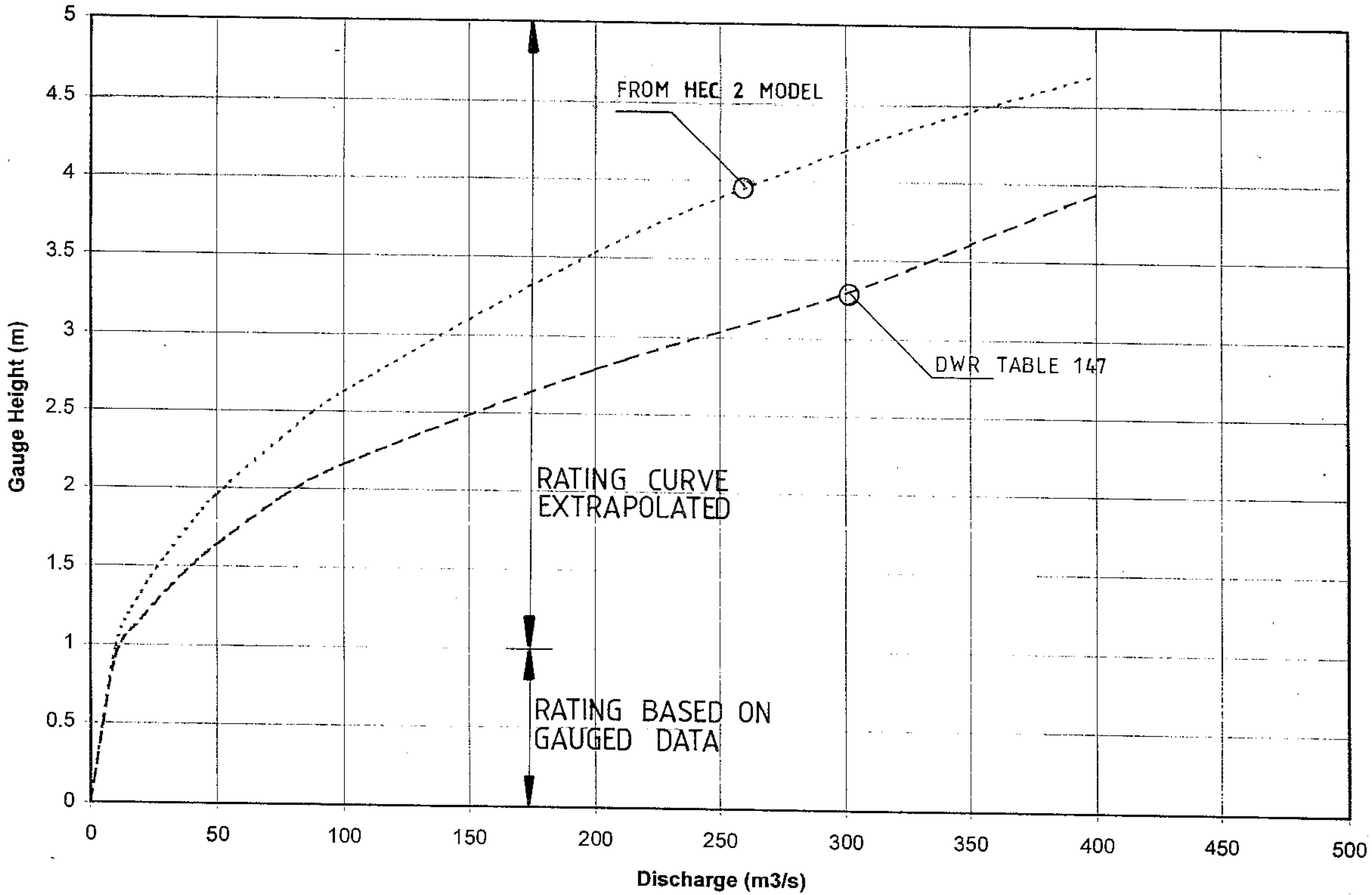

**APPENDIX 3.12**
**MODELLED FLOOD HAZARD ZONES**
**1% A.E.P. UPPER FLOODPLAIN**

4.1 Sunnybank Gauge Rating Curve

4.2 Princes Highway Gauge Rating Curve

# RATING CURVES

APPENDIX 4

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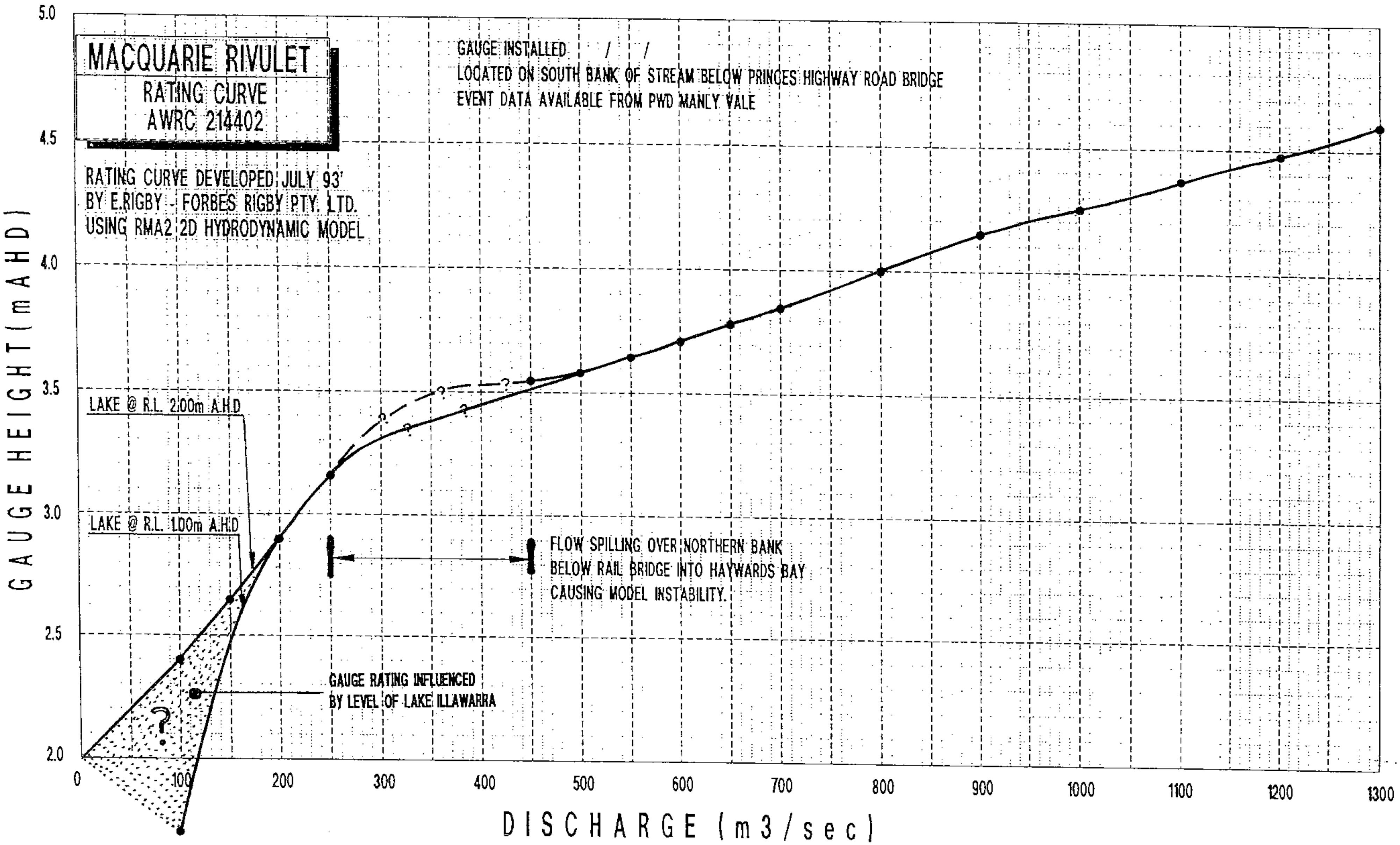
| | SUNNYBANK GAUGE - RATING CURVE | |

**APPENDIX 4.1**
**SUNNYBANK GAUGE**

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| AUG 93' | FORBES RIGBY PTY. LTD. - CONSULTING ENGINEERS | 83093-2 |
| | PRINCES HIGHWAY GAUGE - RATING CURVE | |

**APPENDIX 4.2**
**PRINCES HIGHWAY GAUGE**

5.1 Rigby, E. (1993) 'Modelling Flood Flows in Macquarie Rivulet'

5.2 Boyd et al (1989) 'A Comparison of Design Flood Estimation Methods'

5.3 Rigby, E. (1984) 'Development of a Hydrologic Database for the Illawarra'

# PAPERS PUBLISHED

APPENDIX 5

*Environmental Management, Geo-Water & Engineering Aspects, Chowdhury & Sivakumar (eds)*
 *ISBN 90 5410 099 0*

# Modelling flood flows in Macquarie Rivulet using FESWMS-2DH

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ABSTRACT: A finite element based two dimensional hydraulic model (FESWMS-2DH) was established to model complex flood behaviour in the lower reaches of Macquarie Rivulet, above its point of discharge into Lake Illawarra. Using this model it was possible to directly evaluate the impact of proposed excavation and filling on flood behaviour in this sensitive wetland area. It is the author's conclusion that this model represents a significant improvement over other tools available for modelling two dimensional flood flows and may in some hydraulically complex situations provide the only means of solution currently available.

## 1 INTRODUCTION

Over the last two decades, the increasing power and ready availability of computers has spawned a vast collection of software for modelling the hydraulics of flood flows in channels and streams. In the early stages of development, such software was based on the simplified concept of steady uniform flow such as might be achieved in a laboratory flume.

With time these models evolved to include many of the features of real streams, but most still retained their original one dimensional (1D) structure. Over this same period several pseudo two dimensional models evolved based on '1D' links between nodes or cells to approximate the two dimensional flow domain. It is mostly this class of model that is used today, to model two dimensional flows.

This paper sets out the experiences of the author in establishing and applying a model, which solves the full St Venant equations for flow in two dimensions, to evaluate the impact of various flood plain filling options on flooding in Macquarie Rivulet, a small stream to the south of Sydney, Australia.

## 2 MACQUARIE RIVULET

The catchment of Macquarie Rivulet is located approximately 100 km south of Sydney, on the narrow coastal strip formed by the Illawarra escarpment to the west and Pacific Ocean to the east.

This 105km$^2$ catchment is predominantly rural in character although residential development is expanding rapidly in the lower one third of the catchment.

Macquarie Rivulet is typical of the many mountain streams traversing this coastal strip, with headwaters on the escarpment, falling steeply down the escarpment and over the foothills onto a low lying coastal plain. Like many streams in the region, Macquarie Rivulet discharges into a coastal lagoon (Lake Illawarra) before reaching the sea.

Macquarie Rivulet has a stream length of approximately 22.5 km with a fall of the order of 680 metres over this length. Some 450m of this fall occurs in the first kilometre of the stream's length.

Whilst the upper reaches are therefore quite steep with some spectacular waterfalls, the bed grade for most of the streams length is relatively flat (typically about 2m per km).

Where Macquarie Rivulet discharges into Lake Illawarra a substantial delta has formed, creating a complex wetland habitat around the delta and on the foreshores of the adjacent bays.

As with many streams in the Illawarra, conflict arises between the east to west flowing streams and north/south oriented road and rail network. Substantial impediment to flow in major floods is created by road and rail bridges, over Macquarie Rivulet near its outlet to Lake Illawarra.

The combination of these waterway constrictions and the meandering channel downstream of the bridges creates complex two dimensional flows in all events of sufficient magnitude to overtop the natural levees.

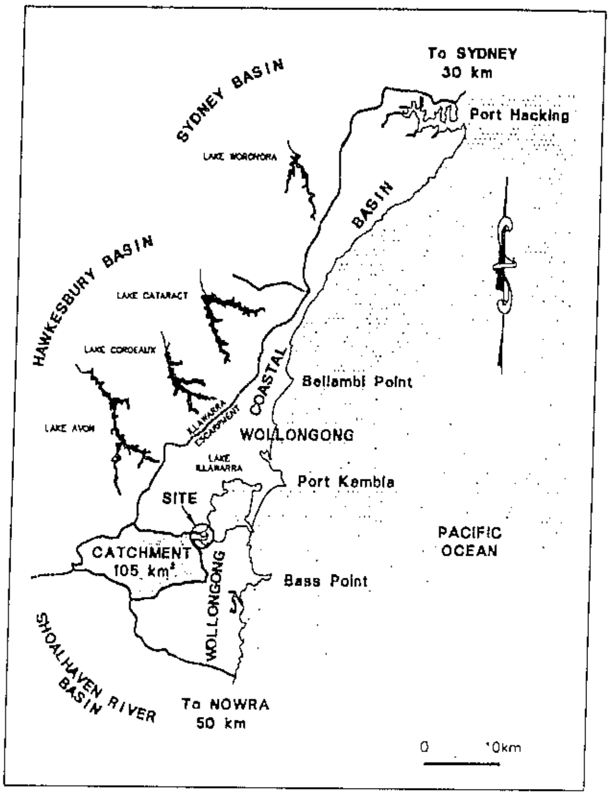


Fig. 1 Location plan

## 3 PROPOSED DEVELOPMENT

A mixed residential and recreational development has been proposed on land bounded by Macquarie Rivulet to the south, the Illawarra rail line to the west, Tallawarra Power Station ash ponds the north and Lake Illawarra to the east.

The conceptual layout for this development comprises residential development on higher land to the north of the site with a golf course on lower land, part of the northern flood plain of Macquarie Rivulet.

The relationship of the development site to the catchment and to other features of the area is reproduced in Figure 1.

In order to meet State Planning guidelines for development on flood prone land, this scheme required filling part of the northern flood plain to raise residential land above the designated (1% AEP) flood event.

Whilst a standard step (1D) backwater model had initially been used to establish predevelopment flood levels adjacent to the site in the designated flood, such a model, even with overbank flows separately modelled, could not be expected to adequately represent the impact of the excavation, filling and reshaping proposed, on flood flows in the vicinity of the site.

## 4 MODEL SELECTION

A Finite Element Surface Water Modelling System for two dimensional flows in a horizontal plane (FESWMS-2DH) was chosen to simulate the complex flow field in the lower reaches of Macquarie Rivulet, for a range of flood plain development options.

This model was developed for the US Federal Highways Administration by the Water Resources Division of the US Geological Survey to provide a means of simulating flows where natural processes and man made structures have created complex hydraulic conditions, that are difficult to evaluate using conventional methods. This modelling system is able to simulate complex flow conditions which are essentially two-dimensional in the horizontal plane. The FESWMS-2DH modelling system may be applied to a broad range of flow conditions such as flow at multiple opening bridge crossings, with or without pressure flow and/or overtopping, flow around islands, or flow over an irregular flood plain. Unsteady flow may be modelled by specifying varying boundary conditions at different points in time.

FESWMS-2DH solves the complete St Venant equations, where two equations describe the conservation of momentum and one equation describes the conservation of mass. Frictional losses may be modelled using the Chezy or Manning equation. Turbulence is modelled using the Boussinesq eddy viscosity concept. The value of the kinematic eddy viscosity may be determined as a function of the shear velocity and flow depth. Optionally the effects of wind stress and the Coriolis force may be included. A Galerkin finite element method is used to solve the resulting system of differential equations. The solution methodology is described by Lee, Froehlich, Gilbert, and Wiche (1983) and details of the model as implemented by the USGS are set out in the associated FESWMS User Manual, Froelich (1989).

Studies by Lee et al (1983), Shearman et al (1986) and Lee & Froehlich (1989) have shown that FESWMS-2DH is capable of simulating the significant features of flow over an irregular flood plain and that the model is able to reproduce the water surface elevation and velocity field near bridge openings more completely and more accurately than one-dimensional models such as HEC-2.

Given, in addition to the above capabilities, the models ability to accept input from an existing digital terrain model (DTM) of the study area and it's ability to display the pre and post development flow fields on screen or on a plotter, it was resolved to trial the model in this study.

## 5 MODEL CONSTRUCTION

Initially a detail survey of the flood plain, creek and adjacent bays was undertaken, to augment existing topographic data.

In conjunction with supplementary data digitised from 1:4000 contoured orthophoto mapping, this data was ingested into Autocad, filtered and exported as 3D faces to the 2D modelling package FESWMS using a small utility program developed by the author.

Particular care was taken to ensure that the shallow depressions and raised areas on the downstream flood plain were correctly represented in the model. Additional (smaller) elements were provided in areas where flow was expected to vary rapidly (viz in the vicinity of both bridge openings).

Consideration was given to the use of curved sided elements to better describe the geometry of the rivulet banks but not adopted as a large proportion of the flow in the event to be modelled occurred above bank level and across the adjacent flood plain.

The triangular and quadrilateral element layout of the model created by the above procedure is reproduced in Fig 2.

Contours of the surface represented by the final element layout were then output and

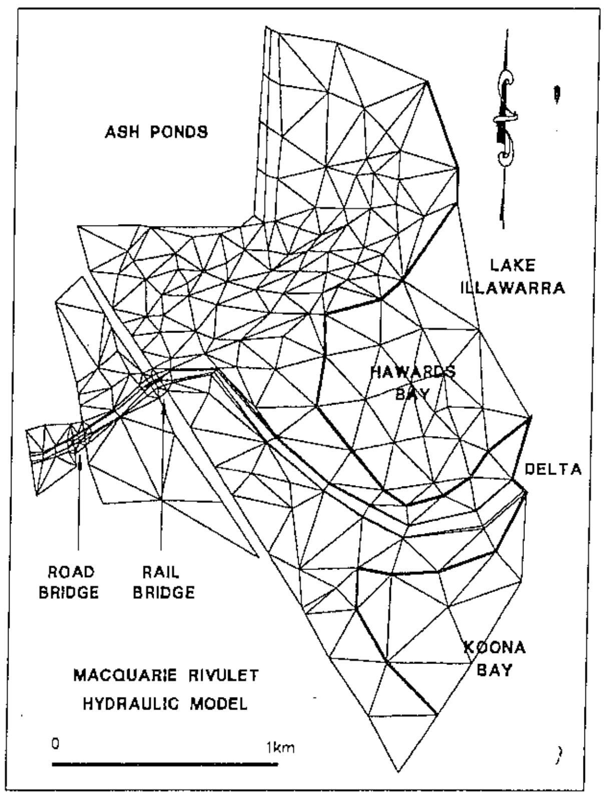


Fig. 2 Finite element network

compared with the original contours from the Autocad DTM to confirm that the surface had been faithfully recreated in the model.

## 6 MODEL APPLICATION

### 6.1 Model Parameters

At the time of the study no data was available for calibration of the model in the study area - hence all results were based on subjective assessment of surface friction and eddy loss parameters following guidelines presented by Chow (1959), Arcement & Schneider (1984) and Lee & Froelich (1989).

Bed friction (Mannings 'n') was specified as a function of depth such that for elements,

(a) In The Creek Waterway
for depth $< 0.1$m, n = 0.100
$> 0.5$m, n = 0.035
with n varying linearly between these limits

(b) On The Flood Plain
for depth $< 0.1$m, n = 0.100
$> 0.5$m, n = 0.055
with n varying linearly between these limits

Kinematic eddy viscosity was specified as,

$2m^2$/sec on the flood plain and
$5m^2$/sec in the creek waterway

Given the short travel time through the reach of interest, relative to the duration of peak flooding - a steady state solution was adopted.

### 6.2 Boundary Conditions

The boundary of the active network was allowed to vary as the solution proceeded, admitting or excluding elements from the active network as they became 'wet' or 'dry'.

A "slip" condition was specified as the default for solid boundaries (forcing flow to be tangential at solid boundaries of the model).

A fixed water surface level of RL 2.0m AHD was specified as a "natural" boundary condition along the eastern extremity (outflow boundary) of the model where the flood plain meets Lake Illawarra (corresponding to the 1% AEP flood level of Lake Illawarra).

A total flow of $1900m^3$/sec was specified as inflow to the model at the western extremity (inflow open boundary) of the model, upstream of the highway bridge (corresponding to the 1% AEP peak discharge in Macquarie Rivulet - Boyd et al (1989)).

### 6.3 Options Modelled

Since the final layout of the proposed development was not known, a series of options for filling of the flood plain were investigated.

These options ranged from what might be considered minimal to maximal filling of the triangular parcel of flood plain land, bounded by the rail embankment to the west, the ash pond embankment to the north, and Macquarie Rivulet to the south. The boundary of each of these fill zones is shown on fig 3.

Simulation of these fill options, ranging from Option A (minimal filling) to Option C

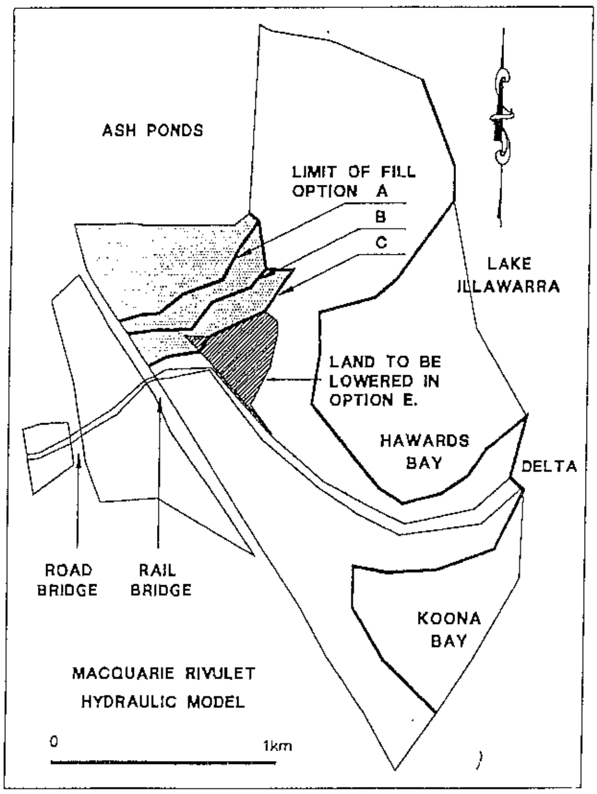


Fig. 3 Earthworks options

(maximal filling), was undertaken by changing the FESWMS "property type" of elements to be filled to zero - thereby excluding these elements from the active network before re-running the model.

In summary this range of fill options had the following impact on flood velocities and levels, relative to existing conditions.

| Fill Option | Flood Level Impact | Velocity Impact |
|---|---|---|
| A (minimal) | Insignificant change | Insignificant change |
| B | +300 above rail bridge | Minimal change |
| C (maximal) | +1000 above rail bridge | Significant change |

Since the impact of fill Options B or C were unacceptable and Option A did not provide sufficient flood free land to support the residential development, a further option (E) was investigated wherein filling to the line of Option B was combined with removal of high ground on the northern flood plain downstream of the bridge.

This elevated deposit of levee material adjacent to the bend in the stream appeared a likely candidate for improving the flow across the flood plain in the designated event and a source of fill for the development. Since final levels for the golf course had not been developed at this time, this initial review of Option E was based on the flood plain to the east of the bend, downstream of the rail bridge, being reduced to RL 1.5m AHD. This combined cut to fill (Option E) produced insignificant net change in flood level or velocity in the study area demonstrating that filling to the line of Option B with compensating cut on the flood plain could be undertaken without adversely impacting flood levels or velocity in the outfall reach.

A further option (D) involving filling to create a more gradual expansion of flow out onto the flood plain below the rail bridge was also modelled, but found to impact levels as much as option B. Since this option adversely impacted flood levels and did not accommodate residential development as well as option B, it was not explored further.

## 7 CONCLUSIONS

- o Whilst all two dimensional flood modelling exercises involve considerable data collection and model establishment time, the model chosen in this study has proven relatively easy to apply and amend.
- o Insights provided by the model into the distribution of flood levels and velocities across the flood plain, and how these change with encroachment of fill onto the floodplain have greatly assisted in the assessment of the impact of earthworks on flooding, flood safety, erosion and sediment transport.
- o With respect to the hydraulics of flood flows in Macquarie Rivulet, the model was able to demonstrate in a clear, quantified manner, the impact that filling would have on flood flows and to confirm that the particular combination of excavation and filling proposed (option E) would not adversely impact flooding.
- o It is the authors conclusion that FESWMS-2DH represents a significant advancement in tools available for modelling two dimensional flows with direct application in areas similar to that outlined in this paper. In more hydraulically complex circumstances involving non steady flows with flow transitions, mixed weir and pressure flows, wind shears and coriolis effects, FESWMS-2DH may provide the only means of solution currently available.

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# A Comparison of Design Flood Estimation Methods

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SUMMARY Seven methods for design flood estimation were applied to two catchments, one of which had a 38 year streamflow record. Both catchments were treated as ungauged, and the accuracy of the estimates was assessed by comparing them to the actual flood frequency curve. Almost all methods over estimated the floods for short average recurrence intervals and underestimated for long recurrence intervals. Reasons for this are discussed and ways of correcting it are suggested. Flood estimates can vary because different models are used, and also because of the assumptions made by the different users. Even when the same model is used, the various assumptions made by the different users caused a spread in the design flood estimates. In the present study the estimates ranged approximately ± 13% about the mean value.

## 1 INTRODUCTION

In 1987 the Illawarra Regional Committee of the Water Research Foundation of Australia commenced assembly of a data base to assist calibration of flood hydrograph models for the Illawarra region (Rigby, 1984). The first application of the data base was a study of design flood estimation methods, and the results are presented in the present paper.

The study applied seven design flood estimation methods to two natural catchments. One catchment was treated as ungauged, although a flood record was available and this was used to assess the accuracy of the flood estimates. The other catchment was ungauged, but since its outlet was located further downstream on the same stream as the gauged catchment , a comparison between estimates made for the two catchments was possible.

The study involved a comparison of flood estimates made using the different models, and also a comparison of estimates made by the different users, using the same model. The results of the study therefore give an indication of the accuracy of the methods, and also of the likely spread of estimates.

Organisations involved in the study were the University of Wollongong, NSW Department of Main Roads (now the Road and Traffic Authority), NSW Public Works Department, Forbes Rigby and Associates, Shoalhaven City Council and Wollongong City Council.

## 2. DESCRIPTION OF CATCHMENTS

### 2.1 Physical and Climatic Data

Two catchments (Sunnybank and Princes Highway Bridge) were used, both on Macquarie Rivulet 15 km south of Wollongong at latitude 34° 34'S and longitude 150° 45'. The catchments extend from the steep slopes of the Illawarra escarpment near Robertson into Lake Illawarra near Albion Park. The total fall from headwaters to outlet is 680 metres. Macquarie Rivulet at Sunnybank (National Station number 214003) has an area of 35.0 $km^2$, stream length 10.5 km and equivalent main stream slope 31.9 m/km. Average annual rainfall is 1540 mm. The catchment is gauged with a streamflow record of 38 years. Macquarie Rivulet at Princes Highway Bridge is located further downstream, with area 105 $km^2$, stream length 22.5 km and stream slope 8.4 m/km. Average annual rainfall is 1287 mm. This catchment is ungauged. Both catchments are predominantly rural, mainly grassed but with some sub-tropical rainforest in the upper escarpment. Minor urban development has occurred in the lower reaches of the Princes Highway Bridge catchment.

### 2.2 Rainfall and Flood Frequency Data.

Design rainfall data for various storm durations were extracted from Australian Rainfall and Runoff (I.E. Aust., 1987) hereafter referred to as ARR. A flood frequency analysis was performed for the 38 years of flood records on the Sunnybank catchment, using the partial series method as described in ARR Chapter 10.

Figure 1 shows the resulting frequency curves for the gauged catchment. Note that the rainfall curves have the same approximate slope for all durations, and that the flood frequency curve has a much steeper slope, indicating that floods increases at a faster rate than rainfall intensities as the average recurrence interval (ARI) increases. This is typical of most catchments in New South Wales and indicates two things. Firstly, that losses may be quite important in converting design rainfalls into design flood discharges. For instance losses may need to be a greater proportion of the total rainfall for low ARI's but be a smaller proportion for high ARI events, so that rainfall excess depths and calculated flood peaks are increased as ARI increases. The current practice, as recommended in ARR, of using constant values of initial loss and continuing loss for all ARIs does provide this effect. However, it may be necessary to further increase the effect by using smaller losses for higher ARIs. Secondly, the greater proportional increase in flood discharge compared to rainfall intensity as ARI increases may indicate that nonlinear models will give better results than linear models. For example if a linear model such as the unit hydrograph is used together with the same proportional losses for each ARI, then the calculated flood frequency curve will be parallel to the rainfall frequency curve, and from Figure 1 this is seen to be incorrect. If either a nonlinear model is used, or smaller losses are used for higher ARIs, then the slope of the calculated flood frequency curve will become steeper and closer to the slope of the actual flood frequency curve.

## 3. MODELS USED IN THE STUDY

All models used are reasonably well known in Australia, and are described in ARR. The following brief descriptions are given.

### (i) Rational Method (RM87) from 1987 ARR.

This is essentially a regional flood frequency method because the runoff coefficient values given in ARR were determined by fitting recorded flood frequency distributions from 308 gauged catchments in eastern Australia. The method involves calculating a storm duration from the catchment time of concentration

$$t_c = 0.76\,A^{0.38} \tag{1}$$

A 10 year runoff coefficient $C_{10}$ is read from a map, then converted to other recurrence intervals $C_Y$.

### (ii) Rational Method (RM77) from 1977 ARR

Although this method is now superseded it was included to provide a comparison with the 1987 version. The major difference between the two methods is that the older version uses runoff coefficients depending on the soil type and rainfall intensity, but these coefficients were not based on recorded flood data so the method should be less accurate. The time of concentration is given by the Bransby-Williams formula

$$t_c = 58.5L\,/\,A^{0.1}\,S^{0.2} \tag{2}$$

### (iii) Cordery-Webb Unit Hydrograph (CWUH) (Cordery and Webb, 1974)

This method includes design losses as well as a unit hydrograph for each catchment. It was developed using data from 21 catchments in eastern NSW. Model parameters are given by

$$C = 0{\cdot}17\,(L/S)^{0.41} \tag{3a}$$
$$K = 0{\cdot}66\,L^{0.57} \tag{3b}$$

Various storm durations must be tried to determine the critical storm duration.

### (iv) RORB Runoff Routing Model (Laurenson and Mein, 1985).

RORB model has been widely used throughout Australia. Relations have been derived between the model parameter $K_c$ and catchment characteristics, and these are summarised in ARR. For eastern NSW,

$$K_c = 1{\cdot}22\,A^{0.46} \tag{4a}$$
$$m = 0{\cdot}8 \tag{4b}$$

### (v) WBNM Runoff Routing Model (Boyd et al, 1987a, b)

This model is similar to RORB and includes many of its features, including storage reservoirs and urbanisation. The major differences are that in WBNM the data requirements and use of the model are simpler, a distinction is made between flow in the streams and flows on catchment surfaces, and optional forms of the storage-discharge relation to allow for different flow conditions are available. The model has been applied by various users to catchments ranging from 0·1 to 10,000 km$^2$.

Both RORB and WBNM are available on floppy disks for PCs. Both models require that a range of storm durations be examined to determine the critical duration. The models do not include design losses and these must be selected, based on recommended values in ARR.

### (vi) PSRM Model

PSRM model was developed in the USA and has been applied in Australia by Rigby and Watts (1983). The model includes an allowance for losses, depending on the soil type and accumulated soil moisture. Runoff hydrographs are calculated using a procedure based on the kinematic wave theory.

### (vii) Regional Flood Frequency (RFF) Method (Boyd, 1978)

The RFF method consists of a set of regression equations relating peak discharge to catchment area, stream length, stream slope and median annual rainfall. One equation is available for each ARI. The method was developed using recorded annual floods on 79 catchments in NSW. Because annual flood series was used, whereas the present study uses partial series, this method is strictly comparable for ARIs of 10 years and greater. For less than 10 years, the method should underestimate slightly. A simple conversion from annual series to partial series is possible using table 10.1 in ARR, and this was done for the 2 and 5 year ARIs in this study to allow results to be compared.

It is worth noting a basic difference between these models. Methods (i) and (vii) are the only ones which were developed using recorded flood frequency data. These should therefore be expected to give the better results. Methods (iii), (iv), (v) and (vi) were developed using recorded rainfall-flood hydrograph events. This means that the parameters of these models should correctly reproduce a flood hydrograph from an excess rainfall hyetograph. Their usefulness for design flood estimation however depends on the combination of design storm temporal pattern and design losses given in Chapters 3 and 6 of ARR. The results of the present study can give some indication of their accuracy.

## 4. METHOD USED IN THE INVESTIGATION

The two catchments, Macquarie Rivulet at Princes Highway Bridge and Macquarie Rivulet at Sunnybank were both treated in this part of the study as ungauged catchments, even though Sunnybank Station does have a 38 year streamflow record which was later used to assess the accuracy of the flood estimates for this catchment. The six organisations taking part in the study were given a catchment map and design rainfall intensity-frequency-duration data extracted from ARR 1987 for each catchment; but no other hydrologic information. Each user was asked to estimate the 2,5,10,20,50 and 100 year ARI floods using any flood estimation methods that they were familiar with, and to do so in general accordance with ARR procedures, although users were able to exercise their own judgement wherever necessary.

Results were assessed in two ways. Firstly a comparison of model performance, by comparing flood estimates made by each model with the flood frequency distribution established from the streamflow record. Secondly, a comparison of the spread of flood estimates made by the various users, for each of the models in turn.

## 5. RESULTS OF MODEL COMPARISON

Figure 2 shows flood frequency estimates made using the various methods, together with the actual flood frequency curve. Figure 2 is for the Sunnybank Station, but results for the larger Princes Highway catchment are very similar in the relative locations of the various estimates.

It is clear that the slopes of all flood frequency curves except the Regional Flood Frequency (RFF) method are flatter than the actual flood frequency curve for this station. This occurs because all methods except RFF use design rainfall data from ARR 1987 and consequently all curves have approximately the same slope as the rainfall frequency curve. Only the RFF method uses different rainfall data (the catchment median annual rainfall) and only this method produces a frequency curve close to the correct slope. While RM87 uses design rainfall data from ARR1987, derived values of the runoff coefficient C were recorded from flood frequency distributions. Consequently the difference in slopes is reflected in RM87 as an increase in C as the recurrence interval increases. Because of this slope of the frequency curve in figure 2 is slightly steeper than the other methods (except RFF).

Since the slope of the flood frequency curve is steeper than the rainfall frequency curve for most catchments, certainly in New South Wales , similar results can be expected on most catchments. This has implications for the choice of model and values of losses used for design, as discussed previously in Section 2.2 This matter is currently being investigated by Boyd and Cordery (1989).

Because of the different slopes of the rainfall and flood frequency curves, all methods overestimate flood discharges for low ARIs and underestimate for high ARIs.

The comparison between Rational Method results using 1977 (RM77) and 1987 (RM87) versions of Australian Rainfall and Runoff is interesting. Firstly, design rainfall intensities are considerably higher for 1987 ARR compared to 1977 ARR for this catchment. For 6 hour duration for example 1987 intensities are 1.5 times 1977 values. Secondly, for 1987, times of concentration using equation 1 are approximately one half the 1977 values calculated using the Bransby-Williams equation (2). Consequently, rainfall intensities used in the 1987 version are considerably higher than those used in the 1977 version. Because 1977 runoff coefficients depend critically on the rainfall intensity, it follows that they are also small, and for the lower ARIs actually become zero. The combination of all these factors causes 1987 Rational method flood peaks to be from 1.5 to 2.5 times greater than 1977 values for the Sunnybank Station, and more than 5 times greater for the Princes Highway Bridge Station.

The Cordery Webb Unit Hydrograph model (CWUH) and models RORB and WBNM have several features in common. They all use the design initial loss and continuing loss values given in ARR 1987. The critical duration storm was found to be between 6 and 9 hours for both Sunnybank and Princes Highway Bridge for all models. They use design parameter values from ARR in the form of equations (3) to (4) given earlier.

Note that the CWUH and RORB models require equations relating the model parameters to catchment characteristics, whereas WBNM requires only a single constant value of parameter C. This is because this model has lag-area relations built into it. A value of C near to 1.5 has been found to apply to a wide range of catchment sizes (0.1 to 10,000 km$^2$) in New South Wales. For this part of the study the parameter of WBNM was set at $C = 1.5$ and the non linearity parameter n was set at 0.23.

Another common feature of the models CWUH, RORB and WBNM is that they were all developed using recorded rainfall-flood events. It is interesting to note therefore that they all produce reasonably similar results, and that they lie toward the middle of the two rational method of flood estimates in Figure 2.

The model PSRM produces a flood frequency curve which is almost identical to RM87, for both Sunnybank and Princes Highway stations. This occurs even though several model parameters associated with soil type and losses must be estimated. Application of PSRM to more catchments is desirable to determine whether this result applies generally.

RM87 produces results which are somewhat higher than all other methods. This finding is consistent with a previous study by Webb and O'Loughlin (1981) in which the Pilgrim and McDermott (1982) version of the Rational Method (on which RM87 is based) consistently gave higher results for coastal NSW catchments.

Table I shows ratio of estimated to actual flood peaks for the data of Figure 2, for three ARIs. Errors in flood peaks are quite large, however, the errors in flood levels would be somewhat less. It should also be remembered that these results are for one catchment only.

TABLE I
RATIO OF ESTIMATED TO ACTUAL FLOOD PEAKS AT SUNNYBANK

| Model | Average Recurrence Interval (years) 2 | 10 | 100 |
|---|---|---|---|
| RM77 | 1.58 | 0.83 | 0.40 |
| RM87 | 2.18 | 1.63 | 0.99 |
| CWUH | 1.94 | 1.12 | 0.56 |
| RORB | 2.00 | 1.34 | 0.75 |
| WBNM | 2.01 | 1.25 | 0.67 |
| PSRM | 2.24 | 1.64 | 0.93 |
| RFF | 1.05 | 0.83 | 0.53 |

Finally, it is interesting to compare in Table II the ratio of flood estimates made by each model for the Princes Highway Bridge and Sunnybank Stations. The 10 year ARI floods were used for this. Estimates for the larger catchment should be larger than those for the smaller catchment, and a commonly used value is the square root of the ratio of catchment sizes ie $(105/35)^{0.5} = 1.73$. While this ratio may not be strictly correct, it does give a basis for comparison.

TABLE II
RATIO OF PRINCES HIGHWAY BRIDGE TO SUNNYBANK FLOOD PEAKS

| Model | Ratio $Q_{10PH} / Q_{10SK}$ |
|---|---|
| RM77 | 0.67 |
| RM87 | 2.17 |
| CWUH | 1.87 |
| RORB | 2.08 |
| WBNM | 2.17 |
| PSRM | 2.11 |
| RFF | 1.46 |

Most models scatter equally about the value 1.73. The exception is RM77 which actually predicts a smaller flood peak for the larger catchment. This anomaly occurs because the Bransby-Williams formula used in RM77 predicts a greatly increased time of concentration (from 4.1 to 9.3 hours) and consequently a much reduced design rainfall intensity (from 28.1 to 17.1 mm/hr). Because the RM77 runoff coefficient is critically dependent on rainfall intensity, it is greatly reduced (from 0.83 to 0.30) and consequently the predicted flood peak is reduced.

## 6. RESULTS OF USER COMPARISON

Although guidelines are given in ARR for the use of the models, users are still able to exercise some judgement and the different assumptions made lead to slightly different flood estimates by the various users, even when using the same model. Different assumptions can be made regarding the following:

(i) Storm duration A plot of calculated flood peak discharge versus storm duration typically rises from low discharges at short durations, to be reasonably horizontal over some range, before decreasing for the longer durations. The plot oscillates and ARR recommends that a smooth curve be drawn through the points. The maximum discharge tends to occur over a range of durations, and some variation in the selected critical duration is possible. For Sunnybank Station, users selected either 6 or 9 hours.

(ii) Losses Cordery and Webb (1974) give a detailed procedure for estimating design initial losses, depending on the catchment area and storm duration. ARR however omits these values and gives a more general statement that initial loss in eastern Australia can range from 10 to 35 mm. For the Sunnybank Station users selected initial loss values ranging from 5 to 13 mm. The well known continuing loss rate of 2.5 mm/hour appears to be accepted as a standard value, and all users adopted this.

(iii) The models RORB and WBNM require that the catchment be divided into sub-areas. The number of sub-areas and the location of their boundaries can be selected by the user, although guidelines are given by Boyd (1985). For Sunnybank Station users selected between 3 and 12 sub-areas.

(iv) Model Parameters When a model is first developed, regression equations relating the model parameters to catchment characteristics are usually provided. Later, other researchers may provide alternative equations for the same region or other regions. The user then has a choice of equations to use.

For the CWUH model, equations were originally given for NSW by Cordery and Webb (1974). ARR summarises equations for various regions within Australia, and an alternative equation for eastern Australia is given. For Sunnybank, values of parameter C in the range 1.82 to 1.93 hours, and values of parameter K from 2.51 to 2.67 hours can be used.

A similar position applies to RORB, and the various regression equations for different regions are summarised in ARR. For Sunnybank, values of $K_c$ can vary between 6.26 to 6.51 according to the equations, but users adopted a wider range from 5.6 to 15.9. For RORB stream segment lengths and mode locations must be specified for all sub-areas and, depending on the values selected, this can also introduce variability into the flood estimates of various users.

For WBNM, the value of parameter C was originally recommended as C = 1.68. Subsequent studies by a range of researchers produced a lower value of C = 1.29. For Sunnybank, users adopted values of C in the range 1.00 to 1.68.

Figure 3 shows flood frequency curves estimated by the various users for Sunnybank Station, using WBNM. Results for WBNM are shown because more users used this model than CWUH and RORB, but similar results can be expected from those models. The various assumptions made by these users lead to a range of estimates of approximately ± 13% about the mean value. The coefficient of variation of the estimates (standard deviation/mean) is 0.091.

It is interesting to note that all users obtained identical results for the 1987 Rational Method. This is because the steps in this procedure are well defined, and also because the method has not yet been revised by the inclusion of additional data.

## 7. CONCLUSIONS

For the study catchments, it was found that the slope of the flood frequency curve was steeper than the design rainfall frequency curves. For those models which use design rainfall intensity data from Australian Rainfall and Runoff therefore, floods are overestimated for low average recurrence intervals and underestimated for high recurrence intervals. It may be possible to correct this difference in slopes by using nonlinear models, or by using smaller losses for the higher recurrence intervals. For the Sunnybank catchment studied here, the use of nonlinear models alone was not sufficient, and it would be necessary to modify the losses to give this correction.

Only one model, the Regional Flood Frequency method, did not use design rainfalls, and it was the only one to produce a flood frequency curve of similar slope to the actual curve.

There was a considerable difference between flood estimates made using the 1977 and 1987 versions of Australian Rainfall and Runoff. The 1987 version produced higher flood estimates than all other models, and this is consistent with other studies.

The models RORB, CWUH and WBNM all produced similar results, with WBNM lying near the mid point of these estimates.

The two models developed using actual flood frequency data, RM87 and RFF, are likely to produce the best estimates. It is interesting to note that PSRM estimates were very close to RM87 values for this catchment, but this result needs to be verified for other catchments.

When flood estimates are made by several users, all using the same model, the various different assumptions lead to a spread of estimated flood peaks. For this study, estimates ranged over ± 13% from the mean.

Finally, it should be remembered that these results are based on two catchments, only one of which is gauged. Some caution in accepting results is necessary. The study should give a good indication of the relative estimates made by the various methods, and also of the spread of estimates made by various users. The comparison of estimated and actual flood frequencies is necessarily limited to one catchment.

## 8. ACKNOWLEDGEMENT

The financial support of the Illawarra Regional Committee of the Water Research Foundation of Australia is acknowledged.

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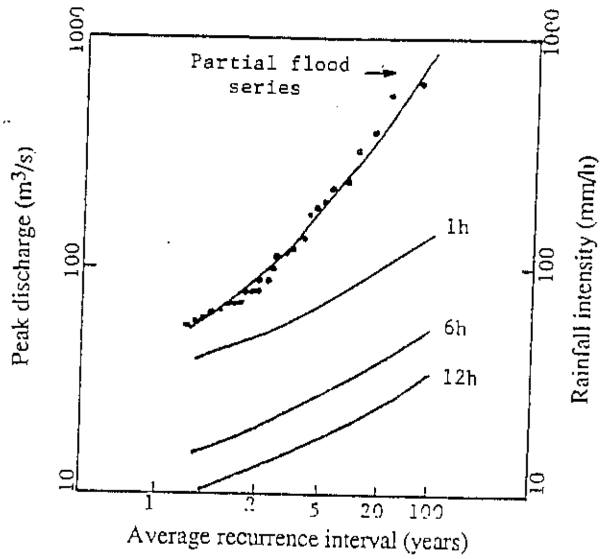


Figure 1 Rainfall and flood frequency curves - Macquarie Rivulet at Sunny Bank

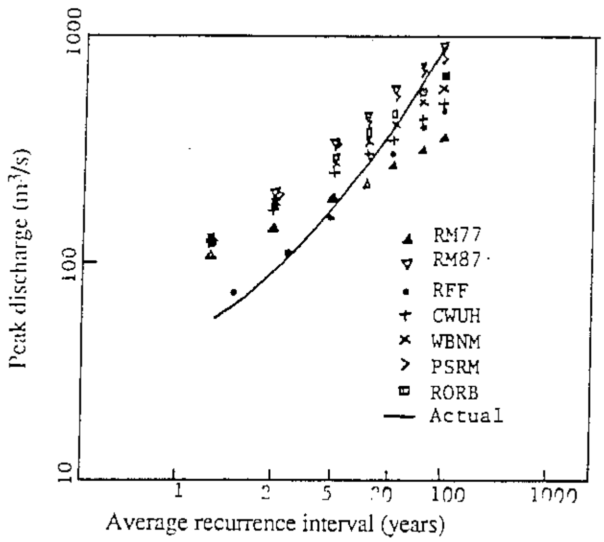


Figure 2 Estimated and actual flood frequency curves - Macquarie Rivulet at Sunny Bank

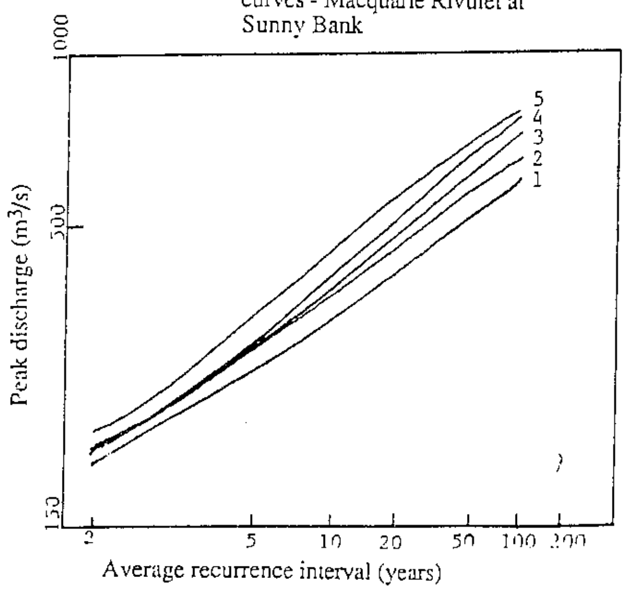


Figure 3 Comparison of flood estimates of various users (1-5) - Macquarie Rivulet at Sunny Bank

# DEVELOPMENT OF A HYDROLOGIC DATA BASE FOR THE ILLAWARRA REGION

E. H. Rigby - Chairman, Hydrology Subcommittee
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SUMMARY: In recent years there has been considerable growth in the development of relatively sophisticated computer based hydrologic models. To date, lack of local data for validation and calibration of these models, has been a serious constraint on their responsible use. In recognition of the potential benefits arising from use of such models, a local group has been formed, as a subcommittee of the Illawarra Regional Committee of the Water Research Foundation of Australia, to collect, correlate and distribute data relevant to the Illawarra region. This paper discusses the reasons for forming such a group, and its progress to date.

## INTRODUCTION:

All Engineering design depends on data being fed into the decision making process at some point. The need for this data ranges from the relatively obvious (as in testing of entirely new materials) to the obscure (as when using some Australian Codes/Standards).

Engineering data may also range from the relatively constant, such as the thermal expansion coefficient of a particular composition of steel, to the highly variable, such as infiltration capacity of a given soil.

In addition, the quantity and quality of data needed to satisfy a particular problem varies greatly with the field of application of the problem.

In general, problems associated with man made materials/structures tend to be much simpler than problems founded in the natural sciences, with simpler data requirements for comparable analytical confidence. Hydrology, the study of the rainfall/runoff process, is one branch of Engineering that is highly dependent on data.

## PRESENT STATE OF THE ART:

The need for hydrologic data has been recognised for many years. Collection of data in sufficient depth to model the natural processes on a national basis has however, been such a daunting prospect, that most workers in the field have been forced to limit data collection to that specific to a given locality or problem. Typical results of such individual effort are outlined in papers by Rigby and Watts(1983) and Sobinoff Pola and O'Loughlin(1983).

A far sighted program was initiated in the late sixties by the Australian Water Resources Council, to collect and correlate hydrologic data on a national basis. This program, known as the Australian Representative Basins Program, produced much good work in the early to mid seventies (refer ARWC,1969, 1972, 1975, 1975) but has published little since releasing the Representative Basins Catalogue in 1975.

Pressure to collect and correlate data might in fact have been greater if our capacity to model the natural processes had been more advanced. Unfortunately, such is the complexity of the problem that all procedures in hydrology (even the most advanced) still represent a considerable simplification of the real processes.

Until recent times, this limited capacity to model the natural processes, and lack of supporting data, made application of all but the simplest approaches to hydrologic problems of questionable value.

Whilst the accuracy of earlier simplified procedures may not have been very good, their widespread use , in a moderately uniform manner (as exemplified by use of the Rational Method for predicting peak discharges) prevented major conflict between users. Many errors were in turn masked by the consistency of results from these simpler models, generating false confidence in the models capabilities.

In more recent times, many sophisticated computer based procedures for modelling the rainfall/runoff process have been developed. These new procedures have clearly established their potential for much improved accuracy and flexibility in design. All depend however, on data to a far greater extent than the older/simpler methods.

Given adequate time for collection of the necessary data, validation and calibration of the new procedures, and education of end users - the change from the old/simple procedures to the new, would be relatively straightforward.

Growth in use of the new procedures has however outpaced both our ability to collect the necessary data and our ability to educate end users. This has in turn led to a scramble for hydrologic data and advice on calibration, considerable general confusion, and lack of uniformity in the application of newer procedures.

Concurrent with the development of these more sophisticated/complex computer based methods in hydrology - our computing capabilities have also undergone major change. In recent times computers have increased an order of magnitude in power and speed and reduced an order of magnitude in cost and size. The net result of this change has been a quantum leap in desk top computing power available to our profession, and an expectation by society that such aids will be routinely used by our profession in solution of engineering problems.

Whilst the above changes alone would have created considerable pressure on data collection to feed the many and varied models, a further more demanding pressure is being generated in our Courts of Law. With the ready availability of these more sophisticated/complex models and computers on which they may be run, we are now unable as a profession, to easily defend ourselves if asked why more advanced design techniques were not used, in those cases where the older/simpler methods have proven inadequate.

Growth in the area of hydrologic modelling has lead to a need for a wide range of data, much of which was considered of academic interest only a few years ago. With collection of data necessary for the calibration and validation of these models in its infancy, there will be times when model sophistication far exceeds model accuracy. In adopting these sophisticated data dependant procedures, we have vastly increased our potential for converting unprocessed garbage into reams of processed garbage - a problem well known to most computer users.

With acquisition of these advanced tools proceeding far ahead of education in their use and collection of data for their calibration, it was felt by several of the present committee that some steps should be taken to address the problem in our region, if at all practicable.

Whilst it was considered impractical and undesirable to constrain distribution or application of these models, it was considered that the two areas of,

User education and

Data for validation/calibration

could be addressed within this region by a group of professionals practising in the Hydrology/Drainage field. Further discussion on this need for local involvement is contained in a paper by Rigby and Watts(1983).

## 2. HYDROLOGY SUBCOMMITTEE:

In August, 1983 an approach was made by the author to the Illawarra Regional Committee of the Water Research Foundation of Australia, to form such a committee. Following this meeting, a draft Terms of Reference was drawn up for the Committee's consideration and adopted in November, 1983.

The Terms of Reference adopted at that time were;

STRUCTURE:

* To comprise those members of the Illawarra Branch of the Water Research Foundation with an interest in regional stormwater management.
* A sub-committee Chairman and Secretary to be elected. Minutes of each meeting to be prepared by the Secretary for inclusion in the minutes distributed by the main committee.
* Members to be drawn from those organisations operating within the Illawarra Region.

MEETINGS:

* Frequency as for the Illawarra Regional Committee - Staggered to fall between meetings of that committee.

OBJECTIVES:

Long Term Goals:

a) The promotion of communication between professionals practising in the stormwater management field in the Illawarra.

b) The establishment of an accessible data base of filtered hydrologic and hydraulic data relevant to the Illawarra Region.

c) The promotion of research relevant to regional problems in stormwater management.

d) The review and development of guidelines relevant to practise in the field of stormwater management in the Illawarra.

Short Term Goals:

a) An inventory of present hydrologic/hydraulic data available within the region.

b) The establishment by consensus of minimum standards for the local validation/calibration of hydrologic/hydraulic models prior to their use in the Illawarra.

c) The establishment by consensus of parameters appropriate to the application of a select range of validated/calibrated models in the region.

d) The establishment by concensus of minimum standards for documentation of the usage of and results derived from the application of hydrologic/hydraulic models in the region.

3. WORK IN PROGRESS:

The first meeting of the subcommittee took place in February, 1984 with meetings following at roughly six weekly intervals. All Councils and Government Departments with an interest in Hydrology were invited to attend, together with representatives from the University of Wollongong, Local Industry and Civil Engineering/Surveying Consulting practices.

Meetings have to date been well represented and very effective in promoting communication amongst those practising in the hydrology/drainage field in the Illawarra region.

With only three meetings to date, the subcommittee has had little time to process information of any kind. Meetings have however provided an opportunity to informally exchange data, to clarify what the short term objectives should be, and to discuss how these objectives might be met.

Prior to actually attempting to collect data, it was agreed that the subcommittee should first compile an index to data held by the respective member organisations. This much could be completed in the short term and would serve to guide members in search of more specific data. This phase is now nearing completion and should be complete by the time this conference takes place.

All attempts to discuss more detailed data collection have met with difficulty, resulting in the main from the lack of any agreed system for identifying catchments/subcatchments etc. It was therefore agreed that a high priority should be placed on the development of an agreed numbering system for catchments within the region.

Of the several systems proposed, a numbering system based on the National Basin numbering scheme (with extensions) was considered most appropriate and forms the basis for present discussion. Considerable difficulty has been experienced in formulating such a scheme, because of the marked contrast between the many physically separate catchments draining to the coast in the

Wollongong Coastal Basin (214), and the single catchment comprising the Shoalhaven Basin (215).

The approach adopted seems at this point to provide a reasonable compromise between a straight hierachial structure and a scheme of acceptable simplicity.

Having progressed thus far, the committee now faces the question of establishing a hydrologic data base - In particular the committee needs to resolve;

1. What data should be collected?
2. How and by whom should it be collected?
3. Who will correlate it?
4. Should it be processed/filtered in any way?
5. How and where should it be stored?
6. In what form should it be made available to users?

Significant debate has already taken place on some of these questions but no real consensus has yet been reached.

As previously noted - models have differing demands on data. It seems likely that the emphasis will initially be on data collection that has the widest possible immediate application.

In particular we would expect this to include;

a) Rainfall/Runoff/Flood Stage data for isolated events
b) Historic rainfall/runoff data.

Additional data would then be gathered, as and when practicable to cover more detail matters of losses/infiltration/soil type/cover etc.

With respect to the basic data described in a) and b) above, a substantial amount has already been collected but not correlated. It is hoped that the committee may be able to arrange correlation of this existing data and its compilation into a usable regional document, as an interim measure.

## 4. FUTURE DIRECTIONS:

Insufficient time has elapsed for the subcommittee to develop clear long term objectives. Whilst data collection and correlation will remain a primary component of the subcommittee's work for some time yet - application of this data to the calibration/validation of models in use in the region is also seen as a high priority.

5. CONCLUSIONS:

Given the short time that the subcommittee has been operational, observations or conclusions relating to the subcommittee's ultimate effectiveness are not yet possible. The subcommittee is however proceeding to meet its short term objectives with considerable enthusiasm and we see no reason why it will not be ultimately able to meet each of the objectives set out in the initial Terms of Reference.

In formalising why and how the present subcommittee should be formed, and looking back on its short period of operation to date, some observations may be made which could assist other regions.

1. There is a widespread and urgent need for professionals practising in a given region to be provided with adequate data for local validation/calibration of hydrologic models.

   Application of the more sophisticated models without local validation or calibration may be confidently relied on to generate results with an error potential far in excess of the simpler models they replace.

2. Whilst adhoc collection of data by indivuals might eventually generate an adequate regional database, the Region must itself accept responsibility for collection, if data is to be provided early enough to be of any real value.

3. Experience with the Illawarra subcommittee suggests that formation of a local group to handle this task is both practicable and effective. Significant improvement in communication between those practising in the region in the hydrology/drainage field is a valuable side benefit.

4. Formation of this group as a subcommittee of the Water Research Foundation of Australia - Illawarra Regional Committee has been a mutually beneficial arrangement, with most members sharing an active interest in both committee and subcommittee activity.

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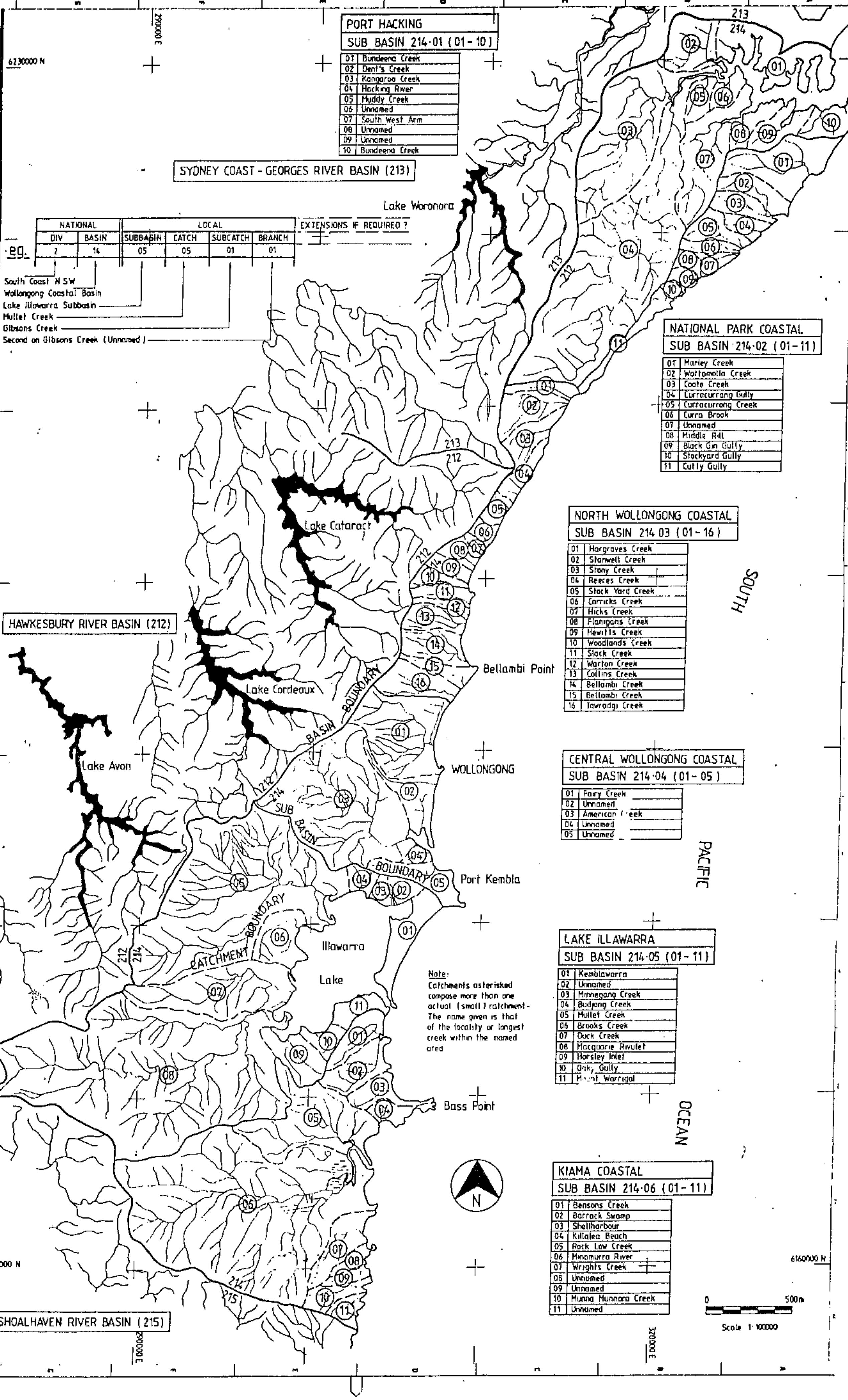
TABLE III-1

RESEARCH NEEDS SUMMARY

International Symposium in Urban Hydrology
Baltimore, Maryland May 30-June 2, 1983

| Research Need / Country | Australia | Canada | United Kingdom | West Germany | Sweden | France | Norway | The Netherlands | Japan | Switzerland | Venezuela | Nigeria | Finland | United States |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Improved Urban Runoff Data Base | X | X | X | X | X | X | X | X | X | X | | X | | X |
| 2. Continuous Runoff Quality Monitors | | | | X | | | | | | | | | | |
| 3. Technology Transfer or Information Exchange Programs | X | | X | | | X | X | | X | | X | X | X | X |
| 4. Areal and Temporal Rainfall Distribution | | X | | | X | | | X | | | X | | | |
| 5. Development of Improved Met. Radar and Measurement Techniques | | | | X | | X | | X | | | X | | | |
| 6. Alternative Methods of Analysis | | | | | | | | | | | X | | | X |
| 7. Reducing Time and Distance Between Research and Implementation | | | | | | | | | | X | | | | |
| 8. Development of Hydrometeorological Data Networks | | | | | | | | | X | | | X | | |
| 9. Model Verification and Testing (Including Regional Validation) | X | X | | | | | X | | | | | X | | |
| 10. Develop and Apply Urban Drainage Master Plans | | | | | | | | | | | | X | | X |
| 11. Management, Financing, Incentives | | | | | | | | | | | | | X | X |
| 12. Better Data on Toxics, Metals (Including Standard Analytical Methods) | | X | | | | | | | | X | | | X | X |
| 13. Ground Water Impacts | | | | | | | | | | | | | | X |
| 14. Data on Rate and Transport of Pollutants—Water Column and Sediments | | X | | X | | | | X | | | | | | X |
| 15. Improved Snowmelt Dara Base | | X | | | X | | X | | | | | | X | X |
| 16. Atmospheric Contribution to Urban Runoff | | | | | | | | | | | | | | X |
| 17. Mini/Micro Computer Applications | X | X | X | | | | | | | | | | | X |
| 18. Improve/Validate Runoff Quality Models | | X | X | | | X | | | | | | | | X |
| 19. Improved Techniques for Sewer System Operational Control | | | | X | | X | | | | | | | | |
| 20. Receiving Water Impacts | | | | | X | | | | | | | | | |




| NATIONAL | | LOCAL | | | |
|---|---|---|---|---|---|
| DIV | BASIN | SUBBASIN | CATCH | SUBCATCH | BRANCH |
| 2 | 14 | 05 | 05 | 01 | 01 |

**Note:** Catchments asterisked compose more than one actual (small) catchment. The name given is that of the locality or longest creek within the named area

PORT HACKING
SUB BASIN 214·01 (01-10)

| | |
|---|---|
| 01 | Bundeena Creek |
| 02 | Dent's Creek |
| 03 | Kangaroo Creek |
| 04 | Hacking River |
| 05 | Muddy Creek |
| 06 | Unnamed |
| 07 | South West Arm |
| 08 | Unnamed |
| 09 | Unnamed |
| 10 | Bundeena Creek |

NATIONAL PARK COASTAL
SUB BASIN 214·02 (01-11)

| | |
|---|---|
| 01 | Marley Creek |
| 02 | Wattamolla Creek |
| 03 | Coote Creek |
| 04 | Curracurrang Gully |
| 05 | Curracurrong Creek |
| 06 | Curra Brook |
| 07 | Unnamed |
| 08 | Middle Rill |
| 09 | Black Gin Gully |
| 10 | Stockyard Gully |
| 11 | Cutly Gully |

NORTH WOLLONGONG COASTAL
SUB BASIN 214 03 (01-16)

| | |
|---|---|
| 01 | Hargraves Creek |
| 02 | Stanwell Creek |
| 03 | Stony Creek |
| 04 | Reeces Creek |
| 05 | Stock Yard Creek |
| 06 | Carricks Creek |
| 07 | Hicks Creek |
| 08 | Flanigans Creek |
| 09 | Hewitts Creek |
| 10 | Woodlands Creek |
| 11 | Slack Creek |
| 12 | Warton Creek |
| 13 | Collins Creek |
| 14 | Bellambi Creek |
| 15 | Bellambi Creek |
| 16 | Towradgi Creek |

CENTRAL WOLLONGONG COASTAL
SUB BASIN 214·04 (01-05)

| | |
|---|---|
| 01 | Fairy Creek |
| 02 | Unnamed |
| 03 | American Creek |
| 04 | Unnamed |
| 05 | Unnamed |

LAKE ILLAWARRA
SUB BASIN 214·05 (01-11)

| | |
|---|---|
| 01 | Kemblawarra |
| 02 | Unnamed |
| 03 | Minnegang Creek |
| 04 | Budjong Creek |
| 05 | Mullet Creek |
| 06 | Brooks Creek |
| 07 | Duck Creek |
| 08 | Macquarie Rivulet |
| 09 | Horsley Inlet |
| 10 | Oak, Gully |
| 11 | Mount Warrigal |

KIAMA COASTAL
SUB BASIN 214·06 (01-11)

| | |
|---|---|
| 01 | Bensons Creek |
| 02 | Barrack Swamp |
| 03 | Shellharbour |
| 04 | Killalea Beach |
| 05 | Rock Low Creek |
| 06 | Minnamurra River |
| 07 | Wrights Creek |
| 08 | Unnamed |
| 09 | Unnamed |
| 10 | Munna Munnora Creek |
| 11 | Unnamed |

FORBES RIGBY & ASSOCIATES PTY. LTD.
Consulting Engineers, Surveyors & Planners
10 Regent Street, Wollongong, N.S.W. 2500 Ph. (042) 28 4133
CIVIL ENGINEERS – STRUCTURAL ENGINEERS – SURVEYORS – TOWN PLANNERS

PROJECT DETAILS: DRAINAGE DIVISION II SOUTH EAST COAST, N.S.W. WOLLONGONG COASTAL BASIN (BASIN 214)

DRAWING DETAILS: BASIN SUBDIVISION DRAFT - 01

SCALES: 1:100000

DESIGN / DRAWN: EHR · CHECKED: RAPW · 11.6.84

PROJECT REFERENCE: 83093 · 1 · Φ

A1

7. SOIL TYPE & COVER:

Predominant Soil type .................... (SCS?)
Predominant Cover .................... (SCS?)

8. PRESENT/FUTURE LANDUSE

Present Landuse ....................
Present Zoning ....................
Future Landuse ....................

9. FORMAL GAUGING:

a) Rainfall

| | | |
|---|---|---|
| Station Number | .................... | .................... |
| Location | .................... | .................... |
| Authority | .................... | .................... |
| Gauge Type | .................... | .................... |
| Recording Interval | .................... | .................... |
| Years of Record | .................... | .................... |
| Availability of Data | .................... | .................... |

b) Streamflow

| | | |
|---|---|---|
| Station Number | .................... | .................... |
| Location | .................... | .................... |
| Authority | .................... | .................... |
| Control Structure | .................... | .................... |
| Gauge Type | .................... | .................... |
| Recording Interval | .................... | .................... |
| Years of Record | .................... | .................... |
| Availability of Data | .................... | .................... |

c) Climate

| | | |
|---|---|---|
| Station Number | .................... | .................... |
| Location | .................... | .................... |
| Authority | .................... | .................... |
| Data Type | .................... | .................... |
| Recording Interval | .................... | .................... |
| Years of Record | .................... | .................... |
| Availability of Data | .................... | .................... |

10. OTHER GAUGING (Rainfall/Streamflow/Stage)

| | | |
|---|---|---|
| Subject Matter | .................... | .................... |
| Collected by | .................... | .................... |
| Year | .................... | .................... |
| Precis | .................... | .................... |
| | .................... | .................... |
| Availability | .................... | .................... |

11. FLOOD SENSITIVITY

No dwellings/properties within floodway ....................
No dwellings/properties within floodplain ....................
Assessed Avg. Annual Damages ....................
Year of Assessment ....................

12. REPORTS - STUDIES

| | | |
|---|---|---|
| Subject | .................... | .................... |
| Author | .................... | .................... |
| Year | .................... | .................... |
| Precis | .................... | .................... |
| | .................... | .................... |
| Availability | .................... | .................... |

Data Keyed to catchment - using 1:25,000 mapping.

**** FOR DISCUSSION ****

1. LOCATION:

Catchment I.D. .................... (214.0503???)
Mainstream Name ....................
C.G. Co-ordinates .................... (AM6,ISG??)
Location ....................
....................
....................

2. MAPPING / AERIAL PHOTOGRAPHY:

Subject .................... ....................
Identification .................... ....................
Scale .................... ....................
Date .................... ....................
Authority .................... ....................
Availability .................... ....................

3. CLIMATE:

Median Spring Temperature ....................
Median Winter Temperature ....................
Median Autum Temperature ....................
Median Summer Temperature ....................
Median Annual Temperature ....................
Median Spring Rainfall .................... (mm)
Median Winter Rainfall .................... (mm)
Medain Autum Rainfall .................... (mm)
Median Summer Rainfall .................... (mm)
Median Annual Rainfall .................... (mm)

4. GEOLOGY:

Description ........................................
........................................

5. GEOMOPHOLOGY:

Description ........................................
........................................

6. GEOMETRY:

a) Linear Parameters

Mainstream Order .................... (Nu)
Bifurcation Ratio .................... (Rb = Nu/(Nu + 1))
Mainstream Length .................... (Lb Km)
Meander Index .................... (Lb / Lvalley)
Overland Flow Length .................... (Lg Km)

b) Areal Parameters

Area .................... (Ab Km2)
Shape (form factor) .................... (Rf = Ab/Lb ** 2)
Drainage Density .................... (D = SIGMA Lu / Ab Km-1)
Channel Maintenance .................... (C = 1/D Km)
Stream Frequency .................... (SIGMA Nu / Ab KM-2)

c) Relief Parameters

Catchment Slope ....................
Mainstream Slope ....................
Valley Side Slope ....................
Mean Elevation .................... (H Km)
Maximum Relief .................... (HR Km)
Relief Ratio .................... (HR/L),(100*HR/P %)
Ruggedness .................... (HD = H*D)
Geometry No. .................... (GN = H*D/S)

# DEVELOPMENT OF
# MACQUARIE RIVULET
# AS A
# REFERENCE CATCHMENT
# FOR THE ILLAWARRA

## COMPENDIUM OF DATA

## DECEMBER 1996

Prepared By:
Water Research Foundation of Australia
Illawarra Regional Committee
Stormwater Subcommittee
Editor : E H Rigby, December 1996

TODAY'S RESEARCH
TOMORROW'S PRACTICE

# DEVELOPMENT OF MACQUARIE RIVULET AS A REFERENCE CATCHMENT FOR THE ILLAWARRA

## COMPENDIUM OF DATA

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# DEVELOPMENT OF MACQUARIE RIVULET AS A REFERENCE CATCHMENT FOR THE ILLAWARRA

## 1. INTRODUCTION

The Water Research Foundation of Australia, Illawarra Regional Group Stormwater Subcommittee has prepared a Report and Compendium of Data on the hydrology of the Macquarie Rivulet Catchment.

The purpose of these two documents is to draw together material collected, and the results of analyses of the hydrology and hydraulics of the Macquarie Rivulet System, by the Stormwater Subcommittee, over the past thirteen years.

It is hoped that this work will form the basis of a readily available, reference dataset in the Illawarra Region, to assist Hydrologists and Engineers preparing drainage studies in the region.

The covering report describes work undertaken by the subcommittee in relation to hydrologic and hydraulic modelling of the Macquarie Rivulet system.

This Compendium of Data forms the basis of hydrologic and hydraulic modelling described in the report, replicating relevant data where such data is available and providing references to the source of data where such data is not readily available.

# 2. CATCHMENT DATA

## 2.1 DESCRIPTION

The 105 $km^2$ catchment of Macquarie Rivulet lies within the Lake Illawarra sub-basin of the Wollongong Coastal Basin The drainage network of Macquarie Rivulet comprises three main arms:

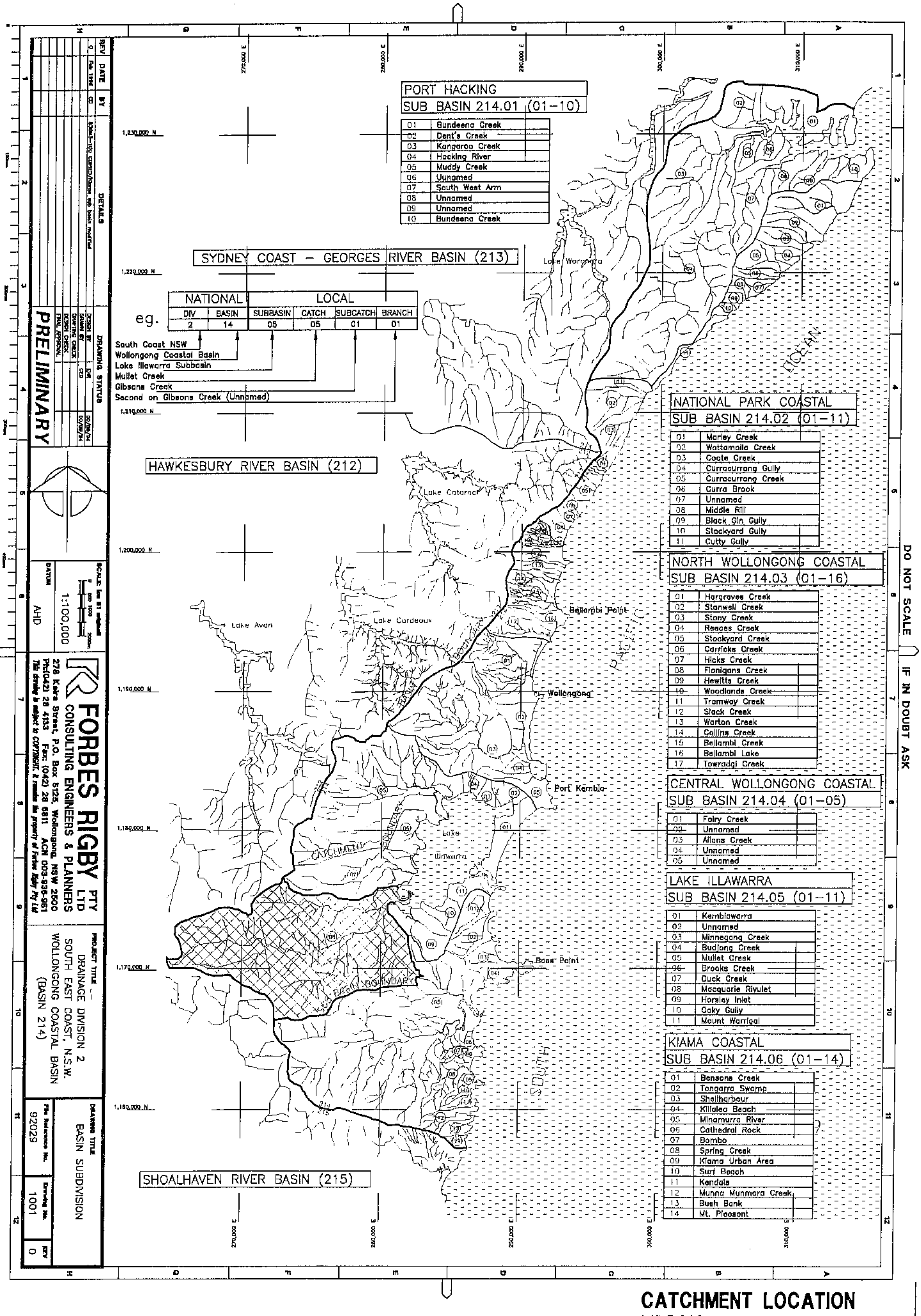
- Macquarie Rivulet (The main arm draining the central portion of the catchment)
- Frazers Creek (A secondary arm draining the south eastern sector)
- Marshal Mount Creek (A secondary arm draining the northern sector)

All three arms combine on the flood plain above the Princes Highway. In large events, flows merge across the full width of this flood plain, to form a single water body from Albion Park down to Lake Illawarra.

All three sub-catchments are predominantly rural with some existing urban development in the lower reaches of Frazers Creek and Macquarie Rivulet, around Albion Park. Areas to the west and south west of Albion Park are at present undergoing significant urban development.

The location of the catchment within the Wollongong Coastal Basin (214) is indicated in Figure 2.1.1.

An overlay of the catchment boundaries in respect to the topography and road system is provided in Figure 2.1.2.




| NATIONAL | | LOCAL | | | |
|---|---|---|---|---|---|
| DIV | BASIN | SUBBASIN | CATCH | SUBCATCH | BRANCH |
| 2 | 14 | 05 | 05 | 01 | 01 |

**PORT HACKING SUB BASIN 214.01 (01-10)**

| | |
|---|---|
| 01 | Bundeena Creek |
| 02 | Dent's Creek |
| 03 | Kangaroo Creek |
| 04 | Hacking River |
| 05 | Muddy Creek |
| 06 | Unnamed |
| 07 | South West Arm |
| 08 | Unnamed |
| 09 | Unnamed |
| 10 | Bundeena Creek |

**NATIONAL PARK COASTAL SUB BASIN 214.02 (01-11)**

| | |
|---|---|
| 01 | Marley Creek |
| 02 | Wattamolla Creek |
| 03 | Coote Creek |
| 04 | Curracurrang Gully |
| 05 | Curracurrong Creek |
| 06 | Curra Brook |
| 07 | Unnamed |
| 08 | Middle Rill |
| 09 | Black Gin Gully |
| 10 | Stockyard Gully |
| 11 | Cutty Gully |

**NORTH WOLLONGONG COASTAL SUB BASIN 214.03 (01-16)**

| | |
|---|---|
| 01 | Hargraves Creek |
| 02 | Stanwell Creek |
| 03 | Stony Creek |
| 04 | Reeces Creek |
| 05 | Stockyard Creek |
| 06 | Carrick's Creek |
| 07 | Hicks Creek |
| 08 | Flanigans Creek |
| 09 | Hewitts Creek |
| 10 | Woodlands Creek |
| 11 | Tramway Creek |
| 12 | Slack Creek |
| 13 | Worton Creek |
| 14 | Collins Creek |
| 15 | Bellambi Creek |
| 16 | Bellambi Lake |
| 17 | Towradgi Creek |

**CENTRAL WOLLONGONG COASTAL SUB BASIN 214.04 (01-05)**

| | |
|---|---|
| 01 | Fairy Creek |
| 02 | Unnamed |
| 03 | Allans Creek |
| 04 | Unnamed |
| 05 | Unnamed |

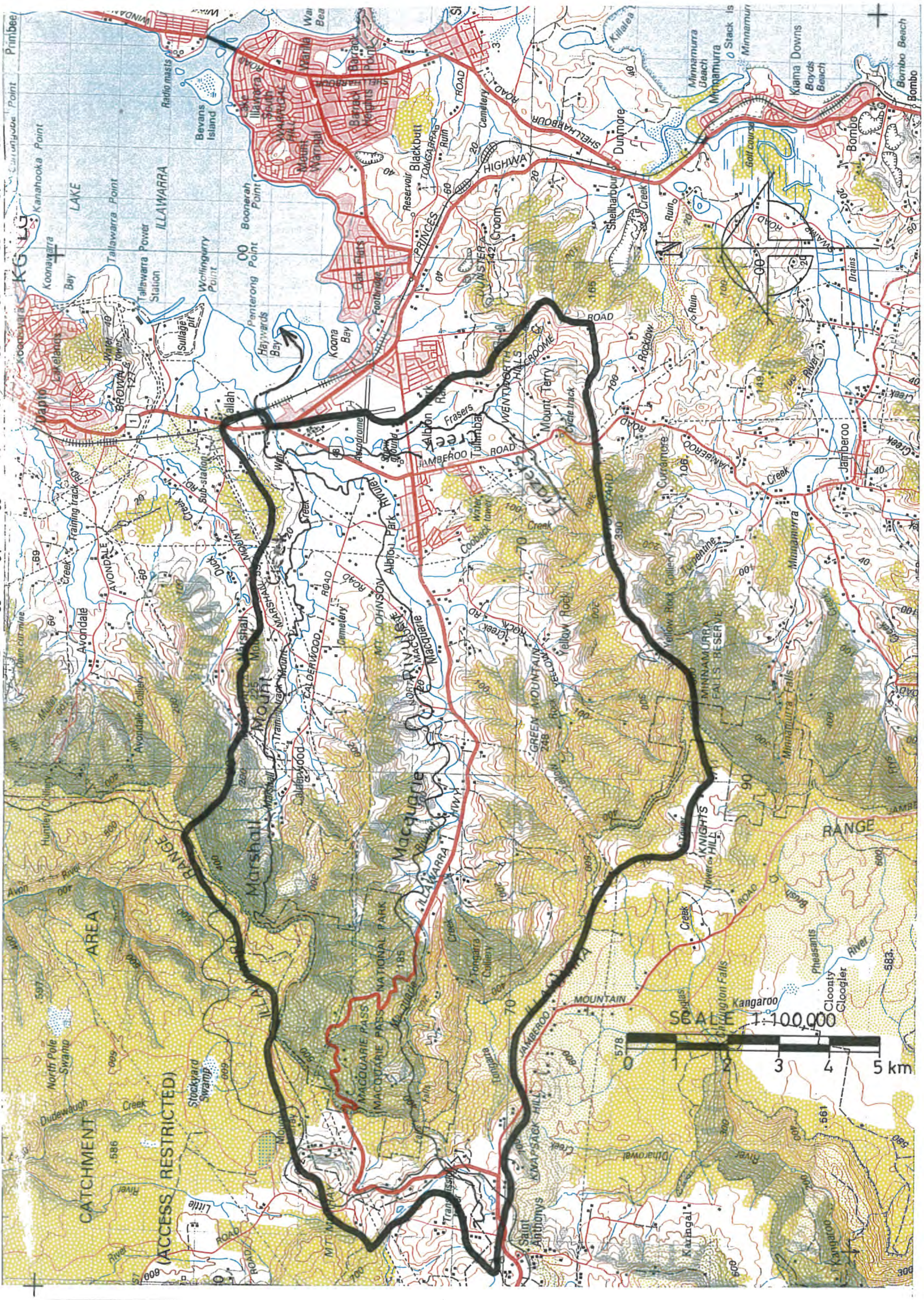
**LAKE ILLAWARRA SUB BASIN 214.05 (01-11)**

| | |
|---|---|
| 01 | Kemblawarra |
| 02 | Unnamed |
| 03 | Minnegang Creek |
| 04 | Budjong Creek |
| 05 | Mullet Creek |
| 06 | Brooks Creek |
| 07 | Duck Creek |
| 08 | Macquarie Rivulet |
| 09 | Horsley Inlet |
| 10 | Oaky Gully |
| 11 | Mount Warrigal |

**KIAMA COASTAL SUB BASIN 214.06 (01-14)**

| | |
|---|---|
| 01 | Bensons Creek |
| 02 | Tongarra Swamp |
| 03 | Shellharbour |
| 04 | Killalea Beach |
| 05 | Minnamurra River |
| 06 | Cathedral Rock |
| 07 | Bombo |
| 08 | Spring Creek |
| 09 | Kiama Urban Area |
| 10 | Surf Beach |
| 11 | Kendalls |
| 12 | Munna Munmara Creek |
| 13 | Bush Bank |
| 14 | Mt. Pleasant |

**CATCHMENT LOCATION**
**FIGURE 2.1.1**




**CATCHMENT BOUNDARY**

**FIGURE 2.1.2**

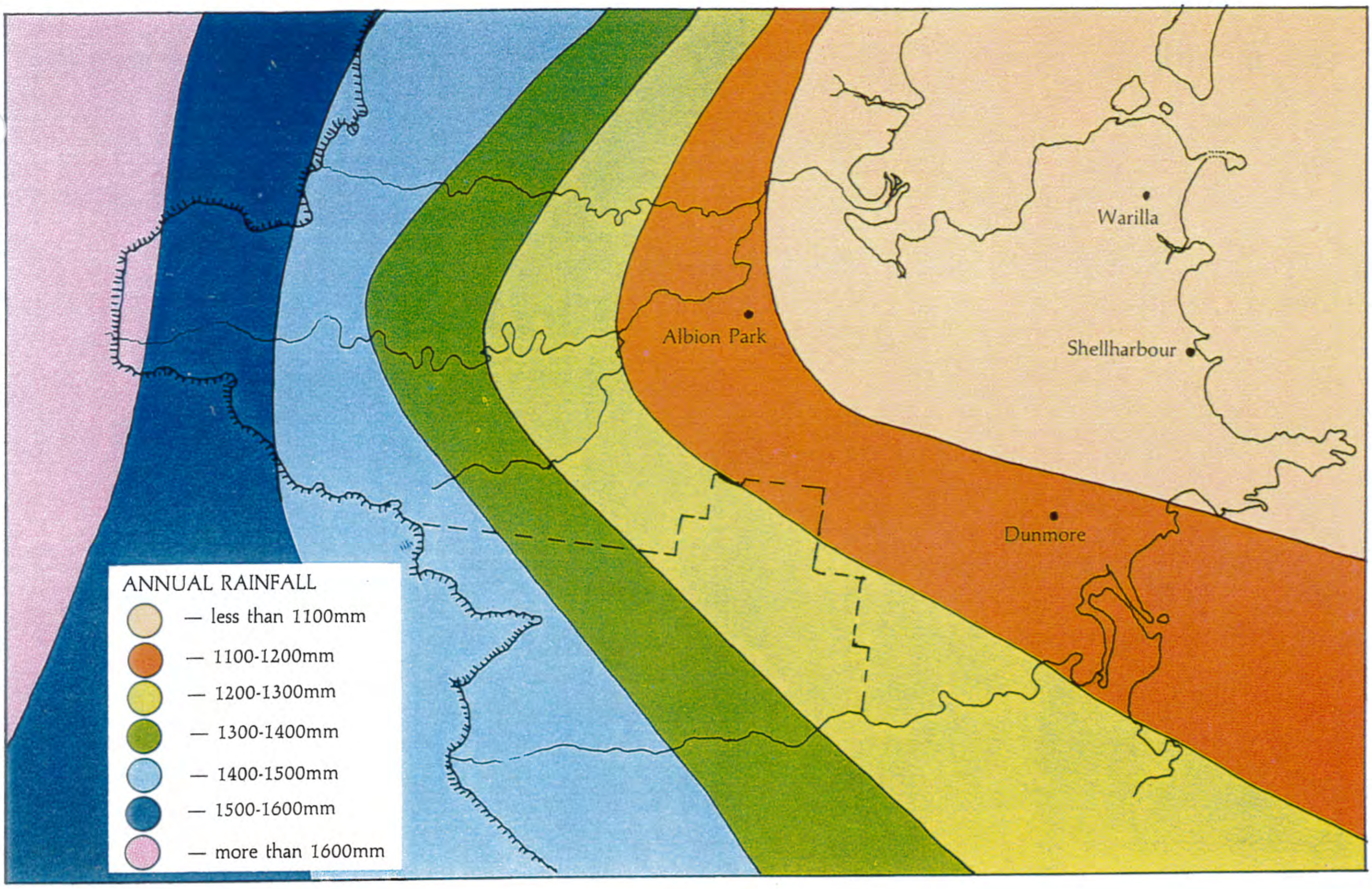
## 2.2 CLIMATE

Rainfall across the catchment exhibits significant spatial variation. A distinct rainfall gradient is apparent in both individual storm events and in long term rainfall records, with intensity increasing towards the escarpment. The Average Annual Rainfall in the upper reaches of the catchment is around 1600mm while the lower reaches receive only 1100mm.

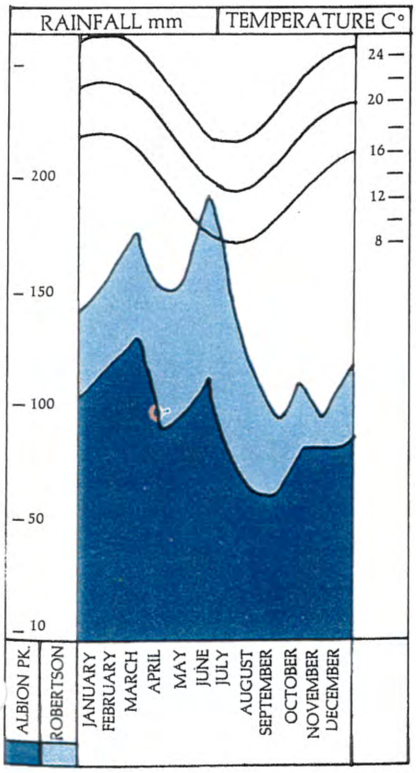
Rainfall also varies significantly between seasons with peak monthly rainfall typically occurring in early Autumn and early Winter (March and June). Minimum monthly rainfall is typically recorded during the late winter and early spring months (August to September).

Further details of climatic variations across the catchment and between seasons are set out in Figure 2.2.1.

## RAINFALL DISTRIBUTION

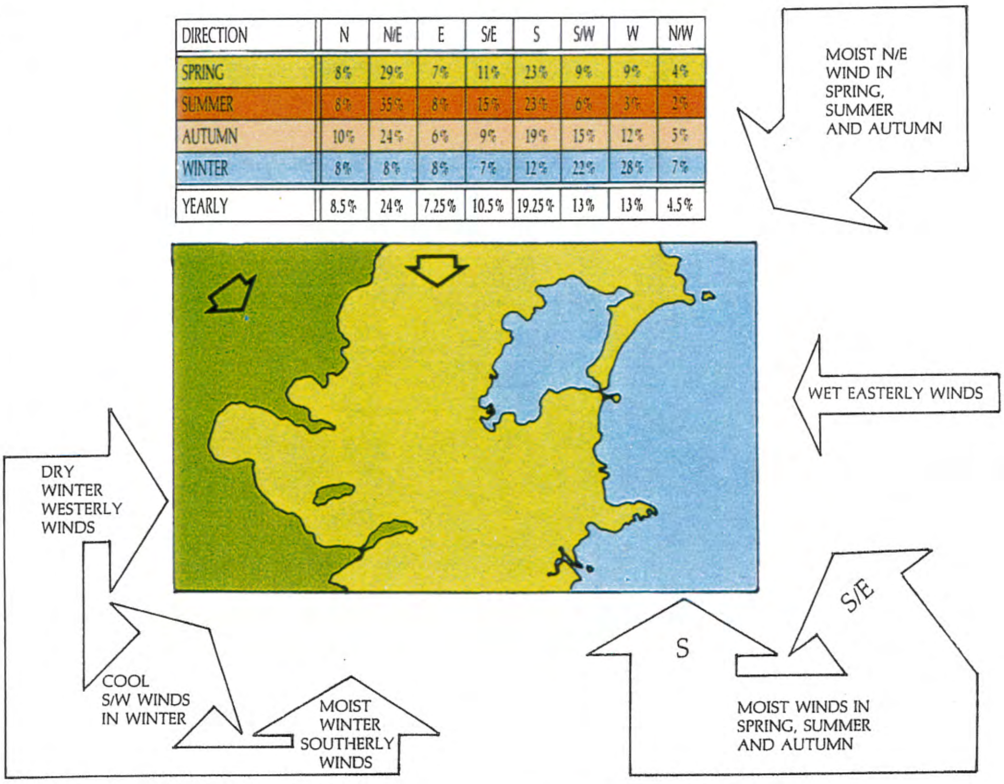



## ANNUAL RAINFALL AND CLIMATE




## WIND CHART

| DIRECTION | N | N/E | E | S/E | S | S/W | W | N/W |
|---|---|---|---|---|---|---|---|---|
| SPRING | 8% | 29% | 7% | 11% | 23% | 9% | 9% | 4% |
| SUMMER | 8% | 35% | 8% | 15% | 23% | 6% | 3% | 2% |
| AUTUMN | 10% | 24% | 6% | 9% | 19% | 15% | 12% | 5% |
| WINTER | 8% | 8% | 8% | 7% | 12% | 22% | 28% | 7% |
| YEARLY | 8.5% | 24% | 7.25% | 10.5% | 19.25% | 13% | 13% | 4.5% |




**SOURCE : DERBYSHIRE & ALLEN - LAND BETWEEN TWO RIVERS**

**CATCHMENT CLIMATE**
**FIGURE 2.2.1**

## 2.3 PHYSIOGRAPHY

The catchment falls within a tapering wedge of coastal land confined to the east by the Tasman Sea and to the west by the Illawarra coastal escarpment. The width of this coastal wedge of land is near zero at Stanwell Park to the north and increases to around 15 km in the vicinity of the Macquarie Rivulet at Shellharbour, to the south. At Kiama, the Illawarra Escarpment runs down to the sea, severing the coastal belt, to the immediate south of the Macquarie Rivulet Catchment.

Runoff from the foothills and escarpment, has over the years created a series of primary spurs, running roughly east-west, from the escarpment down to the sea. Multiple lateral spurs have in turn developed on the primary spurs, running typically north-south. This pattern is readily evident on 1:25,000 topographic maps of the area, the southern Boundary of the catchment being a good example of this process.

Macquarie Rivulet has a stream length of 22.5 km, with total fall from head waters to outlet of 680 metres. The Rivulet's equivalent mainstream slope is 8.4 m/km. The upper reaches are quite steep producing some spectacular water falls down the escarpment. For the majority of its length, the stream meanders along a relatively flat river valley with the lower reaches combining on a broad flat flood plain, above the Princes Highway. The combined streams then discharge into Lake Illawarra, where silt deposition has formed a pronounced delta.

Physiographic parameters for the catchment of Macquarie Rivulet as a whole, and its main subcatchments are set out in Table 2.3.1.

| Catchment (Subcatchment) | Macquarie Rivulet Overall | Macquarie Rivulet to Sunnybank | Yellow Rock Creek | Marshall Mt Creek | Frazers Creek |
|---|---|---|---|---|---|
| **Linear Parameters** | | | | | |
| Mainstream Order | 5 | 5 | 4 | 5 | 4 |
| Mainstream Length (km) | 22.5 | 11.9 | 8.5 | 10.8 | 10.0 |
| Basin Length (km) | 15.6 | 9.0 | 6.5 | 9.5 | 6.7 |
| Meander Index | 1.4 | 1.3 | 1.5 | 1.1 | 1.5 |
| Bifurcation Ratio (Avg) | 4.0 | 4.0 | 4.0 | 4.5 | - |
| Overland Flow Length (Avgm) | 100 | - | - | - | - |
| **Areal Parameters** | | | | | |
| Basin Area (km$^2$) | 105.2 | 35.0 | 17.0 | 20.2 | 13.8 |
| Basin Shape (form factor) | 0.43 | 0.43 | 0.56 | 0.18 | 0.31 |
| Drainage Density (km$^{-1}$) | 3.2 | 2.8 | 3.0 | 3.9 | 3.1 |
| Stream Frequency | 5.0 | 4.2 | 4.3 | 7.2 | 4.1 |
| **Relief Parameters** | | | | | |
| Mainstream Slope | 0.016 | 0.04 | 0.04 | 0.01 | 0.01 |
| Valley Side Slopes | 0.25 | 0.3 | 0.2 | 0.2 | 0.05 |
| Mean Elevation (m) | 300 | 350 | 260 | 140 | 90 |
| Basin Relief (m) | 770 | 760 | 710 | 600 | 350 |
| Ruggedness No. | 2.5 | 2.3 | 2.1 | 2.3 | 1.1 |
| Geometry No. | 10 | 7.6 | 10.6 | 11.7 | 21.6 |

**CATCHMENT PHYSIOGRAPHIC PARAMETERS**

**TABLE 2.3.1**

Catchment contours are reproduced in Figure 2.1.2.

As is apparent from the above, all catchments are somewhat elongated (Marshall Mount Creek in particular) but with the exception of Frazers Creek are topographically similar. Frazers Creek stands out as a much flatter and lower relief subcatchment than the other subcatchments of the Macquarie Rivulet system.

## 2.4 GEOLOGY

The stratigraphy of the catchment generally comprises Triassic age, Narrabeen Group sandstone and siltstone (cliffs), overlying Permian age Illawarra Coal Measures (base of cliffs) with talus foothill slopes (mixture of the above). These in turn run down to residual soils and clays overlying a Permian age Shoalhaven Group, Kiama tuff basement. Quaternary deposits of alluvium, sands and silts are present on flood plains and in swamps.

Throughout the Illawarra, this coastal wedge has a similar east-west profile, with the high (600 metre) escarpment to the west, falling sharply to around the 450 metre contour level, at which point the talus slopes commence. These slopes in turn run down at a 15 to 35% grade to around the 100 metre contour level, where residual soils and clays are encountered. In the residual soil/clay zone, surface slopes are typically in the 5 to 15% range.

At around the 4 metre contour level, the profile again changes, to an overburden of recently transported sediments deposited on a relatively flat grade.

A typical east/west cross section through the catchment is reproduced in Figure 2.4.1 A more detailed description of the geology of the area is provided by Bowman (1966) In the records of the Geological Survey of NSW Vol 14, part 2 and on 1:250,000 mapping by the NSW Department of Mines (sheet Wollongong 5l-56-9).

The distribution and characteristics of soils within the catchment is described by Hazelton (1992) in Soil Landscapes of the Kiama Region prepared for the Department of Conservation and Land Management (NSW) and on the 1:100,000 CaLM Soil Landscape series (sheet 9028).

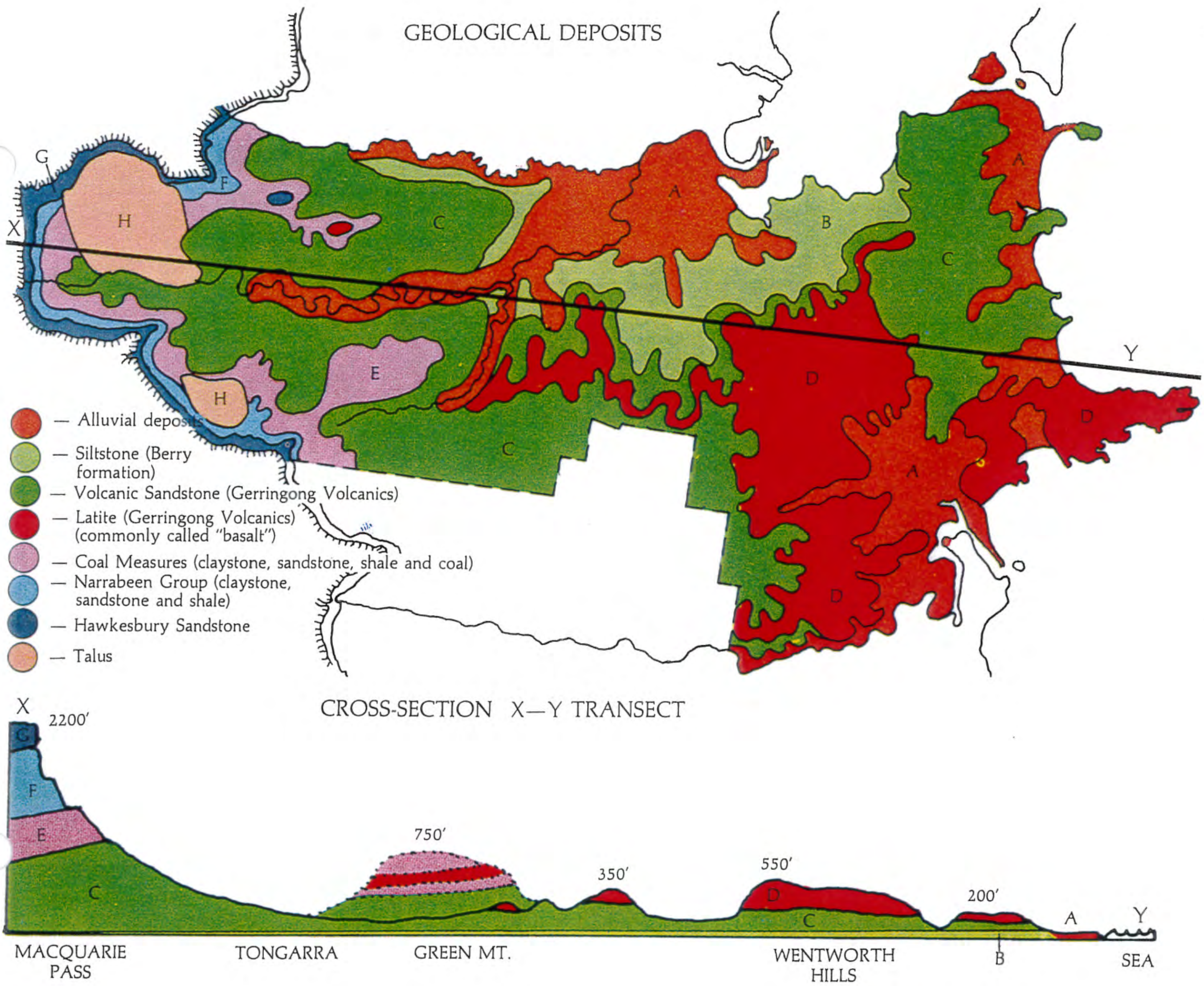
## 2.5 VEGETATION

Little tree cover remains on the flood plain or in the lower sections of the valley, with most of the more accessible land having been cleared for pasture, or more recently, urban development. Urban development has occurred and is currently expanding in the lower portion of the catchment, in and around the villages of Albion Park and Albion Park Rail.

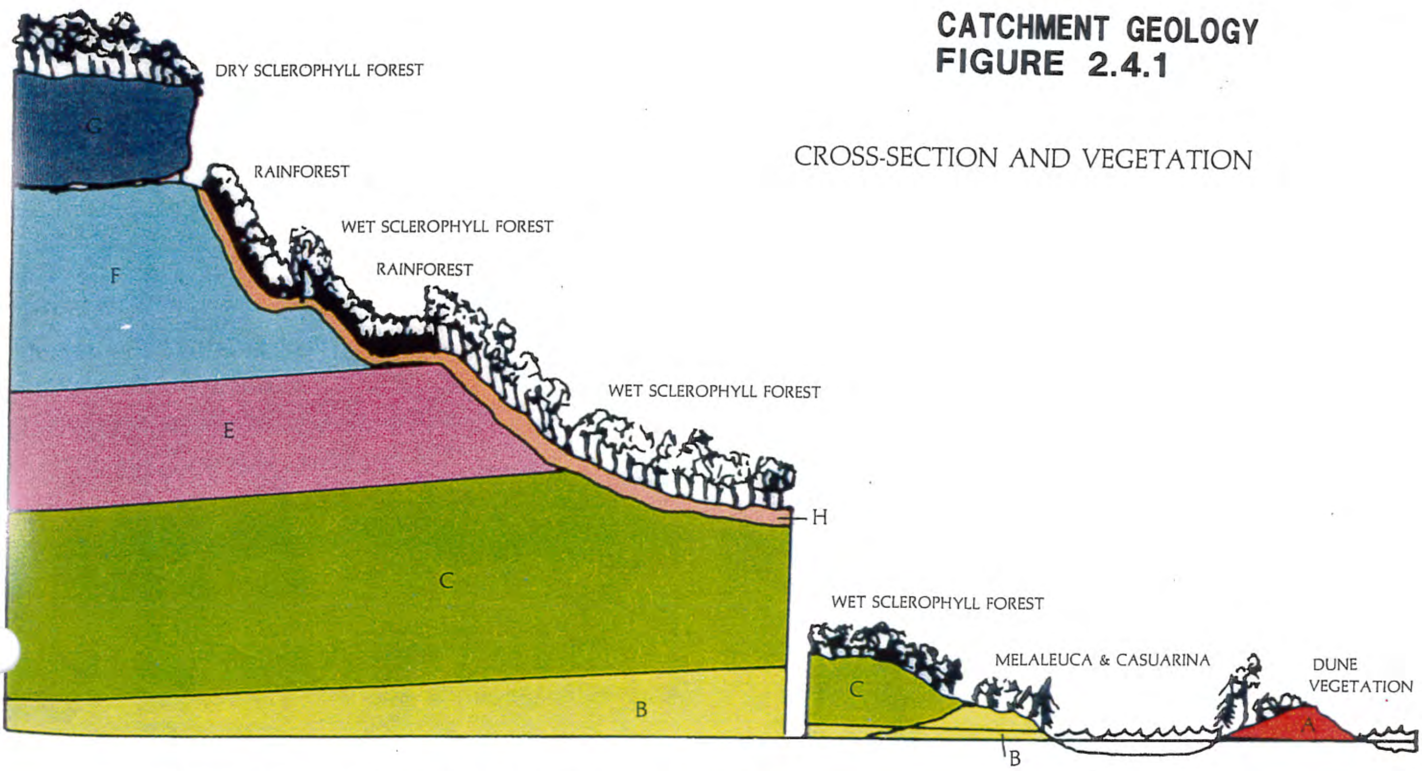
The escarpment and foothills, however, are still heavily wooded with some of the more inaccessible areas, in a relatively natural condition.

Both orthophoto mapping (refer section 2.7) and air photography (refer section 2.8) provide a good guide to the distribution and extent of canopy cover within the catchment.

A typical gradation in species is evident within the catchment as indicated in Figure 2.5.1.




**CATCHMENT GEOLOGY**
**FIGURE 2.4.1**




**SOURCE : DERBYSHIRE & ALLEN - LAND BETWEEN TWO RIVERS**

**CATCHMENT VEGETATION**
**FIGURE 2.5.1**

## 2.6 LANDUSE

The early Illawarra escarpment and foothills supported a cover of dense sub-tropical rainforest. The first major impact on vegetation and land use arose in the early 1800's with felling of the cedar trees. This was in turn followed in the mid 1800's by the clearing of the less dense stands of Blackbutt and Turpentine, on the flatter land, for pasture. Beyond the urban (ever increasing) limits of the village of Albion Park there has been little change in land usage for over 100 years, most of the land around the village having been used as pastoral land since first being cleared in the mid to late 1800's.

In 1843 a road was built connecting Shellharbour with Jamberoo. A bridge was constructed over Macquarie Rivulet in 1858, which together with a punt across Minnamurra River, upgraded access from Shellharbour to the north. In 1909 the original bridge over Macquarie Rivulet was replaced and in 1932 the Princes highway was constructed between Macquarie Rivulet and Minnamurra River. The Princes Highway road bridge was again replaced in 1971 with a concrete structure and the crossing duplicated to provide multi lane access in 1990.

In 1887 the Illawarra Rail line was opened and in 1920 the original `Albion Park' station (then located at Yallah) relocated to Albion Park Rail, forming the nucleus of the village of Albion Park Rail. The existing timber rail bridge over Macquarie Rivulet was replaced in 1982 with a new concrete structure.

The aerodrome at Albion Park was opened in 1941.

In 1972, an industrial estate was created on land to the south of Macquarie Rivulet, between the Princes Highway and Illawarra Rail line.

In the late seventies and early eighties, a series of ash ponds were constructed at Tallawarra power station, infilling part of the flood plain between Macquarie Rivulet and Duck Creek. Wollingurry Creek was diverted to flow around the south eastern corner of these ponds, at this time.

During 1996 a coal washery discard fill emplacement commenced on the northern floodplain of Macquarie Rivulet, downstream of the rail bridge, part of earthworks for a residential subdivision to be constructed at this location.

## 2.7 MAPPING

The catchment area is covered by 1:100.000 and 1:25.000 and partially by 1:10,000 topographic mapping, with 1:10,000 mapping of the eastern half of the catchment available on a coloured orthophoto base. 1:4,000 black and white orthophoto mapping has also been completed in the eastern half of the catchment. 1:10,000 and 1:4,000 orthophoto mapping is on the Integrated Survey Grid (I.S.G.), whereas the 1:25,000 series and higher scale mapping is based on the Australian Mapping Grid (A.M.G.). A summary of available mapping of relevance to the area is listed in Table 2.7.1.

| REF | LOCALITY | TYPE | SCALE | YEAR | SOURCE |
|---|---|---|---|---|---|
| W7370 | Albion Park | Orthophoto | 1:10000 | 1975 | CMA |
| W6470 | Mt Murray | Orthophoto | 1:10000 | 1975,1976 | CMA |
| W7370 - 1 to 9 | Albion Park | Orthophoto | 1:4000 | undated | CMA |
| W6460 - 1 to 9 | Mt Murray | Orthophoto | 1:4000 | undated | CMA |
| 9028 | Kiama | Topographic | 1:100000 | 1983 | NATMAP |
| 9028-1-S | Kiama | Topographic | 1:25000 | 1978 | CMA |
| 9028-1-N | Albion Park | Topographic | 1:25000 | 1977 | CMA |
| 9028-IV-N | Robertson | Topographic | 1:25000 | 1979 | CMA |
| - | Shellharbour | LEP | 1:8000 | 1979 | DEP |
| 9028 | Kiama | Soil Landscape | 1:100,000 | 1993 | CaLM |
| SI56-9 | Wollongong | Geology | 1:250,000 | 1966 | DMR |

**CATCHMENT MAPPING**
**TABLE 2.7.1**

## 2.8 AERIAL PHOTOGRAPHY

Both the Lands Department and B.H.P. Engineering - Land Technologies Division have flown the coast line and escarpment at regular intervals over the last several decades providing comprehensive stereo pair and oblique photography of the coastal strip. Indexes available photography and prints from each organisations are readily available.

## 2.9 GROUND SURVEY

1:4000 orthophoto mapping provides approximate contour levels at 2 metre intervals on the Integrated Survey Grid for the eastern half of the catchment and 1:10,000 orthophotomapping provides coverage at 10 metre intervals for the same area.

To augment the above, cross sections were surveyed across Macquarie Rivulet and Frazers Creek for the Albion Park Flood Study undertaken by the Water Resources Commission in 1986. These sections were located along the creeks at intervals varying from 100 to 300 metres extending from the flood plain at the Albion Park Aerodrome, to the upstream boundary of the Albion Park township. A summary of the surveyed levels and the location and level of permanent survey marks in the Albion Park township is provided in the Albion Park Flood Study.

The State Rail Authority and the Roads and Traffic Authority have detail survey data at the Railway and Highway bridge crossings of Macquarie Rivulet.

In 1979 the State Rail Authority undertook a detail survey of Macquarie Rivulet from the rail bridge down to the lake, providing cross sections for the flood study prepared by Wargon Chapman (1980). The above cross sections are reproduced in Figures 2.9.1 to 3 inclusive.

The lower floodplain, downstream of the Princes Highway, including associated bridges was also surveyed by D Allen - Surveyor in 1990 for a flood study by Forbes Rigby relating to potential development of a land parcel adjacent to Lake Illawarra (refer Figure 2.9.4). It should be noted that earthworks have occurred near the Macquarie Rivulet outlet to Lake Illawarra since this survey was obtained.

Shellharbour Council undertook a survey within the upper flood plain and creek adjacent to Croom Road and the Albion Park Aerodrome for a flood study by Forbes Rigby P/L in 1992. This survey included several sections across the flood plain (refer Figures 2.9.5 to 2.9.8).

Kinhill Engineers obtained additional cross section survey of tributaries located downstream of new developments in Albion Park for a flood study completed in 1993. These additional cross sections were located on Yellow Rock Ck, Hazelton Ck, Fraser CK and their tributaries (refer report - Kinhill (1993)).

In 1994 Lean Lackenby & Hayward kindly undertook the survey of various crossections upstream and downstream of the SunnyBank gauge site, to permit hydraulic modelling of the gauged reach to be undertaken by the Water Research Foundation Stormwater Subcommittee. These cross sections together with a location plan are reproduced in figures 2.9.9 and 10 respectively.

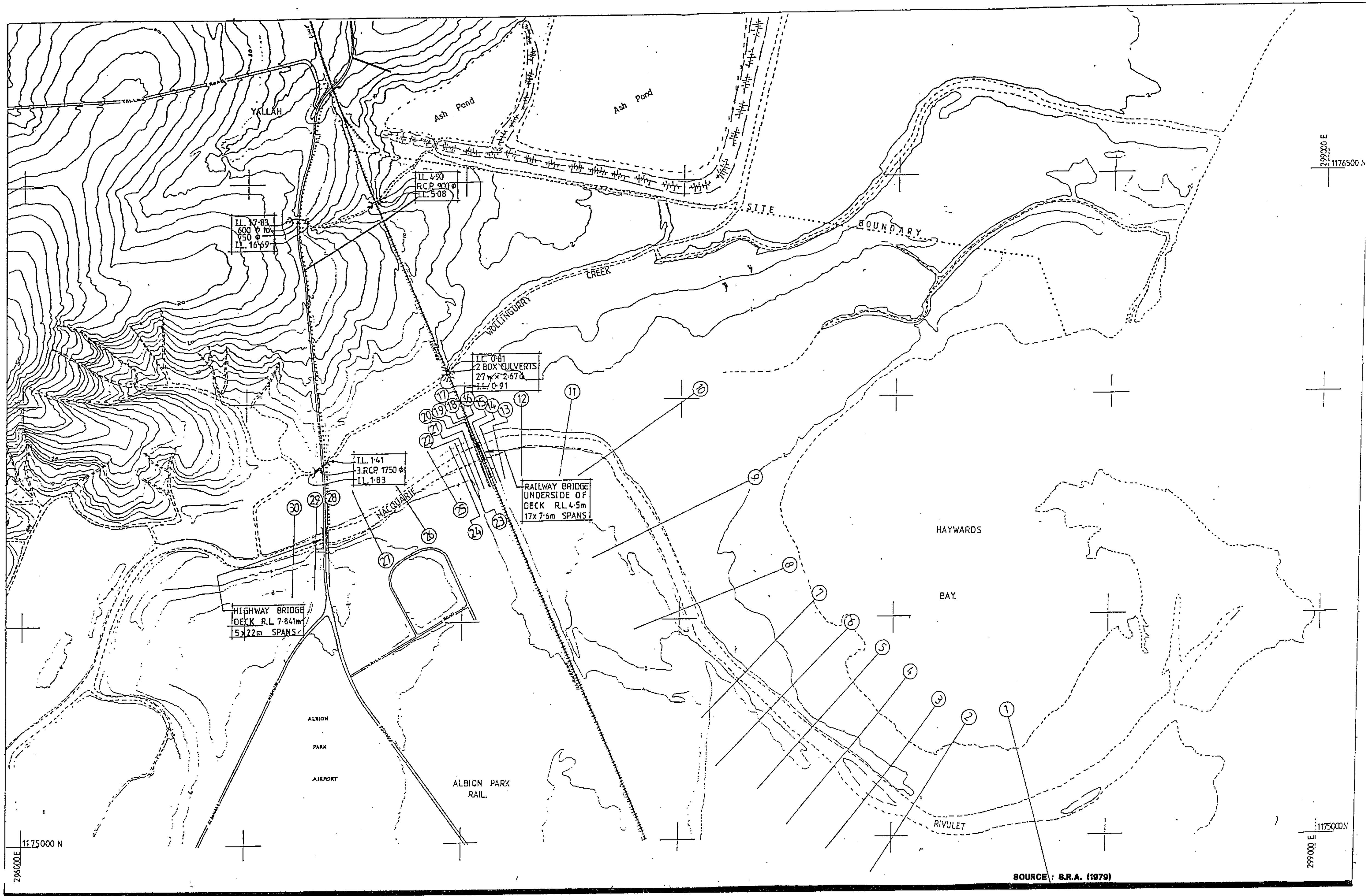



**FIGURE 2.9.1**

**DETAIL SURVEY**

**LOWER REACH OF MACQUARIE RIVULET**

**SECTION LOCATIONS**

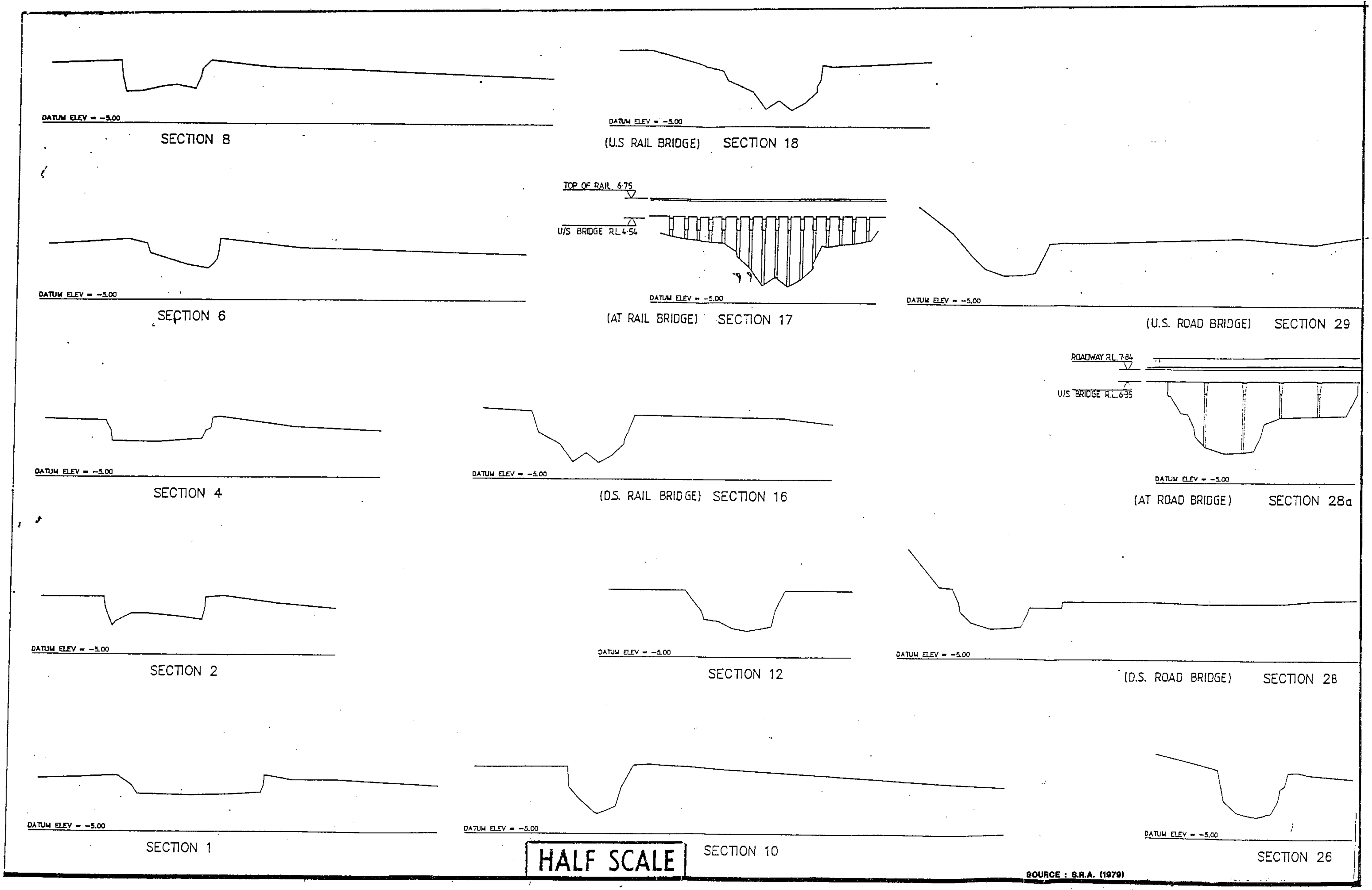



**FIGURE 2.9.2**

**DETAIL SURVEY**

**LOWER REACH OF MACQUARIE RIVULET**

**CROSS SECTIONS - SHEET 1 OF 2**

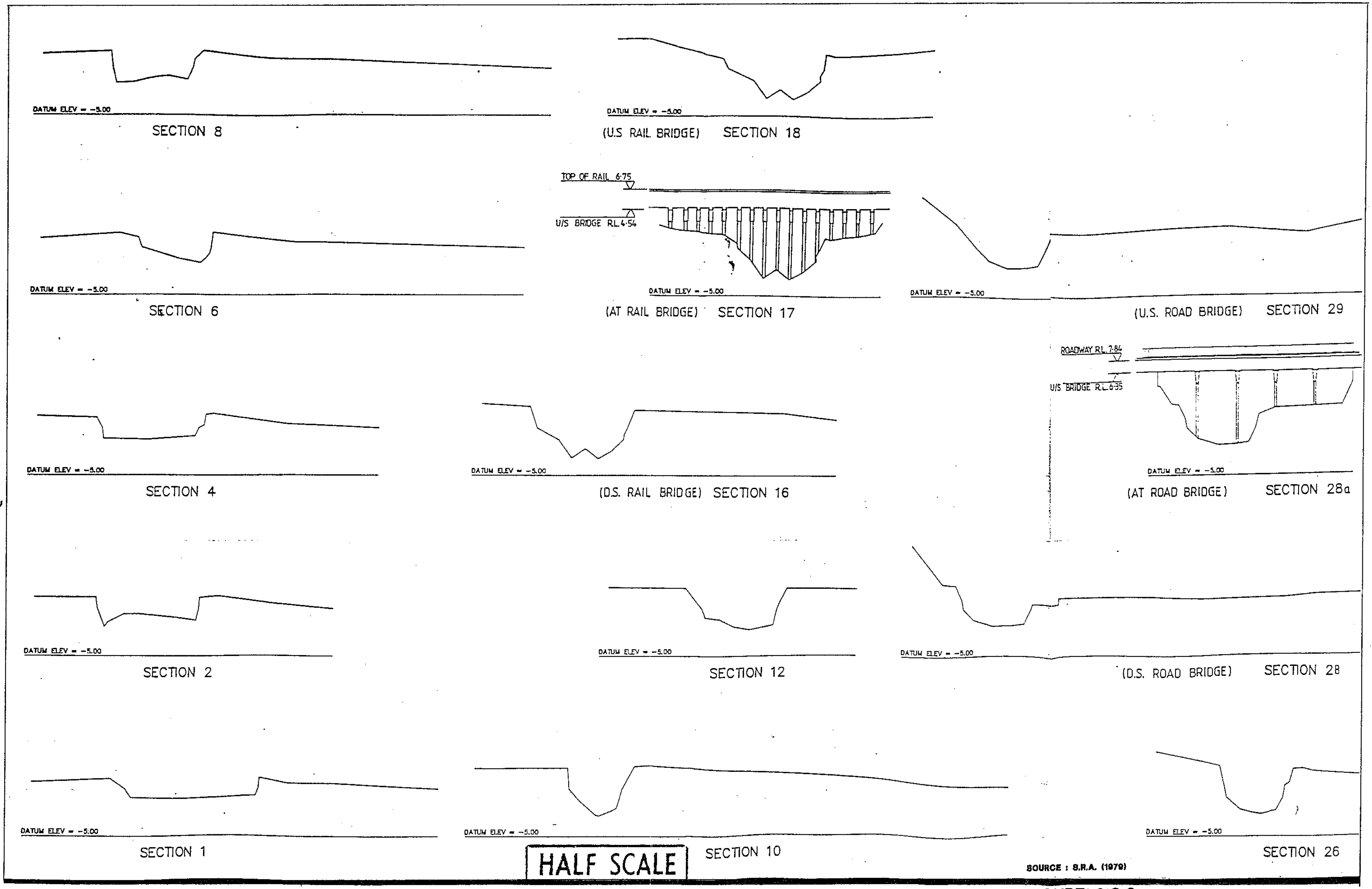



**FIGURE 2.9.3**
**DETAIL SURVEY**
**LOWER REACH OF MACQUARIE RIVULET**
**CROSS SECTIONS - SHEET 2 OF 2**


| REV | DATE | BY | DETAILS | REFERENCE DRAWINGS |
|---|---|---|---|---|
| | | | | |

| DRAWING STATUS | | |
|---|---|---|
| DESIGN | E.H.R. | -- / -- / 91 |
| DRAWN | R.B.D. | 30 / 04 / 91 |
| CHECKED | | / / |
| APPROVED | | / / |

PRELIMINARY ONLY

SCALE 1:4 000

DATUM A.H.D.

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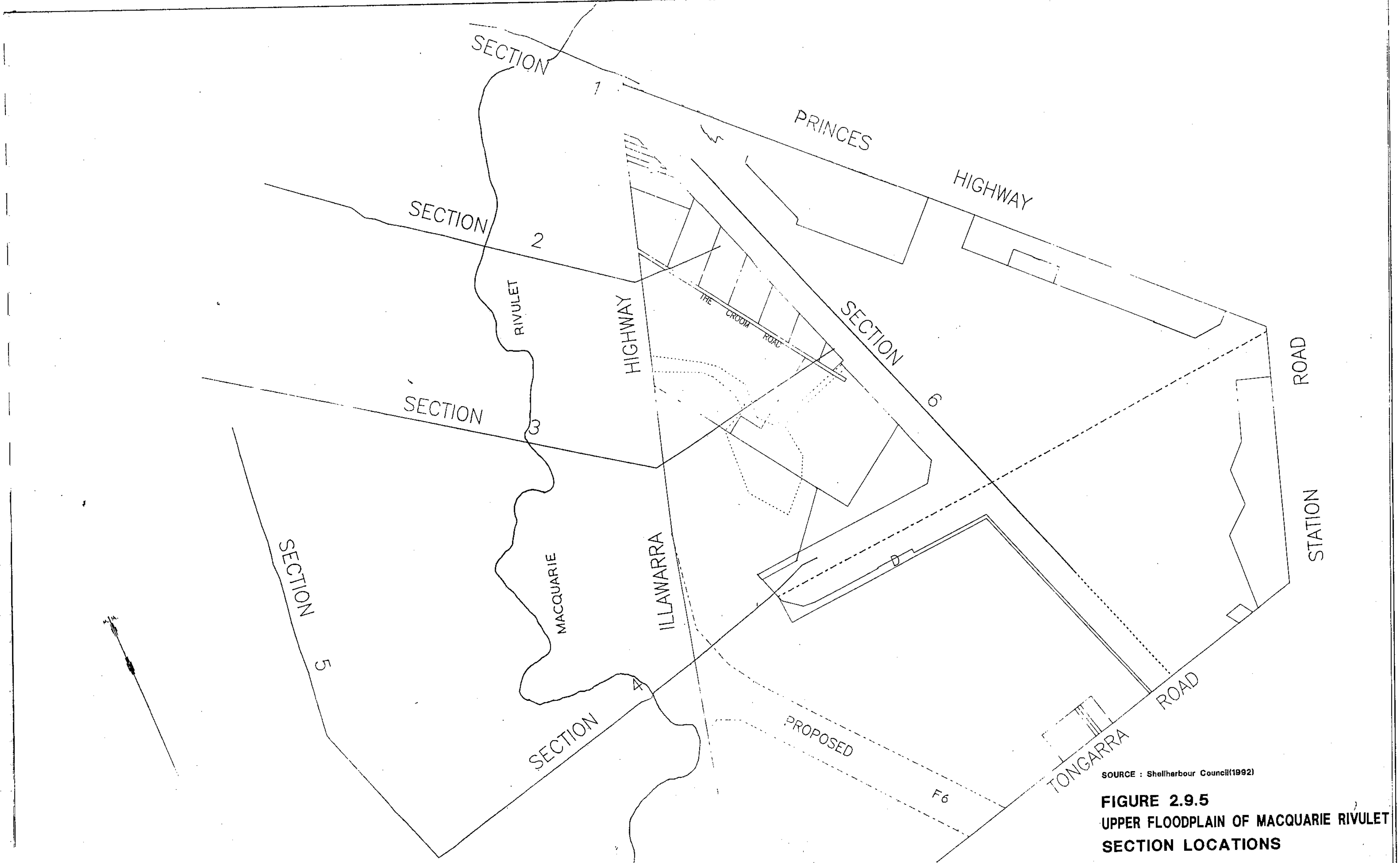
PROJECT TITLE
MACQUARIE RIVULET
REFERENCE CATCHMENT
Wollongong Coastal Basin 214-05-08

DRAWING TITLE
LOWER FLOOD PLAIN
DETAIL SURVEY

| File Reference No. | Drawing No. | REV |
|---|---|---|
| 83093-2 | 3002 | 0 |

FIGURE 2.9.4

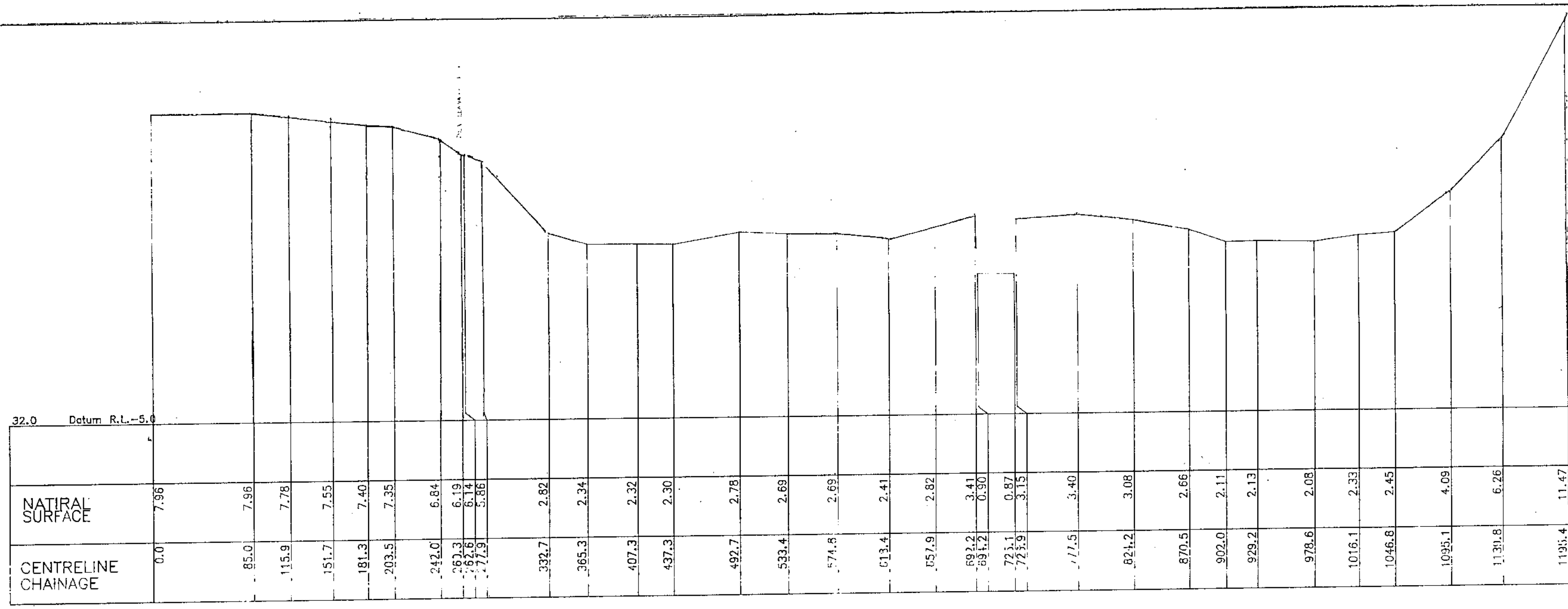
A1




SOURCE : Shellharbour Council(1992)

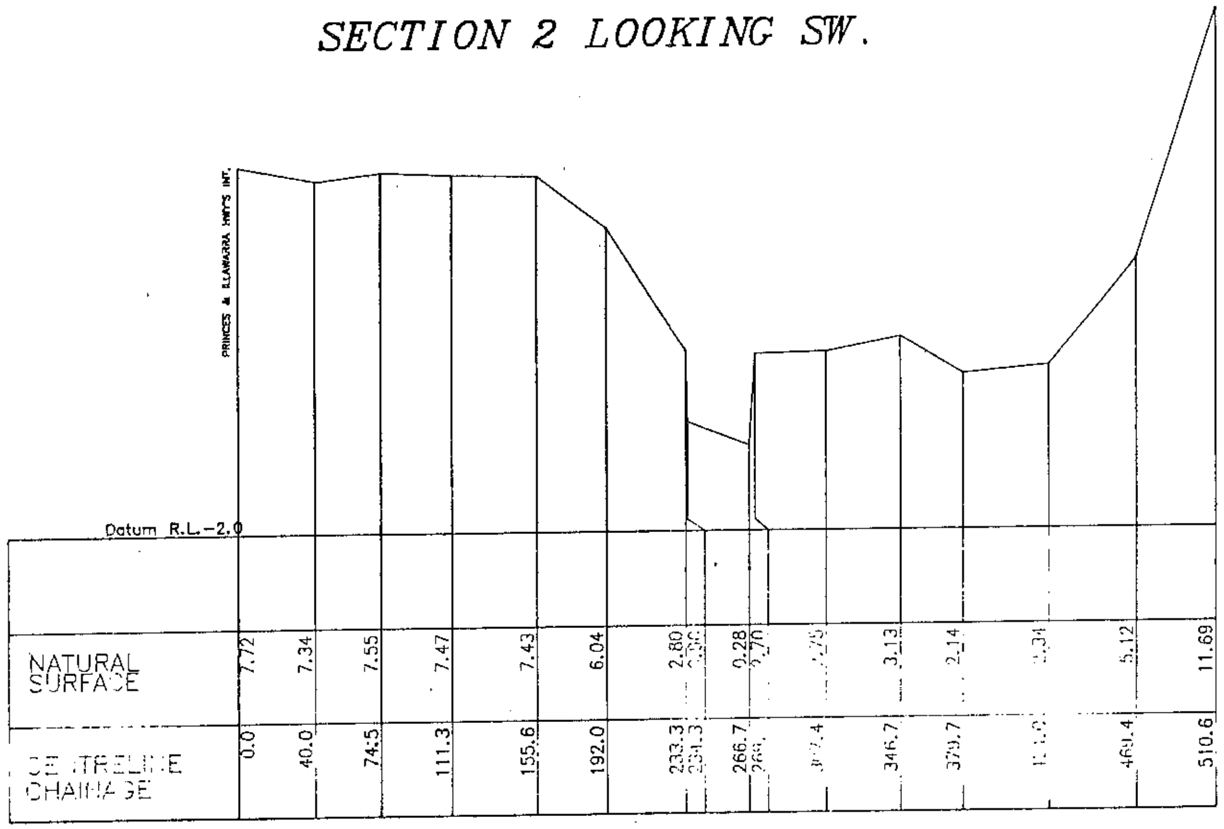
**FIGURE 2.9.5**
**UPPER FLOODPLAIN OF MACQUARIE RIVULET**
**SECTION LOCATIONS**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SCALES PLAN 1:5000 | APPROVED ... DESIGN ENGINEER | ORIGIN OF LEVELS | REFERENCE PLANS | PLAN AMENDED | WORKS AS EXECUTED | MUNICIPALITY OF SHELLHARBOUR | SHEET NO. 1 OF 4 |
| DATUM A.H.D. SURVEYED MS FIELD BOOK 9 LEVEL BOOK 121 DESIGNED DRAWN PK CHECKED | NOTED ... WORKS ENGINEER | P.M. 16702 S.S.M. B.M. R.L. 6.346 | | | COMPLETED BY ... DATE ... DRAWN BY ... REF ... NOTE ALTERATIONS SHOWN IN RED ON ORIGINAL PLAN | *FLOOD STUDY MACQUARIE RIVULET* | MUNICIPAL ENGINEER DATE JULY-92 FILE NO. PLAN NO. 5G-114 |




Scales Horizontal 1:2000
Vertical 1:100

SECTION 2 LOOKING SW.



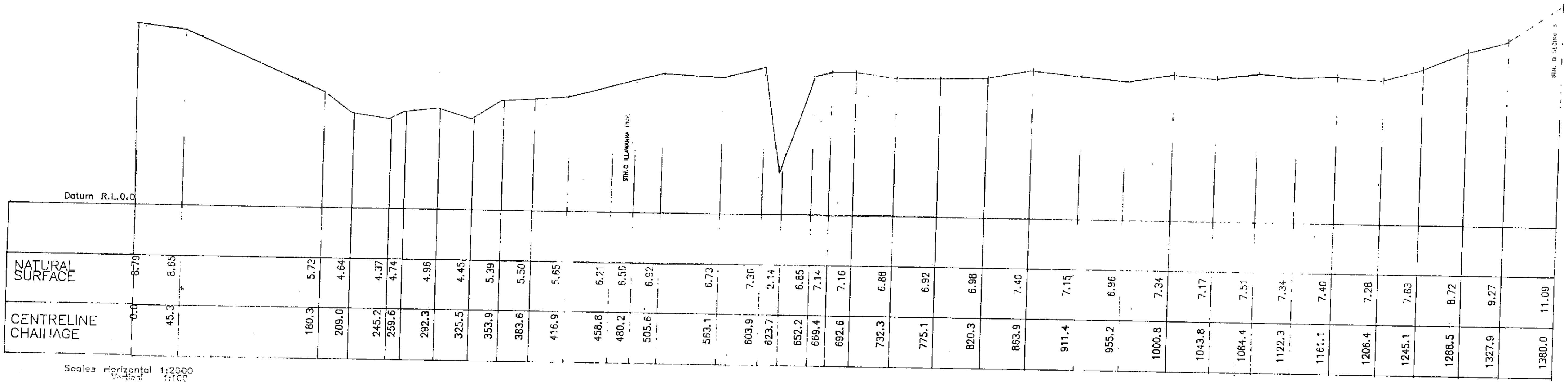

Scales Horizontal 1:2000
Vertical 1:100

SECTION 1 LOOKING SW.

SOURCE : Shellharbour Council(1992)

**FIGURE 2.9.6**
**UPPER FLOODPLAIN OF MACQUARIE RIVULET**
**CROSS SECTIONS - SHEET 1 OF 3**

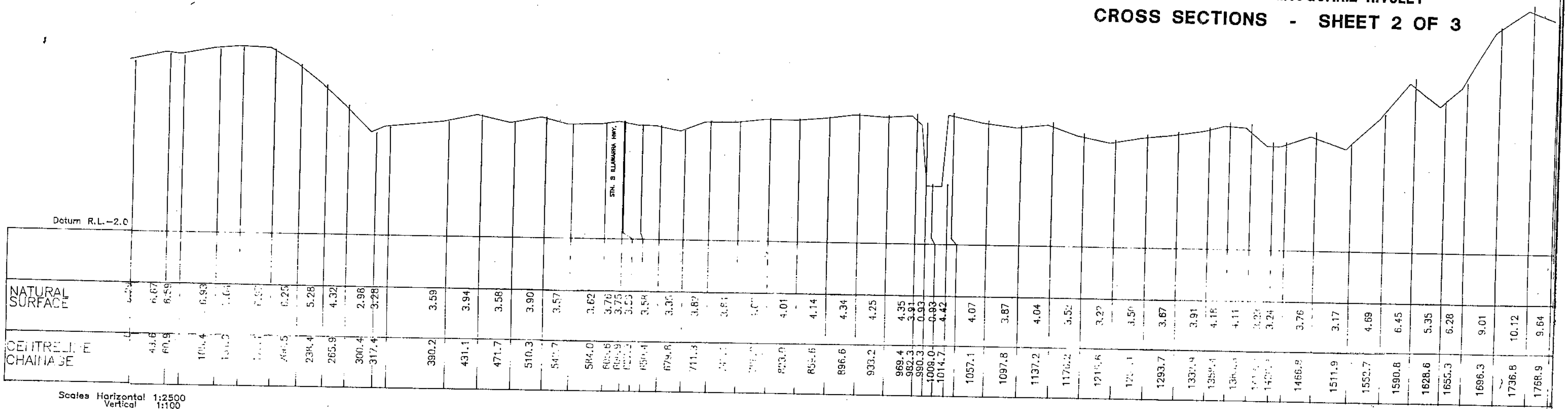
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SCALES: AS SHOWN | APPROVED | ORIGIN OF LEVELS | REFERENCE PLANS | PLAN AMENDED | WORKS AS EXECUTED | MUNICIPALITY OF SHELLHARBOUR | SHEET NO. 2 OF 4 |
| DATUM A.H.D. SURVEYED MS FIELD BOOK 9 LEVEL BOOK 121 | DESIGN ENGINEER | P.M. 16702 | | | COMPLETED BY.......DATE.. | FLOOD STUDY MACQUARIE RIVULET | MUNICIPAL ENGINEER DATE JULY-92 |
| DESIGNED ........ DRAWN PK CHECKED ........ | NOTED | S.S.M. | | | DRAWN BY.......REF....... | | FILE NO. |
| | WORKS ENGINEER | B.M. R.L. 6.346 | | | NOTE ALTERATIONS SHOWN IN RED ON ORIGINAL PLAN | | PLAN NO. 5G-114 |




SECTION 4 LOOKING STH.

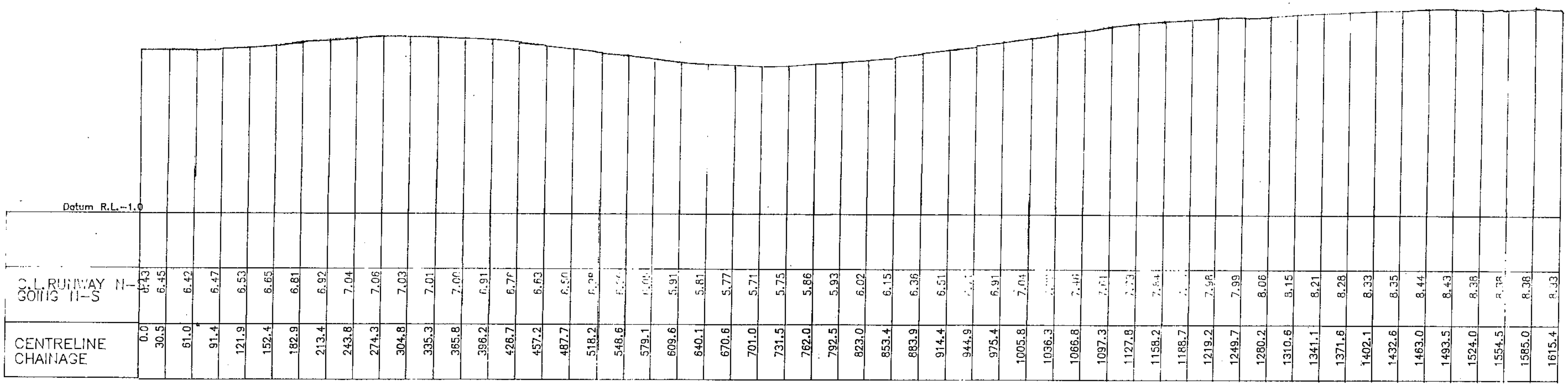
SOURCE : Shellharbour Council(1992)

**FIGURE 2.9.7**
**UPPER FLOODPLAIN OF MACQUARIE RIVULET**
**CROSS SECTIONS - SHEET 2 OF 3**




SECTION 3 LOOKING SW.

| SCALES | APPROVED | ORIGIN OF LEVELS | REFERENCE PLANS | PLAN AMENDED | WORKS AS EXECUTED | MUNICIPALITY OF SHELLHARBOUR | | SHEET NO. 3 OF 4 |
|---|---|---|---|---|---|---|---|---|
| AS SHOWN | DESIGN ENGINEER | P.M. 16702 | | | COMPLETED BY.........DATE.. | FLOOD STUDY MACQUARIE RIVULET | MUNICIPAL ENGINEER DATE JULY-92 | PLAN NO. |
| DATUM A.H.D. SURVEYED MS FIELD BOOK 9 LEVEL BOOK 121 | DESIGNED ........ DRAWN PK CHECKED ........ NOTED | S.S.M. B.M. | | | DRAWN BY..........REF....... | | FILE NO. | 5G-114 |
| | WORKS ENGINEER | R.L. 6.346 | | | NOTE ALTERATIONS SHOWN IN RED ON ORIGINAL PLAN | | | |



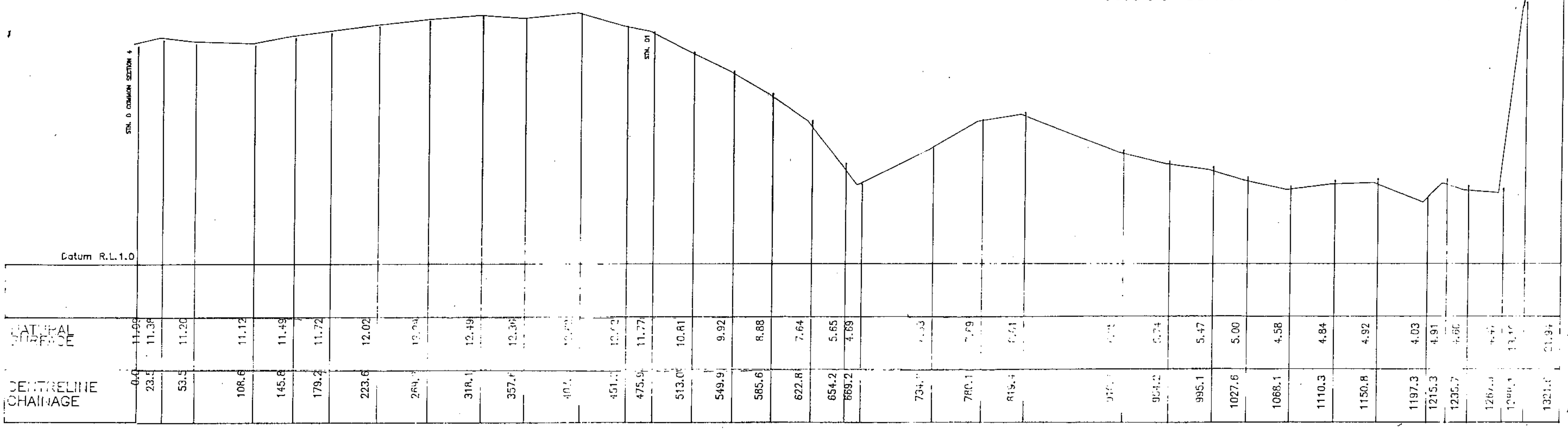

Scales Horizontal 1:2500
Vertical 1:100

## SECTION 6 LOOKING EAST

*N–S RUNWAY CENTRELINE*

SOURCE : Shellharbour Council(1992)

**FIGURE 2.9.8**
**UPPER FLOODPLAIN OF MACQUARIE RIVULET**
**CROSS SECTIONS - SHEET 3 OF 3**




Scales Horizontal 1:2000
Vertical 1:100

## SECTION 5 LOOKING WEST

| SCALES AS SHOWN | APPROVED ........ DESIGN ENGINEER | ORIGIN OF LEVELS | REFERENCE PLANS | PLAN AMENDED | WORKS AS EXECUTED | MUNICIPALITY OF SHELLHARBOUR | MUNICIPAL ENGINEER DATE | SHEET NO. 4 OF 4 |
|---|---|---|---|---|---|---|---|---|
| DATUM H.D. SURVEYED MS FIELD BOOK 9 LEVEL BOOK 121 DESIGNED ........ DRAWN PK CHECKED ........ | NOTED ........ WORKS ENGINEER | P.M. 16702 S.S.M. ........ B.M. ........ R.L. 6.346 | | | COMPLETED BY............DATE... DRAWN BY............REF....... NOTE ALTERATIONS SHOWN IN RED ON ORIGINAL PLAN | FLOOD STUDY MACQUARIE RIVULET | FILE NO. | PLAN NO. 5G-114 |

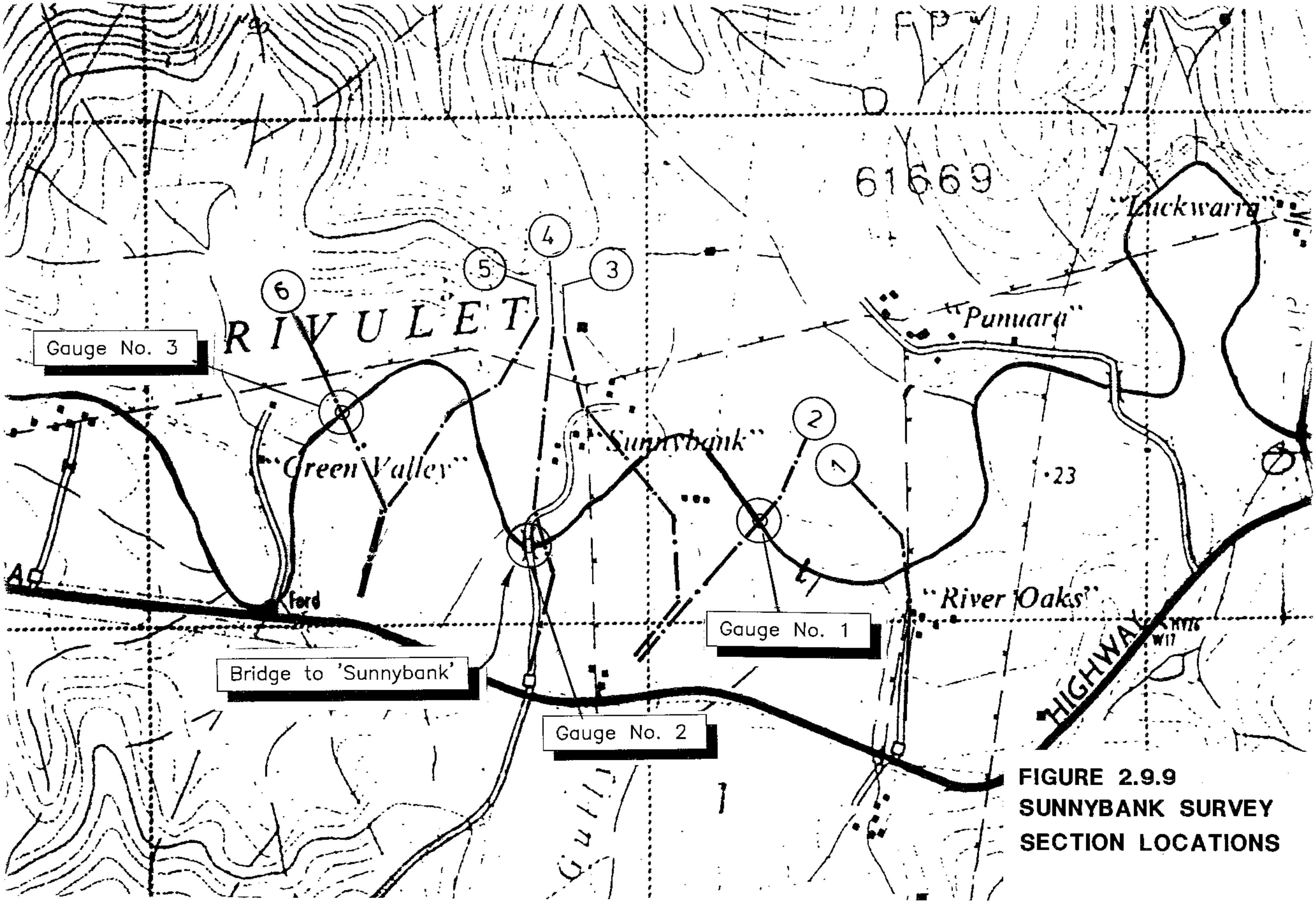
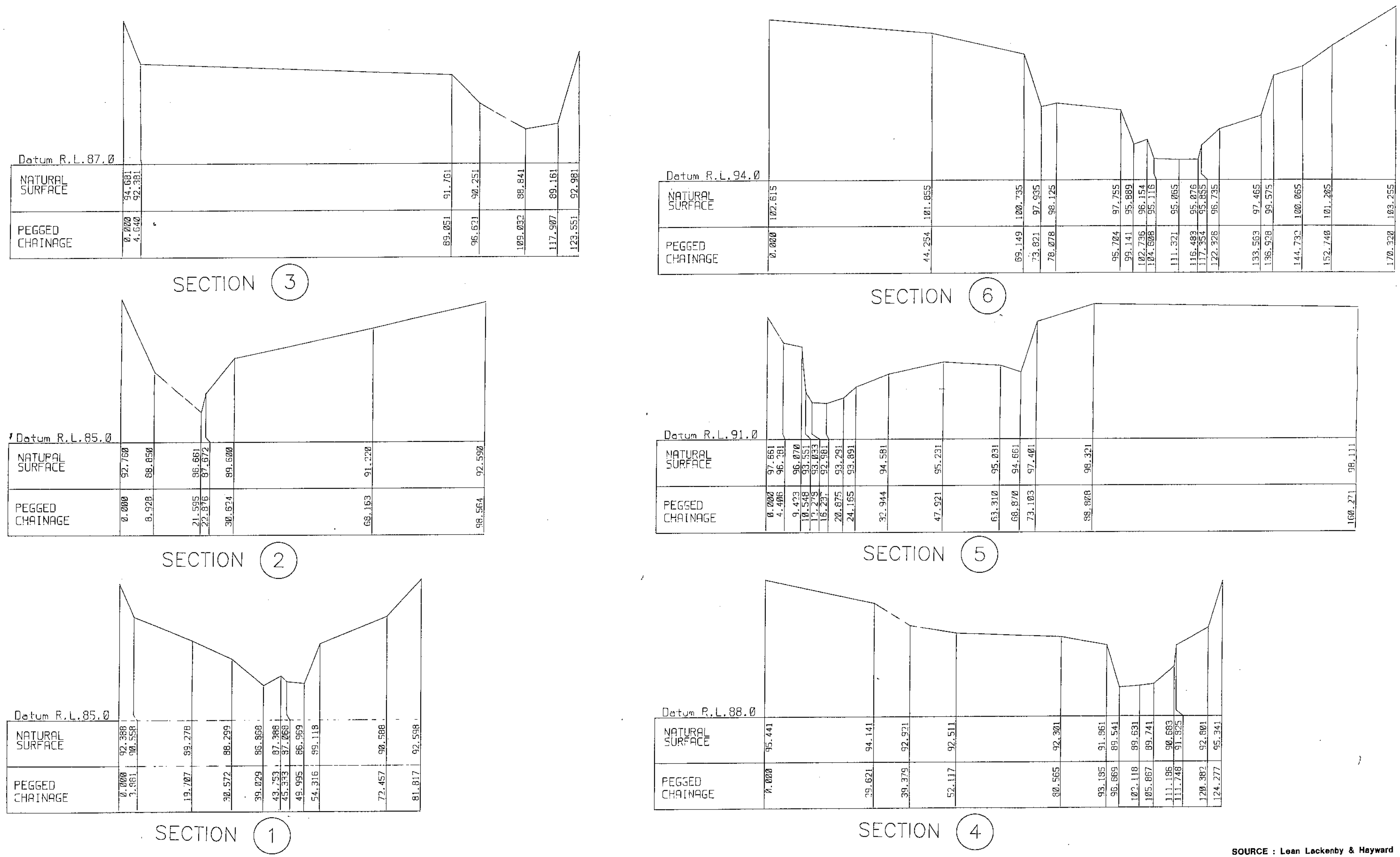



**FIGURE 2.9.9**
**SUNNYBANK SURVEY**
**SECTION LOCATIONS**




Scales Horizontal 1:500
Vertictal 1:100

SOURCE : Lean Lackenby & Hayward

**FIGURE 2.9.10**
**SUNNYBANK SURVEY CROSS SECTIONS**

## 2.10 GROUND PHOTOGRAPHY

Over the years that Subcommittee has been investigating Macquarie Rivulet, a range of photographs have taken to clarify or record features of the system.

Since the ultimate end benefit of this Compendium is likely to vary between users, all photographs of the catchment and streams collected to date by the Subcommittee have been included.

Photography relating to specific events is however separately reproduced in Section 3.3.

**MACQUARIE RIVULET RAIL BRIDGE**
**WOLLINGURRY CREEK IN FOREGROUND**
**LOOKING SOUTH-WEST (19/5/95)**

**LOWER FLOODPLAIN NORTH BANK**
**LOOKING SOUTH-EAST (16/5/95)**
**SHOWING RECENT EARTHWORKS**

**FIGURE 2.10.1**
**GROUND PHOTOGRAPHY**

LOOKING DOWNSTREAM (EAST) FROM
PRINCES HIGHWAY GAUGE SITE

PRINCES HIGHWAY ROAD BRIDGE
LOOKING SOUTH-EAST (16/5/95)

FIGURE 2.10.2
GROUND PHOTOGRAPHY


LOOKING DOWNSTREAM FROM GAUGE SITE NO. 1

FIGURE 2.10.3
GROUND PHOTOGRAPHY


LOOKING UPSTREAM FROM GAUGE SITE NO. 1

FIGURE 2.10.4
GROUND PHOTOGRAPHY


**PUMP LOCATION - BELIEVED TO BE GAUGE SITE NO. 1**


**LOOKING SOUTH TO GAUGE SITE NO. 1**

**FIGURE 2.10.5**
**GROUND PHOTOGRAPHY**


**LOOKING DOWNSTREAM TOWARDS GAUGE SITE NO. 1**

**FIGURE 2.10.6**
**GROUND PHOTOGRAPHY**

GAUGE SITE NO. 2 AT BRIDGE - 16 5 '93

GAUGE SITE No. 2 AT BRIDGE (LOOKING UPSTREAM) - 16 5 '93

FIGURE 2.10.7
GROUND PHOTOGRAPHY


LOOKING DOWNSTREAM TOWARDS BRIDGE


GAUGE ON ROAD SIDE, 20M FROM BRIDGE

FIGURE 2.10.8
GROUND PHOTOGRAPHY

**LOOKING UPSTREAM TOWARDS BRIDGE AND GAUGE SITE NO. 2 - 16 5 '93**

**LOOKING UPSTREAM TOWARDS BRIDGE AND GAUGE SITE NO. 2 - 16 5 '93**

**FIGURE 2.10.9**
**GROUND PHOTOGRAPHY**

GAUGE SITE NO.3
(EASTERN SIDE OF
CREEK)


LOOKING NORTH FROM
GAUGE SITE NO. 3

FIGURE 2.10.10
GROUND PHOTOGRAPHY


GAUGE SITE NO. 3 - WESTERN SIDE OF CREEK
- 16 5 '93


LOOKING EAST AT GAUGE SITE NO. 3
- 16 5 '93

FIGURE 2.10.11
GROUND PHOTOGRAPHY


LOOKING UPSTREAM FROM 70M DOWNSTREAM
OF GAUGE SITE No. 3 - 16 5 '93

LOOKING DOWNSTREAM FROM 70M DOWNSTREAM
OF GAUGE SITE No. 3 - 16 5 '93

FIGURE 2.10.12
GROUND PHOTOGRAPHY

LOOKING UPSTREAM FROM 30M DOWNSTREAM
OF GAUGE SITE No. 3 - 16 5 '93

LOOKING DOWNSTREAM FROM 30M DOWNSTREAM
OF GAUGE SITE No. 3 - 16 5 '93

FIGURE 2.10.13
GROUND PHOTOGRAPHY

LOOKING DOWNSTREAM AT GAUGE SITE NO. 3 - 16 5 '93

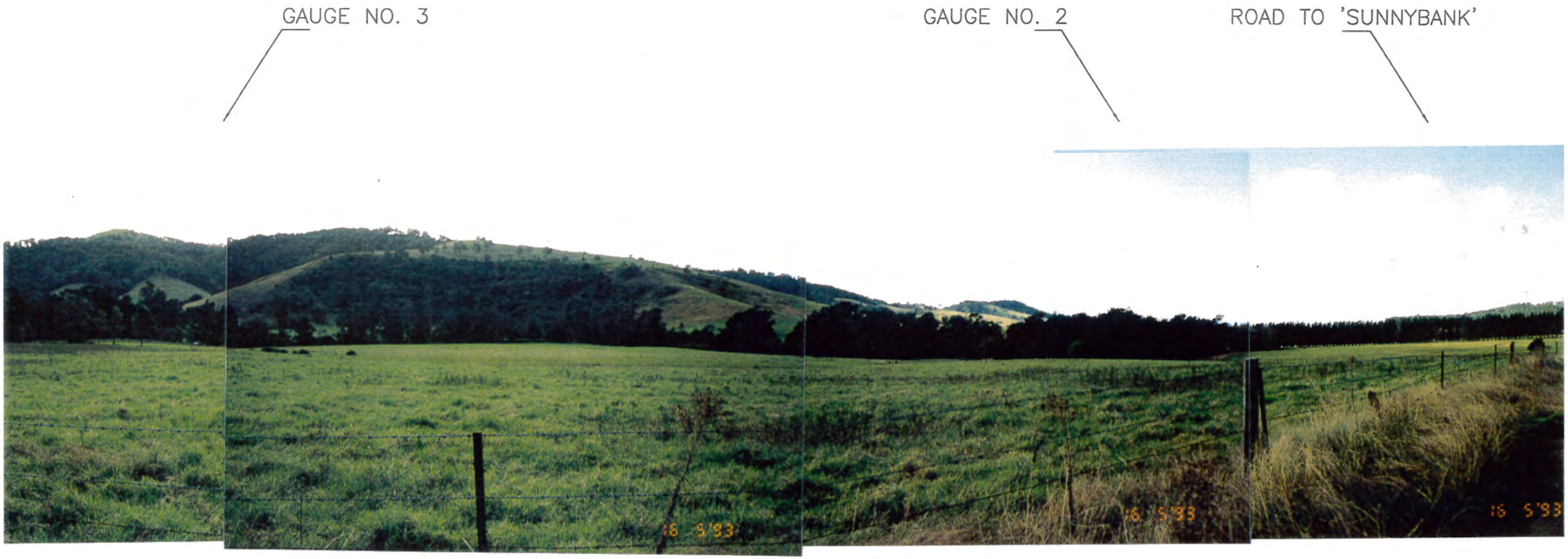
LOOKING DOWNSTREAM FROM 100M DOWNSTREAM OF GAUGE SITE No. 3 - 16 5 '93

FIGURE 2.10.14
GROUND PHOTOGRAPHY

LOOKING DOWNSTREAM TOWARDS GAUGE NO. 3
FROM ENTRANCE TO GREEN VALLEY - 16 5 '93

LOOKING UPSTREAM FROM ENTRANCE TO GREEN
VALLEY - 16 5 '93

**FIGURE 2.10.15**
**GROUND PHOTOGRAPHY**




OVERALL VIEW FROM ILLAWARRA HIGHWAY
TOWARDS MACQUARIE RIVULET AT SUNNYBANK

**FIGURE 2.10.16**
**GROUND PHOTOGRAPHY**

CALDERWOOD ROAD BRIDGE OVER
MACQUARIE RIVULET LOOKING UPSTREAM.

MACQUARIE RIVULET JUST DOWNSTREAM
OF CALDERWOOD ROAD BRIDGE LOOKING
DOWNSTREAM.

FIGURE 2.10.17
GROUND PHOTOGRAPHY

## 2.11 RAINFALL GAUGING

Continuously read gauges were installed by the Public Works Department at Clover Hill, Calderwood, Upper Calderwood, North Macquarie and Yellow Rock in the mid eighties.
The recording interval for these gauges is 5 minutes.

Rainfall gauge locations are as noted in Table 2.11.1. (refer also Figure 2.12.1)

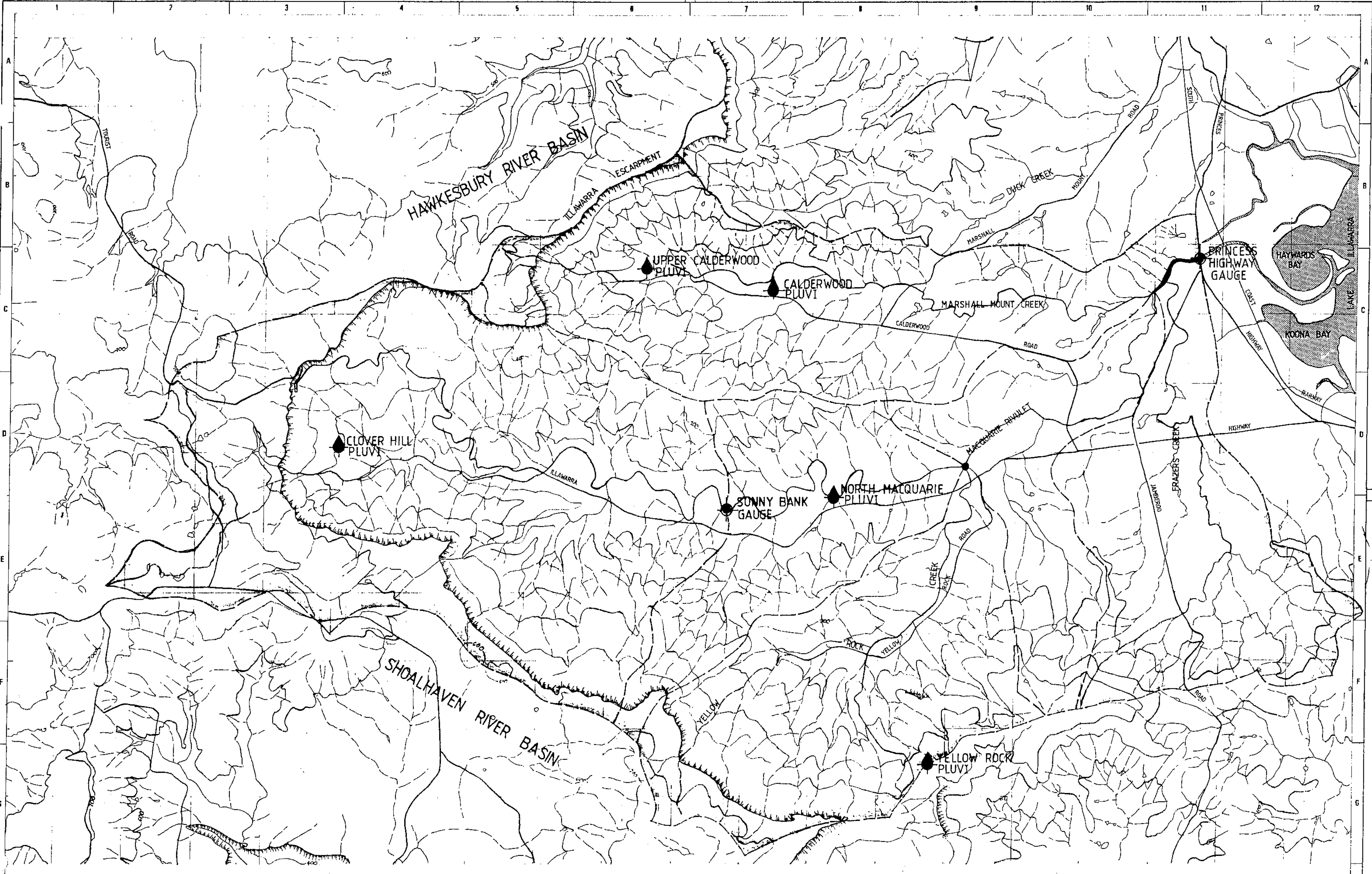
| Gauge Name | Number | Easting | Northing | Period of Operation |
|---|---|---|---|---|
| Calderwood Rd | 35 | 290410 | 6174300 | 6/82- |
| Upper Calderwood | 36 | 288600 | 6174935 | 7/85 - present |
| Nth Macquarie | 37 | 291280 | 6171330 | 6/85 - present |
| Clover Hill | 38 | 284090 | 6172270 | 8/1985 - present |
| Yellow Rock | 39 | 292780 | 6167430 | 1982 - present |
| Huntley | 31 | 290270 | 6178815 | |

**PUBLIC WORKS CONTINUOUSLY READ RAIN GAUGES**

**TABLE 2.11.1**

The Bureau of Meteorology has available daily and monthly rainfall records for stations within and adjacent to the Macquarie Rivulet catchment as listed in Table 2.11.2.

DO NOT SCALE | IF IN DOUBT ASK




| REV. | DATE | BY | DETAILS | CHK. | MF |
|---|---|---|---|---|---|
| Ø | — | — | INITIAL RELEASE | — | |

| DRAWING STATUS | | |
|---|---|---|
| DESIGN | EHR | —/—/85 |
| DRAWN | L S | —/3/85 |
| CHECKED | EHR | —/10/85 |
| APPROVED | | 15/5/95 |

REFERENCE MATERIAL: C.M.A. Topographical map Nº 9028-IV-N, Nº 9028-I-N.

SCALES: 1 : 25 000

DATUM: AHD

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PROJECT TITLE: MACQUARIE RIVULET REFERENCE CATCHMENT

Wollongong Coastal Basin 214-05-08

DRAWING TITLE: CATCHMENT PHYSIOGRAPHY

| File Reference No. | Drawing No. | REV |
|---|---|---|
| 83093-2 | 3001 | 0 |

**FIGURE 2.12.1**

A1

| Station | Number | Latitude | Longitude | Elevation (m AHD) | Record Availability |
|---|---|---|---|---|---|
| Albion Park Post Office | 068000 | 34 34 | 150 47 | 8.0 | 1892-present |
| Albion Park (Parkvale) | 068129 | 34 36 | 150 45 | * | 1962-1967 |
| Yallah (Ianwyn) | 068130 | 34 32 | 150 43 | 85.0 | 1962-1981 |
| Robertson Post Office | 068054 | 34 35 | 150 37 | * | 1890-present |
| Jamberoo (Druewalla) | 068209 | 34 39 | 150 44 | 105.0 | 1963-present |
| Jamberoo (Lorna) | 068032 | 34 39 | 150 47 | 100.0 | 1885-1963 |

* unknown

**BUREAU OF METEOROLOGY DAILY RAINFALL STATIONS**

**TABLE 2.11.2**

## 2.12 STREAM GAUGING

### 2.12.1 Generally

The former Department of Water Resources (now Department of Land and Water Conservation) has recorded flood stage in Macquarie Rivulet near Sunnybank, since August 1949. The Public Works Department has maintained both a continuous and maximum height recorder near the Princes Highway bridge since 1988.

### 2.12.2 Albion Park (SunnyBank) Gauge

In October 1961 the Water Resources `Sunnybank' Gauge was relocated to a site some 640m upstream of the original gauge and in March 1978 again relocated a further 500m upstream of the interim site. During the time these various gauges were in service, a number of rating curves were developed to reflect changes in stream geometry at each site.

No rating data above a discharge of about 10% of the 100 year ARI flow have been confirmed by measurement at any of the existing gauge sites.

| Site | Flowrate (m3/s) | Gauge Height (m) | Date |
|---|---|---|---|
| 3 | 14 | 1.00 | 7/11/84 |
| 2 | 64 | 1.79 | 21/6/75* |
| 2 | 7 | 1.05 | 19/10/76 |
| 1 | 11 | 1.1 | 22/10/59 |

*1975 estimate only based on surface floats.

**TABLE 2.12.1**

**SUMMARY OF ALBION PARK GAUGE SITE CALIBRATION DETAILS (HIGHEST GAUGINGS FOR EACH SITE BASED UPON CURRENT METER READINGS)**

The NSW Department of Water Resources extrapolated the rating curve to higher values based upon the creek cross section at the gauge and downstream bed grade. It is likely, however, that the section has since altered as a result of scour and the DWR rating curve should be considered approximate only (refer Figures 2.12.2 and 2.12.3). The most recent rating curve for the Sunny Bank site is reproduced in Figure 2.12.4. Photographs of the stream in the vicinity of the various gauges are reproduced in Figures 2.10.3 to 2.10.16.

### 2.12.3 Princes Highway Gauge

NSW Public Works maintains both a Maximum Height Recorder and a continuous flood stage recorder on Macquarie Rivulet at the Princes Highway. The gauges are located on the south bank of Macquarie Rivulet, a short distance downstream of the Princes Highway Road Bridge

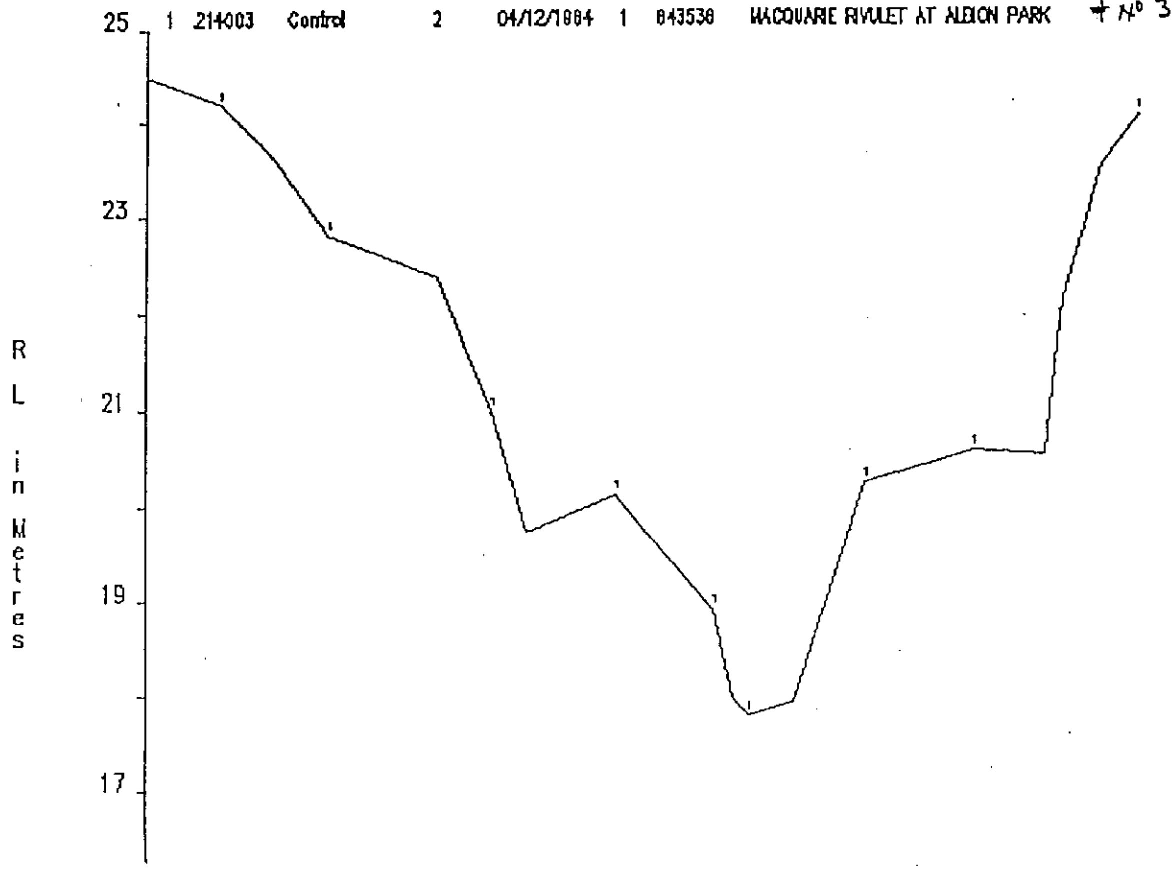
No formal rating curve has been developed for this gauge. Forbes Rigby have however developed an approximate rating curve based upon a two dimensional hydrodynamic model of Macquarie Rivulet (refer covering report). Photographs of the stream in the vicinity of these gauges are reproduced in figure 2.10.2.

# NSW Department of Water Resources

HYSECPL V18 Output 08/03/1992

Cross Section Plots.

| | Station | Type | Section | Date | Run | SectNo | Name | |
|---|---|---|---|---|---|---|---|---|
| 1 | 214003 | Control | 2 | 04/12/1984 | 1 | 843538 | MACQUARIE RIVULET AT ALBION PARK | + No 3 |




| Chainage | R.L. | Comment |
|---|---|---|
| ** 214003 | MACQUARIE RIVULET AT ALBION PARK 913513 XS 1 04/12/1984 Run 1 | |
| 0.000 | 24.491 | ASS RL(24.09) BMGS 201 BOLT IN CONC.NR RECORDER. |
| 8.000 | 24.189 | |
| 14.000 | 23.645 | RIGHT BANK BASE OF TOWERS RL 23.50 |
| 20.000 | 22.818 | |
| 32.000 | 22.378 | |
| 38.000 | 20.983 | |
| 42.000 | 19.728 | |
| 52.000 | 20.120 | |
| 56.000 | 19.652 | |
| 63.000 | 18.917 | |
| 65.000 | 17.978 | |
| 67.000 | 17.778 | |
| 72.000 | 17.928 | |
| 80.000 | 20.238 | |
| 90.000 | 20.510 | |
| 92.000 | 20.573 | |
| 100.000 | 20.528 | |
| 102.000 | 22.155 | |
| 106.000 | 23.538 | BASE OF TOWERS 23.538 LEFT BANK |
| 110.000 | 24.075 | |

**FIGURE 2.12.2**

**MACQUARIE RIVULET CREEK CROSS SECTION AT SUNNYBANK GAUGE**

**(SURVEYED 1984 BY DWR)**

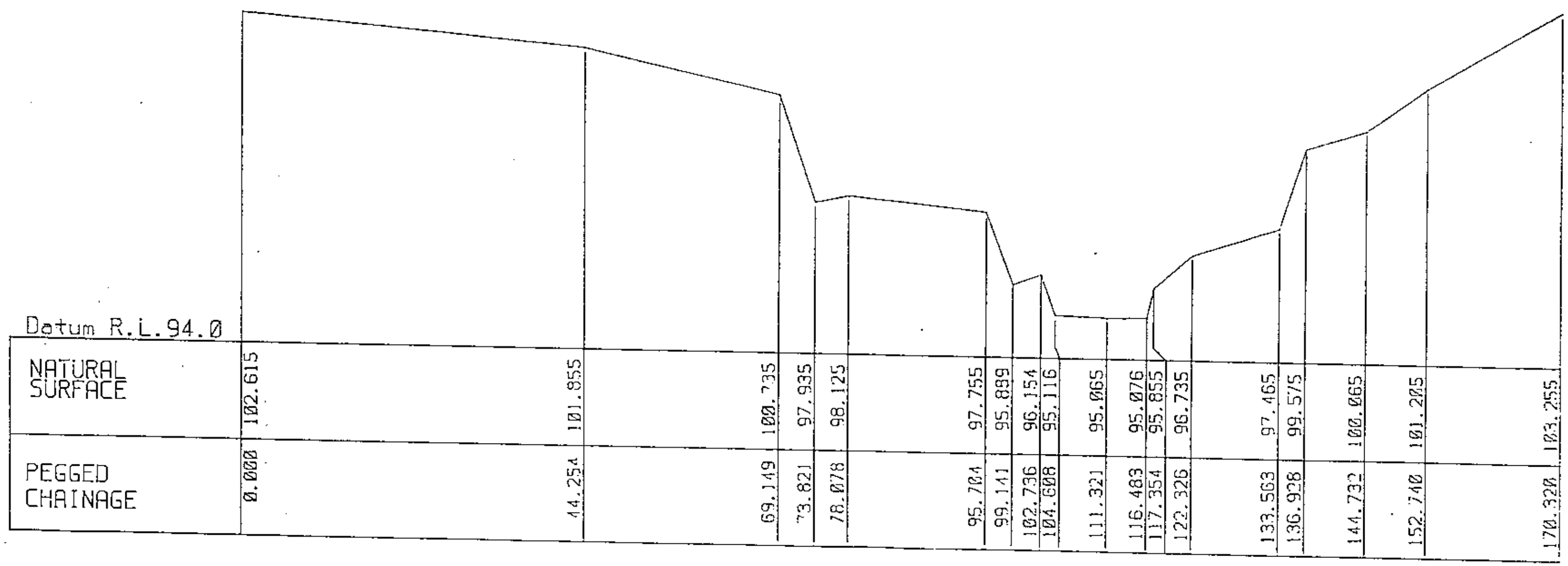



**FIGURE 2.12.3**

**MACQUARIE RIVULET CREEK CROSS SECTION AT SUNNYBANK GAUGE**

**(SURVEYED 1994 BY LEAN LACKENBY & HAYWOOD)**

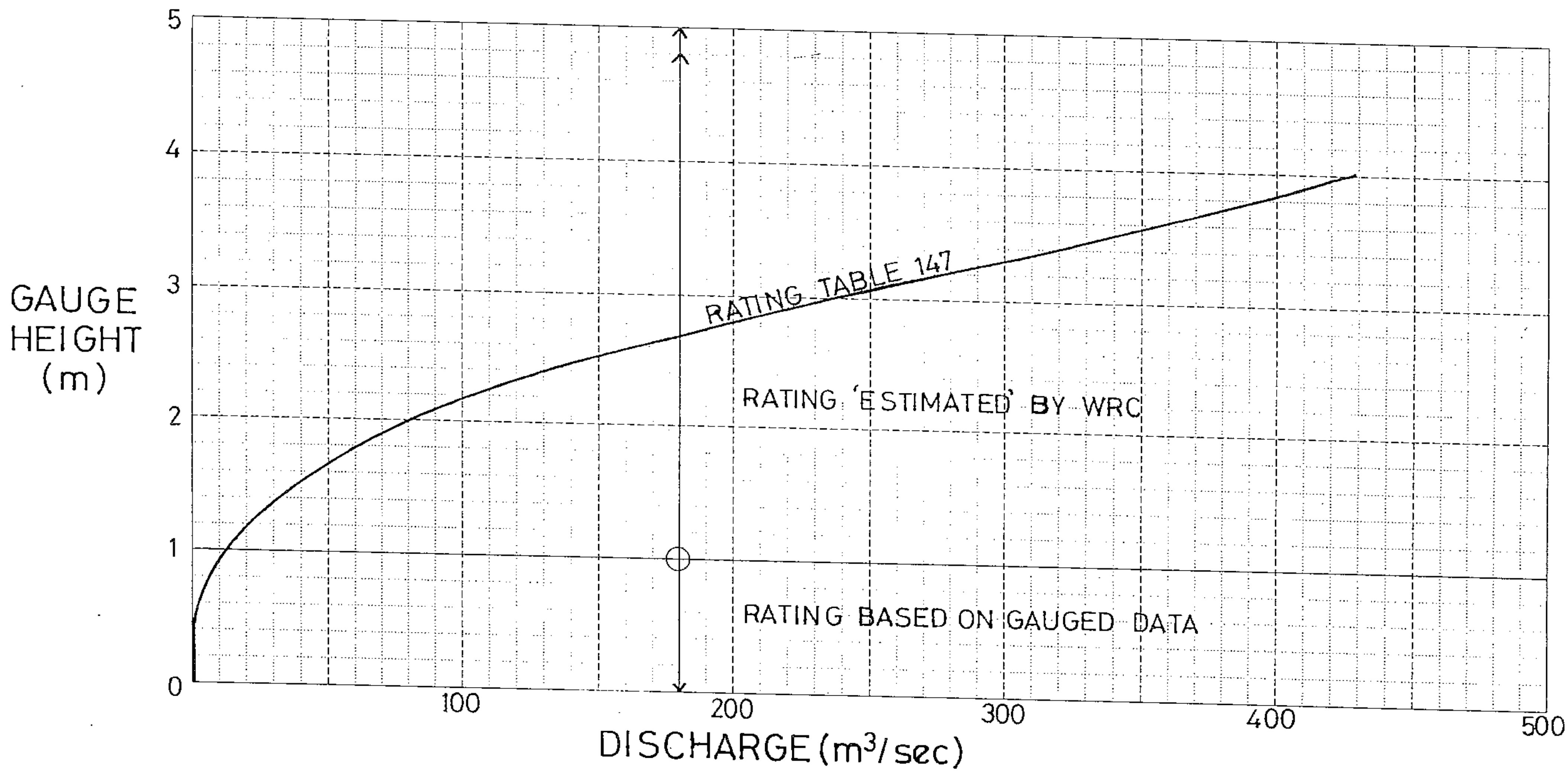



**FIGURE 2.12.4**

**SUNNYBANK GAUGE RATING CURVE DEVELOPED BY WRC**

## 2.13 LAKE ILLAWARRA GAUGING

NSW Public Works operates two continuous water level recorders in Lake Illawarra.

The gauge at Koonawarra has operated since March 1994. The Lake Illawarra entrance gauge has operated since July 1991.

A now discontinued gauge was operated at Cudgeree bay between 1988 and 1992

Both operational gauges record water levels at 15 minute intervals and are downloaded daily. The gauge stations have recently been fitted with water quality recording equipment.

Historic lake level data has been recently reviewed and estimates of Lake level of given AEP developed in a report by Lawson & Treloar (1993). These estimates are reproduced in Table 2.13.1 below.

| Storm Probability (%) | Storm Duration (hrs) | ENTRANCE CONFIGURATION 1977 | Proposed |
|---|---|---|---|
| 1 | 36 | 2.17 | 2.07 |
| 2 | 36 | 1.93 | 1.85 |
| 5 | 48 | 1.67 | 1.59 |
| 10 | 48 | 1.45 | 1.38 |
| 20 | 48 | 1.29 | 1.22 |
| 50 | 48 | 1.00 | 0.95 |
| 100 | 48 | 0.76 | 0.75 |

*Source : Lawson and Treloar, 1993*

**PEAK LAKE LEVEL m (AHD)**

**TABLE 2.13.1**

If entrance improvement works to Lake Illawarra ultimately proceed as presently proposed, Lake levels will marginally reduce for a given AEP as indicated in the 'proposed' column.

# 3. EVENT DATA

## 3.1 HISTORIC FLOODING

### 3.1.1 Event of June 1991 (Condensed Extract from report PWD (1991))

***Introduction***

Over the period 6th to 14th June, a low pressure system moving south from Queensland, and a high pressure system fairly stationary in the Tasman Sea directed humid easterly air onto the South Coast of NSW, causing heaving rainfall over a 6 day period. This heavy rainfall caused minor to moderate flooding throughout the Wollongong area, particularly to the Lake Illawarra/Macquarie Rivulet catchments.

In line with the Department's responsibilities to collect flood data, the South Coast Regional Office (SCRO) proceeded to carry out flood monitoring activities on the 11th and 12th June 1991, and has subsequently collected recorded flood data from its rainfall and water level recorder network throughout the Wollongong Area over the period of the storm.

***Meteorology***

The following reports, issued by the Bureau of Meteorology (BOM) describe the predominant weather conditions occurring during this period :

6.6.91 : A low is expected to form off the Queensland coast overnight and southerly winds will strengthen on the North Coast. The cloud already gathered in the area will release showers and rain to the Coast and adjacent ranges, with heavy falls in the northeast corner. A high pressure is located off the South Coast and will move into the Southern Tasman Sea and stay there.

7.6.91: A low pressure system off the southern Queensland coast is slowly moving south. A high pressure system in the South Tasman is moving slowly east. These systems are directing easterly winds over the NSW coast bringing scattered showers. An approaching cold front over South Australia is assisting in producing rain over parts of inland NSW. The low pressure system is expected to move south-west over NSW during the weekend and this may generate significant rain for the State until Monday.

10.6.91: A low pressure system east of Brisbane extends down to Adelaide. A strong high pressure system is located to the south of Tasmania, and is barely moving These systems are directing easterly winds across the NSW coast bringing high humidity and areas of heavy rain about the coast and adjacent mountain ranges. There is an upper low moving slowly over western NSW and this is contributing to the unsettled weather. A moist and unstable easterly low is being directed onto the NSW coast and heavy shower activity has resulted over the last 24 hours.

| NO. | STATION | THU 6 | FRI 7 | SAT 8 | SUN 9 | MON 10 | TUE 11 | WED 12 | THU 13 | TOTAL (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BULLI (a) | 0.5 | 76.5 | 54.5 | 2.0 | - | - | - | - | 133.5 (d) |
| 2 | RIXONS PASS | 0.0 | 101.0 | 50.0 | 32.0 | 76.0 | 310.5 | 172.0 | 0.5 | 742.0 |
| 3 | RUSSELL VALE | 0.0 | 91.0 | 38.5 | 25.5 | 57.0 | 199.0 | 154.0 | 0.0 | 565.0 |
| 4 | CORRIMAL | 0.0 | 107.0 | 45.0 | 31.0 | 66.5 | 263.5 | 141.5 | 0.0 | 654.5 |
| 5 | MT NEBO | 1.5 | 98.5 | 62.5 | 32.0 | 55.5 | 245.0 | 89.0 | 0.0 | 584.0 |
| 6 | MT KEMBLA | 4.0 | 103.5 | 87.0 | 33.5 | 66.5 | 269.5 | 122.0 | 0.5 | 686.5 |
| 7 | PORT KEMBLA | 7.5 | 56.5 | 57.5 | 26.5 | 68.5 | 156.0 | 145.5 | 0.0 | 518.0 |
| 8 | DOMBARTON | 2.0 | 100.5 | 90.5 | 34.5 | 98.0 | 277.0 | 97.0 | 0.5 | 700.0 |
| 9 | WONGAWILLI | 3.0 | 83.0 | 133.5 | 40.5 | 96.0 | 270.5 | 94.0 | 0.5 | 721.0 |
| 10 | CLEVELAND RD | 10.5 | 90.5 | 149.5 | 20.5 | 66.5 | 207.5 | 93.5 | 0.0 | 638.5 |
| 11 | HUNTLEY | 7.5 | 102.0 | 140.0 | 35.0 | 116.0 | 326.0 | 97.0 | 0.5 | 824.0 |
| 12 | UPPER CALDERWOOD | 10.5 | 88.5 | 159.0 | 67.5 | 127.0 | 338.0 | 137.5 | 0.0 | 928.0 |
| 13 | NORTH MACQUARIE | 7.5 | 90.5 | 155.5 | 78.5 | 114.5 | 334.0 | 90.5 | 0.0 | 871.0 |
| 14 | CLOVER HILL | 12.5 | 96.0 | 147.0 | 84.5 | 169.5 | 367.0 | 124.0 | 0.0. | 1000.5 |
| 15 | YELLOW ROCK | 6.0 | 98.0 | 93.0 | 84.5 | 113.5 | 310.5 | 105.5 | 0.0 | 811.0 |
| 16 | ALBION PK AERO (b) | - | - | - | - | - | - | - | - | - |
| 17 | LITTLE LAKE (c) | 1.5 | 38.5 | 46.0 | 75.0 | 87.0 | 70.5 | - | - | 318.5 (d) |
| | | | | | | | | | | |

Notes : Rainfall totals are for 24 hour period to 0900 hours proceeding date shown

(a) Logger Malfunction on and after 9th June
(b) Logger Malfunction throughout storm period
(c) Logger Malfunction on and after 12th June
(d) Incomplete Totals

**TABLE 3.1.1a**

**DAILY RAINFALL RECORD FOR PWD PLUVIOGRAPHS**

### *Flood Observations*

During the storm event SCRO staff were deployed to undertake flood monitoring procedures. The following observations were recorded :

*10th June 1991*

- Tides :

| | | | | | |
|---|---|---|---|---|---|
| | High | 0554 | 1.4 m | 1816 | 1.9 m |
| | Low | 0000 | 0.5 M | 1141 | 0.5 M |

- Major flooding occurring around Lake Illawarra. The Lake Illawarra Village, Oasis and Oaklands Caravan Parks in danger of being inundated by rising lake waters. Residents awaiting evacuation of Lake Illawarra Police and Citizens Club.

- Princes Highway 4 km south of Kiama blocked by landslide. Other Illawarra roads cut include Jamberoo Road between Kiama and Jamberoo, Dunmore Railway crossing at Bombo, Tongarra Road between Shellharbour and Oak Flats, Montague Street at Fairy Meadow, Redall Parade east and west of Windage Bridge, Macquarie Pass, Illawarra Highway between Albion Park and Princes Highway, Omega Rail Crossing, Northcliffe Drive at Illawarra Yacht Club, and Shellharbour Road at Windang and Blackbutt

*11th June 1991*

- Tides :

| | | | | | |
|---|---|---|---|---|---|
| | High | 0652 | 1.4 m | 1906 | 2.0 m |
| | Low | 0057 | 0.4 m | 1231 | 0.4 M |

- Berkeley Boat Harbour staff gauge recorded 1.80 m AHD at 1200 hours. Fish Co-operative surrounded by floodwaters.

- Carpark to Merinda inundated by approximately 0.45 metres. Eastern pontoon at Illawarra Yacht Club dislodged from mooring (floated off). Refer Photos 2 & 3. Northcliffe Drive just east of Club cut by floodwaters. (Refer Photo 4).

- Windang Road inundated from 10th green at Port Kembla Golf Course to Windang Bowling Club near bridge. Depth of water over road up to 0.5 metres. Single lane of traffic only in each direction.

- Residents of Lake Illawarra Village, Oaklands and Oasis Caravan Parks evacuated by 0400 hours to Lake Illawarra Police and Citizens Club.

- Staff gauge at Judbooley Park, Windang at 1300 hours registered 1.54 m AHD. Resident of Oakland Av stated flood level still 0.15 m below 1984 HFL.

- Entrance to lake approximately 100 m wide. Floodwaters mainly flowing to south of Windang Island at velocity of approximately 2 to 2.5 m/s. Staff gauge at entrance registered 0.95 m AHD at 1330 hours.

***Recorded Flood Levels***

After the storm, the following recorded flood level information was collected :

a) Stage Hydrographs
b) MHI data
c) Surveyed flood levels

a) Stage Hydrographs

The Department as of June 1991 operatives five (5) continuous stage recorders (CSR) in the Wollongong Area. Table 3.1.1b provides a summary of the data recorded during the subject storm.

| STATION | PEAK LEVEL (m AHD) | TIME OF PEAK (Hour) | (Date) |
|---|---|---|---|
| Macquarie Rivulet at Princes Highway | 3.65 | 1045 | 11.6.91 |
| Mullet Creek at Princes Highway | 3.32* [see note (ii)] | 0500 | 12.6.91 |
| Fairy Creek at Princes Highway | 3.32 | 0430 | 12.6.91 |
| Cabbage Tree Creek at Princes Highway | 6.51 | 2145 | 10.6.91 |
| Cudgeree Bay on Lake Illawarra | - | - | - |

**TABLE 3.1.1b**
**CSR INFORMATION SUMMARY**

Examination of the hydrographs show :

i) two separate periods of high water levels, late on June 10th and early June 12th. In the southern suburbs, the period late on the 10th caused the highest peak, whilst in the northern suburbs, the latter period resulted in highest peak water levels.

ii) Mullet Creek was not operational (flat battery) from 0300 hours 7th June to 2100 hours on 11th June, thereby missing the heavy rainfall on the 10th June.

| CREEK | LOCATION | RL (m AHD) |
|---|---|---|
| Duck Creek | Marshall Mt Rd - South Bridge - U/S | 10.970 |
| Macquarie Rivulet | Princes Highway - D/S | 3.600 |
| | Foot of Macquarie Pass - D/S | 66.460 |
| | Illawarra Highway at Tongarra Creek - D/S | 53.630 |
| | Illawarra Highway at Yellow Rock Creek - D/S | 17.610 |
| | "Cricklewood" at Marshall Mt Creek | 43.030 |
| | "Riversdale" at Marshall Mt Creek | 8.470 |
| Bensons Creek | Lake Entrance Road - U/S | 5.920 |

**TABLE 3.1.1c**

**MHI INFORMATION SUMMARY**

Note, the following statistics of the MHI network during the June 1991 flood :

| **Result** | **No.** | **Percentage** |
|---|---|---|
| Recorded | 80 | 23% |
| Did Not Reach | 70 | 20% |
| Underwater | 68 | 20% |
| Damaged/Inaccessible | 128 | 37% |
| TOTAL | 346 | 100% |

c) Surveyed Flood Levels

After the flood photographs of debris marks throughout the Macquarie Rivulet, Duck Creek, Mullet Creek and Lake Illawarra catchments were taken at various road crossings and accessible locations.

The debris marks were surveyed to give comprehensive flood level information for these catchments. Tables 3.1.1a and c detail the additional surveyed flood levels.

| NO. | LOCATION | RL (m AHD) |
|---|---|---|
| 1 | CSR Peak Reading - R/B D/S Princes Highway Bridge | 3.610 |
| 2 | Debris line - R/B U/S Princes Highway Bridge | 3.645 |
| 3 | Debris line - R/B U/S Illawarra Highway floodway | 3.560 |
| 4 | Debris line - R/B U/S Illawarra Highway floodway | 3.560 |
| 5 | Debris in tree - R/B U/S near Illawarra Highway | 8.320 |
| 6 | Debris in fence - R/B End of Hamilton Road | 9.870 |
| 7 | Debris in fence - R/B U/S Calderwood Road Bridge | 11.410 |
| 8 | Debris in fence - R/B western fence on farm U/S Calderwood Road | 11.490 |
| 9 | Debris line - L/B D/S Illawarra Highway at Yellow Rock Creek Bridge | 17.280 |
| 10 | Debris line - L/B U/S Illawarra Highway at Yellow Rock Creek Bridge | 17.580 |
| 11 | Debris in tree - D/S R/B Nth Macquarie Road floodway | 26.580 |
| 12 | Debris in fence - L/B D/S Tongarra Road cul on Central Frazers Creek | 6.390 |
| 13 | Debris in fence - L/B U/S Tongarra Road cul on Central Frazers Creek | 6.570 |
| 14 | Debris line - L/B D/S Tongarra Road Bridge on East Frazers Creek | 7.865 |
| 15 | Debris line - L/B U/S Tongarra Road Bridge on East Frazers Creek | 8.715 |
| 16 | Debris line - L/B U/S Illawarra Highway cul near Taylors Road | 6.075 |
| 17 | Debris line - L/B 100 m U/S Illawarra Highway cul near Taylors Road | 6.220 |
| 18 | Debris in tree - L/B D/S Cascading Basin on West Frazers Creek | 9.750 |
| 19 | Debris line - R/B U/S Cascading Basin on West Frazers Creek | 10.100 |
| 20 | Debris in tree - R/B 150 m D/S Terry Street cul on West Frazers Creek | 10.860 |
| 21 | Debris line - L/B D/S Terry St cul on West Frazers Creek | 12.970 |
| 22 | Debris line - L/B U/S Terry St cul on West Frazers Creek | 13.800 |
| 23 | Debris line - R/B D/S Simpson Pde cul on West Frazers Creek | 22.550 |
| 24 | Debris in fence - R/B U/S Simpson Pde on West Frazers Creek | 24.210 |
| 25 | Debris in tree - L/B at end of Frazers Cres on Central Frazers Creek | 8.620 |
| 26 | Debris in tree - L/B 50 m D/S of causeway to Polo Club on Central Frazers Creek | 13.830 |
| 27 | Debris in fence - L/B U/S footbridge at end of Hughes Drive on Central Frazers Ck | 14.090 |
| 28 | Debris line - L/B D/S Retarding Basin at end of Smith Ave | 16.300 |
| 29 | Debris line - L/B D/S Terry St cul on Central Frazers Creek | 24.600 |
| 30 | Debris in tree - L/B northern end of Polo Field on East Frazers Creek | 12.845 |
| 31 | Debris in tree - L/B in Polo Field on East Frazer Creek | 13.790 |
| 32 | Debris in tree - L/B D/S footpath at end of Hughes Dr on East Frazers Creek | 16.480 |
| 33 | Debris line - R/B D/S Marshall Mt Road culv | 18.150 |
| 34 | Debris in fence - R/B D/S Marshall Mt Road | 18.490 |
| 35 | Debris line - R/B U/S Marshall Mt Road culv | 19.010 |
| 36 | MHI Recording - L/B D/S Illawarra Highway at foot of Macquarie Pass | 66.460 |
| 37 | MHI Recording - R/B D/S Illawarra Highway at Tongarra Creek | 53.630 |
| 38 | MHI Recording - R/B at "Cricklewood" on Marshall Mt Creek | 43.030 |
| 39 | MHI Recording - R/B at "Riversdale" on Marshall Mt Creek | 8.470 |

**TABLE 3.1.1d**

**SURVEYED FLOOD LEVELS**
**MACQUARIE RIVULET**

| NO | LOCATION | RL (m AHD) |
|---|---|---|
| 1 | Debris line - Dixs Wharf, Lake Heights | 1.750 |
| 2 | Debris line - Merinda Wharf/Illawarra Yacht Club, Warrawong | 1.810 |
| 3 | Debris line - Purry Burry Point, Primbee | 1.525 |
| 4 | Water mark on toilet block - Oasis Caravan Park, Windang | 1.790 |
| 5 | Water mark on brick wall - cnr Boundary St & Windang Rd, Windang | 1.785 |
| 6 | Water mark on fence - Judbooley Park, Windang | 1.740 |
| 7 | Debris line - L/B D/S Windang Bridge - 100 m east of jetty | 1.395 |
| 8 | Debris line - L/B D/S Windang Bridge - 250 m east of jetty | 1.145 |
| 9 | Entrance staff gauge reading - R/B | 0.950 |
| 10 | Debris in tree - R/B U/S Windang Bridge - near Pedestrian Bridge to island | 1.500 |
| 11 | Debris in tree - R/B U/S Windang Bridge - south of Pedestrian Bridge on island | 1.705 |
| 12 | Debris in fence - Police Boys Club, Lake Entrance | 1.760 |
| 13 | Debris line - Whyjuck Bay opp No. 241 Reddall Parade, Mt Warrigal | 1.805 |
| 14 | Debris line - Burroo Point near Madigan Blvde, Mt Warrigal | 1.470 |
| 15 | Debris in fence - Central Park, Oak Flats | 1.945 |
| 16 | Debris line - Tallawarra PS inlet channel | 1.950 |
| 17 | Debris line - Koonawarra Bay opp Lakeside Dr | 1.820 |
| 18 | Debris line - Kanahooka Point | 1.840 |
| 19 | Debris line - Berkeley Boat Harbour | 1.800 |

**TABLE 3.1.1e**

**SURVEYED FLOOD LEVELS**
**LAKE ILLAWARRA**

### 3.1.2 Event of April 1988

| | | | | | |
|---|---|---|---|---|---|
| a) | Rainfall at Shellharbour STP | April 28th | 81.0 mm | May 1st | 37.0mm |
| | | April 29th | 66.2 mm | May 2nd | 25.0mm |
| | | April 30th | 145.0mm | | |

Some of the waves were more than 20 feet (6 m).

April's monthly average was exceeded in one 24 hour period when 160 mm of rain fell on Friday the 29th. In 24 hours Mt Keira recorded 137 mm while Wollongong received 122 mm which were the highest rainfalls in NSW.

Prince's Highway at Dunmore under water for several days. Reddall Pde (near Police Boys Club), Lake Illawarra South closed by floodwaters.

Warilla area flooded but not extensively.

Despite the massive rainfall, the municipality (Shellharbour) got off lightly compared to other areas.

*Source : Little Lake Compendium of Data*

b) Coastal Route closed indefinitely
Floods leave region with huge clean up
Dapto auto electrician Rino Olivia relived the nightmare of the 1984 flood as he watched an area of water again rise near his Burringbar Street business
Father feared tragic slide. Destruction rains down on Coledale. Filled Dam not cause.

*Source : Illawarra Mercury*

### 3.1.3 Event of August 1987

Torrential rains caused flooding in Wollongong's Northern Suburbs. SES reported most flooding in from Wollongong to Helensburgh
Mudslide blocked Lawrence Hargrave Drive at Coal Cliff
Reports of flooding in southern Illawarra. Roads cut in Gerringong and Gerroa

*Source - Illawarra Mercury 19/8/87*

### 3.1.4 Event of August 1986

| | | | | |
|---|---|---|---|---|
| Rainfall at Port Kembla | August 5th | 8.0 mm | August 7th | 31.0 mm |
| | August 6th | 102.5 mm | August 8th | 13.0 mm |

"Despite the heavy rain storms last week, the Shellharbour Municipality escaped any major flooding problems".

"The Shellharbour SES received about 17 calls which wee mainly for help to fix roofs and lop trees."

Over 253 mm of rain was recorded from 8:30 am Tuesday to 8:30 am Friday in areas of Wollongong.

Illawarra Highway at Albion Park Rail was closed from Tuesday to Thursday at 2:00 pm, being up to half a metre under water.

The breakwater at Port Kembla had up to 4 metre high waves thrashing against it from Tuesday to Saturday.

Warilla NRMA office received 150 calls from Monday through Friday.

"At about 11:30 am on Friday, the tide was extremely high and waves crashed over annexes on the beachfront at the Surfrider Caravan Park."

### 3.1.5 Event of February 1984

Evacuations from caravan parks on Lake Illawarra. 200 mm of rain reported in 12 hours at some locations over a 12 km stretch of the south coast

Source - Little Lake Flood Study Compendium of Data

### 3.1.6 Event of March 1983

5 hours of torrential rain on 22 March 1983 following three days of continuous rain.
Flooding at Fairy Meadow

Flooding of many houses in northern and southern suburbs. In Shellharbour reports of flooded houses.

Source - Little Lake Flood Study Compendium of Data

### 3.1.7 Event of October 1983

Constant rain throughout night of 13th and morning of 14th October 1983 caused flooding in southern Wollongong suburbs. Albion Park township flooded. Airport under 0.5 m water. Roads into Albion Park were cut off.

Source - Illawarra Mercury 15/10/83

### 3.1.8 Event of April 1978

Moderate flooding in some suburbs. Mr Trevor Batson of Hillside Drive had flood waters in all the rooms of his new home.

Source - Public Works Brief for Macquarie Rivulet Flood Plain Management Study.

### 3.1.9 Event of March 1975

Heavy thunderstorms occurred over the Illawarra and Sydney Metropolitan areas between Sunday 9 March and Tuesday 11 March 1975. For the 24 hours ending 9am, 11 March 1975, rainfall depths of up to 300 mm were recorded in the eastern portion of the Macquarie Rivulet catchment.

(Source - Bureau of Meteorology, 1976)

### 3.1.10 Other Events

(Source :Public Works Brief for Macquarie Rivulet Flood Plain Management Study)

**Event of May 1969**

Mrs J. McGregor of Station Street had flood waters to the porch of her house. It was blamed on the inadequacy of the three storm water pipes under Station Street.

**Event of December 1960**

Terry Street was closed by flood waters up to 4 feet deep and stretching for 200 yards.

**Event of October 1959**

Many homes in Station Street had floor coverings ruined by flood waters.

**Event of February 1959**

Flood waters were reported to be 2 feet deep on the bitumen approach to Macquarie Rivulet bridge.

**Event of March 1959**

Terry Street was completely submerged by 3 - 4' of water between Albion Park and Meadow View Farm.

**Event of May 1950**

The highway at Albion Park was closed for a distance of half a mile by flood waters which were up to 6 feet deep. The flood waters which lapped into the Commercial Hotel and newspaper shop and there was 18 inches of water across the intersection of Flinders and Terry Streets.

**Event of June 1949**

Flood waters reached the corner of Terry and Flinders Streets and the posts along the road north of Albion Park were not visible.

**Event of May 1941**

Flood waters were 6 inches high in O'Gorman and Sons Butchery.

**Resident Interviews**

*Mr King*

Local resident, Mr King recalled that in 1950 the flood waters reached the verandah of the Commercial Hotel. Mr O'Gorman's butcher shop had to have the front and back doors sand bagged to prevent the entry of flood waters. The Commercial Hotel at this time was located on the N.W. side of the intersection of Terry and Flinders Streets. The original hotel was burnt down in 1954 and rebuilt on the adjacent corner where it is now. The 1950 flood also caused 18" of water across the intersection of Terry and Flinders Streets. According to Mr King, the floods have never reached such a height since Council's drainage works on the northern side of the Town.

Minor flooding also occurs in Calderwood Road and flood waters have been up to 2 fee over the deck of Manson's Bridge, but the water has never entered the homes in the bridge's vicinity.

*Shell Garage, Tongara Road*

Mr Harris has lived in Albion Park for sixty odd years and recalls the following details :

1. In 1978, flood waters were one foot over Manson's Bridge, Calderwood Road.
2. Flood waters have on several occasions reached the fence around the police station.
3. Flood waters have regularly entered the General Store and O'Gorman's Butcher Shop.
4. The cricket oval is regularly flooded and water has reached up tot eh concrete path behind where the new supermarket has opened at the show ground entrance.
5. Flood waters have reach the steps of the new 'Commercial Hotel'
6. The houses at the end of Hamilton Street have been flooded.
7. Flood waters have been lessened since the Council removed the wooden bridge near Boles Farm 1965. The council put in concrete bank protection and raised the road and river to prevent the river from breaking tis banks and flowing into the swamp on the southern side of the road. This may have temporarily relieved the flooding caused by the Rivulet combining with the flood waters from Frazers Creek and flooding the Albion Park township. The swamp area south of Boles Farm acted as a retention basin but now the flood waters are forced north westward causing increased

flooding on farms on the other side of the river. Eventually the Rivulet and Frazers Creek flood waters pool back to swamps.

8. In Croome Street, Greenmeadows, is subject to flooding. Flood waters have entered houses on two occasions since the opening of the Estate, and residents have had to remove fence palings to allow other passing of the flood waters.
9. Frazers Creek regularly floods, closing the road but the waters drop as quickly as they rose.

*Mr Russell, Meadow View Farm, Illawarra Highway*

Felt that the 1978 flood was the worst flood he had experienced since the 1960's. Flood waters reached between the two Railings of the front gate (see photo) and the waters reached within 15 feet of his front door as well as reaching the cement slab in front of the dairy.

## 3.2 HISTORIC RAINFALL DATA

Since installation of the pluviometers in the 1980's, rainfall intensities at 5 minute increments have become available at Upper Calderwood, Clover Hill, Yellow Rock, and North Macquarie gauges.

However, during historic events, one or more pluviometers have usually failed. The availability of data from the gauges during some recent historic events is indicated in Table 3.2.1.

Data for the four stations for the June 1991 event are provided on the enclosed computer disk and graphed in Figure 3.2.1.

| Event | Upper Calderwood | Clover Hill | Yellow Rock | North Macquarie |
|---|---|---|---|---|
| June 1991 | ✓ | ✓ | ✓ | ✓ |
| August 1990 | x | ✓ | x | ✓ |
| March 1988 | ✓ | ✓ | x | ✓ |
| August 1986 | ✓ | ✓ | ✓ | ✓ |
| December 1985 | ✓ | x | x | x |

Note: ✓indicates pluviometer functioned throughout event
x indicates pluviometer failure during event

**TABLE 3.2.1**
**PLUVIOMETER DATA FOR RECENT EVENTS**

## 3.3 HISTORIC FLOOD LEVELS

### 3.3.1 Generally

Little specific data is available for flooding in the catchment prior to 1991. Prior to 1991 some anecdotal evidence on flooding had been gathered by the Water Resources Commission, Road Traffic Authority, State Rail Authority, and Council but no deliberate effort had (or has still) been made to collate this earlier data.

### 3.3.2 Event of June 1991

The event of 11th June 1991 is described in detail in section 3.1.1.

Forbes Rigby Pty Ltd and Public Works surveyed debris levels between Albion Park and Lake Illawarra. A compilation of gauge and flood debris levels, from this event is reproduced in Figure 3.3.1 and in tables 3.1.1d and e.

Sunnybank and Princes Highway gauge flood stage recordings from 6/6/91 to 12/6/91, are provided on disk in this compendium.

The peak gauge height recorded at SunnyBank during this event was 3.8 m above gauge datum on 11 June 1991.

The peak gauge height measured at AWRC 214402 Princes Hwy was RL 3.65 m AHD, at 10:45 pm on 11 June 1991.

At Berkeley Boat Harbour, Lake Illawarra peaked at 1.8 m AHD coincident with peak discharge into the lake and a low tide.

### 3.3.3 Other Events

Other recent significant gauged events include:

- **April 1988** - Peak stage recorded at Princes Hwy gauge 3.13 m AHD
- **August 1986** - Peak stage recorded at Princes Hwy gauge 2.95 m AHD
- **December 1985** - Peak stage recorded at Princes Hwy gauge 2.4 m AHD
- **February 1984** Major flooding occurred in the Albion Park township. The then Water Resources Commission surveyed flood debris levels along Macquarie Rivulet. The peak stage recorded at the Sunnybank gauge was 4.15 m above gauge datum

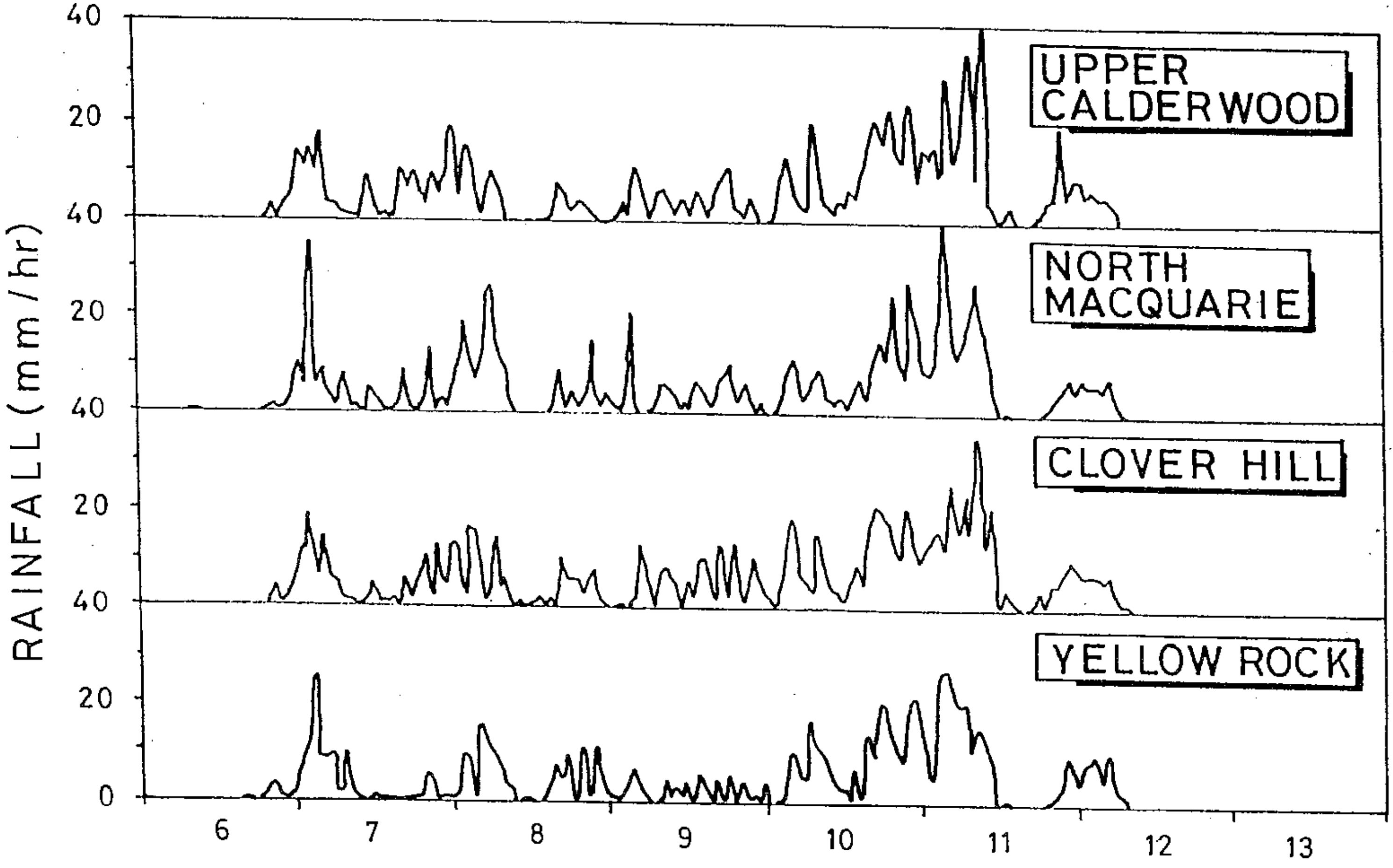



**FIGURE 3.2.1**

**EVENT OF JUNE 1991**
**FUNCTIONAL PLUVIOMETERS**
**RECORDED RAINFALL**


**ILLAWARRA HIGHWAY - SOUTH VIEW TOWARDS ALBION PARK**
**WATER JUST OVER 2m MARK**

**ONLY RECORDED HIGHER ONCE BEFORE, 3m MARK REACHED IN MARCH 1975**

**THIS EVENT LEFT DEBRIS AT THE PEDESTRIAN GATE OF MEADOW VIEW PROPERTY**

**FIGURE 3.3.1**
**EVENT PHOTOGRAPHY**


10.20 am 11/6/91 FLOOD OVERVIEW

PHOTOGRAPH 1 OF 2

VIEW FROM HIGHWAY NORTH OF BRIDGE

TAILING DAMS - LOWER FLOODPLAIN &

LAKE ILLAWARRA BEYOND LOOKING SOUTH-EAST

FIGURE 3.3.2
EVENT PHOTOGRAPHY


10.20 am 11/6/91 FLOOD OVERVIEW PHOTOGRAPH 2 OF 2

FROM HIGHWAY / RAILWAY BRIDGE - YALLAH

VIEW FROM RAILWAY BRIDGE OVER MACQUARIE RIVULET - TAILING DAMS - LAKE ILLAWARRA BEYOND

FIGURE 3.3.3
EVENT PHOTOGRAPHY


MACQUARIE RIVULET BETWEEN ROAD & RAILWAY BRIDGE
VIEWED FROM HIGHWAY - YALLAH / LOOKING SOUTH

FIGURE 3.3.4
EVENT PHOTOGRAPHY


MACQUARIE RIVULET - WESTERN SIDE OF ROAD BRIDGE
TAKEN FROM PICNIC AREA, TOWARDS BRIDGE
WATER HEIGHT NEAR MAXIMUM FOR THIS EVENT

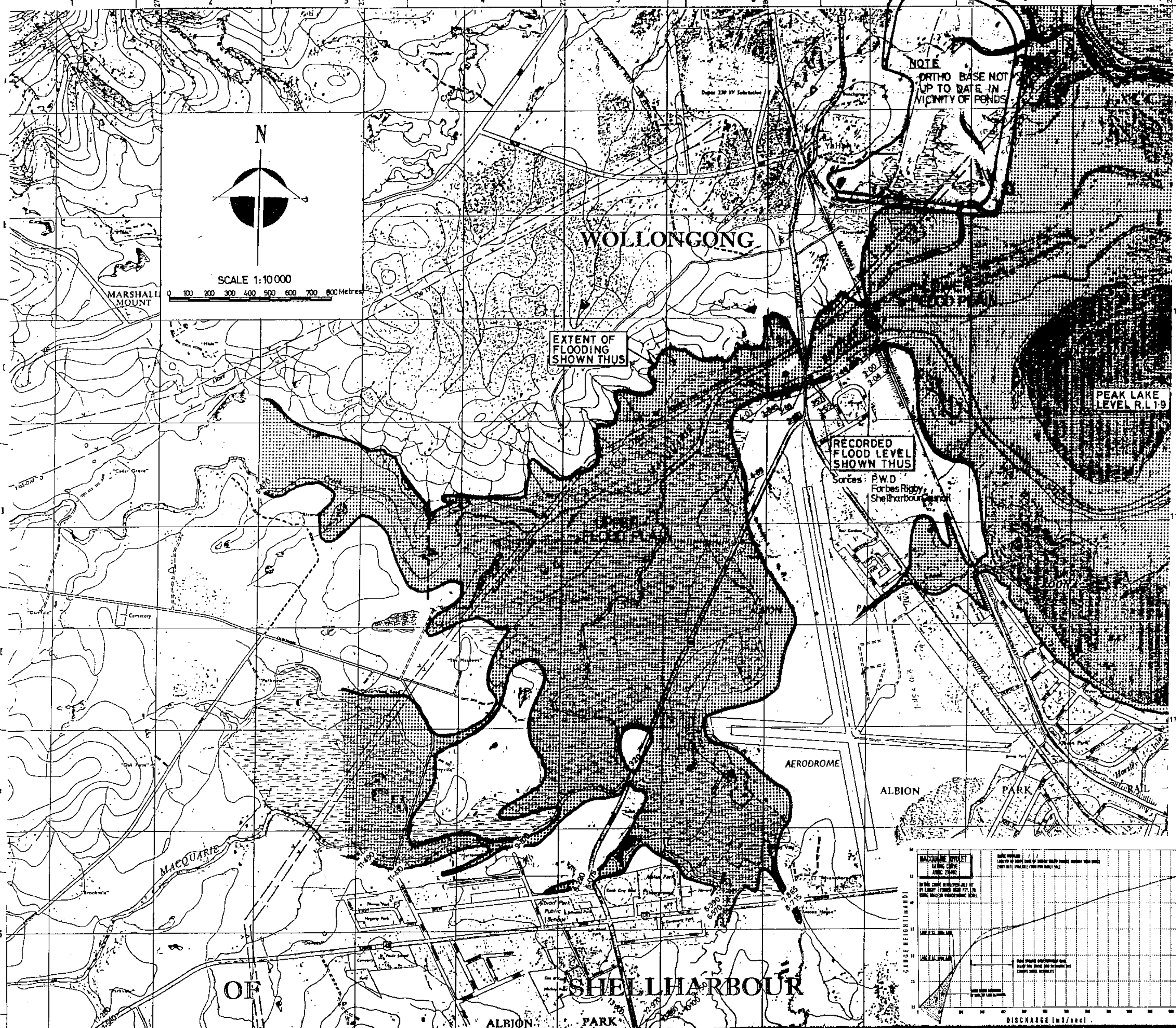

MACQUARIE RIVULET - NORTH-WESTERN SIDE
OF HIGHWAY BRIDGE LOOKING SOUTH

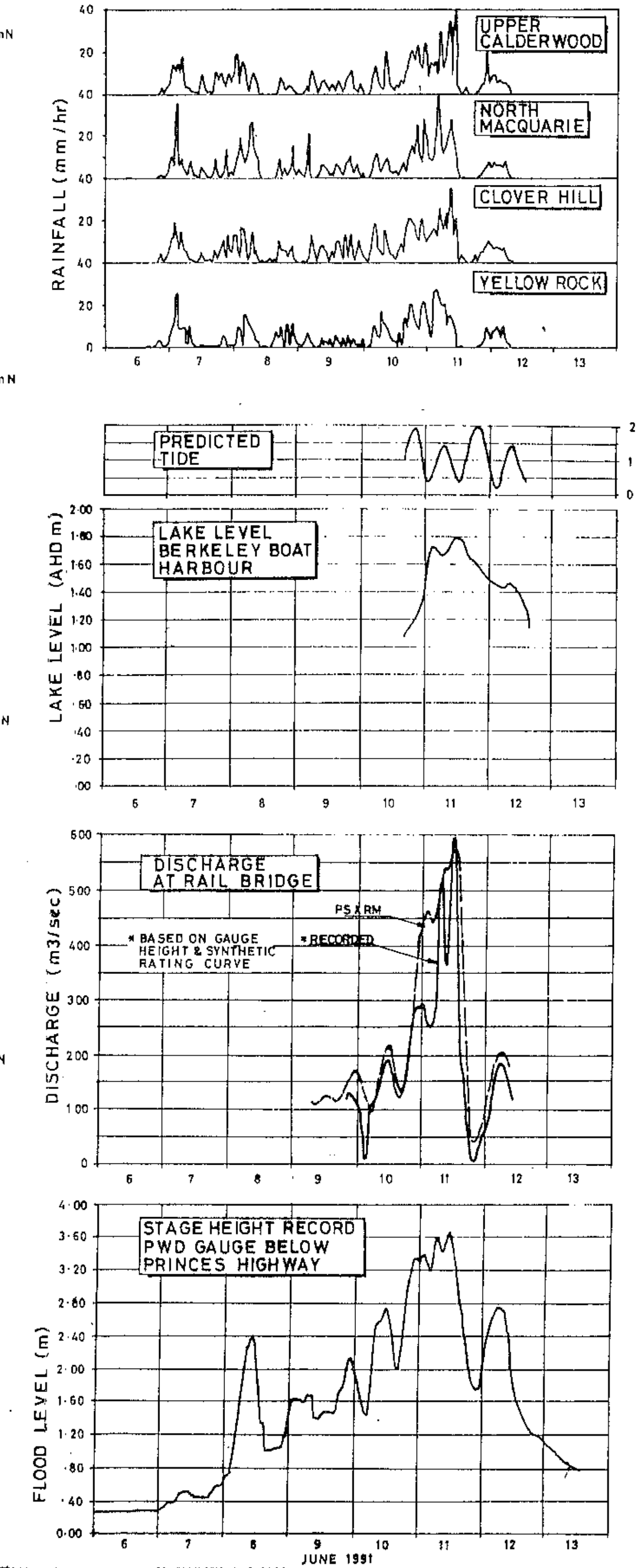
FIGURE 3.3.5
EVENT PHOTOGRAPHY


MACQUARIE RIVULET - UPSTREAM OF RAILWAY BRIDGE
VIEWED FROM SOUTHERN BANK LOOKING NORTH-EAST


MACQUARIE RIVULET - UPSTREAM OF RAILWAY BRIDGE
VIEWED FROM SOUTHERN BANK LOOKING NORTH EAST

FIGURE 3.3.6
EVENT PHOTOGRAPHY




| REV | DATE | BY | APP. | DETAILS |
|---|---|---|---|---|

| DRAWING STATUS | | |
|---|---|---|
| DESIGN | ER | / 10 / 92 |
| DRAWN | APR | / 1 / 93 |
| CHECKED | ER | / 1 / 93 |
| APPROVED | ER | 15/ 1 / 93 |

Location Plan: Wollongong, Port Kembla, Dapto, Princes Hwy, Lake Illawarra, Shellharbour

SCALE: (on A1 Original) 1:10 000

DATUM: A.H.D.

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PROJECT TITLE
MACQUARIE RIVULET
REFERENCE CATCHMENT
Wollongong Coastal Basin 214-05-06

DRAWING TITLE
HYDROLOGIC/HYDRAULIC SUMMARY
STORM OF JUNE 1991.

DRAWING No. 83093 - 2 - 3003 REV 0

**FIGURE 3.3.7** A1

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## *FLOOD STAGE*

Sunnybank
Princes Highway

## *APPENDIX 1*

Event of June 1991

## *RAINFALL*

Upper Calderwood
Clover Hill
Yellow Rock
North Macquarie