IPSWICH RIVERS FLOOD STUDIES

Phase 3

Final Report

Prepared for:

IPSWICH CITY COUNCIL

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Executive Summary

Halliburton KBR Pty Ltd (formerly Brown & Root) was commissioned by Ipswich City Council in April 2001 to carry out the Ipswich Rivers Flood Studies Phase 3. This report follows on from previous flood studies carried out as Phases 1 and 2 of the studies completed in July 2000.

The study area includes the main streams of the predominantly rural areas upstream of the most important urban areas of the city. In addition to the area included in Ipswich City, there was an extension required for part of Boonah Shire immediately upstream of the Ipswich City shire boundary.

This flood study provides relevant information to the Ipswich City Council for its future planning for development on floodplains in the parts of the City included in the study area. The flood study carried out in Phases 1 and 2 of the study provided relevant data for the more closely developed urban areas of the City, while this phase provides results for the mainly rural areas. The study provides the hydrology and hydraulic assessments for the streams included in the study area and also provides relevant data on the calculated design floods as well as sufficient graphical information for the Council to prepare and publish flood inundation maps for the study floodplains.

The study area includes the main catchment of the Bremer River and its most important tributaries and also includes some areas upstream of Ipswich City Council area in Boonah Shire as an extension of the main study area.

The specific streams included in this particular project are as follows:

- Bremer River from the junction with Warrill Creek to 30 km upstream of the City boundary in Mt Walker, including a section in Boonah Shire.
- Western Creek from the Bremer River confluence to about 1 km upstream of the Grandchester–Mt Mort Road Bridge.
- Franklin Vale Creek from the Western Creek junction to Greys Plains Road.
- Warrill Creek from the Cunningham Highway to 30 km upstream of the City Boundary, including a section in Boonah Shire.
- Purga Creek from the Cunningham Highway to Peak Crossing.

The first component of the project is the hydrology. The runoff routing model RAFTS has been used to calculated design floods for the project catchments. The RAFTS model was adopted from the Phases 1 and 2 study which was calibrated on the streamflow data available for the catchment. Design floods were calculated for a range of flood probabilities from an average recurrence interval of 2 years to the Probable Maximum Flood.

Following the completion of the design flood hydrology, the study then involved the hydraulic component. The hydrodynamic model MIKE 11 has been used for the hydraulic analysis. The model was established using surveyed cross sections of the water courses. The model was calibrated on the available water level data for the major historical events, in 1974, 1983, 1989 and 1996. Following calibration, the model was used to calculate flood levels for the range of design flood probabilities.

The results from the hydraulic modelling was then used for preparation of flood inundation maps, using the surveyed cross sections and the floodplain topography. The flood inundation maps have been used to provide a preliminary assessment of flood mitigation options for the catchment.

1 Introduction

Halliburton KBR Pty Ltd (Halliburton KBR) (formerly Brown & Root) was commissioned by Ipswich City Council in April 2001 to carry out the Ipswich Rivers Flood Studies Phase 3.

This report follows on from previous flood studies carried out as Phases 1 and 2 of the Ipswich Rivers Flood Studies completed in July 2000.

The study area included the main streams of the predominantly rural areas upstream of the most important urban areas of the city. In addition to the area included in Ipswich City Council, there was an extension required for part of Boonah Shire immediately upstream of Ipswich City Council.

2 Background

2.1 GENERAL

This flood study is required to provide relevant information to the Ipswich City Council for its future planning for development on floodplains in the parts of the City included in the study area. The flood study carried out in Phases 1 and 2 of the study provided relevant data for the more closely developed urban areas of the City, while this phase provides results for the mainly rural areas.

The study provides the hydrology and hydraulic assessments for the streams included in the study area. It provides relevant data on the calculated design floods as well as sufficient graphical information for the Council to prepare and publish flood inundation maps for the study floodplains.

2.2 ASSUMPTIONS

This project is Phase 3 of the Ipswich Rivers Flood Studies. Phases 1 and 2 of the study were completed by Sinclair Knight Merz and described in a report dated July 2000. This report and the computer models used in the study were provided by Ipswich City Council for the current project.

The approach, parameters and results of Phases 1 and 2 of the study were generally accepted in the current phase, though there were some concerns about particular issues. This assumption was provided in the original study brief and proposal for the project. Relevant concerns are discussed at particular locations in the current report.

3 Study area

3.1 CATCHMENT DESCRIPTION

The study area for the Ipswich Rivers Flood Studies Phase 3 includes the mainly rural areas of the southern parts of the city of Ipswich. The study area includes the main catchment of the Bremer River and its most important tributaries. it also included some areas upstream of Ipswich City Council area in Boonah Shire as an extension of the main study area.

The extent of the study area is illustrated in Figure 3.1.

The Bremer River is located in the south-western parts of the Brisbane River catchment and joins the Brisbane River near the centre of the main city area of Ipswich. The top of the catchment is located in the Liverpool Range and most of he catchment is generally hilly and lightly forested with grazing the most common land use. There is some agriculture in the areas of better soils principally on the alluvial floodplains. Apart from a number of small towns and scattered rural properties, there is little urban development in the upper reaches of the catchment. The urban areas of Ipswich City are located in the lower reaches. The total catchment area of the Bremer River at its junction with the Brisbane River is approximately 1790 km^2.

Warrill Creek is the most important tributary of the Bremer River, joining the river near Amberley, just upstream of the city area. The creek accounts for a major part of the total catchment area of the Bremer River and is of the same order of size as the Bremer River. The headwaters of Warrill Creek are mountainous and form part of the Great Dividing Range, though the middle and lower reaches of the creek include hilly topography. Most of the catchment is used for grazing with some farmland in the flat alluvial floodplain areas. There are a number of small townships including Aratula, Kalbar and Harrisville located in the catchment, and scattered rural development throughout the remainder of the catchment.

Purga Creek is a tributary of Warrill Creek, joining the creek upstream of the junction with the Bremer River. Purga Creek is located to the east of Warrill Creek, where the topography is more flat. The main land use of the catchment is grazing with some farmland on the flatter areas. There is forest in the upper reaches.

Western and Franklinvale Creeks are tributaries in the Bremer River part of the study area. Both catchments are predominantly rural, also with grazing and farming as the main land uses.

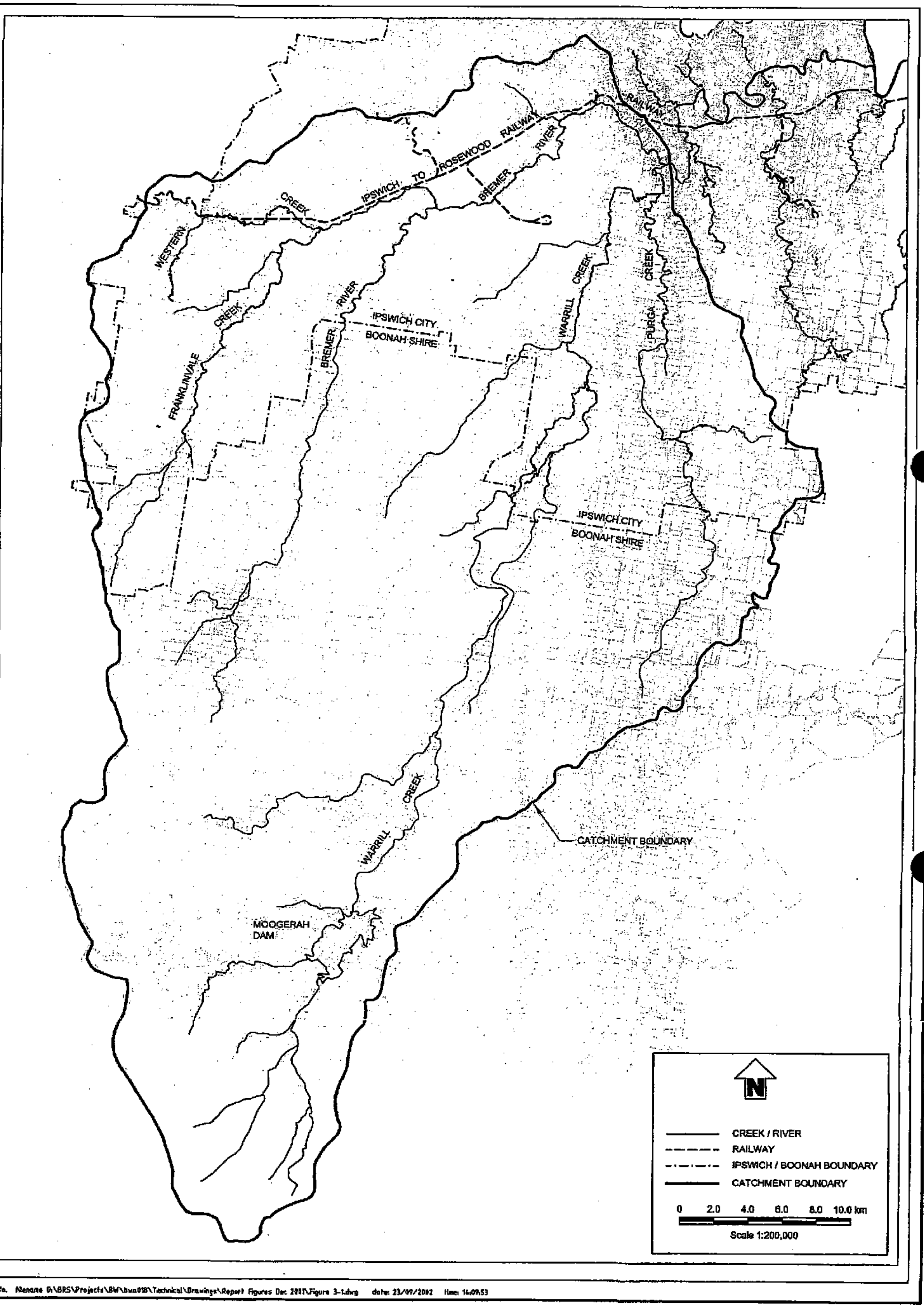

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Figure 3.1
IPSWICH RIVER FLOOD STUDY
STUDY AREA

The specific streams included in this particular project are as follows:

- Bremer River from the junction with Warrill Creek to 30 km upstream of the City Boundary in Mt Walker, including a section in Boonah Shire.
- Western Creek from the Bremer River confluence to about 1 km upstream of the Grandchester–Mt Mort Road Bridge.
- Franklin Vale Creek from the Western Creek junction to Greys Plains Road.
- Warrill Creek from the Cunningham Highway to 30 km upstream of the City Boundary, including a section in Boonah Shire.
- Purga Creek from the Cunningham Highway to Peak Crossing.

The study area is located upstream of the area covered by the Phases 1 and 2 of the project, which was mainly located in the developed urban areas of the City.

3.2 FLOODING PROCESSES

The catchments considered in this report are principally associated with the Bremer River, a tributary of the Brisbane River.

Brisbane River floods are complex and can be produced by rainfall in any one of a number of tributaries. The major tributary upstream of Ipswich is Lockyer Creek, which flows into the river immediately downstream of Wivenhoe Dam. Runoff from upstream of Wivenhoe Dam is routed through the dam, which is operated to provide significant flood mitigation benefits. However, because of the large catchment area and the operation of the flood mitigation dams, floods in the Brisbane River generally rise and fall slowly. There is a flood warning system in the catchment and this helps in mitigating damages.

For the purposes of this review of flooding processes, flooding in the Bremer River, as well as its tributaries, are considered in detail particularly Warrill, Purga and Bundamba Creeks. The Bremer River, as well as Warrill and Purga Creeks and their major tributaries, are the main focuses of this report. There are also a number of smaller tributaries of the Bremer River that are considered too small to be included in this broad flood study. The flooding in this catchment is the most complex and because of the large catchment size, is of the most importance for Ipswich City.

Flooding processes in the most significant urban areas of the catchment are complex with flooding contributions from a number of sources including:

- *Local catchment:* Flooding in the main tributaries can arise from local catchment rainfall. This type of flooding is normally produced from relatively short duration intense rainfall events and is generally of relatively short duration.
- *Bremer River:* Flooding in the Bremer River not only affects the river itself but also affects the tributaries through backwater effects where water backs up tributaries.

- *Brisbane River*: In the same way, backwater from the Brisbane River affects the lower reaches of the Bremer River and its tributaries. Because of the large size of the Brisbane River, with a total catchment area of over 13,000 km^2, the flood response is much slower and major floods are produced from longer duration rainfall events. Floodwaters in these events rise and fall more slowly than in other flood events noted above. The construction of Wivenhoe Dam, which operates in conjunction with Somerset Dam for flood mitigation, has reduced the risk of flooding in the Brisbane River to some degree. The benefits of this flood mitigation system should be included in the floodplain planning process for the City. The study area for the current project is generally above the area affected by back water from the Brisbane River, but it is particularly important further downstream.
- *Combination:* All three flood types can occur in various combinations. However, due to the extensive catchment size, it is unlikely that major flood events will occur in the whole of the catchment completely simultaneously, though the flood types will often be associated with each other.

The lower reaches of the Bremer River and the Brisbane River up to Mt Crosby are tidal and while tidal levels would not be expected to have a significant effect on large floods, there may be some effect on smaller events. This is below the study area for this project, which is all outside the area of tidal influence.

The typical flooding pattern in the lower reaches of the Bremer River was experienced during the significant event that occurred in January 1974. This flood event occurred in the following manner. Flooding occurred firstly in the smaller catchments. The slower responding catchments of the Bremer River and Warrill Creek then rose and finally backwater from the Brisbane River increased water levels. Brisbane River backwater will either slow the outflow of water from the Bremer River or if it is sufficiently delayed could even allow flow upstream in the Bremer River. A point on the lower reaches of one of the smaller tributaries could therefore have three separate flood peaks (local runoff, Bremer River and Brisbane River) from a single major event.

As discussed elsewhere in this report, the determination of the ARI 100-year flood level for locations in the major rivers of Ipswich City is not easy. The actual level in various locations depends on the flooding in the Brisbane and Bremer Rivers, as well as in any one of a number of smaller tributaries. The risk of flooding depends on the combination of risks from the different locations, and consideration needs to be made of the catchment areas, timing of floods and combinations of events.

The Bremer River has had flood records observed for just over 100 years at the City's flood warning gauge at the David Trumpy Bridge. The most significant floods on record with a gauge height of greater than 10 m are presented in Table 3.1.

Table 3.1 Major floods—Bremer River at Ipswich

Date	Gauge height (m)
4 February 1893	24.50
12 January 1898	17.48
27 January 1927	12.98
7 February 1931	15.47
26 January 1947	15.19
31 January 1951	11.69
29 March 1955	13.82
12 June 1967	11.99
14 January 1968	11.69
4 February 1971	11.71
27 January 1974	20.70
28 January 1974	20.70
11 February 1976	13.65
23 June 1983	10.65
4 April 1988	11.20
12 December 1991	13.10
3 May 1996	11.31

3.3 HYDROLOGICAL DATA

Data on flooding in the catchments in this study area are available from a number of sources. With this combination of records, a reasonable picture of a number of flood events can be obtained. The relevant data from these sources has been used in the current project. Data includes:

- *Rainfall:* Pluviograph and daily gauge readings have recorded rainfall records throughout the catchment over time. These records are available generally from the Bureau of Meteorology, which archives rainfall records from throughout Australia, but are also available from Council particularly for major recent flood events.
- *Streamflow data:* Some stream gauges operate on the river and are managed by the Department of Natural Resources and Mines. These provide water levels and flows generally in the upper reaches of the catchment.
- *Flood warning gauges:* These are operated by the Bureau of Meteorology and Council throughout the catchments, including the downstream reaches generally providing water levels without ratings.
- *Observed water levels:* Levels from historical flood events were observed by Council for points in urban areas during major flood events. Council contains records on flood events dating back to before 1900.

4 Previous studies

4.1 INTRODUCTION

There have been a number of previous flood studies carried out for the study area that are relevant to this project.

The most significant of these was the project carried out for the Ipswich City Council by Sinclair Knight Merz, SKM (2000) on the Ipswich Rivers Flood Studies Phases 1 and 2, completed in July 2000, though there have been some other projects completed for the Council as well.

4.2 SINCLAIR KNIGHT MERZ STUDY

The main objective of the Sinclair Knight Merz Phases 1 and 2 report was to ascertain flood levels for major waterways within the currently urbanised areas of Ipswich City. This investigation would form the basis for:

- future assessment of the impacts of development on flooding
- assessment of flood inundation and flood damage
- development of flood mitigation strategies
- determination and adoption of a flood standard for new development and overall floodplain management strategies.

The report looked at several river and stream networks. Those considered relevant to the Phase 3 study are listed below:

- Bremer River (from confluence with Warrill Creek to the Brisbane River).
- Bremer River Tributaries (i.e. Bundamba Creek, Warrill Creek, Purga Creek, Deebing Creek, Ironpot Creek, Mihi Creek, Sandy Creek (Chuwar).

As part of the investigation, the study involved the collection and analysis of all available rainfall, streamflow, and topographic and hydrographic data. From this data, both hydrological and hydraulic models were developed and calibrated using five historical flood events.

Inundation maps for both the 20-year ARI and 100-year ARI events were produced from the investigation.

4.3 OTHER PROJECTS

In addition to the major report described above, a review of previous work carried out on floodplain management for the catchments of concern for the City revealed only very limited information of relevance for Council. The relevant reports are as follows:

- *Bremer River Improvement Trust:* This report was completed in 1975 by Mr M. Moss and G.P. McGown and Associates as an initial appraisal of flooding on the rivers in Moreton Shire, primarily the Bremer River. The report included some factual data but the analysis carried out would not be relevant today.
- *Moreton Shire Major Stream Flooding:* This report was prepared by Munro Johnson and Associates for the former Moreton Shire in 1987, and provided an initial estimate of levels for the ARI 100-year flood for the Bremer River and major tributaries in the Shire. This report however provided only an extremely broad overview and could not be used for detailed floodplain planning.
- *Bundamba Creek Flood Study:* This report was completed by CMPS&F for Ipswich City Council in June 1996, and included a detailed hydrologic and hydraulic study of Bundamba Creek. While the study provided a good coverage of the creek, it was limited by the uncertainty relating to backwater estimates from the Bremer River and the Brisbane River. After completion of the studies of the Bremer River, revision of the Bundamba Creek study with a good appreciation of backwater effects will provide a conclusive study of the creek.
- *Brisbane River and Pine River Flood Studies:* The Department of Natural Resources and Mines completed a flood study for the Brisbane River downstream of Wivenhoe Dam using hydrologic and hydraulic models. While the Bremer River and other tributaries were not included in the hydraulic component of the study, a hydrologic model was developed to provide flood hydrograph inflows to the Brisbane River hydraulic model. This study would provide Brisbane River backwater levels for a Bremer River flood study. However, since the major concern with this project was in the operation of Wivenhoe Dam, its scope focussed on large floods greater than ARI 100 years as a primary interest. Council will have some interest in these large and extreme events, but will primarily be concerned with smaller events. The hydrology components of the study may also be of some use to Council.
- *Bureau of Meteorology Flood Warning:* The Bureau has developed a flood forecasting and warning system for the Bremer River in association with Council and other authorities. This system includes a hydrologic model of the Bremer River and major tributaries and a simple hydraulic component based on rating curves to convert the flood flows calculated by the hydrologic model to flood levels. The catchment hydrology was developed based on recorded streamflow data and provides a second independent (though presumably similar) hydrology model for the catchment. This model has primarily been used for analysis of historical flood events and has not been used for analysis of design events.

- *Others:* It is known that a number of other hydrologic and hydraulic studies have been carried out on the Bremer River and tributaries. These include studies on Moogerah Dam and the Warrill Valley Irrigation Area and other proposed water resource developments in the catchment. Other studies have been carried out for water supply, development and mining projects in the catchment. These studies would all be of limited value for a flood management study for the Bremer River.

In summary therefore, the previous studies, except for the Sinclair Knight Merz study, would be of generally limited value for the requirements of the current project.

5 Hydrology

5.1 PREVIOUS HYDROLOGY STUDIES

Analyses of catchment hydrology have been undertaken on three occasions in the past, in the reports described above. Details of these results are as follows:

- *Department of Natural Resources and Mines:* The Department used RORB to simulate the Brisbane River and its major tributaries as part of the Brisbane River Flood Study undertaken for the South East Queensland Water Board. Nine floods were analysed with up to five gauging stations used in the calibration. These calibration floods included the January 1974 flood, the largest in recent years. This calibration gave acceptable results over the range of flood sizes analysed.

  Since the model was primarily concerned with the main Brisbane River catchment, the hydrologic modelling components are more detailed for the major catchments. The Bremer River and it main tributaries are well modelled but the smaller tributaries are not included in sufficient detail for the current project.

- *Bureau of Meteorology:* The Bureau of Meteorology has calibrated an URBS runoff routing model to eight floods on the Bremer River and its tributaries. This work was carried out as part of their flood forecasting system for the Brisbane and Bremer Rivers. The floods considered by the Bureau are listed in Table 5.1, which also shows the peak flood levels in Ipswich at the David Trumpy Bridge.

Table 5.1 Bureau of Meteorology calibration floods

Event	Peak level—Ipswich (gauge height m)
June 1967	11.9
January 1968	11.6
January 1974	20.7
February 1976	13.6
June 1983	10.6
April 1988	11.2
December 1991	13.1
May 1996	11.3

Since the Bureau is primarily concerned with flood levels, all of the model calibration has been based on the use of levels rather than flows. While this approach is the most appropriate for their purposes which are concerned with forecasting flood levels, flood hydrology for the current flood study requires discharges rather than flood levels.

- *Sinclair Knight Merz report:* This study is discussed in more detail below in this report since it forms the basis of the current project. It used the runoff routing model RAFTS for the catchment hydrology which includes the Bremer River and its tributaries. The data used has been sourced from the two studies mentioned above.

5.2 STUDY REQUIREMENTS

The hydrology for the current project has been based on the results presented by Sinclair Knight Merz report for the Phase 1 and 2 study.

Flood flow hydrographs associated with design rainfall events for Average Recurrence Intervals (ARIs) ranging from 2 years to 500 years, and Probable Maximum Precipitation (PMP) were required at a number of locations along the streams of the study area. This information was required as input data for the hydrodynamic modelling of portions of the waterways. To generate this information, the RAFTS runoff routing model was used. The model used was developed from that previously adopted as part of Phases 1 and 2 of the project. This model converts rainfall excess on the catchment into hydrographs of surface runoff. Figure 5.1 presents the extent and internal network boundaries of the RAFTS model used in current study. The extent of each stream for which RAFTS data was required is as follows:

- *Purga Creek:* Approximately 13 km south of Ipswich City/Boonah Shire Boundary (PUR1) to the Cunningham Highway at the downstream edge (PUROUT).
- *Warrill Creek:* Approximately 15 km south of Moogerah Dam (KA1) to the Cunningham Highway at the downstream edge (AMBOUT).
- *Bremer River:* Approximately 35 km south of Ipswich City/Boonah Shire Boundary (WAL1), Grandchester on Western Creek (WAL13) and Mount Mart on the Franklinvale Creek (WAL 9) to the Bremer River–Warrill Creek junction at the downstream edge (6C).

Ipswich City Council provided the data, models and report generated in the study undertaken previously for Stages 1 and 2 of the Ipswich Rivers flood studies. In addition to the RAFTS model, temporal patterns and rainfall intensities from the study were also used, where appropriate.

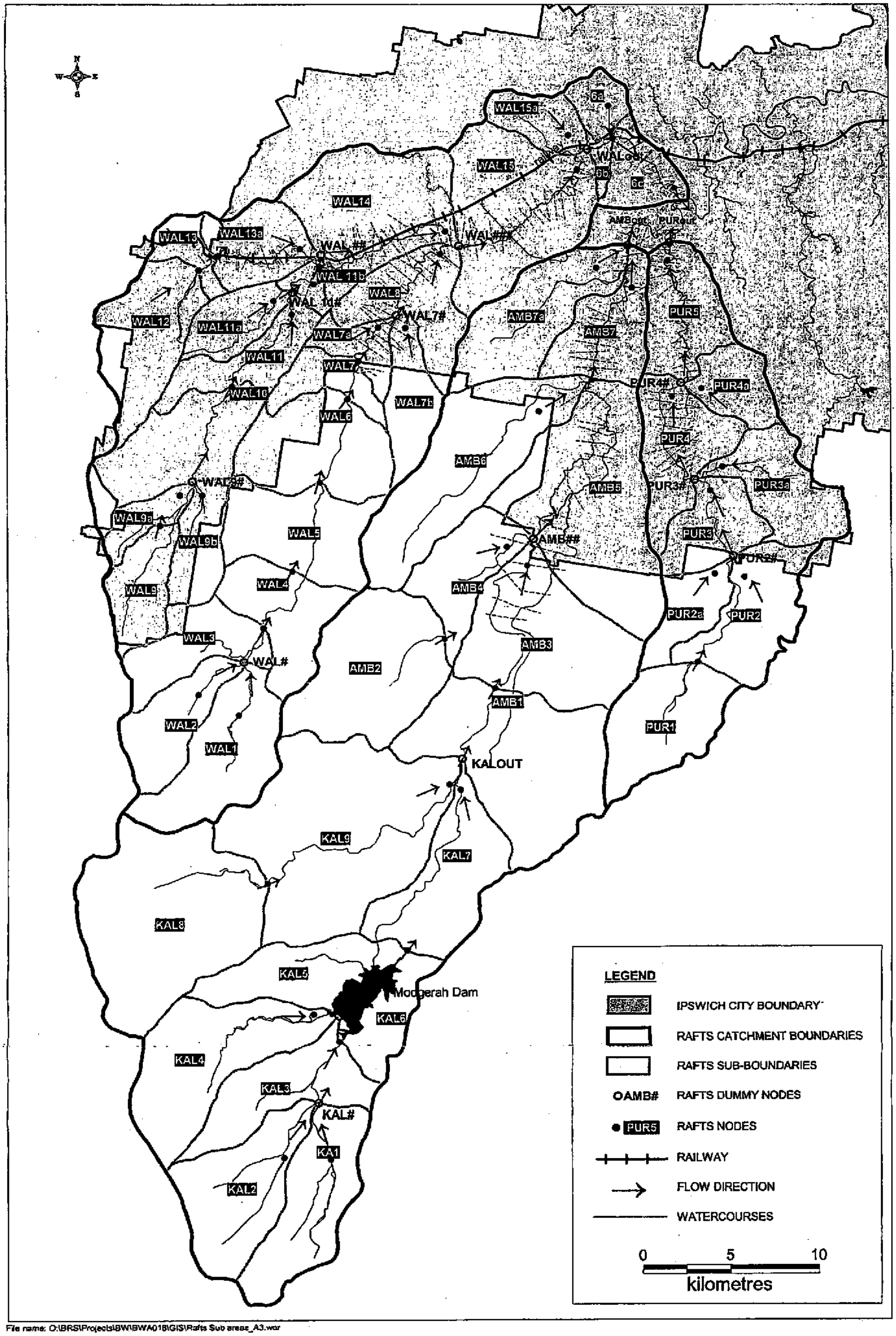

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Figure 5.1
RAFTS SUB AREAS

5.3 PREVIOUS STUDY (IPSWICH RIVERS FLOOD STUDIES PHASES 1 AND 2)

Sinclair Knight Merz (SKM, 2000) was commissioned by the Ipswich Rivers Improvement Trust to undertake flood studies of the major rivers and creeks in Ipswich City area. This culminated in the preparation of the 'Ipswich Rivers Flood Studies Phase One and Phase Two' report in August 2000. In this study, a RAFTS model was used to examine the hydrology across the entire Brisbane River catchment, including the Bremer River, Warrill Creek and Purga Creek.

The RAFTS model developed by SKM was calibrated against flood events recorded in January 1974, June 1983, late April 1989 and May 1996. Seven stream gauges, six pluviometers and approximately twenty rainfall stations situated within the three catchments recorded these historical flood events. Good stream gauge data was available for both the Bremer River and Warrill Creek, with the comparison between the RAFTS model and the recorded data indicating a generally good calibration. At Purga Creek however, the model did not compare well with the recorded data. This poor result was put down to the unreliable data obtained from the Purga stream gauge.

The RAFTS model developed for the previous study was adopted for the current project on the assumption that it was calibrated correctly, and that the design flood flows obtained from the model were also correct. The RAFTS model network, variables and rainfall loss assumptions from this previous study were also used in the preparation of the RAFTS model used in the current study.

A review of the RAFTS result files from the Phases 1 and 2 study revealed that the design Warrill Creek peak discharges presented in the SKM report were obtained at RAFTS node 6D, below the confluence with Purga Creek. In the report it indicates these results were derived from RAFTS node AMBOUT, upstream of the confluence. This error in the report impeded the verification of the revised RAFTS network used for this study.

While there were some concerns about particular issues in the hydrology model from the Phases 1 and 2 of the project, it was adopted for the current phase.

5.4 RAFTS—MODEL DESCRIPTION

The runoff routing model RAFTS was used to generate flood flow hydrographs at a number of locations along Bremer River, Warrill Creek and Purga Creek. The RAFTS network developed in the previous study was modified and used in this study.

The RAFTS program was originally developed by Willing and Partners and the Snowy Mountains Engineering Corporation in 1974, and has been improved and modified subsequently. XP-RAFTS ver.5.0 (1996) was used for this study. The RAFTS model consists of three basic elements, general nodes, basin nodes and links.

General nodes are used in the model to represent catchment areas or junctions. The RAFTS model approximates localised catchment storage effects resulting from the routing of rainfall excess across the catchment area to the downstream outlet. This effect is described by the following equation:

$$S = \left\{ \frac{0.285 A^{0.52}}{(1+U)^{1.97} S_c^{0.5}} \right\} Q^m$$

Where: S = storage (m^3h/s)

A = catchment area (km^2)

Q = discharge (m^3/s)

U = fraction urbanised

S_c = drainage slope (%)

m = non-linear storage exponent, by default = 0.715.

From this equation it can be seen that storage in a general node can be defined by nodes area, slope and fraction urbanised. An addition factor for surface roughness (Manning's n) is also used in RAFTS.

From the previous study the following common variables were adopted for all general nodes:

S_c = 2 %

U = 0.0 %

n = 0.05.

Basin nodes route the inflow hydrograph through a user defined storage relationship. In this study Moogerah Dam, in the upper reaches of the Warrill Creek catchment, was defined by a basin node with a stage—storage and a stage—discharge relationship.

Links are used in the RAFTS model to covey flow between nodes. In this study, the links were described by lag times. This effectively delays the hydrograph outflow from one node to next by the defined lag time.

Initial and continuing rainfall losses were used, with different losses applied to each river or creek and ARI event. The initial and continuing losses used in the study were identical to those used in the previous study.

The losses used in the investigation are presented in Table 5.2 below:

Table 5.2 Adopted rainfall loss parameters

	Bremer River and Warrill Creek		Purga Creek	
ARI (years)	Initial loss (mm)	Continuing loss (mm/h)	Initial loss (mm)	Continuing loss (mm/h)
2	70.0	2.5	15.0	2.5
5	70.0	2.5	15.0	2.5
10	55.0	2.5	15.0	2.5
20	40.0	2.5	15.0	2.5
50	20.0	2.0	10.0	2.5
100	0.0	1.5	5.0	2.5
200	0.0	0.0	0.0	0.0
500	0.0	0.0	0.0	0.0
PMP	0.0	0.0	0.0	0.0

It should be noted that Franklinvale Creek and Western Creek, both of which are tributaries of the Bremer River, have been assigned identical rainfall parameters as the Bremer River.

In addition, rainfall hyetographs were defined at each node and the rainfall excess, after losses were satisfied, was routed into runoff. Most rainfall input data used in the study were obtained from the previous study.

5.5 OBJECTIVES

The primary aim of the RAFTS model for the current study was to provide inflow hydrographs for the MIKE 11 hydrodynamic model for the model extent. To optimise the representation of smaller tributaries in the area of interest, the RAFTS model generated by SKM for Phases 1 and 2 was revised for the current study. Figures 5.2 to 5.4 are schematics of the networks generated for this project. Typically when a catchment area (node) is subdivided the link lags need to be increased to compensate for the loss of storage resulting from the reduced catchment area.

5.5.1 Purga Creek

A number of catchment areas were altered in the Purga Creek network, to include some significant tributaries. Areas in subcatchments PUR2, PUR3 and PUR4 were subdivided. The original Purga Creek network contained no lags. To ensure that the model reproduced as closely as possible the results obtained from the SKM model, preserving the model calibration, the revised network also contained no lags in the main channel. On the new tributary inflows significant lags were applied to compensate for the reduced storage resulting from division of subcatchment areas.

5.5.2 Warrill Creek

Only minimal changes were made to this catchment area, with node AMB7 subdivided to reflect the divided nature of this subcatchment. In addition, the area associated with node AMB5 should have been assigned to node AMB6 and visa-versa. These nodes had their areas swapped.

5.5.3 Bremer River

To obtain input data at the correct locations on the upstream edge of the MIKE 11 model area nodes WAL7, WAL9, WAL11 and WAL13 were subdivided. To define the small catchment of Guilfoyles Creek near Walloon a portion of node WAL15 was divided off.

5.6 MODEL CALIBRATION

To verify that the RAFTS model developed for this study remained calibrated, after changes to the network described above, the peak discharges for the 2-year and 100-year ARI floods were compared. Table 5.3 presents a comparison of the flows from the two models.

Table 5.3 RAFTS model verification—peak flows (critical duration)

	Purga Creek @ node—PUROUT dur. = 4.5 hours			Warrill Creek @ node—AMBOUT dur. = 18 hours			Bremer River @ node—6C dur. = 18 hours		
ARI (years)	Current (m^3/s)	Previous (m^3/s)	Diff %	Current (m^3/s)	Previous (m^3/s)	Diff %	Current (m^3/s)	Previous (m^3/s)	Diff %
2	295	277	+6.5	198	199	-0.5	128	125	+2.4
100	1,247	1,266	-1.5	2,575	2,577	-0.1	1,546	1,544	+0.1

The results for Warrill Creek and the Bremer River compare well. Some difficulties were encountered matching the Purga Creek flows. This discrepancy resulted from the lack of lags or storage in the main channel. The results achieved however were sufficiently similar to allow them to be adopted.

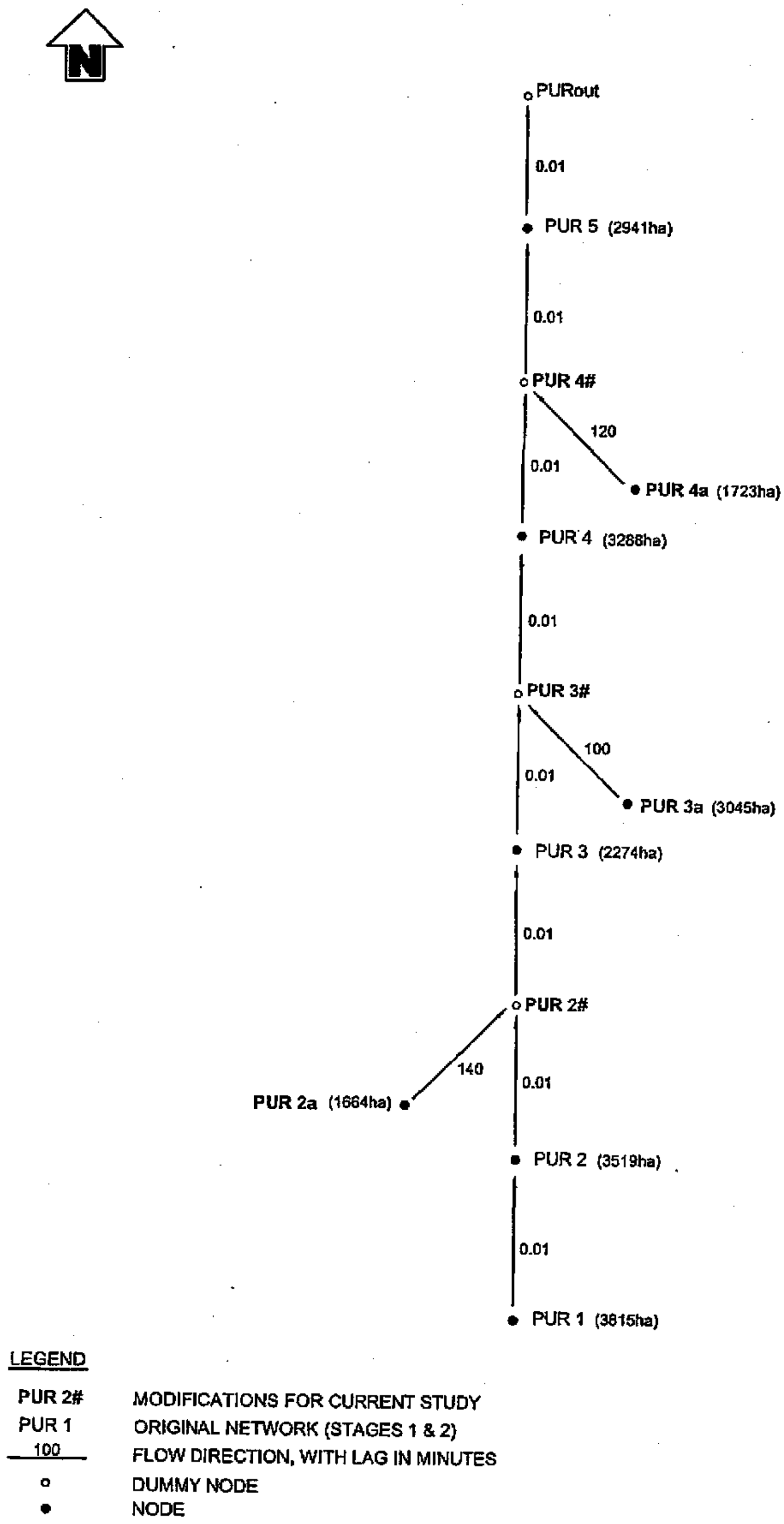

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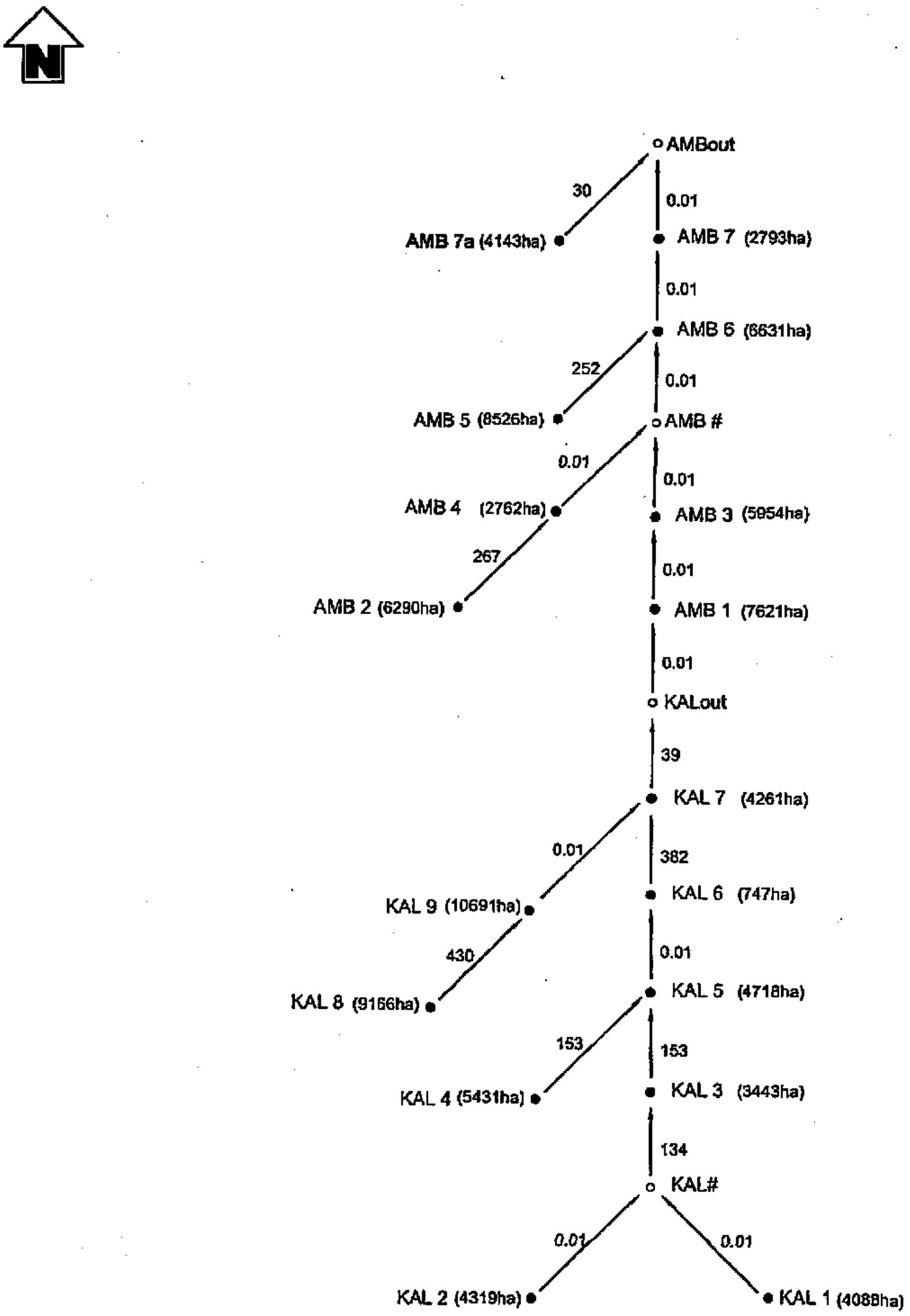
Figure 5.2
IPSWICH FLOOD STUDY
PURGA CREEK



LEGEND

AMB 7a	MODIFICATIONS FOR CURRENT STUDY
KAL 3	ORIGINAL NETWORK (STAGES 1 & 2)
100	FLOW DIRECTION, WITH LAG IN MINUTES
○	DUMMY NODE
●	NODE

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Figure 5.3
IPSWICH FLOOD STUDY
WARRILL CREEK

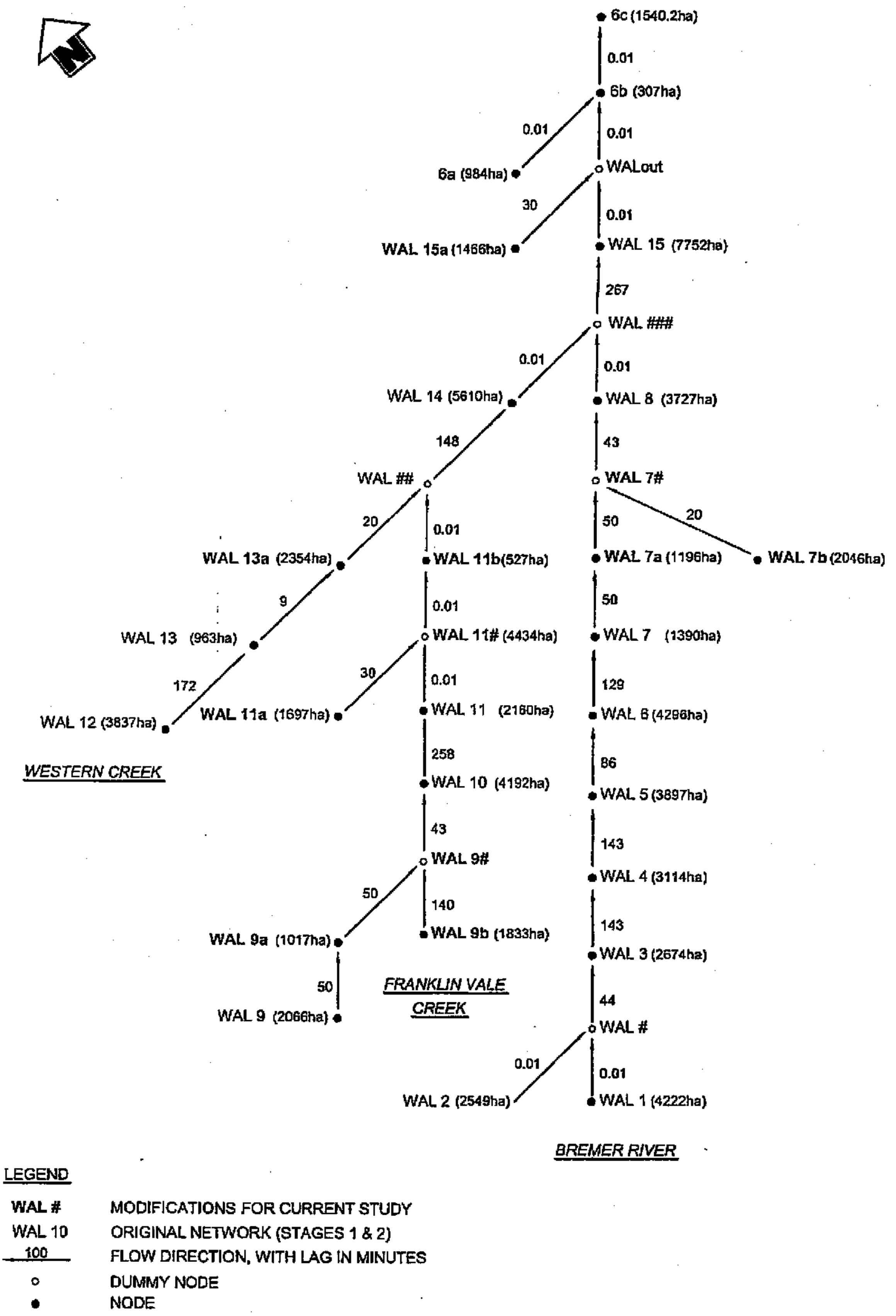

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Figure 5.4
IPSWICH FLOOD STUDY
WALLOON CATCHMENT

5.7 HISTORICAL EVENTS

5.7.1 Introduction

Calibration of the RAFTS model developed for Phases 1 and 2 of the Ipswich Rivers Flood Study was undertaken using historical flood events from January 1974, June 1983, late April 1989 and May 1996. Results for the historical floods were required for use as input data for the MIKE11 model.

5.7.2 Model differences (historical and design)

A number of differences existed between each of the historical flood RAFTS networks and the design floods network. The main differences are as follows:

- Variations in numerous internodal lags throughout the networks, with differences also existing between the each of the historical floods.
- A detention basin at node AMB# was present in all the historical flood networks and not present in the design network.
- A small detention basin at node PUR5 was present in the 1974 flood network only.

The model was adopted with these differences to maintain consistency with the results in the Phases 1 and 2 study.

5.7.3 Rainfall losses

Initial and continuing losses adopted for the historical events were the same as those adopted in the previous study. The losses adopted are listed in Table 5.4.

Table 5.4 Adopted rainfall losses - historical events

Event	Initial loss (mm)	Continuing loss (mm/h)
Jan. 1974	0.0	0.0
June 1983	0.0	0.4
April 1989	0.0	0.4
May 1996	100.0	1.1

The Phases 1 and 2 report based these loss parameters upon matching recorded peak discharges, volumes and matching the limb of recorded hydrographs.

5.7.4 Historical model results

The historical flood networks were modified to include the changes as described previously. Results for the historical flood events are presented in Table 5.5. These results also provide an additional verification of the modifications made to the design network.

Table 5.5 **Historical peak flood flows from both current and previous RAFTS models**

Event	Purga Creek @ node—PUROUT dur. = 4.5 hours			Warrill Creek @ node—AMBOUT dur. = 18 hours			Bremer River @ node—6C dur. = 18 hours		
	Current (m^3/s)	Previous (m^3/s)	Diff %	Current (m^3/s)	Previous (m^3/s)	Diff %	Current (m^3/s)	Previous (m^3/s)	Diff %
Jan. 1974	854	841	+1.5	2,290	2,309	-0.8	1,438	1,455	-1.2
June 1983	366	366	0.0	352	360	-2.2	1,546	1,544	+0.1
April 1989	248	243	+2.0	286	287	-0.3	292	280	+4.3
May 1996	588	578	+1.7	426	425	+0.2	957	924	+3.6

The peak flows obtained from the modified networks compare well with previous study results.

5.8 DESIGN RAINFALL

5.8.1 Introduction

Storm events ranging from the 2-year ARI event to the PMP were investigated in this study. For each of these ARIs, a range of storm durations were also simulated. RAFTS was then used to produce inflow hydrographs necessary as input for the MIKE 11 model.

5.8.2 2-year to 100-year ARI events

The design rainfall depths and histograms for 2, 5, 10, 20, 50 and 100-year ARI events, with storm durations of 3, 4.5, 6, 9, 12, 18 and 24 hours were obtained from the Phases 1 and 2 RAFTS 'hydsys' storm data files. Design rainfall intensities were derived using Intensity Frequency Duration techniques described in Chapter 2 of Australian Rainfall and Runoff (Institution of Engineers Australia, 1987).

Design intensities were derived at approximately twenty locations across the three catchments, corresponding to existing rainfall stations. This rainfall data was then mapped and design rainfall intensities interpolated at each node (subcatchment).

A number of nodes from the previous RAFTS model were subdivided to create new nodes in the current model. Rainfall intensities from the subdivided nodes were applied uniformly to the new nodes.

5.8.3 Probable Maximum Precipitation (PMP)

A significant variable in the determination of a PMP rainfall depth is the catchment area. The catchment areas being considered in this study differ from those of the previous study. As a result, the PMP rainfall depths were reassessed and found to be significantly larger than those adopted for the previous study.

Derivation of PMP rainfall depths for storm durations of less than or equal to 6 hours was undertaken using the technique described in the Bureau of Meteorology Bulletin 53.

Derivation of the PMP rainfall depths for storm durations greater than 6 hours were based on the Australian Rainfall and Runoff 1998 Book VI—Estimation of Large to Extreme Floods. The variables used in the derivation of the PMP rainfall depths are listed in Table 5.6.

Table 5.6 Variables used in the derivation of PMP

Catchment	Area (km^2)	Latitude (°)	Coast (km)	Height (m AHD)
Bremer River	654.4	27.7	80	300
Warrill Creek	916.2	27.8	80	300
Purga Creek	222.8	27.8	80	300

Where 'coast' is the distance of the centroid of the catchment to the nearest ocean and 'height' relates to the average elevation of the intervening barrier (mountain range). Using these variables and either the Bulletin 53 method or the Generalised Tropical Storm Method (GSTM) PMP equations a series of rainfall depths were derived.

Representative PMP rainfall depths are presented in Table 5.7.

Table 5.7 PMP rainfall depths

Duration (hrs)	Bremer River (mm)	Warrill Creek (mm)	Purga Creek (mm)	Western Creek (mm)
3	330	310	400	450
4	380	350	450	510
5	410	380	480	550
6	440	410	530	600
12	720	690	760	
24	1,010	980	1,080	
48	1,460	1,420	1,560	

PMP rainfall depths over the Western Creek catchment were derived for durations up to 6 hours, using the Bulletin 53 methodology. Due to the small size of this catchment rainfall depths for durations of greater than 6 hours were derived within the broader Bremer River catchment.

A temporal pattern based on Bulletin 53 was adopted universally. The spatial distribution of the rainfall derived in the previous study was adopted for the current study.

5.8.4 200-year and 500-year ARI events

Rainfall depths for storm events with ARIs of between 100 years and the PMP are determined by considering the PMP, 100-year and 50-year events. Derivation of the temporal and spatial patterns for these rare events is entirely dependent on the temporal patterns adopted for the PMP.

The method adopted for the derivation of these rare events is described in detail in Book VI of AR&R 1998. To determine the magnitude of the design 200 and 500-year events rainfall depths from the 50-year and 100-year ARI events and the PMP are used. For the purpose of determining the intermediate rainfall depths the PMP was assigned an ARI of 10^6 years, based on the recommended value for the catchment sizes. Intermediate rainfall depths were then determined for the 2,000-year and 5,000-year ARI, to provide intermediate points on a log normal plot of ARI versus rainfall depth. A frequency curve is then drawn, passing through all the points and an areal design rainfall read off at the desired ARI.

Table 5.8 500-year ARI rainfall depths

Duration (hrs)	Bremer River (mm)	Warrill Creek (mm)	Purga Creek (mm)	Western Creek (mm)
3	162	151	165	220
4	168	161	175	234
5	176	172	185	250
6	186	179	193	261
12	214	212	222	
24	295	291	298	

Table 5.9 200-year ARI rainfall depths

Duration (hrs)	Bremer River (mm)	Warrill Creek (mm)	Purga Creek (mm)	Western Creek (mm)
3	141	133	140	194
4	148	141	148	205
5	154	150	155	218
6	162	157	163	229
12	186	187	189	
24	255	253	254	

5.9 DESIGN FLOWS

A summary of the results obtained from the RAFTS model is presented in Tables 5.10, 5.11, and 5.12. These tables contain a full set of downstream peak discharges generated using the RAFTS model.

Table 5.10 Purga Creek at node PUROUT—peak discharge

Storm duration (h)	Peak discharge (m^3/s) storm ARI—years								
	2	5	10	20	50	100	200	500	PMP
3	259	428	540	698	952	1,198	1,373	1,730	5,575
4							1,422	1,809	6,007
4.5	295	463	577	739	1,005	1,247			
5							1,425	1,827	5,848
6	292	456	559	419	959	1,172	1,413	1,767	5,930
9	229	372	463	588	789	948			
12	240	379	465	586	751	902	1,073	1,309	5,315
18	*198*	*289*	*344*	*423*	*536*	*627*			
24	115	226	293	400	551	716	788	961	4,039
48									2,964

Table 5.11 Warrill Creek at node AMBOUT—peak discharge

Storm duration (h)	Peak Discharge (m^3/s) Storm ARI—years								
	2	5	10	20	50	100	200	500	PMP
3	1	1	217	695	1,557	2,415	5.193	6,169	15,431
4							5,245	6,120	17,170
4.5	1	44	328	841	1,717	2,556			
5							5,117	5,991	17,027
6	1	87	363	390	1,657	2,426	5,004	5,842	16,551
9	1	123	408	802	1,582	2,237			
12	19	211	474	881	1,549	2,138	4,106	4,746	17,595
18	198	421	746	1,177	1,900	2,575			
24	122	286	488	807	1,311	1,898	4,117	4,775	16,665
48									14.363

Table 5.12 Bremer River at node 6C—peak discharge

Storm duration (h)	Peak discharge (m^3/s) storm ARI—years								
	2	5	10	20	50	100	200	500	PMP
3	0	2	179	453	874	1,269	1,816	2,074	4,474
4							1,917	2,200	5,048
4.5	0	35	253	524	947	1,326			
5							2,009	2,319	5,312
6	0	61	282	291	964	1,368	2,084	2,389	5,618
9	0	77	303	531	989	1,425			
12	10	136	337	647	1,095	1,545	2,458	2,794	9,297
18	128	299	498	747	1,187	1,546			
24	80	200	299	478	943	1,396	2,676	3,084	10,586
48									8,542

A critical duration event for each ARI in each of the three catchments was determined using the above results. These critical durations are summarised in Table 5.13.

Note that for rare events in Warrill Creek (Table 5.11) the peak discharges are relatively even. As a result the critical duration for these storms fluctuates widely. This result is due to the even nature of the temporal pattern used for rare events and the relatively long and uniform shape of the Warrill Creek catchment. For the more frequent events initial losses combined with a peakier temporal pattern produce a critical duration at the longer (18-hour) period.

Table 5.13 Critical duration peak discharges

	Purga Creek @ node PUROUT		Warrill Creek @ node AMBOUT		Bremer River @ node 6C	
ARI (years)	Crit. dur. (h)	Peak Q (m^3/s)	Crit. dur. (h)	Peak Q (m^3/s)	Crit. dur. (h)	Peak Q (m^3/s)
2	4.5	295	18	198	18	128
5	4.5	463	18	421	18	299
10	4.5	577	18	746	18	498
20	4.5	739	18	1,177	18	747
50	4.5	1,005	18	1,900	18	1,187
100	4.5	1,247	18	2,575	18	1,546
200	5	1,425	4	5,245	24	1,906
500	5	1,827	3	6,169	24	2,207
PMP	4	7,494	12	17,595	24	8,135

For each of the design flood events presented in Tables 5.10, 5.11 and 5.12 RAFTS output files containing hydrograph information at all nodes in the area covered by the MIKE 11 models were also generated. A summary of the nodes where results were obtained are presented in Tables 5.14, 5.15, 5.16, 5.17 and 5.18. The type of hydrograph generated at each node can be either local, incorporating flows from the relevant node only, or total, containing the routed runoff from that node and all nodes upstream. Also contained in the following tables are the MIKE 11 model inflow locations.

Figure 5.5 is a graphical representation of the locations of the inflow hydrographs.

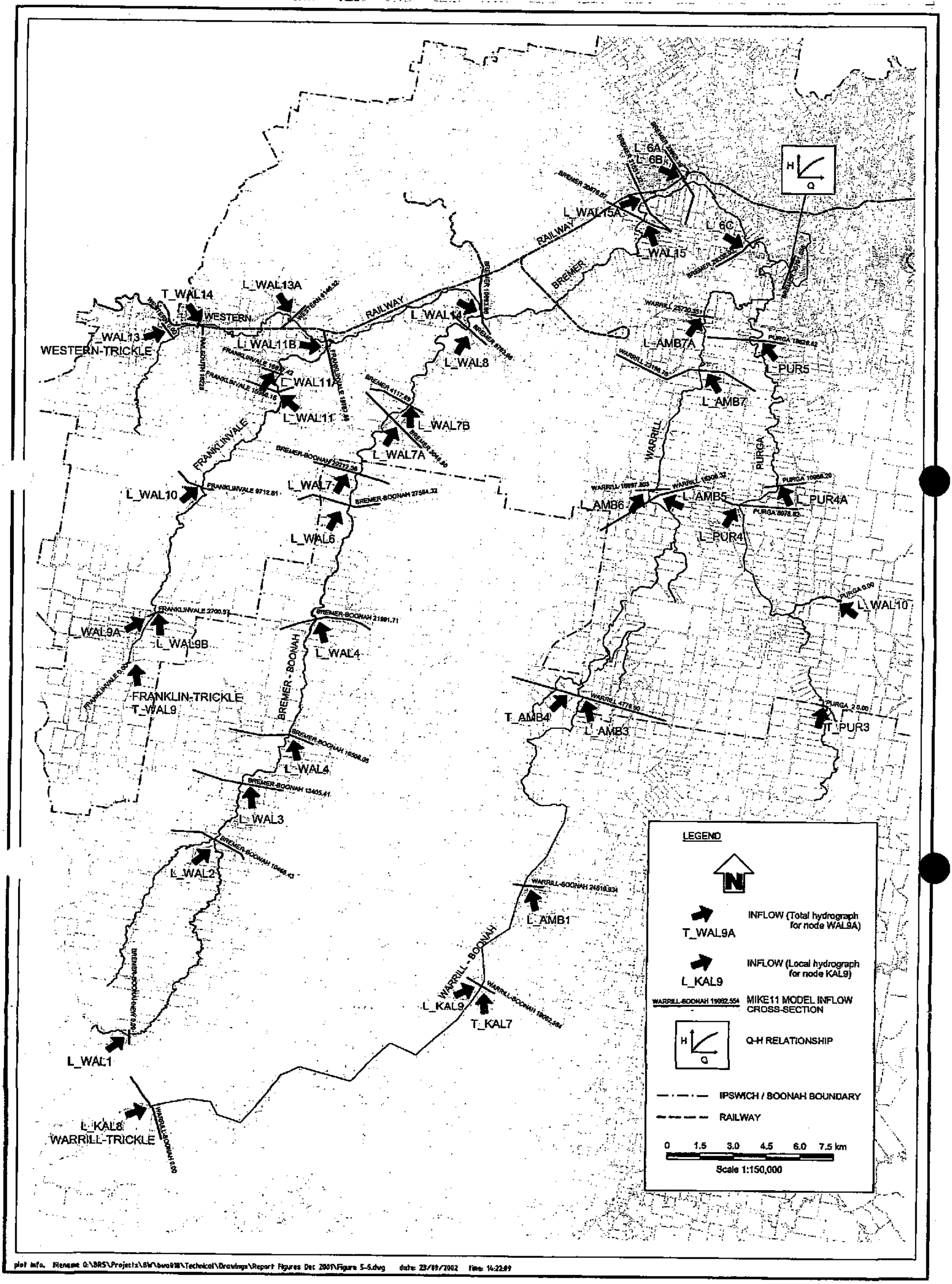

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Figure 5.5
IPSWICH RIVER FLOOD STUDY
MIKE11 MODEL
INFLOW LOCATIONS

Table 5.14 Purga Creek RAFTS output nodes

Node name	Hydrograph type	MIKE 11 inflow location (branch and chainage) (m)
PUR3A	Local	Purga 0.000
PUR3	Total	Purga_2 0.000
PUR4	Local	Purga 8978.823
PUR4A	Local	Purga 10988.203
PUR5	Local	Purga 18629.818

Table 5.15 Warrill Creek RAFTS output nodes

Node name	Hydrograph type	MIKE 11 inflow location (branch and chainage) (m)
KAL8	Local	Warrill_Boonah 0.000
KAL7	Total	Warrill_Boonah 19062.554
KAL9	Local	Warrill_Boonah 19062.554
AMB1	Local	Warrill_Boonah 24619.934
AMB3	Local	Warrill 4788.898
AMB4	Total	Warrill 4788.898
AMB5	Local	Warrill 16308.318
AMB6	Local	Warrill 16697.803
AMB7	Local	Warrill 23196.776
AMB7A	Local	Warrill 25720.351

Table 5.16 Bremer River RAFTS output nodes

Node name	Hydrograph type	MIKE 11 inflow location (branch and chainage) (m)
WAL1	Local	Bremer_Boonah 0.000
WAL2	Local	Bremer_Boonah 10466.430
WAL3	Local	Bremer_Boonah 13405.408
WAL4	Local	Bremer_Boonah 16506.063
WAL5	Local	Bremer_Boonah 21991.711
WAL6	Local	Bremer_Boonah 27584.323
WAL7	Local	Bremer_Boonah 29212.579
WAL7A	Local	Bremer 3048.804
WAL7B	Local	Bremer 4117.691
WAL8	Local	Bremer 9783.663
WAL15	Local	Bremer 20876.67
WAL15A	Local	Bremer 21851.313
6A	Local	Bremer 23968.389
6B	Local	Bremer 23968.389
6C	Local	Bremer 28338.03

Table 5.17 Franklinvale Creek RAFTS output nodes

Node name	Hydrograph type	MIKE 11 inflow location (branch and chainage) (m)
WAL9	Total	Franklinvale 0.000
WAL9A	Local	Franklinvale 2700.965
WAL9B	Local	Franklinvale 2700.965
WAL10	Local	Franklinvale 9712.809
WAL11	Local	Franklinvale 15950.149
WAL11A	Local	Franklinvale 16877.423
WAL11B	Local	Franklinvale 19787.884

Table 5.18 Western Creek RAFTS output nodes

Node name	Hydrograph type	MIKE 11 inflow location (branch and chainage) (m)
WAL13	Total	Western 0.000
WAL13A	Local	Western 6146.918
WAL14	Local	RailSouth 16228

5.10 CATCHMENT URBANISATION

Catchment urbanisation causes an increase in flood levels from both an increase in impervious area (producing a reduction in losses from rainfall) and from improvements in stream conveyance (causing a reduction in travel times). Floodplain management should include an allowance for future catchment development to ensure that flood planning levels allow for any increase in flood levels.

For the case of the catchments included in this project, the catchments are predominantly rural and future development will result in urbanisation of a small proportion of the total.

In addition, any future urbanisation will be located in the downstream reaches. Development in the lower reaches of a catchment allows runoff from this area to discharge before runoff from the main catchment arrives. This factor can tend to reduce runoff but because of the small area affected in this case, the effect will be insignificant.

Therefore while it would be regarded as desirable to consider future urbanisation, the impact for this project would be insignificant. There would be no value therefore in completing this analysis in this case.

5.11 CONCLUSIONS

It was assumed that the RAFTS model developed during Phase 1 and 2 of the Ipswich Rivers Flood Study was calibrated to an acceptable standard, and has been adopted for this stage of the study with minimal changes. Changes that have been made to the RAFTS model were necessary to accommodate the extraction of data for use in the

MIKE 11 model. The revised RAFTS model network was verified against design peak flood flows. Errors in this section impeded the verification process.

Where possible, the hydrology has been adopted without alteration, including the design events up to 100-year ARI for all catchments and the rarer events over the Purga Creek catchment. New design PMP, 200-year ARI and 500-year ARI rainfall events were developed for the Bremer River and Warrill Creek, based on the techniques described in Australian Rainfall and Runoff 1998.

6 Hydraulic model establishment

6.1 GENERAL

The software package MIKE 11 (version 2000B) is being used to undertake the hydraulic modelling. MIKE 11 is a full hydrodynamic one-dimensional model that can be networked to represent quasi-two dimensional flow conditions, and is widely accepted for this type of application. A network of flow paths is set up, and cross-sections are used to define their flow capacity and storage volume. The model also includes hydraulic structures for culverts, bridges and weirs. The runoff routing model RAFTS is used to generate input hydrographs for the MIKE 11 model.

6.2 AVAILABLE SURVEY DATA

The MIKE 11 model requires data to represent cross-sections, roughness values, culverts and weirs. The available data used to prepare these inputs included:

- surveyed cross-sections of the Bremer River, Western Creek, Warrill Creek, Franklinvale Creek and Purga Creek, provided by both Ipswich City Council and Department of Natural Resources and Mines;
- bridge and culvert surveys from Ipswich City Council;
- aerial photography;
- on-site photography.

Where the MIKE 11 model required to be extended into Boonah Shire, necessary survey information and details of hydraulic structures were supplied by Boonah Shire Council.

The data used in the MIKE 11 model and described here was all obtained from field survey and was regarded as accurate. Checks of the consistency of the data indicated that it was suitable for the hydraulic modelling required in this project.

In addition to the surveyed cross sections, photogrammetry was also supplied to provide the general extent of the floodplain.

There were primarily two main sources of photogrammetry relevant to the generation of the Digital Elevation Model used in the Phase 3 study. Photogrammetry was supplied from both Ipswich City Council and the Department of Natural Resources and Mines (DNR&M), both of which had different contour intervals and accuracy limits. The extent of the photogrammetric information supplied for each source is presented graphically in Figure 6.1.

The Ipswich City Council photogrammetric information was supplied at 0.5m contour intervals and predominantly covers an area located downstream of the Phase 3 study site. There was a small region of 0.5m contour information used in the generation of the DEM in the region downstream of Five Mile Bridge on the Bremer River. The accuracy disclaimer on the ICC photogrammetry information has been claimed to be less than 90% of the half contour interval. This suggests that the levels obtained in this location are less than +-0.25m. Comparisons between the field survey and DEM levels have indicated that the disclaimer on the accuracy limits appear to be acceptable.

The photogrammetric information supplied by DNR&M covers most of the area within the study site. Unlike the ICC photogrammetric information, the contour interval for this data is at 5 m. Again, the disclaimer on this information is stated to be less than 90% of the half contour information (i.e. +2.5 m); however, analysis on the accuracy between the DEM and the field survey has indicated that the difference in elevation is closer to 5 m. This larger than expected difference in elevation may have been caused by the fact that even though 5m contours were used in the generation of the surface TIN, the 20 m grid used to extract elevations may be introducing additional error into elevations.

Therefore while the field survey has been regarded as sufficiently accurate for the hydraulic modelling, there are apparent problems with the accuracy of the photogrammetry for the general floodplain survey.

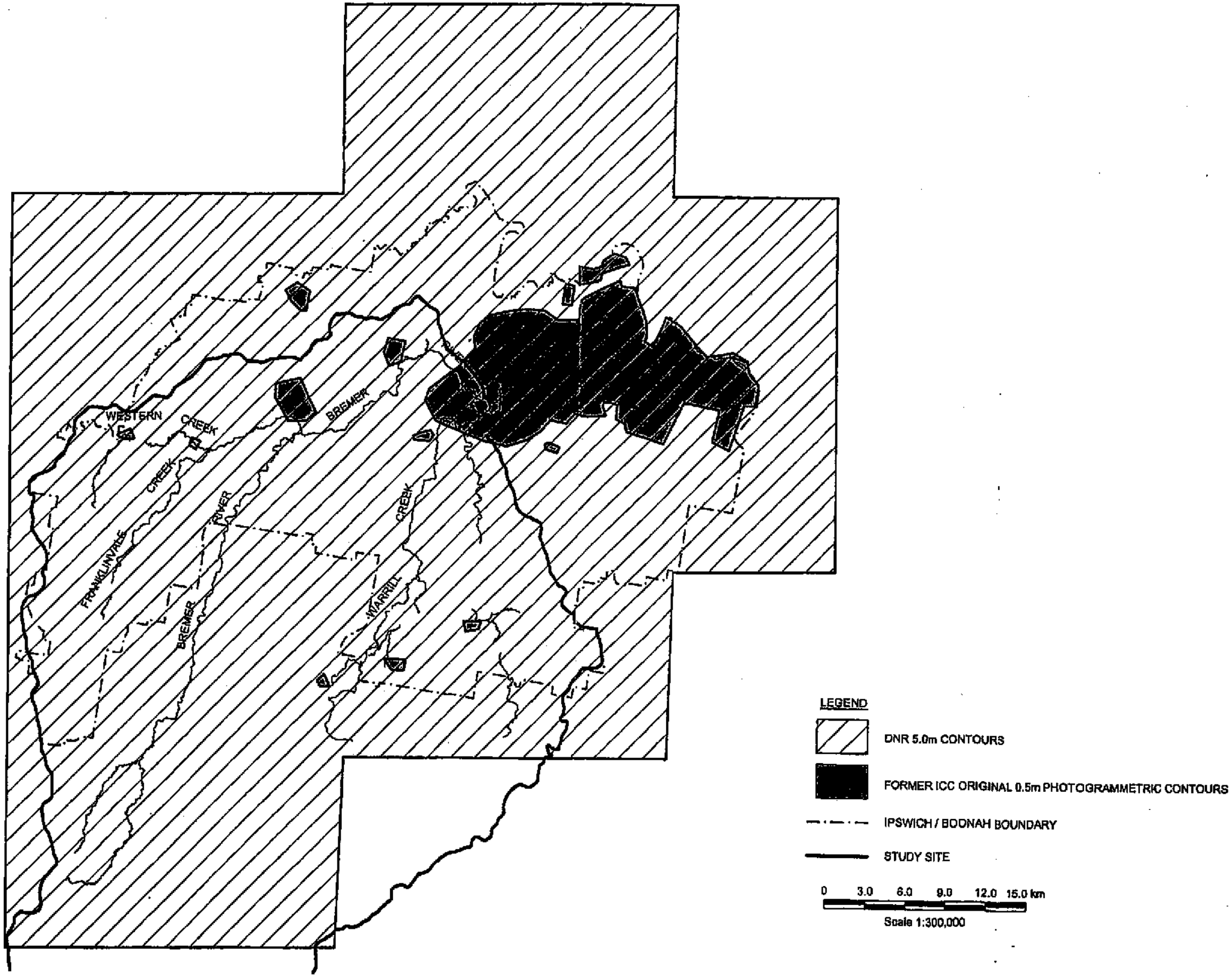

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Figure 6.1
PHOTOGRAMMETRIC INFORMATION USED IN THE CREATION OF THE DEM

6.3 MODEL SET-UP AND ASSUMPTIONS

6.3.1 Model layout and major reaches

The MIKE 11 model layout is shown in Figure 6.2. The model layout has been developed to provide the best representation of flow patterns in an ARI 100-year flood event although flow patterns greater than the 100-year event, are also accurately represented. As the larger events are not contained within the channel and escape onto the flood plain, the total length of each of the reaches have been adjusted to simulate the behaviour of the catchment. In short, the meandering channel has not been used in determining the cross-section chainages.

Notwithstanding, flow patterns for smaller flood events may differ from the adopted flow paths in some areas, especially where the channels meander significantly.

On Western Creek, the Ipswich to Rosewood railway line runs parallel (predominantly west to east) to the watercourse and divides the valley. To accurately represent the hydraulics of the railway, the creek was broken up and modelled as two distinct flow paths. The flow path located to the North of the railway is called 'RailNorth', and the flow path to the South is called 'RailSouth.'

The hydraulic model covering the Phase 3 Flood Study consists primarily of 8 branches. These are briefly summarised below:

- 'Bremer_Boonah' 0–29,212 m represents the Bremer River located in Boonah Shire within the study area.
- 'Bremer' 0–30,791 m represents the Bremer River located in Boonah Shire within the study area.
- 'Warrill_Boonah' 0–30,305 m represents Warrill Creek located in Boonah Shire within the study area.
- 'Warrill' 0–33,860 m represents Warrill Creek from the study area boundary to its junction with 'Bremer' 30,091 m.
- 'Purga' 0–22,343 m represents Purga Creek from the study area boundary to its junction with 'Warrill' 30,886 m.
- 'RailNorth' 0–16,228 m represents Western Creek north of the railway line from the study area boundary to its junction with 'Bremer' 11,310 m.
- 'RailSouth' 0–16,228 m represents Western Creek south of the railway line from the study area boundary to its junction with 'Bremer' 11,310 m.
- 'Franklinvale' 0–20,087 m represents Franklinvale Creek to its junction with Western Creek (or RailSouth 8,324 m).

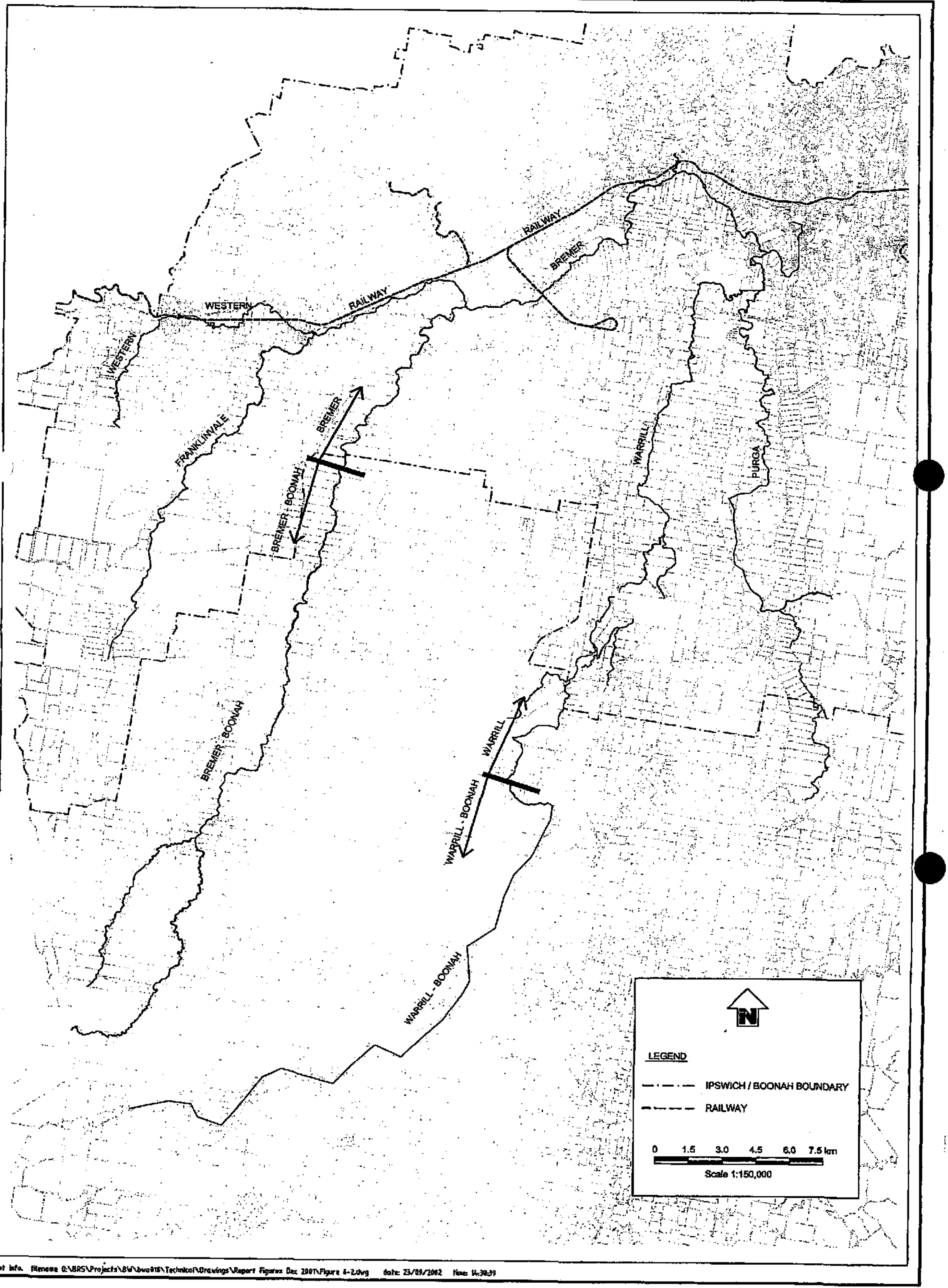

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Figure 6.2
IPSWICH RIVER FLOOD STUDY
MIKE11 MODEL LAYOUT

6.3.2 Cross-links and transfer of flow

Short additional flow paths (with culvert and/or weir structures) were added at specific locations to allow transfer between these major flow paths, particularly between 'RailSouth' and 'RailNorth'. Additional storages (or 'side storages') outside the boundaries of the major flow paths were also included in the model. The determination and location of side storage was estimated from a 1m contour interval map. Additional storages deemed to have a significant impact on flood level, which were incorporated into the MIKE 11 model were at the intersection of Campbell's Gully and Guilfoyles Creek with the Bremer River. Potential storages located on Franklinvale Creek were not incorporated into the model due to the steep terrain and insufficient small storage volume.

Additional 'cross-links' have been included into the hydraulic model at the confluences of the major reaches. Flow via these cross-links is controlled by a weir structure. The controlling weir structure is defined by a 'ridge-line' or 'high ground', which separates the two reaches. Multiple weir structures have been used in representing flow patterns when the Ipswich to Rosewood railway line is overtopped. The locations of these cross-links and controlling weirs are presented in Figure 6.3.

6.3.3 Culvert structures

Major culverts (located under both rail and road crossings) on the primary flow paths were included into the MIKE 11 model. A total of 66 individual structures have been modelled within the study site. These structures were selected as they were deemed to have sufficient hydraulic impact that is capable of affecting peak water levels upstream and downstream and hence alter the flood regulation lines.

Detailed field survey information in conjunction with details contained within Council's GIS system was often sufficient to accurately represent each of the structures. Where there was a lack of structure information (e.g. deck thickness), photographs of the bridge crossings were used in making assumptions.

Table 6.1 is a summary of all structures included in the model. The locations of each of these structures are presented graphically in Figure 6.4.

6.3.4 Bridge modelling approach

Bridge crossings located within the study site have been modelled as a irregular shaped culvert using a stage-water way width relationship. The effect of piers and abutment locations on the waterway area were taken into account when deriving these relationships. The underside of the bridge deck was used to define the vertical limitation of the irregular shaped culvert.

For each of the bridge structures (or irregular shaped culverts), a global Manning's n roughness value of 0.02 has been applied. This value has been previously adopted for similar structures in similar projects. This assumption provides a realistic representation of the head loss across bridge structures. For standard culvert structures, a Manning's n value of 0.015 has been used.

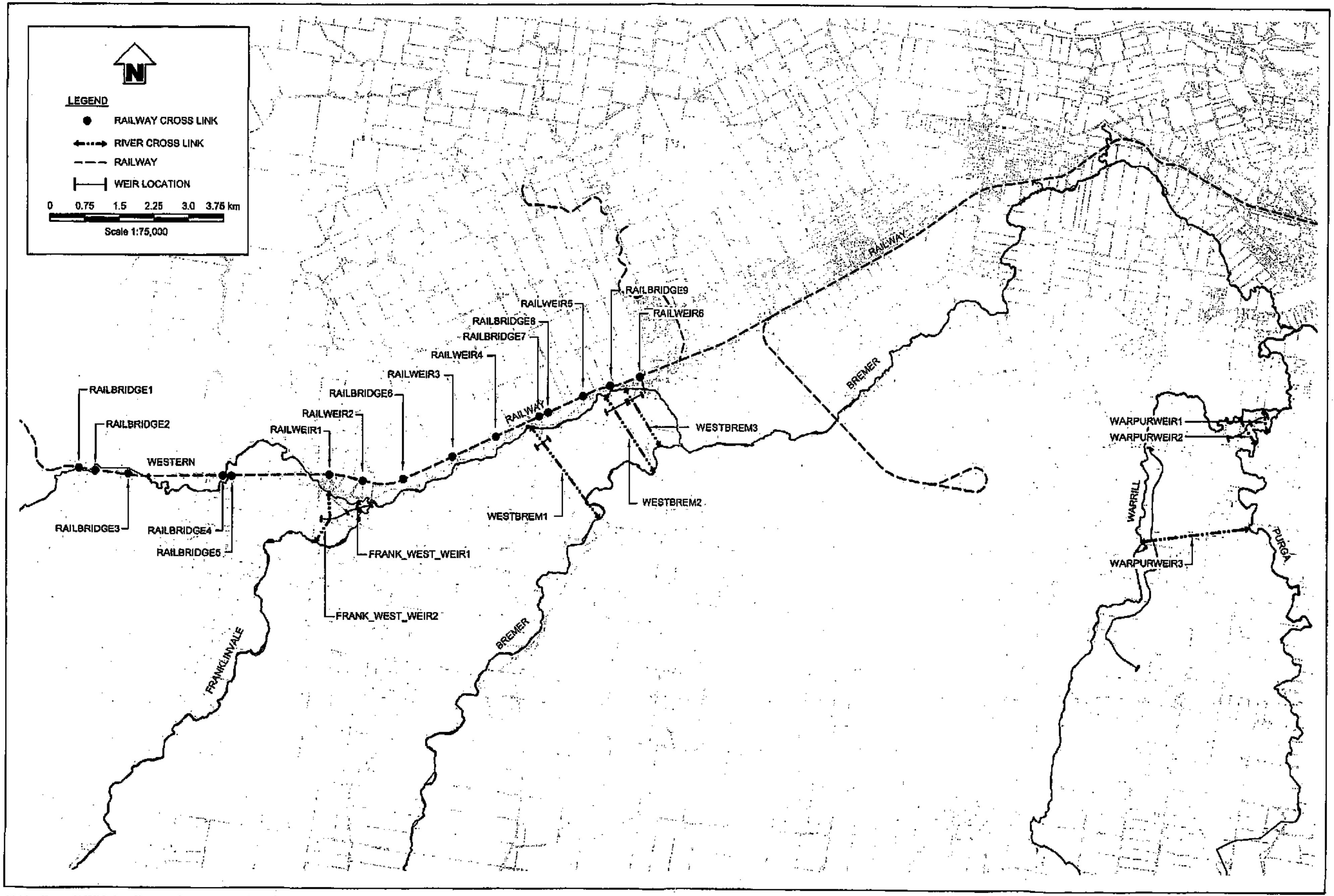

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Figure 6.3
IPSWICH FLOOD STUDY
CROSS LINKS

6.3.5 Weir structures

Weir structures were also incorporated into the model and were used to model flows overtopping roads and embankments. For each bridge/culvert structure a weir has been applied.

Weirs have been modelled by using stage-water way width relationships.

6.3.6 Model assumptions

There were several assumptions made in the hydraulic model that must be clearly understood when considering the results of the analysis. The key assumptions include:

- the model flow paths are reasonably accurate representations of real flow patterns for the modelled floods;
- culverts remain unblocked by debris;
- the waterway size and shape does not change (i.e. no erosion or deposition);
- the roughness values for the waterways do not change during or between flood events.

Table 6.1 Summary of hydraulic structures

	Reach	Chainage (m)	U/s invert (m AHD)	D/s invert (m AHD)	Length (m)	Manning's n	No. of culverts	Structure details	Culvert obvert (m AHD)	Controlling weir level (m AHD)	Structure no.	Crossing name
1	Bremer	2482.00	43.72	43.72	9.00	0.015	5	3.66m x 2.7m RCBC	46.42	46.73	23249	Mt. Walker West
2	Bremer	9793.663	33.70	33.70	10.00	0.02	1	26.6m wide	37.83	38.74	n/a	Rosewood–Warrill View Road
3	Bremer	11482.63	33.50	33.50	3.40	0.020	1	15.8m wide	36.12	37.08	6401	Keane's Road
4	Bremer	14410.00	27.11	27.11	10.00	0.020	1	46.5m wide	34.10	34.78	50001	Jeebropilly
5	Bremer	15070.00	29.41	29.41	10.00	0.020	1	60.8m wide	33.35	34.05	50002	7 Mile Creek
6	Bremer	19370.00	22.81	22.81	10.00	0.020	1	35.4m wide	26.88	27.52	50003	5 Mile Creek
7	Bremer	29525.00	11.12	11.12	6.00	0.020	1	71.6m wide	16.50	17.50	7401	3 Mile Creek
8	Bremer-Boonah	11926.89	91.79	91.79	10.00	0.020	1	56.0m wide	95.76	96.45	n/a	n/a
9	Bremer-Boonah	11926.89	96.46	96.41	10.00	0.015	6	1.8 x 1.2m RCBC	97.66	96.45	n/a	n/a
10	Bremer-Boonah	13934.22	82.53	82.53	5.00	0.020	1	17.9m wide	86.39	86.73	n/a	n/a
11	Bremer-Boonah	16512.06	76.10	76.10	10.00	0.020	1	43.0m wide	79.33	80.03	n/a	n/a
12	Bremer-Boonah	24551.71	56.64	56.64	5.00	0.015	3	2.7m x 0.9m RCBC	57.54	57.78	n/a	n/a
13	Franklinvale	5623.15	91.72	91.72	4.10	0.020	1	8.2m wide	95.59	96.29	4208	Franlinvale Road
14	Franklinvale	8835.62	82.39	82.39	5.00	0.020	1	11.5m wide	87.45	85.32	4351	Meadow Flat Road
15	Franklinvale	17032.00	57.54	57.54	3.00	0.020	1	8m wide	59.26	59.96	5305	Cummings Road
16	Purga	2996.06	45.73	45.73	6.50	0.020	1	35.9m wide	49.34	49.92	1008	Ipswich-Boonah Road
17	Purga	12796.29	24.26	24.26	4.80	0.020	1	34.0m wide	28.42	29.47	7302	Purga School Road
18	Purga	19940.56	16.16	16.16	10.30	0.020	1	63.2m wide	26.06	22.19	n/a	Old Cunningham Hway
19	Purga	19940.56	15.67	15.67	9.00	0.020	1	40.2m wide	22.36	22.19	n/a	Old Cunningham Hway
20	Purga	19940.56	19.45	19.45	9.00	0.020	1	14.0m wide	21.84	22.19	n/a	Old Cunningham Hway
21	Purga_2	30.85	59.15	59.10	8.46	0.015	6	1.2 x 1.2 RCBC	59.35	60.33	n/a	Washpool Road
22	Purga_2	30.85	57.99	57.96	11.76	0.015	3	0.375m RCP	58.36	60.33	n/a	Washpool Road
23	Purga_2	2888.285	50.12	50.12	3.30	0.020	1	15.4m wide	52.36	53.71	7202	Dwyers Road Bridge
24	RailBridge1	10.00	84.20	84.20	10.00	0.015	72	1.2m x 0.95m RCBC	85.15	86.00	72681	Ipswich-Rosewood R'way
25	RailBridge2	10.00	79.55	79.55	10.00	0.020	1	23.5m wide	84.15	85.15	72682	Ipswich-Rosewood R'way
26	RailBridge3	10.00	72.00	72.00	10.00	0.020	1	20.7m wide	77.70	81.44	72684	Ipswich-Rosewood R'way
27	RailBridge3	10.00	79.62	79.62	10	0.015	1	2.5m x 1.8m RCBC	81.37	81.44	72683	Ipswich-Rosewood R'way
28	RailBridge4	10.00	67.40	67.40	10.00	0.020	1	16.5m wide	69.97	70.75	72686	Ipswich-Rosewood R'way

Table 6.1 (continued)

	Reach	Chainage (m)	U/s invert (m AHD)	D/s invert (m AHD)	Length (m)	Manning's n	No. of culverts	Structure details	Culvert obvert (m AHD)	Controlling weir level (m AHD)	Structure no.	Crossing name
29	RailBridge5	10.00	64.06	64.06	10.00	0.020	1	33.2m wide	69.56	70.66	72687	Ipswich-Rosewood R'way
30	RailBridge6	10.00	52.28	52.28	10.00	0.015	2	1.5m x 1.7m RCBC	53.94	n/a	n/a	Ipswich-Rosewood R'way
31	RailBridge7	10.00	45.66	45.66	10.00	0.020	1	17.3m wide	47.31	n/a	72692	Ipswich-Rosewood R'way
32	RailBridge8	10.00	43.58	43.58	10.00	0.020	1	21.1m wide	46.63	n/a	72693	Ipswich-Rosewood R'way
33	RailBridge9	10.00	43.60	43.60	10.00	0.02	1	18.4m wide	44.97	n/a	n/a	Ipswich-Rosewood R'way
34	RailBridge9	10.00	41.80	41.80	10.00	0.02	1	27.1m wide	44.50	n/a	n/a	Ipswich-Rosewood R'way
35	RailBridge9	10	40.67	40.67	10.00	0.02	1	27.2m wide	43.73	n/a	n/a	Ipswich-Rosewood R'way
36	RailSouth	9781.72	44.79	44.79	8.00	0.020	1	36.1m wide	52.47	50.70	5303	Kuss Road
37	RailSouth	12400.00	40.80	40.80	4.20	0.020	1	18.6m wide	43.41	44.05	5405	Strongs Bridge
38	RailSouth	14848.00	35.09	35.09	4.20	0.020	1	21.8m wide	40.91	41.14	n/a	Warrill View Road
39	Railweir1	10.00	57.93	57.93	10.00	0.015	1	1.8m x 2.1 RCBC	60.08	60.00	72690	Ipswich-Rosewood R'way
40	Railweir1	10.00	56.87	56.87	10.00	0.015	1	1.2m x 1.2m RCBC	58.12	60.00	72691	Ipswich-Rosewood R'way
41	Railweir4	10.00	47.55	47.45	10.00	0.015	5	1.8m x 1.5m RCBC	49.05	49.68	72694	Ipswich-Rosewood R'way
42	Railweir5	10.00	43.40	43.40	10.00	0.020	1	22.9m wide	46.72	46.62	n/a	Ipswich-Rosewood R'way
43	Railweir6	10.00	40.11	40.11	10.00	0.02	1	24.4m wide	42.37	46.33	n/a	Ipswich-Rosewood R'way
44	Warrill	2434.10	53.62	53.62	5.00	0.015	10	1.2m RCP	54.82	49.26	72636	Wilsons Plains Road
45	Warrill	2434.10	49.74	49.74	5.00	0.020	1	16.6m wide	57.17	49.26	72635	Private Rd
46	Warrill	3493.49	51.02	50.97	4.95	0.015	1	2.4m x 0.65m RCBC	51.67	46.18	72639	n/a
47	Warrill	4788.90	46.98	46.98	4.20	0.020	1	27.9m wide	49.53	49.22	6202	Fresser's Bridge
48	Warrill	6402.07	44.34	44.33	5.00	0.015	1	0.3m RCP	44.64	42.29	6402	n/a
49	Warrill	7121.27	42.70	42.70	5.00	0.015	1	2.1m x 0.6m RCBC	43.30	38.63	72645	Private Rd
50	Warrill	7121.27	42.40	42.40	5.00	0.015	1	3.3m x 0.9m RCBC	43.30	38.63	72645	Private Rd
51	Warrill	11589.99	36.69	36.69	5.50	0.020	1	23.2m wide	40.75	37.40	6205	Mutdapilly-Churchbank Rd
52	Warrill	11589.99	36.72	36.70	5.50	0.015	5	1.2m x 0.48m RCBC	37.20	37.40	6205	Mutdapilly-Churchbank Rd
53	Warrill	25720.35	17.11	17.11	10.00	0.020	1	99.3m wide	26.84	26.84	72700	Cunningham Road
54	Warrill-Boonah	3392.50	133.85	133.85	10.00	0.020	1	32.7m wide	136.84	137.54	50023	Villis Bridge
55	Warrill-Boonah	15989.89	78.42	78.42	8.00	0.020	1	37.0m wide	87.46	88.06	50026	Maclean Bridge
56	Warrill-Boonah	19454.64	68.76	68.76	10.00	0.020	1	51.6m wide	77.80	75.08	50022	Kalbar Bridge
57	Warrill-Boonah	26310.71	59.10	59.10	8.00	0.020	1	32.4m wide	64.22	64.92	50027	-

Table 6.1 (continued)

	Reach	Chainage (m)	U/s invert (m AHD)	D/s invert (m AHD)	Length (m)	Manning's n	No. of culverts	Structure details	Culvert obvert (m AHD)	Controlling weir level (m AHD)	Structure no.	Crossing name
58	Warrill-Boonah	30804.86	53.77	53.77	7.35	0.020	1	24.1m wide	60.30	57.58	50021	Walter Harsant Bridge
59	Warrill-Boonah	30804.86	54.00	54.00	7.35	0.020	1	40.0m wide	58.30	57.58	6104	Radford Rd
60	Warrill-Boonah	30804.86	59.00	59.00	5.10	0.015	2	1.2m x 0.6m RCBC	60.40	57.58	6105	Radford Rd
61	Warrill-Boonah	30804.86	59.20	59.20	5.10	0.015	2	1.2m x 0.6m RCBC	60.20	57.58	6192	Wilsons Plains
62	Western	858.96	85.28	85.28	7.30	0.015	4	0.9m x 0.9m RCBC	86.18	85.74	72679	Rosewood-Laidley Road
63	Western	858.96	85.31	85.31	7.30	0.015	3	0.95m x 0.8m RCBC	86.11	85.74	72680	Rosewood-Laidley Road
64	Western	858.96	79.43	79.43	7.30	0.020	1	23.8m wide	85.95	85.74	72678	Grandchester-Mt Mort Road
65	Western	6898.85	54.09	54.09	4.50	0.020	1	27.3m wide	60.29	59.96	5301	Hiddenvale Road
66	Western	6898.85	55.62	55.62	4.50	0.020	1	39.8m wide	60.92	59.96	5301	Hiddenvale Road

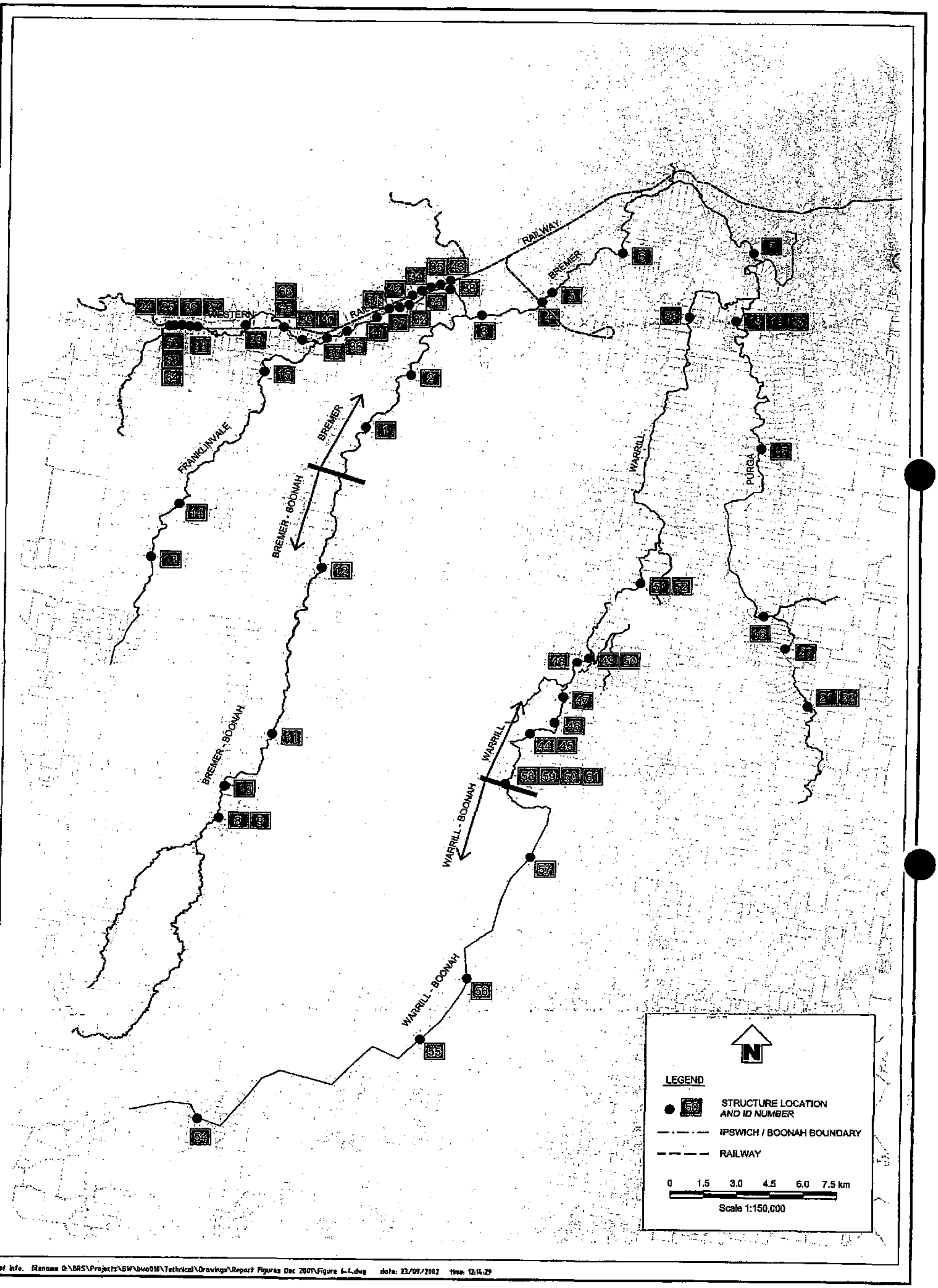

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Figure 6.4
IPSWICH RIVER FLOOD STUDY
STRUCTURE LOCATIONS

6.3.7 Tailwater boundary conditions

A water level—discharge relationship (or Q-H relationship) was used as the downstream boundary condition for the MIKE 11 model.

An initial derivation of the Q-H relationship to be used for the model was obtained from the SKM model used in Phases 1 and 2. The Q-H relationship consistent with the SKM model was based on the assumptions of Manning's n values of 0.13 for the floodplain and an n value of 0.17 for the channel.

This relationship was considered to be to be over-conservative and it is recommended that for this Phase 3 investigation, a new level–discharge relationship be derived from adopting a global Manning's n of 0.090. This has resulted in lower water levels for given discharges.

6.4 MODEL CALIBRATION

To calibrate the model, four major rainfall events were investigated. These are:

- January 1974
- June 1983
- April 1989
- April 1996.

For each event, stream gauge data from the following locations were used:

1. Bremer River at Walloon
2. Warrill Creek at Amberley
3. Purga Creek at Loamside.

The locations of each of these stream gauges are presented in Figure 6.5. Table 6.2 is a summary of the approximate MIKE 11 Branch and Chainage equivalent to the location of each of the stream gauges.

Table 6.2 Location of Stream Gauges

Stream gauge	Approximate MIKE 11 location (branch and chainage) (m)
Bremer River at Walloon	Bremer 22410.57
Warrill Creek at Amberley	Warrill 25710.35
Purga Creek at Loamside	Purga 15308.54

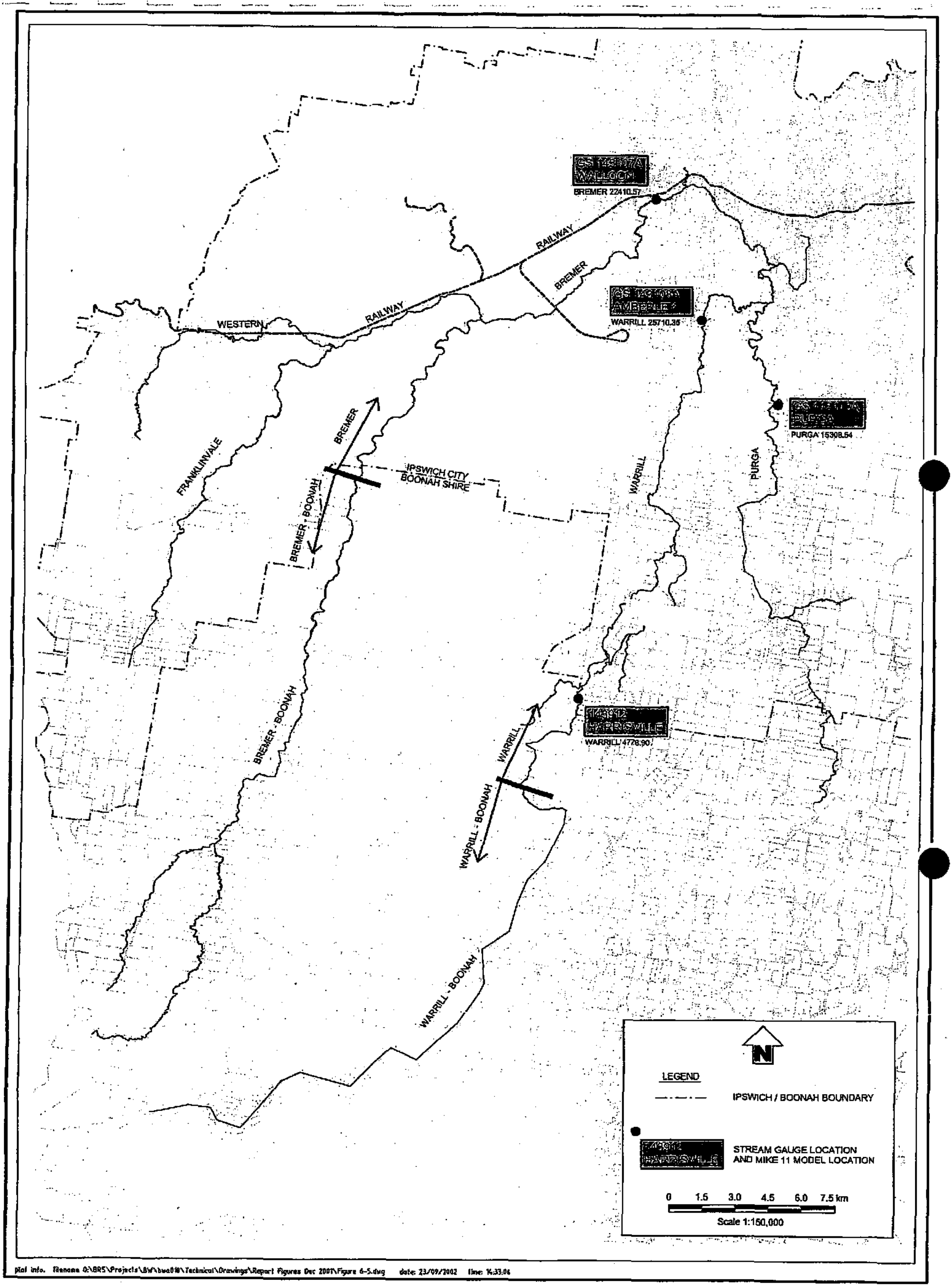

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Figure 6.5
IPSWICH RIVER FLOOD STUDY
STREAM GAUGE LOCATIONS

With the exception of the gauging station located on Bremer River, the remaining gauges have recorded peak water elevations for all four historical events. No historical information was available at the Bremer River gauge for the January 1974 event.

Table 6.3 compares the recorded and calculated peak water levels at the three gauging station locations for each of the historical events.

Table 6.3 Model calibration—comparison of peak water levels

Stream gauge	Storm year	Observed peak water elevation (m AHD)	Calculated peak water elevation (m AHD)	Difference (m)
Bremer at Walloon	1974	n/a	28.51	n/a
	1983	24.78	25.58	0.30
	1989	23.62	23.65	0.03
	1996	25.78	26.11	0.33
Warrill Creek at Amberley	1974	28.69	28.59	-0.10
	1983	25.13	24.96	-0.17
	1989	23.56	24.11	0.55
	1996	25.18	24.99	-0.19
Purga Creek at Loamside	1974	27.65	27.88	0.23
	1983	26.08	26.63	0.55
	1989	25.75	26.10	0.35
	1996	26.39	27.17	0.78

The calibration of the MIKE 11 did not involve alteration to the RAFTS modelling undertaken in earlier studies, as a result limited parameters for calibration were able to be modified.

Adjustment of the Manning's n roughness has been used to calibrate the model, and an iterative approach was adopted to obtain the best calibration of the model. This approach resulted in relatively 'smooth' or low global Manning's n value of 0.045. Although lower than the n value of 0.05 used in the storage calculations (for RAFTS model), this value is still within reasonable limits. Comparison of the roughness values used in the previous study however, has identified that the roughness values adopted previously appear to be higher than those recommended in literature.

Figures 6.6 to 6.16 illustrate the comparison of peak water levels produced from the MIKE 11 modelling with the associated gauging station for each of the historical events.

6.4.1 1974 calibration event

Results produced from the 1974 calibration event (the largest of the recorded historical events) are presented in Figures 6.6 and 6.7. From these, it can be seen that both the modelled peak water levels are within 0.23 m of those recorded and the timing of the peaks have coincided within acceptable limits. Also evident from these figures is that both recording gauges operating during the event have a significantly longer falling limb than the modelled stage hydrograph. This may have resulted from the adoption of a lower Manning's n value throughout the study site.

In addition to using the three available stream gauge information, observed water elevations located relevant to the study site recorded during the 1974 event were also used in the calibration of the hydraulic model.

There were three locations of observed water elevations that could be used in the calibration. Most of these observations were taken near Amberley Airfield which is located at the downstream end of the study area, near the confluence of the Bremer River and Warrill Creek.

Table 6.4 is a summary of model results with the observed peak water levels.

Table 6.4 Model calibration—comparison of model results with observed peak water levels (1974 Event Only)

Observation Point No.	Location description of observed peak water level	Approximate MIKE 11 location (branch and chainage) (m)	Observed peak water elevation (m AHD)	Calculated peak water elevation (m AHD)	Difference (m)
1	Warrill Creek *(approx 485m downstream of Cunningham Highway)*	Warrill 26219.35	28.64	28.05	-0.59
2	Bremer River *(approx 740m d/s of junction of Bremer River and Warrill Creek)*	Bremer 30791.04	26.0	26.6	0.61
3	Bremer River *(at junction of Bremer River and Warrill Creek)*	Bremer 30091.04	26.6 - 26.7	26.67	0.03

The three locations presented in the above table were utilised in the calibration of the hydraulic model, however it should be recognised that this information may contains a significant degree of inaccuracy and uncertainty.

Issues concerned with the suitability of these points for calibration are discussed below:

Point 1 - Warrill Creek (approx 485m d/s of Cunningham Highway)

An observed peak water surface elevation of 28.64m AHD was recorded at a location approximately 485m d/s of the Cunningham Highway. In comparison, a modelled peak elevation at this location was 28.05m AHD, 0.59m lower than the observed. It should be noted that at the Warrill Creek gauging station located at Amberley which is located near the Cunningham Highway, the recorded 1974 peak elevation was 28.69m AHD, only a small difference of 0.04m from the observed water level. At this gauging station, the MIKE11 model was accurate to within 0.1m (refer Table 6.3).

The small variation in level (0.04m in 485m) between the gauging station and the observed water level may indicate a backwater effect caused by a constriction along

Warrill Creek or from the confluence of Bremer River and Warrill Creek. As the model is matching observations at the confluence of Bremer River and Warrill Creek, it is believed the former may be occurring here. Unfortunately there were no observations along Warrill or Purga Creek for the other three historical events to support this.

Point 2 - Bremer River (740m d/s of junction of Bremer River and Warrill Creek)

Several peak water level observations were recorded at a location 740m d/s of the junction of Bremer River and Warrill Creek. This area is also located where the Q-H boundary for hydraulic model is applied. The observed water levels recorded here were 26.0m AHD, approximately 0.67m lower than that obtained from hydraulic modelling. It is believed that this observed spot level is not considered accurate, due to several other peak elevation observations located a short distance upstream being considerably higher (ie. approx. 26.7m AHD).

Furthermore, approximately 2580m downstream of the Point 2, additional observations of 25.4m AHD were recorded. If the observed peak water level of 26.0m AHD did occur, an extremely flat water slope of 0.02% would need to occur in order to match the recordings further downstream.

Point 3 - Bremer River (at junction of Bremer River and Warrill Creek)

Point 3 is located very close to Amberley Airfield and is considered the most reliable of the peak water observations. The observed level here was recorded at 26.6 - 26.7m AHD which compares favourably to the modelled peak water elevation of 26.67m AHD.

6.4.2 1983 calibration event

With the exception of the Warrill Creek at Amberley Station, the calibration achieved for the 1983 event was the least accurate of the four historical events. Model results produced at the remaining stations on Bremer River and Purga Creek were both higher than the recorded levels by 0.80 m and 0.55 m respectively.

The continuing overestimation of peak levels at the monitoring stations despite the low Manning's n values indicate there could be inconsistencies with the hydrology generated during the previous study.

The timing of the modelled peak levels for the 1983 event at both Warrill and Purga Creek are quite acceptable with those measured.

6.4.3 1989 calibration event

This event is the smallest of the historical events examined in the calibration analysis. A comparison of modelled and measured peak levels has again indicated that the model is overestimating. Peak levels are within 0.55m for both Warrill and Purga Creeks but are only within 0.03 m for the Bremer River station gauge.

The hydrology used for this event has produced 'twin peaks' in the MIKE 11 model results, however the shape of these modelled stage hydrographs do not seem to have occurred at the monitoring stations of Warrill Creek and Purga Creek. The Bremer

River at Walloon station, despite demonstrating two distinct 'peaks' during the event, shows some difference in the timing of the event.

6.4.4 1996 calibration event

The latest historical event used in the calibration of the hydraulic model has produced a good match between peak levels, and the shape and timing of the stage hydrographs. All of the monitoring stations in the study site have measured several peaks in this storm event. Stations located at Bremer River and Purga Creek have identified four peaks, while the station at Warrill Creek monitored 3 distinctive flatter peaks.

Despite, model results at the Purga Creek Station overestimating peak levels by 0.78m, the remaining stations at Bremer River and Warrill Creek have produced model results within 0.33 m and 0.19 m respectively.

6.4.5 Calibration conclusions

Isolated lower values of Manning's n values may have been adopted to improve the calibration results presented in Table 6.3 above, however this may affect the timing of the peak levels. In conclusion, without adjustment to the loss parameters of each of the catchment, the calibration of the MIKE 11 has been achieved to acceptable limits.

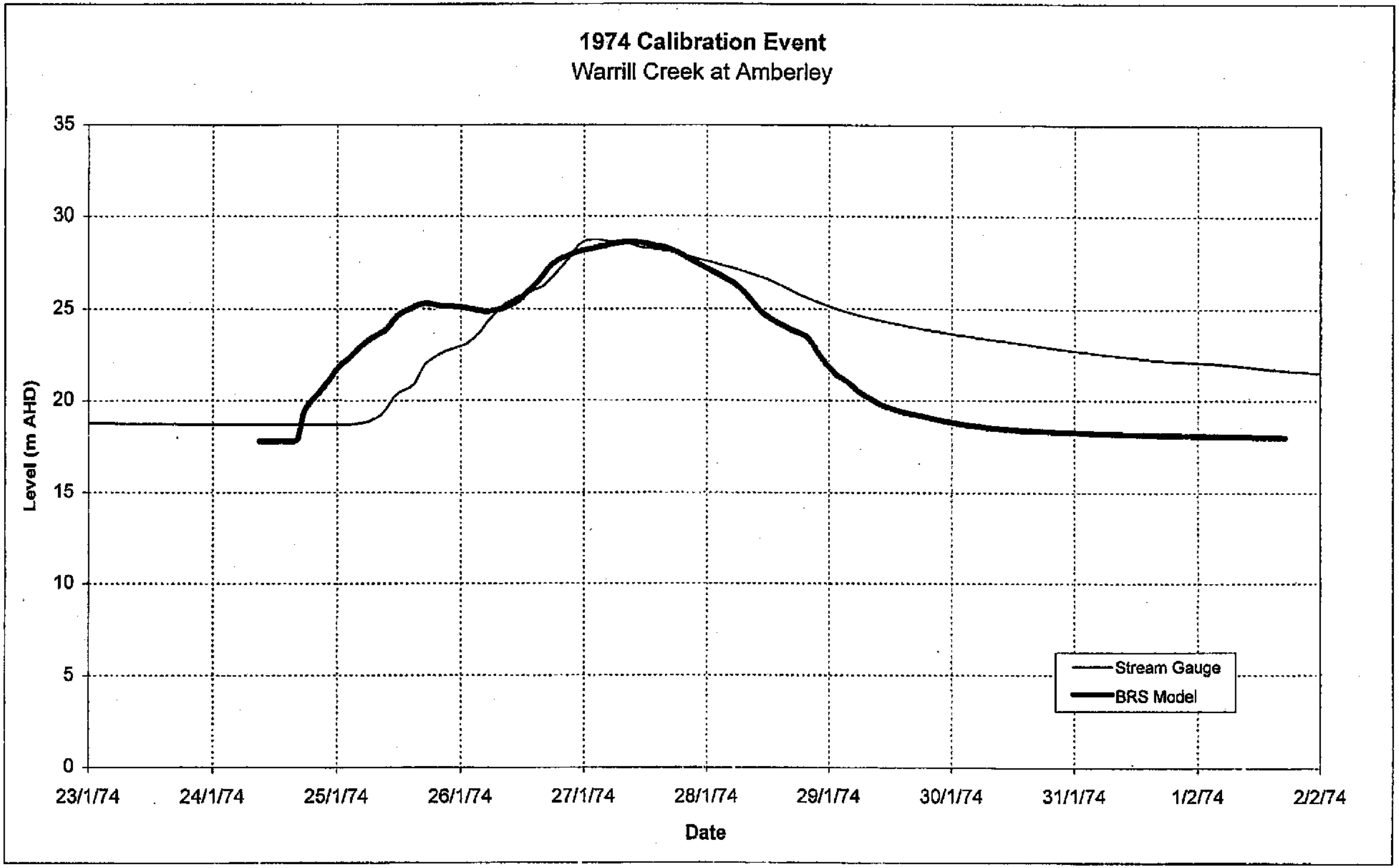

Figure 6.6
1974 Calibration Event
Warrill Creek at Amberley

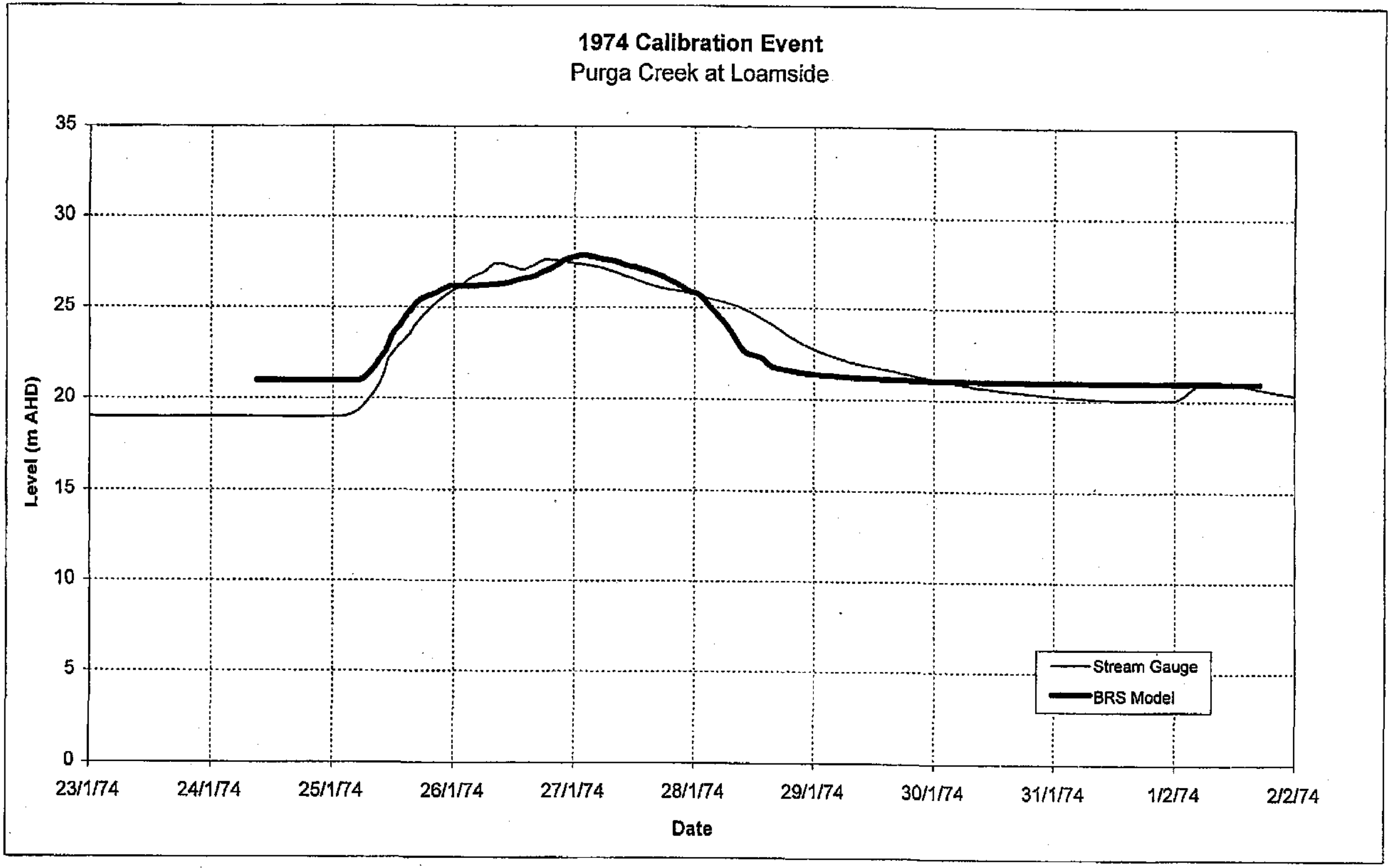

Figure 6.7
1974 Calibration Event
Purga Creek at Loamside

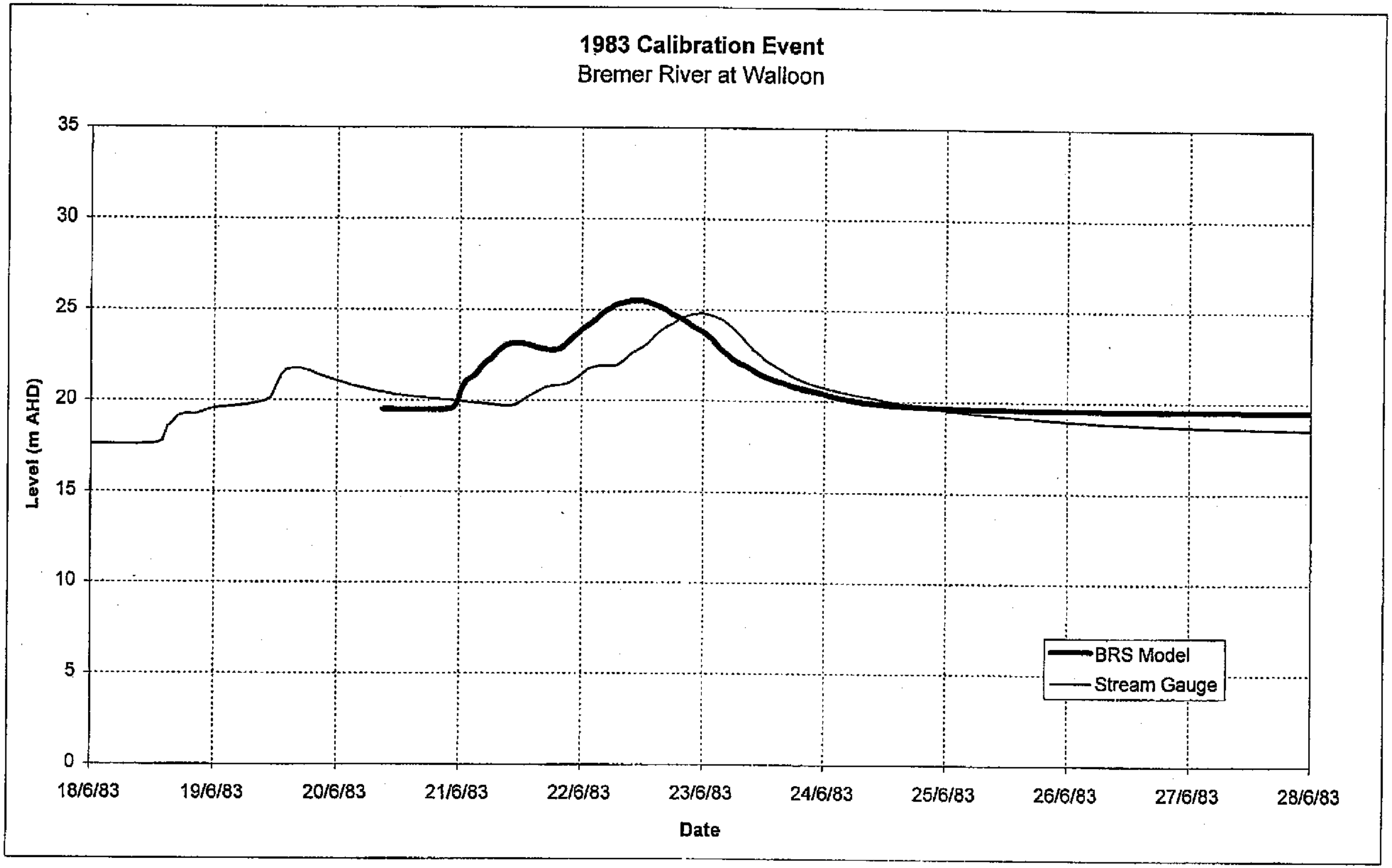

Figure 6.8
1983 Calibration Event
Bremer River at Walloon

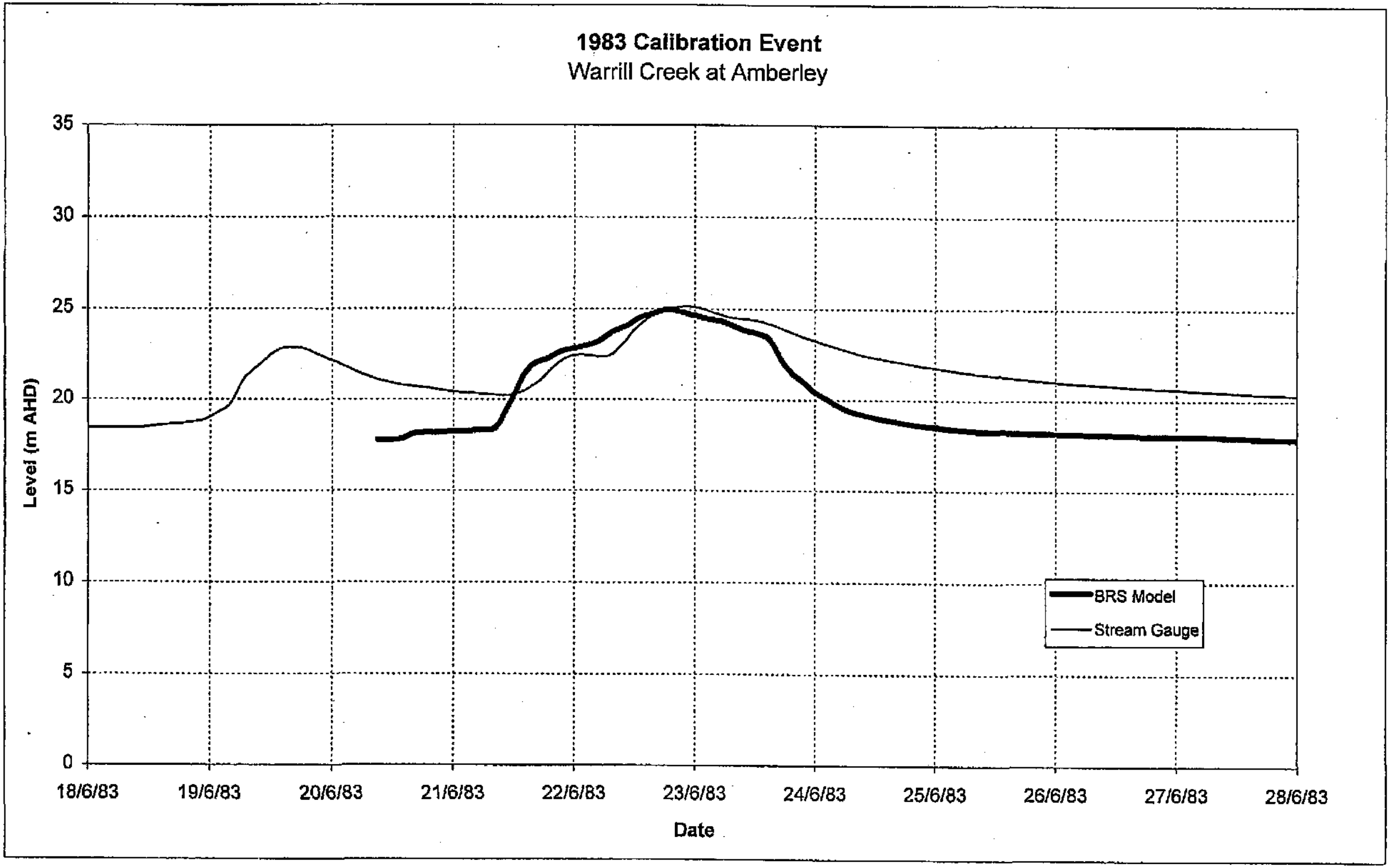

Figure 6.9
1983 Calibration Event
Warrill Creek at Amberley

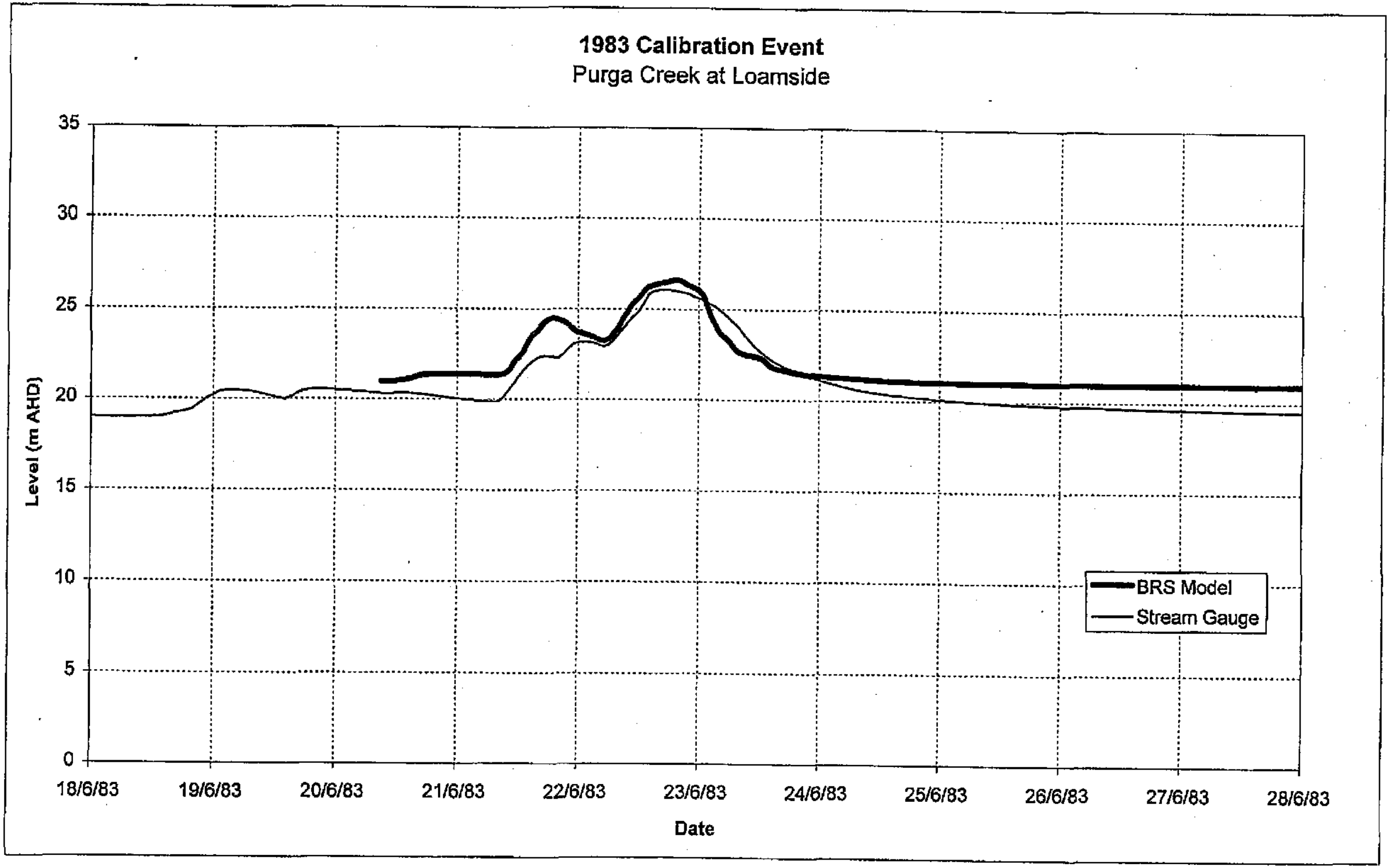

Figure 6.10
1983 Calibration Event
Purga Creek at Loamside

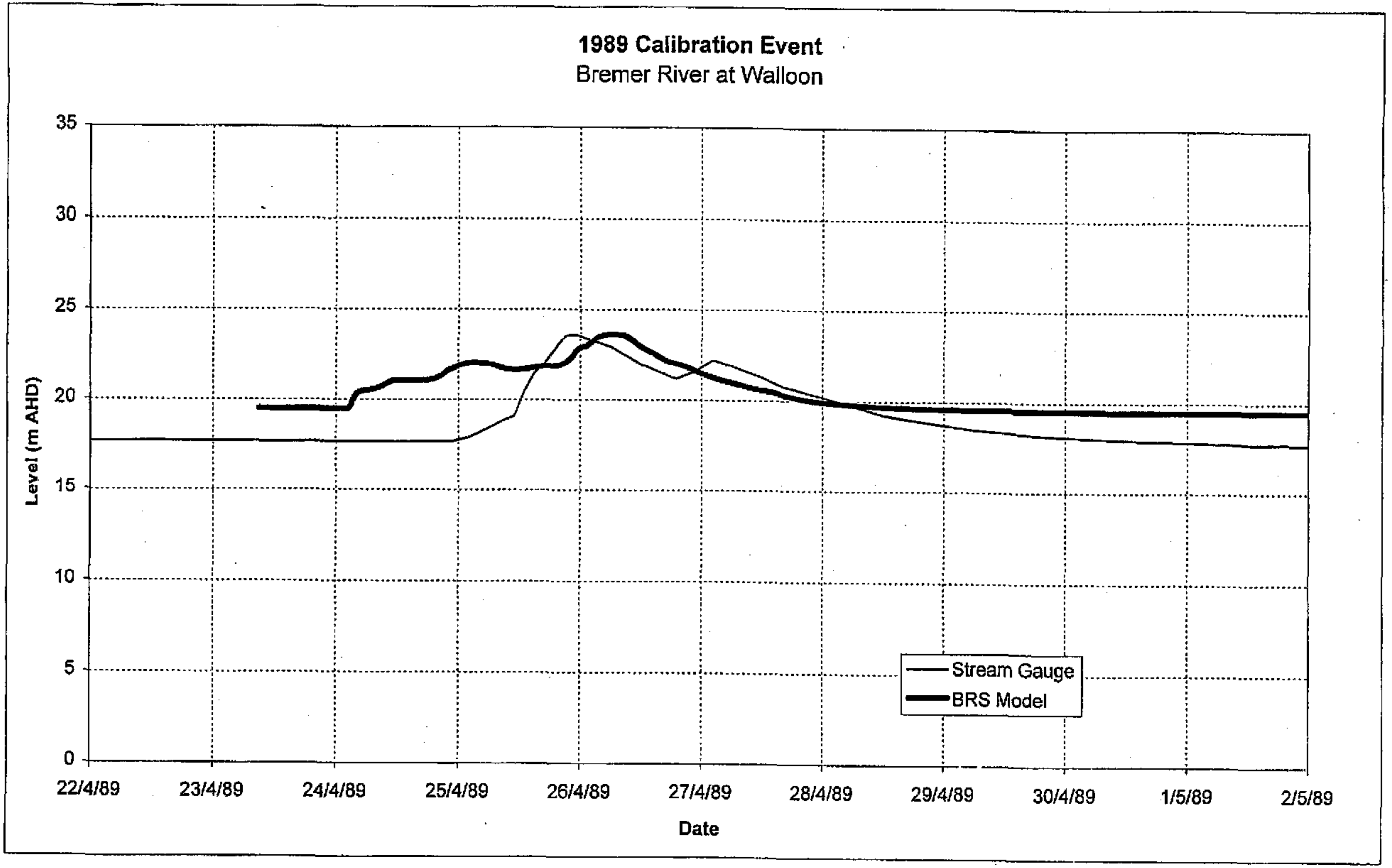

Figure 6.11
1989 Calibration Event
Bremer River at Walloon

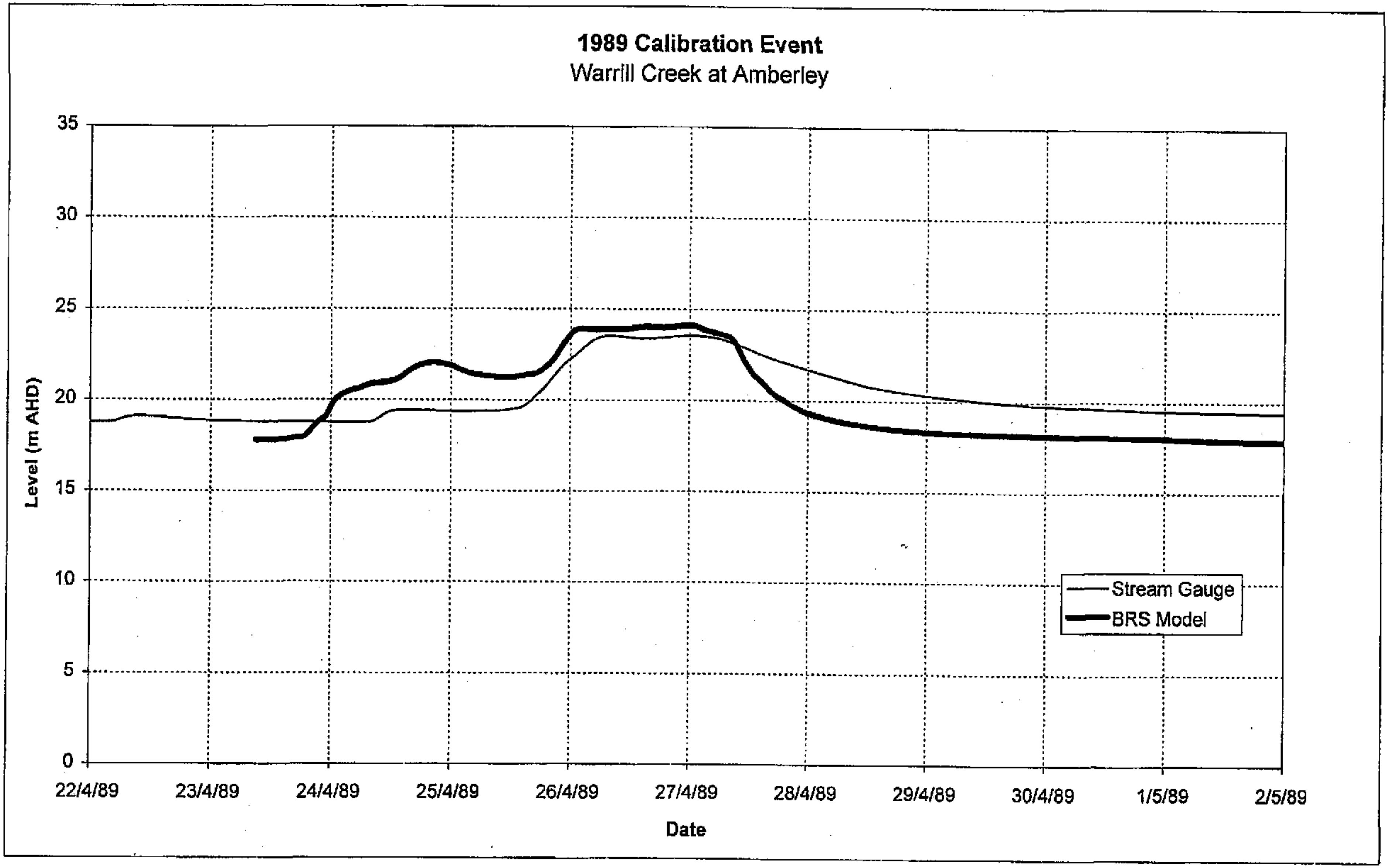

Figure 6.12
1989 Calibration Event
Warrill Creek at Amberley

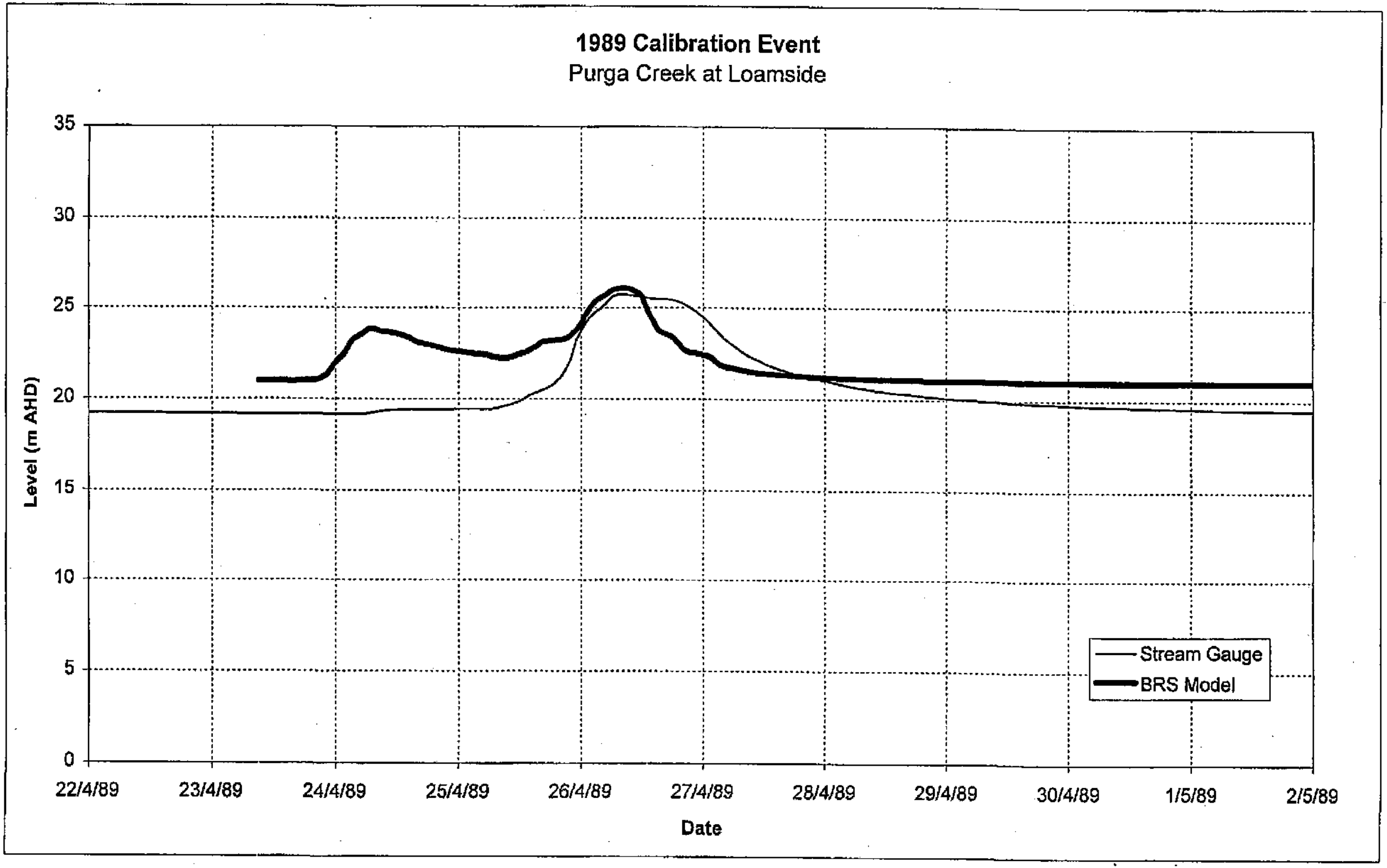

Figure 6.13
1989 Calibration Event
Purga Creek at Loamside

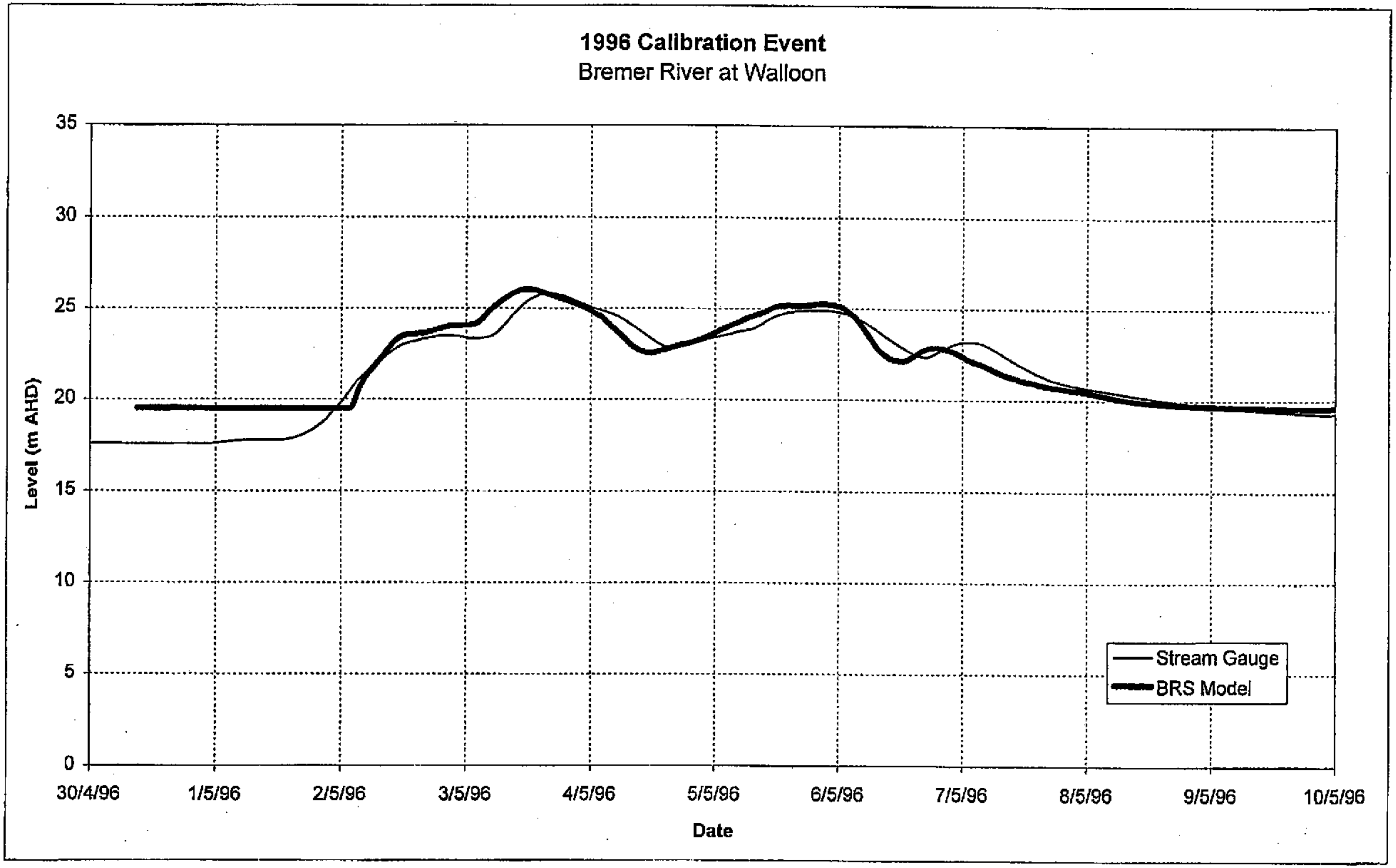

Figure 6.14
1996 Calibration Event
Bremer River at Walloon

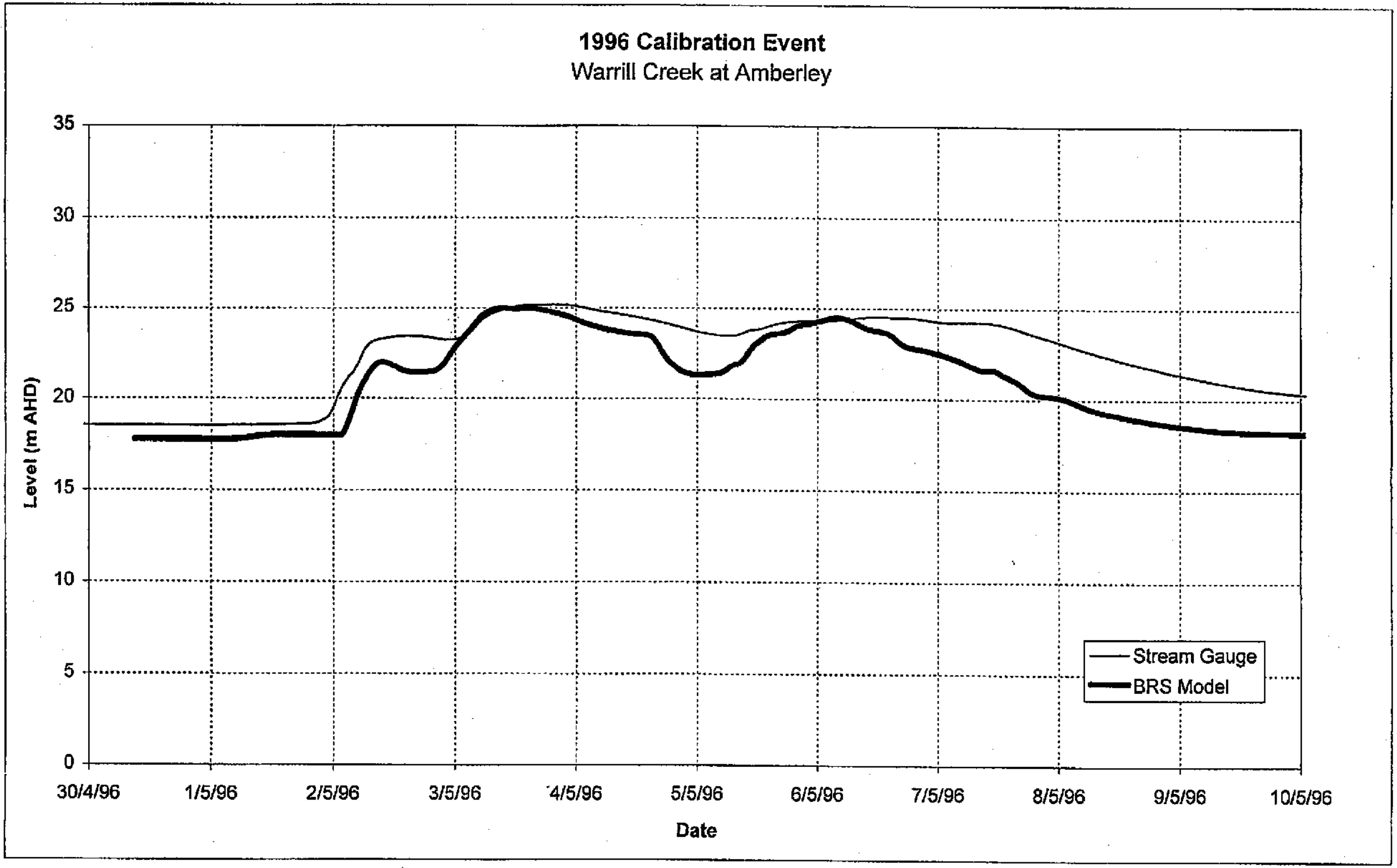

Figure 6.15
1996 Calibration Event
Warrill Creek at Amberley

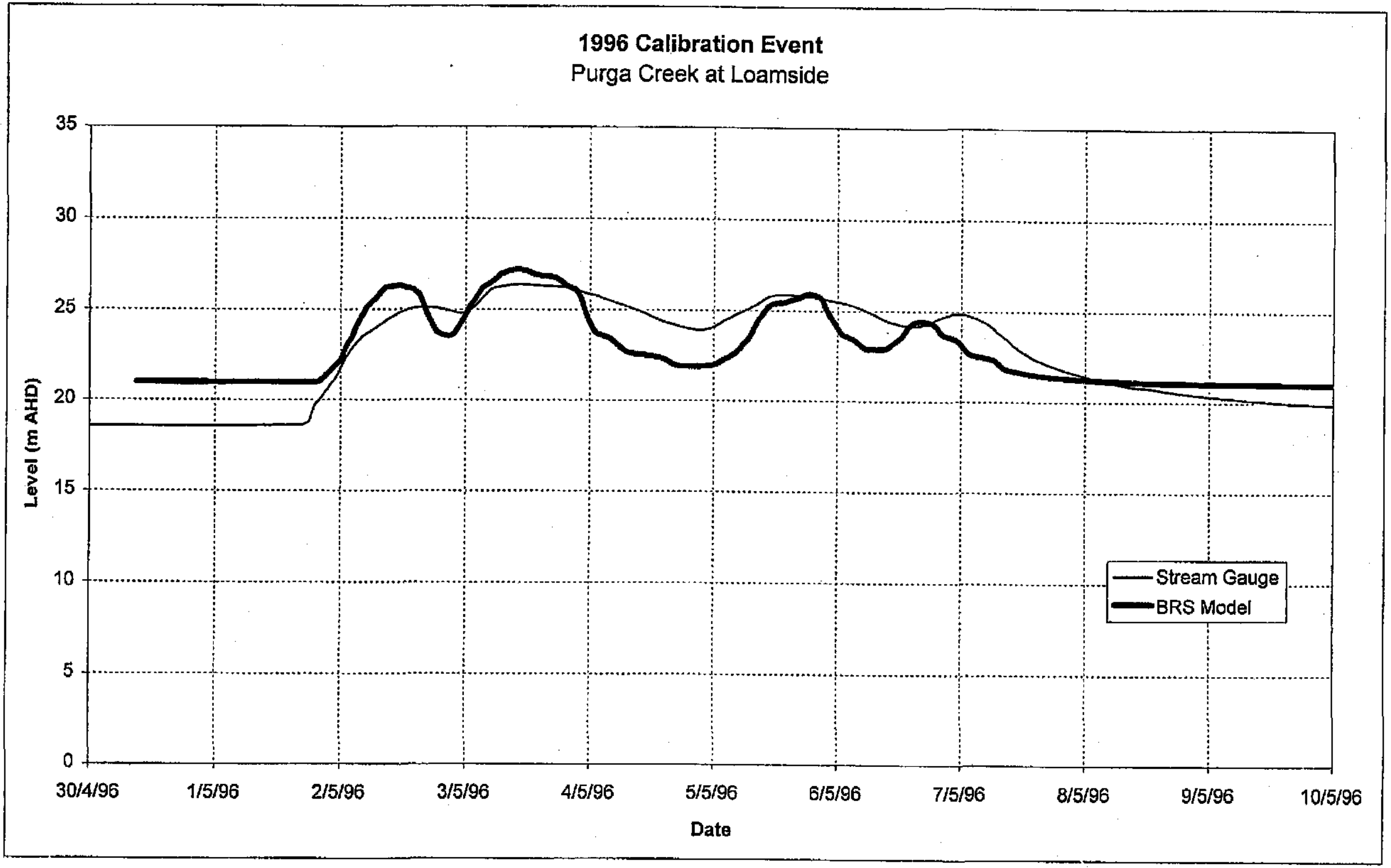

Figure 6.16
1996 Calibration Event
Purga Creek at Loamside

7 Design event hydraulic analysis

7.1 INTRODUCTION

This study involves the determination of flood inundation lines for Ipswich City Council such that future planning and development on floodplains located in the study area can be undertaken. Previous studies in the area have targeted the developed areas of Ipswich. However, this study area concentrates on the mainly rural area of the catchment.

After the calibration of the MIKE 11 hydrodynamic model, a series of storm events were investigated. In this study, the storm events analysed were the 2, 5, 10, 20, 50, 100, 200 and 500-year ARIs and the PMP event. For each of these ARIs, storm durations ranging from 3 hours to 24 hours were simulated.

The maximum water elevations and flows obtained from each of the storm durations have been summarised in Appendix Tables A.1 and A.2 respectively. The maximum water levels contained in Table A.1 are suitable for the production of the inundation plans.

7.2 CRITICAL STORM DURATIONS

The loss parameters used in the investigation presented in Table 5.2 have had a significant impact on the determination of the critical duration for each of the study branches. In particular, the high initial losses assigned to the Bremer River, Warrill Creek, Franklinvale Creek and Western Creek for the smaller events require that a significant amount of rainfall must fall onto the catchment before runoff is produced. For the large ARI events where the total rainfall is large and the initial loss is at its smallest, the effect of the initial loss is negligible. However, for the smaller events, where there is less rainfall and the initial losses are highest, the initial loss condition parameter governs when the catchment starts to produce runoff.

Depending on where in the temporal pattern that is taken up in the initial loss has controlled the peak flow and subsequent peak level in the channel.

As a result, the adoption of high initial losses have caused the longer duration storms such as 18 hours, being critical for the smaller events. The exception to this being the upper reaches of Purga Creek, where smaller loss parameters have been applied and subsequently not so much rainfall is necessary to produce runoff.

Despite the 24-hour event producing more rainfall than the 18-hour event, the temporal pattern of the 18-hour event has a significantly higher peak late in the event that causes the peak discharge.

For the ARIs greater than 50 years, the increased rainfall intensities and rainfall volumes have resulted in shorter duration storms producing the peak discharge for a majority of the upper reaches in the study site. Critical durations for these regions are usually less than 6 hours and commonly less than 4.5 hours. For the lower regions of the catchments, where the catchment grade flattens the longer durations (i.e. greater than 12 hours) are producing critical elevations.

Table 7.1 is a summary of the critical durations for both the upper and lower reaches of each branch as determined from the hydraulic modelling for the design events.

Table 7.1 Critical durations

					ARI				
Region	2 h	5 h	10 h	20 h	50 h	100 h	200 h	500 h	PMP h
Upper Bremer-Boonah	18	18	18	18	4.5	4.5	3	3	4
Lower Bremer-Boonah	18	18	18	18	12	6	6	6	12
Upper Bremer	18	18	18	18	12	6	6	6	12
Lower Bremer	18	18	18	18	18	18	24	24	12
Upper Franklinvale	18	6	18	4.5	4.5	3	3	3	4
Lower Franklinvale	18	6	18	18	4.5	4.5	5	5	12
Upper Warrill-Boonah	18	18	18	18	6	4.5	4	4	4
Lower-Warrill-Boonah	18	18	18	18	18	18	6	6	12
Upper Warrill	18	18	18	18	18	18	6	6	12
Lower Warrill	18	18	18	18	18	18	24	24	12
Upper Purga	4.5	4.5	4.5	4.5	4.5	4.5	3	3	3
Lower Purga	18	18	18	18	18	18	24	24	24
Upper Western	18	18	18	18	4.5	4.5	3	3	12
Lower Western	18	6	18	18	12	6	3	3	12

7.3 COMPARISON OF RESULTS WITH PHASE 1 AND 2 STUDY

To simplify the hydraulic model for the Phase 3 study, the junction of the Bremer River and Warrill Creek has been used as the location for the downstream boundary condition. As discussed in Section 6.3.7, the Q-H relationship used in this study has been derived using a cross-section (BREM1000700) from the Phases 1 and 2 modelling. The lower Manning's n value of 0.045 applied in this study (deemed necessary) in this area to generate the Q-H relationship has subsequently produced lower peak water elevations than those previously produced in previously modelling. As the water levels for the upstream end of the Phases 1 and 2 study join onto the tailwater levels for the current study any inconsistency at the model boundaries requires attention.

However it should be noted that the lower levels produced by the hydraulic model for this study in this location tend to support the flood level observations made by Council at One Mile Bridge (located approximately 4km downstream of the junction of Warrill Creek and Bremer River).

For consistency, the Phases 1 and 2 model cross-sections for the lower reaches of Warrill Creek (WAR100000 to WAR108140) and Purga Creek (PUR 100000 to PUR102502) have been re-used for the Phase 3 study. Despite this, the model used here has required modifications to the cross-links between the two reaches by redefining the weir details connecting Warrill and Purga Creeks.

As a result of the modified weir connectivity, a combination of the adoption of a different downstream boundary condition, and the difference between the flood routing between the hydrology and hydraulic modelling have caused different peak water elevations in the lower reaches of Warrill and Purga Creeks. As expected these differences in flood level have resulted in inconsistencies between flood levels in this region.

8 Flood mitigation

8.1 INTRODUCTION

This project has considered the flood issues for the mainly rural areas of the City of Ipswich, and has provided calculated flood levels and areas of inundation for these streams. The potential for flood mitigation measures can also be investigated using the results from the project.

While the potential flood mitigation measures can only be reviewed as a preliminary assessment, more detailed analysis would be needed to determine the real feasibility. This section gives an indication of several possible options.

There are non-structural flood mitigation measures, including floodplain zoning and planning. The results in this report, particularly the flood inundation maps and the design flood levels, provide suitable material to develop these measures.

Where there are existing flood prone properties, structural flood mitigation measures may be more appropriate. These include measures such as flood mitigation dams and retention basins, channel works and levees. A number of such measures have been suggested over the years for several locations throughout the catchment and more have been identified during the progress of the current project.

As well as the potential damage to property, many of the bridges in the catchment have a low flood immunity and upgrading of the bridges would be useful to improve the evacuation and communication during flood events.

These measures are discussed here.

8.2 FLOOD STORAGES

Flood storages include flood mitigation dams as well as smaller flood detention basins. The effectiveness of flood mitigation storages depends on the volume of storage available as well as the location of the storage in relation to the flood prone property. The reduction of flood peak produced by the storage is related to the volume of the storage in relation to the volume of the flood and the storage should be located as close (upstream) as possible to the flood prone property.

In the case of the streams included in this study area, the catchments are all relatively large so the required volume of any flood mitigation storage must also be large. As well, there are limited dam sites available in the catchments. The locations where flood mitigation dams may be of value could be in small sub-catchments, and this type of catchment has not been the main focus of this project.

There is a high cost in the construction of dams, and there are considerable social and environmental concerns so it is difficult to gain approvals for dam construction.

Because of the high costs and sometimes limited benefits from construction of flood mitigation storages, they are also difficult to justify economically.

Several potential flood mitigation dam sites have been identified in the past for the catchments included in the current study area.

Major dam sites have been identified for Mt Walker Creek and for Warrill Creek at Aratula. These dams would operate as water supply dams as well as flood mitigation storages. Construction of dams at these sites would inundate extensive areas of land, leading to high costs of construction and there would be limited benefits because of the locations, which are well above the areas of particular concern. Major flood mitigation dams must be justified by favourable economic performance and these major dams would be difficult to justify.

It is noted that Wivenhoe and Somerset Dams, in the Brisbane River system, do provide flood mitigation benefits to the lower reaches of the Bremer River, but the major justification of these dams has been for water supply.

8.3 CHANNEL WORKS

Channel works for flood mitigation are constructed widening and straightening of stream channels to allow the flood flows to pass through the flood prone regions more quickly to reduce flood levels. Channel works require earth works and sometimes extensive clearing of vegetation.

Channel works are generally expensive and also usually have considerable environmental concerns. There is also the possibility that the channel works may transfer flood problems to another downstream part of the catchment by increasing the rate of flow through the channel. There are also technical problems since channel works require relatively steep channel slopes, to limit the extent of works. Where the channel is relatively flat, the widening of the channel may not provide sufficient benefits to justify the cost, because the channel must extend for a considerable distance downstream.

In the case of the study area in the Ipswich City, the channels are relatively flat and there is a considerable discharge spread over a wide and flat floodplain. In addition, many of the potential flood prone areas are located downstream in the catchment. Both of these lead to a relatively low benefit from channel works.

The identified flood mitigation problem areas and projects in the catchment have not shown any that could benefit from channel works.

8.4 LEVEES

Levees could be a valuable option for particular locations where there is an existing area of flood prone property. In addition, because levees constrict the width of flow paths, the area to be protected by levees must be in a reach of the water course where these problems are relatively limited. Levees have been used in the project area, for example, for the flood protection of the Jeebropilly Mine on lower reaches of the Bremer River.

Levees therefore could be the most applicable flood mitigation measure for existing flood prone properties in the project area.

The levees are proposed for flood mitigation for events in the main streams, and therefore are designed to limit the inundation from the main stream. However they must also consider the issue of runoff from inside the levee as well as the flow in the main water course. This means that there must be an allowance for diversion of water from inside the levee. In some cases, the flood problems identified by the Council are affected by local catchment runoff, so the current study does not provide means of assessing the benefits.

Levees must also meet the requirements for economic performance of any flood mitigation project, before the scheme can be approved.

Ipswich City Council identified several locations where levees could be considered. Details of these locations are as follows.

- Harrisville. There are some low-lying parts of Harrisville that are inundated from Warrill Creek and a secondary channel of the creek. The creek is wide at this point, and a levee surrounding the low areas could be of value. The flood problems in the town could also be partly caused by flow in minor water courses, including Normanby Gully. More detailed assessment would be necessary to prove the value of any proposed levee, both from Warrill Creek and from the local catchment.
- Peak Crossing. While the township of Peak Crossing is close to Purga Creek, the reported flood problems in the town are believed to be more related to local runoff than to the creek itself. The flood study reported here only considers the main creek and not the minor water courses.
- Rosewood. The town of Rosewood is located on Western Creek close to the junction with the Bremer River. Most of the town is located to the north of the railway line, and the flooding problems in the town are therefore due to the local runoff from the tributaries of Western Creek.
- Walloon. Walloon is located in the lower reaches of the Bremer River to the north of the railway line. Walloon is affected by both flooding from the Bremer River and from local catchments to the north of the railway line. The local catchment flooding is outside the region covered by this study, but there is a small part of the town to the south of the railway where there could be some benefits from a levee on the Bremer River. Any levee though would need to be considered in conjunction with flood mitigation of the local tributaries, so the benefits of a levee cannot be determined from the current study.
- Karrabin. Karrabin is located on the northern side of the lower reaches of the Bremer River. However review of the flood inundation maps shows that flooding in Karrabin is not from the Bremer River, so the identified flooding problems are outside the area of the current project.
- Calvert. The township of Calvert is located on Western Creek, near the junction with Franklin Vale Creek. Based on the review of the inundation maps, most of the town seems to be affected by major flood events, though to a shallow depth. A levee for protection of the town from flooding would need to completely

surround the town. This could be a benefit for flooding, but there could be possible problems with diversion of flow and afflux. Further analysis of the levees would be of value to define the effectiveness of the levees and the impacts.

- Grandchester. The town of Grandchester is located on Western Creek, near the upstream end of the study area of this project. Low lying areas of the town are affected by flooding from Western Creek. There could be benefits from a levee to protect this part of the town, and further analysis to determine the costing and impacts would be justified.
- Rural areas. There is sometimes a justification to protect high value agricultural land from flooding by levees, and there are large areas of such land especially in the Warrill Creek catchment. The protection of agricultural land is difficult to justify economically. Therefore while there may be some small areas, where this type of flood mitigation is justified, the particular benefits would need to be carefully analysed.

There is a place for flood mitigation with levees, but it is difficult to prove the benefits and provide justification. The above list provides some possible flood mitigation measures that are worth further detailed assessment to determine their value. However it is noted that several of the options identified are on local catchments that ae outside the project area included in the current project.

8.5 BRIDGE UPGRADING

The hydraulic modelling includes the analysis of all the bridges over the streams of the study area. Assessment of these bridges shows that there are few bridges in the study area with a flood immunity of better than an average recurrence interval of 5 years (ARI 5 years). This result from the hydraulic modelling is consistent with the observations of the local transport network for the catchments. A summary of flood immunity levels for each hydraulic structure in the hydraulic model is presented in Figure 8.1.

While the local community has accommodated these closures during flood events, better communication during floods would be a benefit to the community.

Review of the bridges in the project area has shown that most of the major crossings are in regions with very wide floodplains, and improvement in flood immunity would require the raising of roads for considerable lengths.

The raising of these roads would require additional waterways in the form of secondary bridges and culverts on the floodplain, a considerable cost. As well the additional embankment would mean that there could be greater impacts caused by afflux in the area immediately upstream.

Because of the difficulty and cost of improving the flood immunity of the road network, the selection of the most appropriate roads to be raised will need careful consideration. It is suggested that only few of the roads could be raised after the analysis of the road network.

Table 8.1 Summary of flood immunity for all hydraulic structures

	Reach	Chainage (m)	Controlling weir level (m AHD)	Structure Flood Immunity (ARI)	Crossing name
1	Bremer	2482.00	46.73	2	Mt. Walker West
2	Bremer	9793.663			Stevenson Bridge (Flood)
3	Bremer	11482.63	37.08	<2	Keane's Road (Flood)
4	Bremer	14410.00	34.78	5	Jeebropilly Railway Crossing
5	Bremer	15070.00	34.05	2	7 Mile Creek Bridge
6	Bremer	19370.00	27.52	2	5 Mile Creek Bridge
7	Bremer	29525.00	17.50	2	3 Mile Creek Bridge
8	Bremer-Boonah	11926.89	96.45	20	n/a
9	Bremer-Boonah	*11926.89*	*96.45*	20	n/a
10	Bremer-Boonah	13934.22	86.73	5	n/a
11	Bremer-Boonah	16512.06	80.03	10	n/a Adams Bridge (Flood)
12	Bremer-Boonah	24551.71	57.78	<2	n/a Stokes Crossing (Flood)
13	Franklinvale	5623.15	96.29	<2	Franlinvale Road
14	Franklinvale	8835.62	85.32	2	Meadow Flat Road
15	Franklinvale	17032.00	59.96	<2	Cummings Road
16	Purga	2996.06	49.92	<2	Ipswich-Boonah Road
17	Purga	12796.29	29.47	<2	Purga School Road
18	Purga	19940.56	22.19	10	Cunningham Hway
19	Purga	19940.56	22.19	10	Cunningham Hway
20	Purga	19940.56	22.19	10	Cunningham Hway
21	*Purga_2*	*30.85*	*60.33*	<2	*Washpool Road*
22	Purga_2	30.85	60.33	<2	Washpool Road
23	Purga_2	2888.285	53.71	2	Dwyers Road Bridge
24	RailBridge1	10.00	86.00	>100	Ipswich-Rosewood R'way
25	RailBridge2	10.00	85.15	>100	Ipswich-Rosewood R'way
26	RailBridge3	10.00	81.44	>100	Ipswich-Rosewood R'way
27	RailBridge3	10.00			
28	RailBridge4	10.00	70.75	>100	Ipswich-Rosewood R'way
29	RailBridge5	10.00	70.66	>100	Ipswich-Rosewood R'way
30	RailBridge6	10.00			
31	RailBridge7	10.00			
32	RailBridge8	10.00			
33	*RailBridge9*	*10.00*			
34	RailBridge9	10.00			
35	RailBridge9	10.00			
36	RailSouth	9781.72	50.70	~~2~~ 5	Kuss Road
37	RailSouth	12400.00	44.05	2	Strongs Bridge
38	RailSouth	14848.00	41.14	~~<2~~ 50	Warrill View Road
39	RailWeir1	10.00			
40	RailWeir1	10.00			
41	RailWeir4	10.00			
42	RailWeir5	10.00			
43	RailWeir6	10.00			
44	Warrill	2434.10	49.26	<2	Wilsons Plains Road

Table 8.1 (continued)

	Reach	Chainage (m)	Controlling weir level (m AHD)	Structure Flood Immunity (ARI)	Crossing name
45	Warrill	2434.10	49.26	<2	Private Rd
46	Warrill	3493.49	46.18	<2	n/a
47	Warrill	4788.90	49.22	>100 < Y	Fresser's Bridge
48	Warrill	6402.07	42.29	<2	n/a
49	Warrill	7121.27	38.63	<2	Private Rd
50	Warrill	7121.27	38.63	<2	Private Rd
51	Warrill	11589.99	37.40	<2	Mutdapilly-Churchbank Rd
52	Warrill	11589.99	37.40	<2	Mutdapilly-Churchbank Rd
53	Warrill	25720.35	26.84	20	Cunningham Road
54	Warrill-Boonah	3392.50	137.54	10	Villis Bridge
55	Warrill-Boonah	15989.89	88.06	>100	Maclean Bridge
56	Warrill-Boonah	19454.64	75.08	5	Kalbar Bridge
57	Warrill-Boonah	26310.71	64.92	2	-
58	Warrill-Boonah	30804.86	57.58	<2	Walter Harsant Bridge
59	Warrill-Boonah	30804.86	57.58	<2	Radford Rd
60	Warrill-Boonah	30804.86	57.58	<2	Radford Rd
61	Warrill-Boonah	30804.86	57.58	<2	Wilsons Plains
62	Western	858.96	85.74	>100	Rosewood-Laidley Road
63	Western	858.96	85.74	>100	Rosewood-Laidley Road
64	Western	858.96	85.74	>100	Grandchester-Mt Mort Road
65	Western	6898.85	59.96	>100	Hiddenvale Road
66	Western	6898.85	59.96	>100	Hiddenvale Road

9 Conclusion

This report has provided the conclusions for the Ipswich Rivers Flood Studies Phase 3. It has analysed the flood behaviour of the major watercourses in the rural areas of Ipswich City, including sections of the Bremer River and Warrill Creek immediately upstream in Boonah Shire.

The project has built on previous work carried out for the Council as part of the Phases 1 and 2 project. This earlier work developed hydrology and hydraulic analysis for the Council in the downstream, more urban portions of the catchment.

The model procedures and parameters developed as part of the Phases 1 and 2 project have been generally adopted for the Phase 3 project. While there are some inconsistencies in the approaches, the previous work has been modified to the minimum extent possible.

The results from this project provide flood levels for a range of design flood probabilities to allow floodplain planning for the Council in the study area.

10 References

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Appendix A

MODEL RESULTS

Table A.1 Model results—Peak water elevations (m AHD)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	*0.00*	*969909*	49.92	50.82	51.41	51.79	52.36	52.75	53.68	53.90	55.57	52.75	51.40	50.20	51.75
BREMER	364.80	970274	49.52	50.21	50.68	50.98	51.66	52.05	53.14	53.36	55.03	52.07	50.66	49.72	50.95
BREMER	1613.53	971522	46.46	47.65	48.02	48.23	48.79	49.24	50.72	50.94	52.64	49.26	48.01	46.95	48.21
BREMER	2207.67	972117	46.35	47.47	47.78	47.96	48.43	48.72	49.63	49.88	51.49	48.73	47.77	46.83	47.94
BREMER	2472.00	972381	46.25	47.33	47.61	47.77	48.23	48.50	49.37	49.63	51.05	48.51	47.60	46.71	47.75
BREMER	2492.00	972401	46.20	47.20	47.54	47.74	48.21	48.48	49.36	49.62	51.03	48.49	47.54	46.60	47.72
BREMER	2522.86	972432	46.15	47.13	47.47	47.66	48.14	48.40	49.29	49.54	50.96	48.42	47.47	46.54	47.64
BREMER	3048.80	972958	45.35	46.22	46.59	46.75	47.15	47.43	48.24	48.48	50.10	47.45	46.62	45.79	46.72
BREMER	3579.79	973489	44.60	45.41	45.78	45.92	46.31	46.58	47.38	47.63	49.52	46.60	45.80	45.06	45.89
BREMER	4117.69	974027	43.93	44.64	45.05	45.26	45.65	45.95	46.82	47.07	49.04	45.98	45.14	44.42	45.20
BREMER	4658.71	974568	42.64	43.62	44.26	44.52	44.94	45.24	46.07	46.29	48.16	45.28	44.40	43.20	44.46
BREMER	5466.45	975375	41.45	42.54	43.39	43.58	43.97	44.26	45.03	45.23	47.29	44.29	43.48	42.08	43.53
BREMER	6137.27	976046	41.19	42.15	42.83	43.04	43.50	43.81	44.65	44.86	46.94	43.84	42.91	41.73	42.98
BREMER	6902.98	976812	40.59	41.47	41.84	42.10	42.60	42.93	43.86	44.07	46.14	42.95	41.94	41.12	42.05
BREMER	7597.07	977506	39.87	40.90	41.40	41.67	42.16	42.47	43.08	43.27	45.38	42.41	41.53	40.34	41.66
BREMER	8229.47	978138	39.16	40.30	40.86	41.12	41.62	41.95	42.62	42.83	45.00	41.90	40.99	39.76	41.12
BREMER	9006.19	978915	38.54	39.79	40.25	40.47	40.96	41.38	42.05	42.28	44.48	41.33	40.36	39.29	40.52
BREMER	9783.66	979693	38.18	39.46	39.80	40.03	40.63	41.14	41.81	42.04	44.16	41.10	39.94	38.98	40.19
BREMER	9803.66	979713	38.15	39.11	39.63	40.02	40.63	41.14	41.80	42.03	44.13	41.09	39.93	38.81	40.18
BREMER	9936.78	979846	38.10	39.05	39.57	39.99	40.60	41.11	41.77	42.00	44.08	41.07	39.89	38.77	40.16
BREMER	10391.51	980300	37.97	38.93	39.49	39.93	40.54	41.05	41.68	41.90	43.93	41.01	39.83	38.63	40.10
BREMER	10893.66	980803	37.91	38.81	39.38	39.82	40.44	40.93	41.50	41.70	43.59	40.90	39.73	38.51	40.01
BREMER	11315.68	981225	37.72	38.52	38.97	39.31	39.89	40.39	40.86	41.02	42.68	40.36	39.24	38.27	39.50
BREMER	11477.63	981387	37.54	38.25	38.66	38.99	39.60	40.04	40.46	40.61	42.23	40.01	38.93	38.05	39.18
BREMER	11487.63	981397	37.22	38.03	38.46	38.77	39.33	39.70	40.19	40.35	42.08	39.67	38.71	37.81	38.98
BREMER	11874.52	981783	36.71	37.47	37.87	38.06	38.46	38.84	39.29	39.44	41.10	38.82	38.02	37.28	38.18
BREMER	12230.92	982140	36.44	37.16	37.57	37.73	38.08	38.39	38.83	38.98	40.72	38.37	37.70	36.98	37.82
BREMER	12694.60	982604	35.65	36.32	36.54	36.75	37.17	37.55	38.11	38.30	40.34	37.52	36.71	36.08	36.87
BREMER	13268.91	983178	33.55	35.19	35.64	35.92	36.35	36.75	37.42	37.63	39.93	36.72	35.88	34.68	36.04

Kraans Rd.

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	13870.20	983779	32.85	34.72	35.38	35.65	36.05	36.47	37.13	37.35	39.67	36.44	35.61	34.22	35.75
BREMER	14389.82	984299	32.62	34.50	35.18	35.43	35.84	36.27	36.94	37.16	39.43	36.25	35.39	33.85	35.53
BREMER	14400.00	984309	32.62	34.49	35.17	35.42	35.84	36.27	36.94	37.15	39.42	36.24	35.38	33.84	35.52
BREMER	14420.00	984329	32.61	34.42	35.04	35.38	35.83	36.26	36.93	37.14	39.41	36.23	35.34	33.81	35.51
BREMER	14831.22	984740	32.58	34.34	34.90	35.22	35.71	36.15	36.82	37.04	39.25	36.12	35.17	33.65	35.36
BREMER	15060.00	984969	32.52	34.27	34.81	35.14	35.62	36.07	36.73	36.94	39.10	36.04	35.10	33.51	35.28
BREMER	15080.00	984989	32.51	34.18	34.79	35.13	35.61	36.06	36.72	36.93	39.08	36.03	35.09	33.49	35.27
BREMER	15311.88	985221	32.12	33.71	34.39	34.76	35.23	35.70	36.40	36.63	38.83	35.67	34.71	32.96	34.90
BREMER	15747.83	985657	31.39	32.65	33.50	33.88	34.43	34.92	35.64	35.89	38.10	34.89	33.82	32.25	34.05
BREMER	16340.42	986249	30.46	31.65	32.49	32.81	33.38	33.90	34.58	34.81	37.17	33.87	32.75	31.33	32.97
BREMER	16706.22	986615	29.90	31.17	32.06	32.42	33.04	33.54	34.19	34.42	36.93	33.52	32.36	30.79	32.60
BREMER	17221.72	987131	29.51	30.66	31.50	31.99	32.73	33.29	33.92	34.15	36.55	33.27	31.92	30.31	32.22
BREMER	17933.08	987842	28.89	29.96	30.79	31.27	31.95	32.55	33.22	33.44	36.26	32.54	31.17	29.61	31.54
BREMER	18398.80	988308	28.38	29.42	30.28	30.81	31.39	31.91	32.66	32.88	36.19	31.89	30.70	29.06	31.05
BREMER	19050.94	988960	27.49	28.62	29.44	29.99	30.71	31.41	32.24	32.45	36.14	31.39	29.90	28.25	30.23
BREMER	19360.00	989269	27.08	28.30	29.08	29.61	30.39	31.20	32.02	32.23	36.09	31.19	29.53	27.96	29.85
BREMER	19380.00	989289	27.02	28.00	28.86	29.47	30.36	31.18	32.00	32.21	36.07	31.17	29.38	27.68	29.76
BREMER	19419.49	989328	26.97	27.96	28.82	29.42	30.32	31.15	31.97	32.17	36.07	31.14	29.33	27.64	29.71
BREMER	20485.54	990395	25.69	26.74	27.53	28.12	29.12	30.07	31.00	31.22	36.01	30.10	28.05	26.47	28.47
BREMER	20876.67	990786	24.97	26.13	27.03	27.70	28.82	29.71	30.79	31.01	36.00	29.78	27.66	25.90	28.15
BREMER	21565.85	991475	23.70	25.06	26.07	26.75	28.10	29.13	30.39	30.61	35.97	29.27	26.71	24.77	27.27
BREMER	21851.32	991760	23.49	24.72	25.69	26.34	27.66	28.70	30.03	30.28	35.96	28.90	26.31	24.47	26.87
BREMER	22410.57	992320	22.62	23.93	24.91	25.61	26.98	28.26	29.47	29.73	35.93	28.51	25.58	23.65	26.11
BREMER	22931.36	992840	22.00	23.36	24.36	25.06	26.38	27.75	28.99	29.25	35.91	28.10	25.05	23.09	25.55
BREMER	23375.87	993285	21.33	22.70	23.69	24.43	25.63	26.91	28.46	28.93	35.90	27.59	24.44	22.43	24.92
BREMER	23968.39	993877	20.98	22.34	23.39	24.17	25.33	26.50	28.25	28.83	35.88	27.39	24.20	22.06	24.66
BREMER	24384.48	994293	20.81	22.15	23.18	23.93	25.08	26.29	28.17	28.77	35.88	27.30	23.95	21.86	24.40
BREMER	24891.36	994800	19.97	21.64	22.74	23.49	24.56	25.76	28.01	28.66	35.86	27.08	23.49	21.31	23.92
BREMER	25371.48	995280	19.51	21.04	22.07	22.91	24.19	25.45	27.90	28.58	35.86	26.92	22.87	20.74	23.37
BREMER	25882.25	995791	19.24	20.67	21.55	22.30	23.86	25.19	27.83	28.54	35.84	26.84	22.18	20.42	22.84

7 mile

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	26265.02	996174	19.08	20.40	21.22	22.03	23.75	25.12	27.82	28.52	35.84	26.81	21.84	20.19	22.61
BREMER	26341.55	996251	18.96	20.24	21.06	21.90	23.69	25.08	27.81	28.52	35.84	26.81	21.68	20.05	22.49
BREMER	26773.64	996683	18.42	19.49	20.35	21.38	23.38	24.93	27.78	28.50	35.84	26.76	20.96	19.32	22.02
BREMER	27056.11	996965	18.16	19.20	20.14	21.28	23.30	24.88	27.77	28.49	35.84	26.74	20.79	19.06	21.93
BREMER	27398.71	997308	17.47	18.75	19.84	21.10	23.22	24.81	27.75	28.49	35.83	26.72	20.53	18.67	21.78
BREMER	27591.25	997500	17.23	18.59	19.79	21.10	23.23	24.81	27.75	28.49	35.84	26.72	20.51	18.55	21.79
BREMER	27839.23	997748	16.91	18.29	19.64	21.01	23.19	24.80	27.75	28.48	35.83	26.71	20.39	18.33	21.71
BREMER	28051.84	997961	16.58	18.09	19.55	20.98	23.17	24.78	27.74	28.48	35.83	26.71	20.33	18.22	21.68
BREMER	28338.03	998247	15.87	17.86	19.42	20.91	23.14	24.76	27.74	28.47	35.83	26.70	20.24	18.10	21.62
BREMER	28868.29	998777	15.50	17.75	19.36	20.88	23.11	24.74	27.73	28.47	35.83	26.69	20.19	18.05	21.59
BREMER	29126.92	999036	15.37	17.69	19.32	20.85	23.09	24.73	27.73	28.47	35.82	26.69	20.16	18.02	21.55
BREMER	29472.75	999382	15.08	17.61	19.26	20.80	23.05	24.70	27.73	28.46	35.82	26.69	20.12	17.98	21.51
BREMER	29515.00	999424	15.08	17.61	19.26	20.80	23.05	24.70	27.73	28.46	35.82	26.69	20.12	17.98	21.51
BREMER	29535.00	999444	15.07	17.58	19.25	20.79	23.04	24.69	27.72	28.46	35.82	26.68	20.11	17.97	21.50
BREMER	29578.39	999487	15.06	17.58	19.26	20.80	23.05	24.69	27.72	28.46	35.82	26.68	20.11	17.97	21.51
BREMER	29891.04	999800	15.00	17.51	19.19	20.76	23.03	24.69	27.72	28.46	35.82	26.68	20.06	17.93	21.47
BREMER	30091.04	1000000	15.00	17.52	19.20	20.76	23.02	24.68	27.71	28.45	35.81	26.68	20.07	17.93	21.46
BREMER	30791.04	1000700	14.96	17.46	19.14	20.70	22.97	24.63	27.65	28.39	35.72	26.61	20.01	17.88	21.41
BREMER-BOONAHNEW	0.00	940696	230.53	231.94	232.30	232.53	233.20	233.53	234.32	234.56	236.03	233.14	231.99	227.90	232.60
BREMER-BOONAHNEW	1136.88	941833	194.96	197.95	198.95	199.49	201.01	202.21	204.81	205.52	207.99	200.80	198.18	193.99	199.59
BREMER-BOONAHNEW	2273.76	942970	177.07	177.86	178.24	178.39	178.74	179.01	179.65	179.85	181.17	178.70	177.93	176.82	178.42
BREMER-BOONAHNEW	3442.63	944139	161.00	161.51	161.83	162.03	162.60	163.02	164.24	164.42	165.68	162.52	161.58	160.82	162.07
BREMER-BOONAHNEW	4611.50	945308	145.28	145.98	146.55	146.92	148.14	148.53	149.31	149.39	150.34	148.07	146.04	144.95	147.23
BREMER-BOONAHNEW	5925.69	946622	131.71	132.67	133.11	133.31	133.88	134.52	135.00	135.12	135.87	133.84	132.80	131.47	133.32
BREMER-BOONAHNEW	7239.89	947936	118.11	118.33	118.62	118.77	119.81	120.25	120.58	120.73	121.38	119.78	118.35	117.77	118.85

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER-BOONAHNEW	8388.95	949085	110.39	110.60	110.77	110.86	111.15	111.33	111.69	111.79	112.43	111.08	110.63	110.32	110.85
BREMER-BOONAHNEW	9869.34	950566	102.20	102.59	102.89	103.05	103.55	103.83	104.31	104.44	105.15	103.47	102.66	102.07	103.14
BREMER-BOONAHNEW	10466.43	951163	99.10	100.26	100.56	100.70	101.08	101.23	101.55	101.80	102.89	101.04	100.42	98.71	100.62
BREMER-BOONAHNEW	11916.88	952613	93.77	94.67	95.19	95.53	96.68	96.91	97.23	97.33	98.07	96.67	94.82	93.42	95.33
BREMER-BOONAHNEW	11936.88	952633	93.74	94.63	95.06	95.34	96.20	96.46	96.71	96.81	97.54	96.19	94.73	93.39	95.18
BREMER-BOONAHNEW	12500.00	953196	90.68	91.62	92.12	92.44	93.08	93.20	93.56	93.68	94.52	93.06	91.74	90.36	92.25
BREMER-BOONAHNEW	13405.41	954102	87.03	87.55	88.12	88.41	88.77	89.05	89.50	89.66	90.75	88.83	87.70	86.55	88.39
BREMER-BOONAHNEW	13930.22	954627	85.30	86.26	86.91	87.06	87.31	87.52	87.76	87.83	88.48	87.38	86.42	84.67	87.04
BREMER-BOONAHNEW	13938.22	954635	85.23	85.89	86.22	86.36	86.71	87.18	87.63	87.73	88.46	86.82	85.97	84.65	86.33
BREMER-BOONAHNEW	14388.66	955085	84.49	85.20	85.74	85.84	86.16	86.46	86.86	86.96	87.67	86.25	85.33	83.83	85.81
BREMER-BOONAHNEW	15447.36	956144	81.27	82.08	82.63	82.75	83.01	83.36	83.85	83.99	84.84	83.11	82.26	80.75	82.74
BREMER-BOONAHNEW	16506.06	957202	78.25	79.11	79.84	80.43	81.00	81.27	81.71	81.84	82.74	81.13	79.04	77.84	80.39
BREMER-BOONAHNEW	16518.06	957214	78.22	79.09	79.70	80.15	80.78	81.06	81.50	81.64	82.60	80.91	79.01	77.82	80.10
BREMER-BOONAHNEW	18166.50	958863	72.19	73.44	74.11	74.70	75.74	76.20	76.60	76.71	77.59	75.94	73.27	71.59	74.71
BREMER-BOONAHNEW	19093.71	959790	70.42	71.77	72.47	73.03	73.33	73.50	73.94	74.06	74.96	73.40	71.59	69.82	73.01
BREMER-BOONAHNEW	20723.30	961420	67.37	68.07	68.70	69.14	69.42	69.56	69.97	70.11	71.33	69.47	68.07	66.87	68.98
BREMER-BOONAHNEW	21991.71	962688	64.75	65.41	65.67	65.87	66.41	66.72	67.55	67.81	69.88	66.62	65.54	64.45	65.88

Table A.1 (continued)

Stokes Crossing

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER-BOONAHNEW	23828.91	964525	59.92	60.94	61.43	61.78	62.87	63.38	64.67	65.05	67.61	63.20	61.19	59.48	61.82
BREMER-BOONAHNEW	24500.00	965196	58.87	59.49	59.82	60.09	61.24	61.87	63.00	63.44	65.87	61.66	59.66	58.55	60.11
BREMER-BOONAHNEW	24546.71	965243	58.85	59.45	59.76	60.01	61.14	61.80	62.92	63.36	65.75	61.59	59.60	58.53	60.03
BREMER-BOONAHNEW	24556.71	965253	58.22	58.95	59.40	59.79	61.10	61.74	62.73	63.06	65.47	61.54	59.18	57.96	59.83
BREMER-BOONAHNEW	24600.00	965296	58.10	58.83	59.29	59.67	61.00	61.66	62.62	62.94	65.26	61.44	59.06	57.83	59.73
BREMER-BOONAHNEW	26500.72	967197	54.22	55.47	56.04	56.41	57.36	58.15	58.62	58.78	60.18	58.04	55.80	53.79	56.46
BREMER-BOONAHNEW	27584.32	968281	52.74	54.05	54.72	55.09	55.64	55.91	56.53	56.68	58.24	55.88	54.56	52.90	55.22
BREMER-BOONAHNEW	29212.58	969909	49.92	50.82	51.41	51.79	52.36	52.75	53.68	53.90	55.57	52.75	51.40	50.20	51.75
FRANK_WEST_WEIR1	0.00		56.59	57.18	57.58	57.94	58.93	59.22	59.33	59.43	60.08	58.98	57.35	56.62	58.06
FRANK_WEST_WEIR1	5.00		56.59	57.18	57.58	57.94	58.93	59.22	59.33	59.43	60.08	58.98	57.35	56.62	58.06
FRANK_WEST_WEIR1	15.00		54.40	55.44	55.95	56.23	56.80	57.23	58.00	58.36	59.45	56.93	56.39	55.45	56.47
FRANK_WEST_WEIR1	20.00		54.40	55.44	55.95	56.23	56.80	57.23	57.99	58.36	59.45	56.93	56.39	55.45	56.47
FRANK_WEST_WEIR2	0.00		52.58	54.31	54.90	55.19	55.91	56.20	56.37	56.48	57.89	55.98	54.85	52.73	55.26
FRANK_WEST_WEIR2	5.00		52.58	54.31	54.90	55.19	55.91	56.20	56.37	56.48	57.89	55.98	54.85	52.73	55.26
FRANK_WEST_WEIR2	15.00		51.93	54.13	54.76	55.05	55.47	55.82	56.14	56.33	57.90	55.56	54.77	52.67	55.11
FRANK_WEST_WEIR2	20.00		51.93	54.13	54.76	55.05	55.47	55.82	56.14	56.33	57.90	55.56	54.77	52.67	55.11
FRANKLINVALE	0.00		125.84	126.48	126.93	127.56	128.25	128.46	128.60	128.70	129.40	128.19	126.61	125.79	128.01
FRANKLINVALE	4.73		125.80	126.44	126.89	127.52	128.22	128.44	128.58	128.67	129.37	128.16	126.57	125.74	127.98

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	425.97		123.43	124.20	124.67	125.10	125.93	126.31	126.48	126.59	127.51	125.83	124.34	123.35	125.39
FRANKLINVALE	885.68		120.33	121.10	121.56	121.92	123.11	123.57	123.82	123.96	125.20	123.03	121.24	120.25	122.10
FRANKLINVALE	1365.29		116.46	117.13	117.54	117.87	118.73	119.33	119.78	120.04	121.86	118.59	117.25	116.40	118.02
FRANKLINVALE	1768.94		112.22	112.81	113.16	113.44	114.21	114.76	115.68	115.78	116.43	114.09	112.92	112.16	113.58
FRANKLINVALE	2251.85		108.02	108.43	108.66	108.83	109.36	109.83	110.23	110.47	112.66	109.27	108.49	107.96	108.92
FRANKLINVALE	2700.97		104.59	105.79	106.43	106.84	107.89	108.65	109.14	109.40	111.45	107.70	105.92	104.44	107.00
FRANKLINVALE	2996.01		103.91	104.76	105.18	105.63	106.82	107.58	108.01	108.22	109.43	106.62	104.84	103.78	105.80
FRANKLINVALE	3548.88		101.72	102.83	103.49	103.99	105.00	105.68	106.08	106.28	107.11	104.85	102.96	101.56	104.17
FRANKLINVALE	4061.92		100.71	101.70	102.48	102.97	103.94	104.31	104.49	104.65	105.37	103.83	101.84	100.60	103.13
FRANKLINVALE	4449.29		99.27	100.26	100.92	101.49	102.68	102.91	103.09	103.22	103.83	102.59	100.38	99.15	101.65
FRANKLINVALE	4833.58		98.38	99.09	99.52	99.98	101.18	101.45	101.60	101.70	102.31	101.12	99.18	98.30	100.16
FRANKLINVALE	5112.51		96.03	97.09	97.86	98.61	99.82	100.31	100.52	100.69	101.39	99.63	97.24	95.92	98.87
FRANKLINVALE	5620.66		93.95	95.22	96.34	97.35	98.41	98.78	98.96	99.07	99.78	98.27	95.40	93.72	97.63
FRANKLINVALE	5625.69		93.93	95.18	96.18	97.08	97.95	98.32	98.54	98.67	99.42	97.88	95.35	93.71	97.36
FRANKLINVALE	6032.32		92.29	93.25	93.83	94.59	95.70	96.03	96.20	96.34	97.10	95.60	93.37	92.16	95.06
FRANKLINVALE	6470.57		91.31	92.20	92.66	93.21	94.02	94.24	94.44	94.59	95.40	93.91	92.30	91.19	93.46
FRANKLINVALE	6973.07		90.30	91.13	91.56	92.01	92.44	92.73	92.91	93.05	93.78	92.34	91.23	90.17	92.06
FRANKLINVALE	7246.79		89.58	90.29	90.66	91.06	91.63	91.97	92.11	92.21	92.82	91.49	90.37	89.48	91.13
FRANKLINVALE	7528.59		88.63	89.30	89.69	90.20	90.53	90.74	90.87	90.96	91.58	90.48	89.38	88.54	90.23
FRANKLINVALE	7787.11		87.66	88.47	88.99	89.33	89.87	90.05	90.18	90.29	90.91	89.84	88.56	87.57	89.43
FRANKLINVALE	8320.85		86.56	87.55	87.89	88.25	88.68	88.85	88.98	89.09	89.70	88.65	87.63	86.46	88.32
FRANKLINVALE	8827.31		84.87	86.16	86.61	86.83	87.05	87.16	87.25	87.31	87.69	87.03	86.29	84.69	86.88
FRANKLINVALE	8843.31		84.17	85.00	85.53	85.98	86.87	86.97	87.05	87.11	87.58	86.85	85.10	84.07	86.16
FRANKLINVALE	9321.57		82.07	82.79	83.25	83.72	84.68	84.94	85.20	85.46	86.25	84.63	82.90	81.98	83.93
FRANKLINVALE	9712.81		80.71	81.47	81.86	82.16	83.27	83.82	84.39	84.79	85.69	83.20	81.75	80.66	82.41
FRANKLINVALE	10500.52		78.02	78.56	78.94	79.23	80.08	80.66	81.39	81.56	82.59	80.03	78.82	77.98	79.43
FRANKLINVALE	10961.24		76.50	77.32	77.79	78.11	78.82	79.32	79.98	80.10	80.96	78.78	77.64	76.46	78.25
FRANKLINVALE	11455.91		75.09	76.05	76.60	76.90	77.54	77.80	77.96	78.09	78.94	77.52	76.40	75.02	77.03
FRANKLINVALE	11873.29		73.81	74.79	75.26	75.52	76.06	76.37	76.50	76.63	77.51	76.04	75.09	73.73	75.67
FRANKLINVALE	12328.45		71.91	73.25	73.46	73.60	74.00	74.33	74.51	74.64	75.51	73.98	73.40	71.84	73.68

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	12742.32		70.58	71.34	71.68	71.83	72.30	72.75	72.99	73.16	74.00	72.28	71.62	70.54	71.93
FRANKLINVALE	13141.89		70.13	70.61	70.82	70.94	71.28	71.55	71.68	71.80	72.61	71.26	70.77	70.10	71.03
FRANKLINVALE	13578.62		68.84	69.79	70.19	70.34	70.60	70.79	70.90	71.00	71.69	70.59	70.13	68.78	70.42
FRANKLINVALE	14043.78		67.07	68.38	68.98	69.20	69.33	69.47	69.55	69.62	70.18	69.33	68.91	67.01	69.23
FRANKLINVALE	14524.77		64.93	66.42	66.80	67.06	67.41	67.67	67.80	67.91	68.67	67.40	66.66	64.86	67.15
FRANKLINVALE	15001.90		64.52	65.71	66.12	66.31	66.68	66.91	67.01	67.10	67.67	66.67	66.00	64.45	66.43
FRANKLINVALE	15473.17		63.34	64.49	64.86	64.98	65.26	65.47	65.57	65.66	66.30	65.24	64.80	63.25	65.04
FRANKLINVALE	15950.15		62.01	63.19	63.75	63.87	64.22	64.50	64.64	64.77	65.65	64.24	63.69	62.02	63.92
FRANKLINVALE	16400.35		61.29	62.40	62.86	63.04	63.44	63.79	63.91	64.04	64.98	63.47	62.72	61.30	63.11
FRANKLINVALE	16877.42		61.05	61.51	61.78	61.89	62.16	62.42	62.57	62.70	63.83	62.20	61.66	61.07	61.92
FRANKLINVALE	17030.13		60.91	61.27	61.50	61.59	61.83	62.09	62.23	62.36	63.45	61.87	61.42	60.93	61.61
FRANKLINVALE	17033.13		60.80	61.27	61.50	61.58	61.82	62.08	62.22	62.35	63.43	61.86	61.42	60.81	61.60
FRANKLINVALE	17335.54		59.71	60.55	60.82	60.89	61.16	61.40	61.54	61.67	62.73	61.20	60.73	59.74	60.92
FRANKLINVALE	17728.16		58.59	59.46	59.69	59.89	60.15	60.45	60.61	60.76	61.79	60.20	59.58	58.62	59.90
FRANKLINVALE	18170.90		57.38	58.22	58.57	58.91	59.42	59.75	59.93	60.08	61.02	59.48	58.40	57.42	58.96
FRANKLINVALE	18565.51		56.59	57.18	57.58	57.94	58.93	59.22	59.33	59.43	60.08	58.98	57.35	56.62	58.06
FRANKLINVALE	19787.88		52.58	54.31	54.90	55.19	55.91	56.20	56.37	56.48	57.89	55.98	54.85	52.73	55.26
FRANKLINVALE	20087.00		51.64	54.10	54.75	55.04	55.45	55.79	56.02	56.15	57.63	55.54	54.74	52.18	55.10
PURGA	0.00	80168	60.60	60.76	60.86	60.94	61.02	61.08	61.16	61.25	61.78	60.97	60.66	60.51	60.72
PURGA	1345.80	81514	55.45	55.52	55.56	55.65	55.78	55.90	55.96	56.02	56.50	55.73	55.48	55.41	55.51
PURGA	1912.30	82081	49.69	50.18	50.44	50.79	51.09	51.27	51.56	51.87	52.91	50.28	49.21	48.67	49.48
PURGA	2986.06	83155	48.27	48.48	48.68	48.86	49.11	49.28	49.47	49.71	50.95	49.17	48.42	48.14	48.71
PURGA	3006.06	83175	48.26	48.47	48.67	48.85	49.10	49.27	49.46	49.70	50.94	49.16	48.42	48.13	48.71
PURGA	3345.71	83514	48.03	48.22	48.41	48.56	48.77	48.92	49.07	49.29	50.54	48.83	48.17	47.92	48.44
PURGA	4502.41	84671	46.58	46.69	46.79	46.91	47.08	47.19	47.31	47.48	48.39	47.12	46.65	46.50	46.81
PURGA	5004.51	85173	44.81	44.89	45.01	45.14	45.32	45.45	45.57	45.75	46.83	45.38	44.86	44.73	45.03
PURGA	5474.54	85643	44.13	44.27	44.42	44.57	44.90	45.01	45.12	45.28	46.24	44.95	44.23	44.03	44.44
PURGA	5938.99	86107	43.38	43.55	43.73	43.91	44.44	44.53	44.62	44.75	45.60	44.48	43.51	43.20	43.75
PURGA	6450.77	86619	42.64	42.80	42.90	43.01	43.12	43.22	43.30	43.43	44.37	43.17	42.77	42.57	42.93
PURGA	6997.75	87166	41.47	41.77	41.85	41.95	42.08	42.18	42.27	42.41	43.28	42.13	41.75	41.24	41.87

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
PURGA	7491.57	87660	40.08	40.19	40.29	40.39	40.49	40.58	40.65	40.77	41.64	40.53	40.17	40.04	40.31
PURGA	7945.62	88114	38.82	38.93	39.04	39.12	39.22	39.31	39.38	39.50	40.27	39.26	38.91	38.76	39.06
PURGA	8450.21	88619	37.31	37.40	37.46	37.53	37.62	37.72	37.81	37.92	38.68	37.67	37.39	37.25	37.47
PURGA	8978.82	89147	35.28	35.42	35.56	35.72	35.91	36.07	36.21	36.40	37.86	36.00	35.40	35.17	35.60
PURGA	10515.22	90684	33.62	33.83	33.99	34.15	34.36	34.55	34.71	34.94	36.83	34.47	33.79	33.50	34.04
PURGA	10988.20	91157	33.17	33.33	33.47	33.61	33.81	34.00	34.18	34.43	36.63	33.93	33.30	33.10	33.53
PURGA	11344.89	91513	32.72	32.94	33.09	33.25	33.50	33.72	33.93	34.20	36.61	33.64	32.89	32.53	33.15
PURGA	11781.18	91950	32.18	32.54	32.71	32.88	33.15	33.38	33.61	33.91	36.58	33.30	32.47	31.82	32.77
PURGA	12363.30	92532	31.15	31.73	31.92	32.12	32.44	32.71	32.96	33.31	36.54	32.62	31.63	30.81	32.00
PURGA	12786.29	92955	30.48	30.95	31.23	31.49	31.86	32.14	32.39	32.72	36.49	32.05	30.87	30.10	31.33
PURGA	12806.29	92975	30.46	30.94	31.22	31.48	31.85	32.13	32.38	32.71	36.49	32.04	30.86	30.06	31.32
PURGA	13281.62	93450	29.73	30.34	30.58	30.83	31.19	31.42	31.66	31.98	36.46	31.34	30.28	29.22	30.67
PURGA	13569.12	93738	29.05	29.79	30.03	30.31	30.70	30.97	31.23	31.58	36.46	30.88	29.74	28.61	30.14
PURGA	14068.76	94237	28.09	28.80	29.09	29.39	29.78	30.10	30.38	30.74	36.45	30.00	28.71	27.62	29.21
PURGA	14460.16	94629	27.69	28.23	28.54	28.80	29.14	29.40	29.63	29.91	36.44	29.32	28.09	27.22	28.64
PURGA	14799.07	94968	27.18	27.78	28.07	28.29	28.58	28.79	28.99	29.26	36.44	28.73	27.63	26.72	28.15
PURGA	15308.54	95477	26.27	26.74	27.05	27.35	27.73	27.97	28.20	28.85	36.44	27.88	26.63	26.10	27.17
PURGA	15971.04	96139	25.80	26.30	26.64	26.88	27.28	27.55	28.10	28.83	36.44	27.42	26.20	25.58	26.73
PURGA	16563.37	96732	25.18	25.75	26.17	26.42	26.87	27.10	28.07	28.81	36.43	27.13	25.67	24.87	26.25
PURGA	17169.76	97338	23.98	24.49	24.83	25.24	25.73	25.88	28.06	28.80	36.44	27.10	24.43	23.75	25.11
PURGA	17826.32	97995	23.62	24.16	24.40	24.89	25.09	25.27	28.06	28.80	36.43	27.09	24.12	23.37	24.83
PURGA	18140.67	98309	23.42	24.04	24.28	24.81	24.98	25.14	28.05	28.80	36.43	27.08	24.00	23.14	24.76
PURGA	18629.82	98798	22.70	23.25	23.69	24.20	24.43	25.00	28.05	28.79	36.43	27.08	23.23	22.47	24.16
PURGA	19241.91	99410	21.71	22.25	22.86	23.42	24.03	24.99	28.04	28.79	36.42	27.07	22.35	21.51	23.48
PURGA	19930.56	100099	21.06	21.59	22.03	22.67	23.63	24.99	28.04	28.78	36.41	27.06	21.86	20.90	22.92
PURGA	19950.56	100119	21.05	21.58	22.02	22.66	23.62	24.98	28.03	28.78	36.39	27.06	21.85	20.89	22.91
PURGA	20954.56	101123	20.37	20.86	21.29	21.86	23.55	24.98	28.02	28.75	36.32	27.04	21.38	20.30	22.38
PURGA	21686.56	101855	18.56	19.07	20.06	21.45	23.53	24.97	28.00	28.74	36.31	27.01	20.98	19.36	22.09
PURGA	22343.56	102512	16.80	18.50	19.93	21.43	23.52	24.96	27.98	28.72	36.29	26.99	20.88	19.10	22.00
PURGA_2	0.00		61.35	61.86	62.19	62.31	62.53	62.70	62.79	62.96	64.49	62.84	61.85	61.50	62.36

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
PURGA_2	20.00		61.33	61.82	62.12	62.24	62.47	62.64	62.72	62.89	64.43	62.77	61.81	61.49	62.28
PURGA_2	42.25		60.63	61.81	62.10	62.22	62.33	62.47	62.57	62.81	64.41	62.64	61.79	61.39	62.18
PURGA_2	2886.45		53.33	54.27	54.36	54.45	54.59	54.70	54.78	54.94	56.12	54.83	54.30	53.94	54.49
PURGA_2	2890.12		52.81	53.92	54.00	54.08	54.20	54.30	54.37	54.50	55.54	54.45	53.96	53.05	54.13
PURGA_2	4652.28		48.27	48.48	48.68	48.86	49.11	49.28	49.47	49.71	50.95	49.17	48.42	48.14	48.71
RAILBRIDGE1	0.00		81.59	82.75	83.42	83.73	84.81	85.01	85.38	85.48	86.17	84.79	83.86	82.11	83.97
RAILBRIDGE1	4.00		81.59	82.75	83.42	83.73	84.81	85.02	85.38	85.48	86.18	84.79	83.86	82.11	84.14
RAILBRIDGE1	16.00		81.70	82.93	83.68	84.01	84.82	85.03	85.39	85.49	86.31	84.80	84.16	82.25	84.24
RAILBRIDGE1	20.00		81.70	82.93	83.68	84.01	84.83	85.03	85.39	85.50	86.30	84.81	84.16	82.25	84.24
RAILBRIDGE2	0.00		80.89	81.87	82.34	82.48	82.69	82.91	83.32	83.43	84.17	82.69	82.49	81.37	82.51
RAILBRIDGE2	4.00		80.86	81.84	82.32	82.46	82.64	82.87	83.27	83.39	84.13	82.65	82.46	81.34	82.49
RAILBRIDGE2	16.00		80.08	80.64	81.02	81.30	81.98	82.27	82.89	82.97	83.61	81.95	81.59	80.33	81.66
RAILBRIDGE2	20.00		78.62	79.81	80.49	80.94	81.82	82.16	82.82	82.90	83.55	81.79	81.34	79.18	81.43
RAILBRIDGE3	0.00		74.86	76.31	77.36	77.77	78.65	78.85	79.43	79.50	80.15	78.61	77.95	75.56	78.03
RAILBRIDGE3	4.00		74.86	76.31	77.37	77.77	78.67	78.88	79.48	79.57	80.28	78.62	77.96	75.57	78.04
RAILBRIDGE3	16.00		74.87	76.34	77.40	77.81	78.74	78.98	79.62	79.74	80.63	78.69	78.01	75.58	78.10
RAILBRIDGE3	20.00		74.87	76.34	77.40	77.81	78.72	78.95	79.57	79.68	80.48	78.68	78.01	75.59	78.09
RAILBRIDGE4	0.00		66.17	67.24	67.80	68.13	68.97	69.42	70.21	70.31	71.42	68.96	68.38	66.75	68.45
RAILBRIDGE4	4.00		66.17	67.44	67.80	68.14	68.98	69.42	70.21	70.32	71.50	68.98	68.42	66.91	68.48
RAILBRIDGE4	16.00		67.37	67.55	67.80	68.16	69.00	69.43	70.11	70.20	71.00	68.99	68.42	67.47	68.50
RAILBRIDGE4	20.00		67.37	67.55	67.80	68.17	69.01	69.43	70.10	70.19	70.96	69.00	68.43	67.47	68.52
RAILBRIDGE5	0.00		65.93	66.72	66.98	67.15	67.71	67.96	68.46	68.64	71.22	67.72	67.26	66.45	67.28
RAILBRIDGE5	4.00		65.93	66.72	66.97	67.13	67.69	67.94	68.44	68.61	71.40	67.70	67.23	66.45	67.27
RAILBRIDGE5	16.00		65.92	66.71	66.95	67.11	67.66	67.89	68.37	68.51	69.60	67.67	67.21	66.44	67.24
RAILBRIDGE5	20.00		65.92	66.71	66.94	67.09	67.65	67.87	68.35	68.48	69.53	67.65	67.19	66.44	67.22
RAILBRIDGE6	0.00		50.66	52.72	53.59	54.20	54.67	54.97	55.18	55.28	56.66	54.75	53.65	51.15	54.28
RAILBRIDGE6	4.00		50.66	52.72	53.59	54.20	54.67	54.97	55.18	55.28	56.66	54.75	53.65	51.15	54.28
RAILBRIDGE6	16.00		52.16	53.22	54.18	54.52	55.21	55.83	56.49	56.64	57.73	55.40	54.75	52.82	54.82
RAILBRIDGE6	20.00		52.16	53.23	54.21	54.53	55.21	55.84	56.49	56.64	57.73	55.40	54.75	52.83	54.83
RAILBRIDGE7	0.00		44.12	45.39	45.80	46.03	46.39	46.73	47.04	47.17	48.08	46.48	45.98	44.68	46.10

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILBRIDGE7	4.00		45.66	45.66	45.80	46.03	46.37	46.72	47.02	47.16	48.05	46.46	45.98	45.66	46.10
RAILBRIDGE7	16.00		45.66	45.66	45.94	46.16	46.52	46.76	47.05	47.17	48.42	46.58	46.18	45.66	46.25
RAILBRIDGE7	20.00		44.73	45.43	45.94	46.17	46.54	46.79	47.08	47.19	48.45	46.61	46.19	44.85	46.27
RAILBRIDGE8	0.00		44.05	45.36	45.79	46.02	46.37	46.65	46.97	47.07	48.07	46.46	45.97	44.57	46.09
RAILBRIDGE8	4.00		44.05	45.36	45.79	46.02	46.35	46.63	46.94	47.02	47.99	46.44	45.96	44.57	46.08
RAILBRIDGE8	16.00		44.05	45.36	45.79	46.02	46.39	46.68	46.96	47.10	48.32	46.45	45.97	44.58	46.09
RAILBRIDGE8	20.00		44.49	45.37	45.79	46.02	46.41	46.71	47.01	47.14	48.39	46.48	45.99	44.64	46.08
RAILBRIDGE9	0.00		41.38	41.99	42.04	42.12	42.41	42.64	42.83	42.90	44.85	42.50	42.07	41.87	42.18
RAILBRIDGE9	4.00		41.38	41.99	42.04	42.12	42.41	42.63	42.83	42.89	44.87	42.50	42.07	41.87	42.18
RAILBRIDGE9	16.00		41.38	42.00	42.05	42.12	42.43	42.75	43.13	43.32	45.85	42.54	42.08	41.88	42.19
RAILBRIDGE9	20.00		41.62	41.75	41.84	41.96	42.57	43.00	43.93	44.03	45.68	42.68	41.94	41.63	42.06
RAILNORTH	868.96		81.70	82.93	83.68	84.01	84.93	85.19	85.80	86.08	87.16	84.90	84.17	82.25	84.25
RAILNORTH	1029.84		81.70	82.93	83.68	84.01	84.83	85.03	85.39	85.50	86.30	84.81	84.16	82.25	84.24
RAILNORTH	1399.96		78.62	79.81	80.49	80.94	81.82	82.16	82.82	82.90	83.55	81.79	81.34	79.18	81.43
RAILNORTH	1506.31		78.39	79.56	80.22	80.65	81.52	81.85	82.48	82.55	83.12	81.49	81.07	78.95	81.16
RAILNORTH	2115.29		74.87	76.34	77.40	77.81	78.72	78.95	79.57	79.68	80.48	78.68	78.01	75.59	78.09
RAILNORTH	2593.10		74.82	76.33	77.40	77.77	78.34	78.45	78.71	78.75	79.35	78.31	77.90	75.57	77.96
RAILNORTH	3353.67		72.01	73.19	73.52	73.99	74.51	74.65	74.93	74.97	75.60	74.50	74.10	72.58	74.14
RAILNORTH	3796.28		69.92	70.81	70.97	71.87	72.58	72.74	73.09	73.15	73.92	72.57	72.03	70.34	72.09
RAILNORTH	4285.17		67.37	67.55	67.80	68.17	69.01	69.43	70.10	70.19	70.96	69.00	68.43	67.47	68.52
RAILNORTH	4381.13		66.72	66.96	67.20	67.88	68.62	69.05	69.68	69.77	70.52	68.61	68.17	66.86	68.18
RAILNORTH	4558.22		65.92	66.71	66.94	67.09	67.65	67.87	68.35	68.48	69.53	67.65	67.19	66.44	67.22
RAILNORTH	5081.62		62.42	63.29	64.05	64.42	65.85	66.11	66.65	66.75	67.57	65.86	64.63	62.76	64.69
RAILNORTH	6908.85		56.22	56.98	57.33	57.52	57.91	58.33	58.84	59.76	60.69	58.03	57.69	56.90	57.71
RAILNORTH	7346.49		56.19	56.87	56.98	57.08	57.31	57.55	57.98	58.14	59.42	57.37	57.17	56.85	57.19
RAILNORTH	8032.56		54.19	55.71	56.02	56.26	56.84	57.16	57.71	57.90	59.28	56.92	56.54	55.63	56.59
RAILNORTH	8789.28		52.52	54.28	54.98	55.40	56.32	56.78	57.42	57.63	59.05	56.45	55.76	53.66	55.84
RAILNORTH	9029.00		52.16	53.23	54.21	54.53	55.21	55.84	56.49	56.64	57.73	55.40	54.75	52.83	54.83
RAILNORTH	9269.34		51.49	52.18	52.63	52.67	52.80	52.95	53.19	53.28	53.90	52.85	52.70	51.90	52.72
RAILNORTH	9771.72		50.61	50.78	51.46	51.53	51.71	51.86	52.09	52.17	52.66	51.76	51.59	50.75	51.61

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILNORTH	9791.72		50.59	50.75	51.43	51.50	51.69	51.83	52.05	52.13	52.61	51.73	51.56	50.72	51.58
RAILNORTH	10377.33		49.40	49.55	49.73	49.92	50.31	50.39	50.52	50.58	51.14	50.33	50.07	49.50	50.12
RAILNORTH	10796.10		48.30	48.33	48.47	48.63	48.96	49.12	49.37	49.47	50.32	49.01	48.76	48.33	48.80
RAILNORTH	11379.36		47.65	47.74	47.95	48.08	48.36	48.53	48.78	48.88	49.89	48.41	48.15	47.67	48.20
RAILNORTH	11963.54		46.37	46.98	47.41	47.49	47.69	47.84	48.06	48.15	49.21	47.74	47.53	46.67	47.57
RAILNORTH	12390.00		44.73	45.43	45.94	46.17	46.54	46.79	47.08	47.19	48.45	46.61	46.19	44.85	46.27
RAILNORTH	12410.00		44.49	45.37	45.79	46.02	46.41	46.71	47.01	47.14	48.39	46.48	45.99	44.64	46.08
RAILNORTH	13468.00		42.05	43.79	44.07	44.27	44.52	44.74	45.11	45.20	46.55	44.56	44.25	42.76	44.40
RAILNORTH	13868.00		41.62	41.75	41.84	41.96	42.57	43.00	43.93	44.03	45.68	42.68	41.94	41.63	42.06
RAILNORTH	14628.00		40.18	40.19	40.18	40.37	41.02	41.46	41.91	42.05	45.50	41.37	40.26	40.19	40.53
RAILNORTH	14728.00		40.15	40.15	40.15	40.34	41.01	41.46	41.80	41.98	45.50	41.37	40.23	40.15	40.51
RAILNORTH	14838.00		40.15	40.15	40.15	40.34	41.01	41.46	41.79	41.98	45.50	41.37	40.23	40.15	40.51
RAILNORTH	14858.00		40.15	40.15	40.15	40.34	41.01	41.46	41.79	41.98	45.50	41.37	40.23	40.15	40.51
RAILNORTH	16228.00		37.91	38.81	39.38	39.82	40.44	40.93	41.50	41.70	43.59	40.90	39.73	38.51	40.01
RAILSOUTH	868.96		81.70	82.93	83.68	84.01	84.93	85.19	85.80	86.08	87.16	84.90	84.17	82.25	84.25
RAILSOUTH	1029.84		81.59	82.75	83.42	83.73	84.81	85.01	85.38	85.48	86.17	84.79	83.86	82.11	83.97
RAILSOUTH	1399.96		80.89	81.87	82.34	82.48	82.69	82.91	83.32	83.43	84.17	82.69	82.49	81.37	82.51
RAILSOUTH	1506.31		80.83	81.85	82.19	82.37	82.52	82.67	83.00	83.06	83.60	82.53	82.37	81.34	82.39
RAILSOUTH	2115.29		74.86	76.31	77.36	77.77	78.65	78.85	79.43	79.50	80.15	78.61	77.95	75.56	78.03
RAILSOUTH	2593.10		71.56	72.61	73.40	73.63	74.19	74.83	75.75	76.05	78.23	74.16	73.74	72.14	73.79
RAILSOUTH	3353.67		68.96	70.39	71.32	71.69	72.43	73.01	73.82	74.08	74.94	72.41	71.87	69.64	71.94
RAILSOUTH	3796.28		67.50	68.77	69.67	70.09	71.02	71.50	72.09	72.21	72.89	71.00	70.32	68.06	70.42
RAILSOUTH	4285.17		66.17	67.24	67.80	68.13	68.97	69.42	70.21	70.31	71.42	68.96	68.38	66.75	68.45
RAILSOUTH	4381.13		66.13	67.13	67.57	67.83	68.61	69.05	69.80	69.90	71.31	68.62	68.05	66.69	68.12
RAILSOUTH	4558.22		65.93	66.72	66.98	67.15	67.71	67.96	68.46	68.64	71.22	67.72	67.26	66.45	67.28
RAILSOUTH	6908.85		56.22	56.98	57.33	57.52	57.91	58.33	58.84	59.76	60.69	58.03	57.69	56.90	57.71
RAILSOUTH	7346.49		54.40	55.44	55.95	56.23	56.80	57.23	57.99	58.36	59.45	56.93	56.39	55.45	56.47
RAILSOUTH	8032.56		51.93	54.13	54.76	55.05	55.47	55.82	56.14	56.33	57.90	55.56	54.77	52.67	55.11
RAILSOUTH	8324.00		51.64	54.10	54.75	55.04	55.45	55.79	56.02	56.15	57.63	55.54	54.74	52.18	55.10
RAILSOUTH	8789.28		51.14	53.39	54.22	54.69	55.13	55.44	55.65	55.76	57.14	55.21	54.23	51.62	54.76

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILSOUTH	9029.00		50.66	52.72	53.59	54.20	54.67	54.97	55.18	55.28	56.66	54.75	53.65	51.15	54.28
RAILSOUTH	9269.34		49.97	51.98	52.92	53.48	53.84	54.20	54.45	54.58	56.15	53.95	53.04	50.47	53.53
RAILSOUTH	9771.72		48.61	50.69	51.79	52.14	52.64	53.18	53.39	53.53	55.02	52.81	51.88	49.11	52.21
RAILSOUTH	9791.72		48.59	50.66	51.77	52.13	52.63	53.16	53.38	53.51	54.96	52.80	51.86	49.09	52.20
RAILSOUTH	10377.33		47.71	49.80	50.50	50.91	51.32	51.88	52.06	52.16	53.30	51.47	50.54	48.21	50.95
RAILSOUTH	10796.10		47.10	49.28	49.73	50.15	50.41	50.69	50.90	51.00	52.21	50.48	49.76	47.63	50.19
RAILSOUTH	11379.36		46.23	48.00	48.24	48.43	49.02	49.29	49.50	49.62	50.79	49.09	48.25	46.67	48.56
RAILSOUTH	11963.54		45.29	46.09	46.43	46.67	47.54	47.80	48.01	48.11	49.15	47.60	46.46	45.44	46.78
RAILSOUTH	12163.54		44.63	45.64	45.93	46.11	46.47	46.82	47.11	47.24	48.31	46.56	46.04	45.02	46.18
RAILSOUTH	12390.00		44.12	45.39	45.80	46.03	46.39	46.73	47.04	47.17	48.08	46.48	45.98	44.68	46.10
RAILSOUTH	12410.00		44.05	45.36	45.79	46.02	46.37	46.65	46.97	47.07	48.07	46.46	45.97	44.57	46.09
RAILSOUTH	13468.00		42.37	43.25	43.60	43.81	44.01	44.16	44.34	44.46	45.70	44.06	43.78	42.75	43.86
RAILSOUTH	13868.00		41.38	41.99	42.04	42.12	42.41	42.64	42.83	42.90	44.85	42.50	42.07	41.87	42.18
RAILSOUTH	14628.00		39.12	39.90	40.21	40.53	41.26	41.61	41.92	42.05	43.97	41.49	40.40	39.44	40.69
RAILSOUTH	14728.00		38.91	39.67	40.01	40.34	41.01	41.46	41.79	41.96	43.92	41.37	40.22	39.24	40.51
RAILSOUTH	14838.00		38.58	39.33	39.73	40.09	40.69	41.30	41.70	41.85	43.83	41.21	39.99	38.95	40.25
RAILSOUTH	14858.00		38.49	39.29	39.69	40.04	40.65	41.08	41.57	41.78	43.76	41.03	39.94	38.92	40.21
RAILSOUTH	16228.00		37.91	38.81	39.38	39.82	40.44	40.93	41.50	41.70	43.59	40.90	39.73	38.51	40.01
RAILWEIR1	0.00		54.40	55.44	55.95	56.23	56.80	57.23	57.99	58.36	59.45	56.93	56.39	55.45	56.47
RAILWEIR1	5.00		54.40	55.44	55.95	56.23	56.80	57.23	57.99	58.36	59.45	56.93	56.39	55.45	56.47
RAILWEIR1	15.00		56.19	56.87	56.98	57.08	57.31	57.55	57.98	58.14	59.42	57.37	57.17	56.85	57.19
RAILWEIR1	20.00		56.19	56.87	56.98	57.08	57.31	57.55	57.98	58.14	59.42	57.37	57.17	56.85	57.19
RAILWEIR2	0.00		51.93	54.13	54.76	55.05	55.47	55.82	56.14	56.33	57.90	55.56	54.77	52.67	55.11
RAILWEIR2	5.00		51.93	54.13	54.76	55.05	55.47	55.82	56.14	56.33	57.90	55.56	54.77	52.67	55.11
RAILWEIR2	15.00		54.19	55.71	56.02	56.26	56.84	57.16	57.71	57.90	59.28	56.92	56.54	55.63	56.59
RAILWEIR2	20.00		54.19	55.71	56.02	56.26	56.84	57.16	57.71	57.90	59.28	56.92	56.54	55.63	56.59
RAILWEIR3	0.00		47.71	49.80	50.50	50.91	51.32	51.88	52.06	52.16	53.30	51.47	50.54	48.21	50.95
RAILWEIR3	5.00		47.71	49.80	50.50	50.91	51.32	51.88	52.06	52.16	53.30	51.47	50.54	48.21	50.95
RAILWEIR3	15.00		49.40	49.55	49.73	49.92	50.31	50.39	50.52	50.58	51.14	50.33	50.07	49.50	50.12
RAILWEIR3	20.00		49.40	49.55	49.73	49.92	50.31	50.39	50.52	50.58	51.14	50.33	50.07	49.50	50.12

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILWEIR4	0.00		46.23	48.00	48.24	48.43	49.02	49.29	49.50	49.62	50.79	49.09	48.25	46.67	48.56
RAILWEIR4	5.00		46.23	48.00	48.24	48.43	49.02	49.29	49.50	49.62	50.79	49.09	48.25	46.67	48.56
RAILWEIR4	15.00		47.64	47.74	47.95	48.08	48.36	48.53	48.78	48.88	49.89	48.41	48.15	47.67	48.20
RAILWEIR4	20.00		47.65	47.74	47.95	48.08	48.36	48.53	48.78	48.88	49.89	48.41	48.15	47.67	48.20
RAILWEIR5	0.00		42.37	43.25	43.60	43.81	44.01	44.16	44.34	44.46	45.70	44.06	43.78	42.75	43.86
RAILWEIR5	4.00		42.37	43.28	43.60	43.83	44.04	44.21	44.42	44.52	45.69	44.09	43.80	42.75	43.88
RAILWEIR5	16.00		42.05	43.78	44.05	44.23	44.51	44.74	45.10	45.19	46.55	44.55	44.22	42.76	44.36
RAILWEIR5	20.00		42.05	43.79	44.07	44.27	44.52	44.74	45.11	45.20	46.55	44.56	44.25	42.76	44.40
RAILWEIR6	0.00		38.91	39.67	40.01	40.34	41.01	41.46	41.79	41.96	43.92	41.37	40.22	39.24	40.51
RAILWEIR6	4.00		38.91	39.67	40.01	40.34	41.01	41.46	41.79	41.96	43.92	41.37	40.22	39.24	40.51
RAILWEIR6	16.00		40.14	40.15	40.14	40.34	41.01	41.46	41.80	41.98	45.50	41.37	40.23	40.14	40.51
RAILWEIR6	20.00		40.15	40.15	40.15	40.34	41.01	41.46	41.80	41.98	45.50	41.37	40.23	40.15	40.51
WARPURWEIR1	0.00		20.37	20.86	21.29	21.86	23.55	24.98	28.02	28.75	36.32	27.04	21.38	20.30	22.38
WARPURWEIR1	5.00		20.37	20.86	21.29	21.86	23.55	24.98	28.02	28.75	36.32	27.04	21.38	20.30	22.38
WARPURWEIR1	15.00		17.47	18.98	20.41	22.00	24.13	25.18	28.02	28.76	36.32	27.07	21.39	19.68	22.27
WARPURWEIR1	20.00		17.47	18.98	20.41	22.00	24.13	25.18	28.02	28.76	36.32	27.07	21.39	19.68	22.27
WARPURWEIR2	0.00		18.56	19.07	20.06	21.45	23.53	24.97	28.00	28.74	36.31	27.01	20.98	19.36	22.09
WARPURWEIR2	5.00		18.56	19.07	20.06	21.45	23.53	24.97	28.00	28.74	36.31	27.01	20.98	19.36	22.09
WARPURWEIR2	15.00		16.96	18.73	20.19	21.75	23.90	25.08	28.01	28.75	36.31	27.03	21.16	19.40	22.15
WARPURWEIR2	20.00		16.96	18.73	20.19	21.75	23.90	25.08	28.01	28.75	36.31	27.03	21.16	19.40	22.15
WARPURWEIR3	0.00		23.86	24.81	25.74	26.93	28.05	28.47	29.84	30.11	36.48	29.38	26.29	25.48	26.28
WARPURWEIR3	5.00		23.86	24.81	25.74	26.93	28.05	28.47	29.84	30.11	36.48	29.38	26.29	25.48	26.28
WARPURWEIR3	15.00		23.62	24.16	24.40	24.89	25.09	25.27	28.06	28.80	36.47	27.09	24.12	23.37	24.83
WARPURWEIR3	20.00		23.62	24.16	24.40	24.89	25.09	25.27	28.06	28.80	36.43	27.09	24.12	23.37	24.83
WARRILL	0.00	74280	57.65	58.44	58.69	59.00	59.31	59.47	60.06	60.21	61.63	59.63	58.62	58.67	58.75
WARRILL	1033.45	75313	56.01	56.39	56.58	56.91	57.22	57.37	57.95	58.06	59.42	57.53	56.53	56.56	56.64
WARRILL	2424.10	76704	52.01	52.70	53.30	54.16	54.52	54.77	55.47	55.65	57.23	54.97	53.05	53.20	53.51
WARRILL	2444.10	76724	52.00	52.70	53.29	54.15	54.51	54.76	55.41	55.57	57.21	54.96	53.04	53.19	53.50
WARRILL	3488.49	77768	50.42	51.85	52.36	52.73	53.57	53.99	54.22	54.25	55.41	54.13	52.11	52.28	52.46
WARRILL	3498.49	77778	50.41	51.84	52.36	52.72	53.01	53.18	53.68	53.82	55.39	53.32	52.10	52.27	52.45

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	3683.49	77963	50.35	51.74	52.19	52.35	52.58	52.76	53.18	53.30	54.95	52.88	51.95	52.12	52.24
WARRILL	4778.90	79059	49.85	50.17	50.34	50.62	50.93	51.02	51.75	51.92	54.19	51.26	50.33	50.31	50.38
WARRILL	4798.90	79079	49.80	50.16	50.33	50.62	50.92	51.02	51.74	51.91	54.18	51.26	50.33	50.31	50.37
WARRILL	6397.07	80677	44.93	45.82	46.73	48.10	49.24	49.58	50.87	51.04	53.51	50.15	46.70	46.56	46.94
WARRILL	6407.07	80687	44.88	45.63	46.40	47.62	48.60	48.88	50.27	50.58	53.49	49.38	46.37	46.26	46.56
WARRILL	7111.27	81391	43.76	44.72	45.47	46.31	46.92	47.27	49.27	49.81	52.83	47.90	45.45	45.35	45.62
WARRILL	7131.27	81411	43.75	44.71	45.46	46.30	46.87	47.12	49.12	49.34	51.91	47.73	45.44	45.34	45.61
WARRILL	8514.13	82794	43.06	44.01	44.64	45.41	46.04	46.18	47.05	47.28	49.69	46.50	44.61	44.51	44.79
WARRILL	9896.98	84177	41.98	43.02	43.66	44.45	45.30	45.39	45.98	46.13	47.84	45.59	43.63	43.53	43.81
WARRILL	10941.75	85221	40.16	41.10	41.90	42.83	43.48	43.60	44.33	44.51	46.35	43.86	41.87	41.75	42.07
WARRILL	11579.99	85860	38.91	39.65	40.30	41.17	42.07	42.34	43.38	43.55	45.07	42.76	40.27	40.16	40.47
WARRILL	11599.99	85880	38.34	39.58	40.20	40.95	41.59	41.82	42.60	42.78	44.80	42.10	40.17	40.05	40.40
WARRILL	12312.49	86592	37.44	38.79	39.30	39.74	40.06	40.20	41.06	41.30	43.65	40.49	39.27	39.16	39.47
WARRILL	12938.26	87218	37.08	38.29	38.76	39.12	39.44	39.59	40.61	40.91	43.31	39.94	38.74	38.67	38.85
WARRILL	13459.92	87740	36.65	37.67	38.12	38.54	38.97	39.15	40.33	40.66	42.94	39.58	38.11	38.04	38.18
WARRILL	13716.44	87996	36.15	37.25	37.77	38.21	38.66	38.85	40.05	40.38	42.53	39.30	37.76	37.66	37.84
WARRILL	14151.04	88431	35.27	36.69	37.36	37.78	38.19	38.35	39.39	39.64	41.74	38.72	37.34	37.21	37.42
WARRILL	15218.95	89499	34.02	35.46	36.22	36.70	37.11	37.27	38.10	38.32	40.57	37.64	36.20	36.03	36.30
WARRILL	15709.63	89989	33.19	34.43	35.05	35.60	36.18	36.45	37.46	37.73	40.17	37.01	35.07	34.94	35.16
WARRILL	16308.32	90588	32.63	33.81	34.38	34.93	35.47	35.75	37.00	37.33	39.88	36.54	34.59	34.29	34.58
WARRILL	17201.96	91482	31.87	33.09	33.71	34.31	34.87	35.18	36.47	36.76	39.02	36.01	33.93	33.61	33.91
WARRILL	18218.98	92499	30.63	31.58	32.11	32.56	32.98	33.21	34.29	34.58	37.73	33.88	32.28	32.04	32.26
WARRILL	18724.52	93004	29.91	31.04	31.56	32.04	32.53	32.76	33.87	34.14	37.55	33.47	31.76	31.44	31.75
WARRILL	19155.35	93435	29.38	30.75	31.38	31.86	32.37	32.60	33.69	33.95	37.43	33.31	31.59	31.22	31.58
WARRILL	19737.18	94017	28.58	30.13	30.97	31.55	32.10	32.33	33.40	33.65	37.24	33.03	31.21	30.79	31.20
WARRILL	20169.55	94449	27.85	29.27	30.28	31.08	31.77	32.02	33.12	33.37	37.09	32.75	30.64	30.10	30.62
WARRILL	20702.56	94982	27.25	28.62	29.53	30.31	30.99	31.29	32.59	32.85	36.90	32.20	29.96	29.31	29.95
WARRILL	20969.75	95249	27.04	28.38	29.28	30.05	30.63	30.92	32.40	32.68	36.88	31.99	29.74	29.05	29.73
WARRILL	21848.19	96128	26.10	27.33	27.99	28.66	29.42	29.83	31.71	32.00	36.63	31.29	28.21	27.86	28.19
WARRILL	23196.78	97476	24.17	25.23	26.16	27.20	28.22	28.62	30.01	30.28	36.51	29.54	26.62	25.93	26.61

Table A.1 **(continued)**

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	23701.37	97981	23.86	24.81	25.74	26.93	28.05	28.47	29.84	30.11	36.48	29.38	26.29	25.48	26.28
WARRILL	24126.72	98406	23.68	24.60	25.48	26.65	27.89	28.34	29.78	30.05	36.47	29.30	26.01	25.23	26.01
WARRILL	24580.02	98860	23.42	24.28	25.09	26.18	27.50	27.99	29.57	29.87	36.46	29.03	25.57	24.85	25.58
WARRILL	25048.56	99328	23.04	24.00	24.83	26.06	27.38	27.86	29.37	29.70	36.46	28.81	25.38	24.59	25.40
WARRILL	25710.35	99990	22.41	23.53	24.33	25.72	27.09	27.59	29.18	29.52	36.43	28.59	24.96	24.11	25.00
WARRILL	25730.35	100010	22.37	23.47	24.32	25.59	26.91	27.33	29.03	29.47	36.37	28.53	24.94	24.10	24.98
WARRILL	26219.35	100499	21.89	23.02	23.85	25.13	26.43	26.82	28.60	29.13	36.34	28.06	24.46	23.62	24.54
WARRILL	26693.35	100973	21.32	22.39	23.20	24.55	26.04	26.50	28.43	29.01	36.33	27.86	23.85	22.98	24.01
WARRILL	27315.35	101595	20.67	21.60	22.39	23.85	25.45	26.06	28.29	28.92	36.33	27.63	23.13	22.17	23.41
WARRILL	27873.35	102153	20.10	21.12	21.99	23.49	25.02	25.77	28.20	28.87	36.33	27.43	22.80	21.73	23.16
WARRILL	28487.35	102767	19.31	20.46	21.43	22.95	24.67	25.55	28.14	28.83	36.32	27.31	22.33	21.08	22.80
WARRILL	29252.35	103532	18.30	19.54	20.74	22.26	24.31	25.31	28.07	28.79	36.32	27.16	21.66	20.17	22.40
WARRILL	29849.35	104129	17.47	18.98	20.41	22.00	24.13	25.18	28.02	28.76	36.32	27.07	21.39	19.68	22.27
WARRILL	30164.35	104444	16.96	18.73	20.19	21.75	23.90	25.08	28.01	28.75	36.31	27.03	21.16	19.40	22.15
WARRILL	30886.35	105166	16.80	18.50	19.93	21.43	23.52	24.96	27.98	28.72	36.29	26.99	20.88	19.10	22.00
WARRILL	31173.35	105453	16.64	18.37	19.82	21.32	23.45	24.92	27.95	28.69	36.24	26.95	20.75	18.96	21.91
WARRILL	31526.35	105806	16.46	18.21	19.72	21.23	23.39	24.88	27.92	28.66	36.18	26.91	20.64	18.80	21.83
WARRILL	32023.35	106303	16.20	18.01	19.58	21.10	23.29	24.83	27.86	28.60	36.10	26.85	20.48	18.57	21.73
WARRILL	32284.35	106564	15.98	17.86	19.47	20.98	23.20	24.78	27.82	28.57	36.06	26.80	20.35	18.39	21.63
WARRILL	32634.35	106914	15.56	17.66	19.31	20.85	23.10	24.73	27.78	28.52	35.98	26.74	20.18	18.13	21.53
WARRILL	33250.35	107530	15.19	17.58	19.25	20.81	23.06	24.71	27.76	28.51	35.99	26.72	20.12	18.02	21.50
WARRILL	33860.35	108140	15.00	17.52	19.20	20.76	23.02	24.68	27.71	28.45	35.81	26.68	20.07	17.93	21.46
WARRILL-BOONAH	0.00	43465	169.52	169.85	169.95	170.02	170.17	170.34	170.65	170.74	171.55	170.27	169.89	169.91	170.01
WARRILL-BOONAH	1763.90	45229	146.19	146.57	146.80	147.04	147.29	147.65	148.32	148.43	149.23	147.41	146.68	146.72	147.00
WARRILL-BOONAH	2771.21	46236	139.12	139.72	139.86	139.96	140.40	140.63	140.95	141.08	142.07	140.55	139.77	139.79	139.93
WARRILL-BOONAH	3385.00	46850	135.43	136.32	137.08	137.72	138.28	138.65	139.09	139.23	140.39	138.57	136.63	136.74	137.64

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	3400.00	46865	135.41	136.30	137.01	137.37	138.09	138.64	139.07	139.22	140.37	138.56	136.60	136.71	137.31
WARRILL-BOONAH	4501.05	47966	129.56	130.01	130.46	130.77	131.37	132.45	133.24	133.40	134.75	131.99	130.20	130.27	130.70
WARRILL-BOONAH	5743.62	49208	117.39	118.11	118.76	119.18	119.82	120.65	123.22	123.57	126.23	120.38	118.39	118.49	119.08
WARRILL-BOONAH	6448.72	49914	115.38	116.09	116.62	116.99	117.57	118.31	119.92	120.70	124.13	118.07	116.32	116.40	116.90
WARRILL-BOONAH	7295.14	50760	113.02	113.78	114.27	114.62	115.20	115.94	117.53	118.37	121.14	115.71	113.99	114.06	114.53
WARRILL-BOONAH	8223.07	51688	110.16	110.87	111.51	111.94	112.57	113.37	114.93	115.97	117.85	113.13	111.14	111.23	111.84
WARRILL-BOONAH	9097.24	52562	105.21	106.07	106.85	107.36	108.15	109.12	110.95	111.16	112.55	108.85	106.40	106.51	107.24
WARRILL-BOONAH	10614.64	54079	99.41	100.13	100.73	101.14	101.73	102.30	103.27	103.70	105.20	102.05	100.39	100.48	101.05
WARRILL-BOONAH	12056.87	55522	94.13	94.64	95.14	95.57	96.19	96.58	97.62	97.86	99.66	96.45	94.83	94.90	95.44
WARRILL-BOONAH	13180.04	56645	88.60	89.60	90.51	91.13	92.17	92.74	94.63	94.77	96.88	92.54	90.00	90.12	90.96
WARRILL-BOONAH	14463.88	57929	85.58	86.81	87.82	88.47	89.54	90.34	91.28	91.53	93.50	90.07	87.26	87.39	88.29
WARRILL-BOONAH	14878.92	58344	84.81	85.85	86.75	87.33	88.34	89.46	90.31	90.41	92.67	89.11	86.25	86.37	87.17
WARRILL-BOONAH	15984.89	59450	80.44	81.78	83.02	83.68	84.59	85.50	88.18	88.20	89.20	85.26	82.23	82.47	83.53
WARRILL-BOONAH	15994.89	59460	80.39	81.67	82.98	83.63	84.52	85.39	87.23	87.28	88.11	85.16	82.19	82.34	83.48
WARRILL-BOONAH	17217.81	60683	77.25	78.38	79.31	80.00	80.68	81.08	81.66	81.94	83.09	80.94	78.62	78.76	79.93
WARRILL-BOONAH	18308.24	61773	75.86	76.94	77.75	78.93	79.56	79.77	80.26	80.46	81.95	79.99	77.45	77.68	78.41
WARRILL-BOONAH	18901.08	62366	75.58	76.73	77.60	78.73	79.39	79.68	80.05	80.22	81.81	79.85	77.09	77.48	78.30

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	19441.64	62906	73.32	74.29	75.69	76.44	77.03	77.40	78.01	78.36	80.57	77.61	75.14	75.57	76.13
WARRILL-BOONAH	19461.64	62926	73.27	74.17	74.85	76.28	76.77	77.16	77.74	78.00	79.86	77.43	74.48	74.75	76.07
WARRILL-BOONAH	20991.60	64456	70.11	70.85	71.45	71.71	72.53	72.82	73.27	73.46	75.55	73.01	71.22	71.42	71.52
WARRILL-BOONAH	22471.48	65936	67.91	69.41	70.06	70.41	71.53	71.70	72.02	72.16	73.75	71.83	69.87	70.04	70.14
WARRILL-BOONAH	23063.09	66528	66.65	67.59	68.23	69.11	70.21	70.37	70.68	70.84	72.43	70.49	67.85	68.14	68.50
WARRILL-BOONAH	24050.26	67515	65.87	66.26	66.59	66.93	67.39	67.67	68.31	68.56	70.77	67.88	66.48	66.57	66.70
WARRILL-BOONAH	25131.10	68596	65.30	65.75	66.18	66.48	66.84	67.08	67.70	67.90	69.86	67.18	66.14	66.16	66.24
WARRILL-BOONAH	26305.71	69771	64.17	64.97	65.57	65.78	66.06	66.24	66.71	66.85	68.33	66.32	65.54	65.57	65.61
WARRILL-BOONAH	26315.71	69781	64.13	64.65	65.57	65.77	66.05	66.23	66.70	66.83	68.31	66.31	65.53	65.56	65.60
WARRILL-BOONAH	28136.46	71601	61.93	62.28	63.08	63.34	63.70	63.90	64.48	64.65	66.50	64.06	63.04	63.07	63.13
WARRILL-BOONAH	29113.49	72578	60.05	60.63	60.986	61.433	61.925	62.192	62.95	63.17	65.284	62.407	60.898	60.957	61.068
WARRILL-BOONAH	30794.86	74260	57.671	58.45	58.696	59.008	59.323	59.481	60.067	60.22	61.657	59.641	58.632	58.674	58.755
WARRILL-BOONAH	30814.86	74280	57.649	58.44	58.687	58.998	59.314	59.472	60.056	60.208	61.632	59.632	58.623	58.665	58.746
WESTBREM1	0.00		44.626	45.64	45.932	46.112	46.467	46.822	47.113	47.244	48.313	46.563	46.041	45.019	46.179
WESTBREM1	5.00		44.626	45.64	45.931	46.11	46.464	46.819	47.11	47.24	48.311	46.561	46.039	45.019	46.177
WESTBREM1	15.00		39.868	40.90	41.401	41.672	42.156	42.469	43.079	43.274	45.377	42.412	41.526	40.342	41.663
WESTBREM1	20.00		39.868	40.90	41.401	41.671	42.156	42.468	43.078	43.274	45.377	42.412	41.526	40.342	41.663
WESTBREM2	0.00		41.381	41.99	42.04	42.116	42.406	42.636	42.828	42.895	44.849	42.495	42.072	41.874	42.183
WESTBREM2	5.00		41.381	41.99	42.039	42.114	42.402	42.629	42.817	42.881	44.847	42.49	42.071	41.874	42.18
WESTBREM2	15.00		38.099	39.05	39.574	39.99	40.602	41.115	41.772	41.998	44.083	41.068	39.89	38.766	40.157

Table A.1 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WESTBREM2	20.00		38.099	39.05	39.574	39.99	40.602	41.114	41.772	41.998	44.083	41.068	39.89	38.766	40.157
WESTBREM3	0.00		39.119	39.90	40.212	40.526	41.255	41.609	41.92	42.049	43.973	41.491	40.4	39.442	40.693
WESTBREM3	5.00		39.119	39.90	40.212	40.526	41.255	41.609	41.92	42.048	43.982	41.491	40.4	39.442	40.693
WESTBREM3	15.00		37.974	38.93	39.49	39.927	40.543	41.05	41.681	41.901	43.928	41.007	39.829	38.631	40.103
WESTBREM3	20.00		37.974	38.93	39.49	39.927	40.543	41.05	41.681	41.901	43.928	41.007	39.829	38.631	40.103
WESTERN	0.00		87.325	88.36	88.98	89.476	89.822	90.017	90.364	90.467	91.309	89.811	89.53	87.775	89.555
WESTERN	494.03		84.59	85.48	86.316	86.814	87.928	88.158	88.557	88.689	89.536	87.914	87.079	84.957	87.189
WESTERN	848.96		81.712	82.94	83.694	84.038	84.974	85.437	86.433	86.553	87.701	84.935	84.201	82.257	84.269
WESTERN	868.96		81.703	82.93	83.676	84.012	84.929	85.187	85.802	86.076	87.157	84.899	84.169	82.248	84.248
WESTERN	5081.62		62.418	63.29	64.053	64.422	65.848	66.112	66.653	66.745	67.568	65.861	64.632	62.76	64.694
WESTERN	5666.88		59.706	60.76	61.581	62.024	63.038	63.823	64.866	64.951	65.674	63.102	62.291	60.168	62.357
WESTERN	6146.92		58.928	59.70	60.226	60.571	61.238	61.932	63.16	63.3	64.195	61.431	60.868	59.55	60.895
WESTERN	6888.85		56.237	57.03	57.494	57.825	58.462	59.162	60.308	60.524	61.48	58.653	58.098	56.933	58.123
WESTERN	6908.85		56.219	56.98	57.328	57.524	57.912	58.325	58.842	59.756	60.689	58.028	57.688	56.898	57.705

Table A.2 Model results—Peak flows (m³/s)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	182.40	970091	71	173	265	338	574	781	1702	2013	6377	785	261	98	328
BREMER	989.17	970898	72	173	264	337	572	777	1696	2009	6373	783	261	98	328
BREMER	1910.60	971820	71	173	264	337	572	776	1684	2000	6369	782	261	95	328
BREMER	2339.84	972249	71	172	264	337	571	775	1681	1996	6368	782	261	93	328
BREMER	2507.43	972416	71	172	264	337	571	775	1680	1994	6431	782	261	93	328
BREMER	2785.83	972695	71	172	264	337	571	775	1678	1992	6365	782	261	93	328
BREMER	3314.30	973223	72	177	274	354	586	793	1705	2023	6616	814	283	105	336
BREMER	3848.74	973758	72	176	274	353	585	793	1698	2014	6601	813	283	105	336
BREMER	4388.20	974297	72	185	292	383	613	845	1747	2077	7044	869	322	128	354
BREMER	5062.58	974972	73	185	287	383	612	844	1743	2075	7036	869	323	127	354
BREMER	5801.86	975711	73	184	280	382	608	839	1727	2053	7011	866	321	127	354
BREMER	6520.13	976429	73	183	280	380	604	836	1719	2043	6996	864	320	126	353
BREMER	7250.02	977159	73	183	280	379	604	836	1717	2040	6981	863	320	126	353
BREMER	7913.27	977822	72	226	386	535	874	1298	2383	2818	8875	1214	455	125	529
BREMER	8617.83	978527	72	224	386	534	873	1293	2374	2807	8857	1212	454	123	529
BREMER	9394.93	979304	71	219	385	532	868	1277	2361	2792	8834	1205	453	121	527
BREMER	9870.22	979779	73	225	397	553	896	1316	2409	2853	9442	1288	496	145	585
BREMER	10164.14	980073	73	245	426	592	993	1527	2753	3263	10348	1436	527	154	637
BREMER	10642.58	980552	73	243	424	589	989	1526	2784	3316	10813	1433	525	154	638
BREMER	11104.67	981014	73	344	544	738	1192	1799	3070	3637	13074	1734	699	258	864
BREMER	11396.65	981306	73	344	544	738	1192	1799	3070	3636	13074	1734	699	258	864
BREMER	11681.07	981590	73	344	544	738	1192	1799	3069	3636	13072	1734	699	258	864
BREMER	12052.72	981962	122	344	544	738	1191	1798	3068	3634	13064	1733	699	257	863
BREMER	12462.76	982372	122	344	544	738	1190	1797	3065	3629	13043	1732	699	257	863
BREMER	12981.75	982891	122	346	543	738	1189	1793	3056	3617	13011	1730	698	257	863
BREMER	13569.55	983479	122	342	541	736	1186	1781	3040	3596	12986	1724	697	253	861
BREMER	14130.01	984039	122	327	537	735	1180	1767	3025	3573	12965	1717	695	245	858
BREMER	14394.91	984304	122	325	536	734	1178	1762	3019	3566	12957	1715	694	244	857
BREMER	14625.61	984535	121	323	535	734	1176	1759	3015	3560	12951	1713	694	243	856
BREMER	14945.61	984855	121	317	534	733	1139	1756	3011	3554	12944	1711	693	242	855

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	15195.94	985105	121	316	534	733	1174	1755	3009	3552	12940	1711	692	242	855
BREMER	15529.86	985439	121	316	534	733	1174	1755	3007	3549	12935	1711	692	242	854
BREMER	16044.13	985953	121	316	534	733	1173	1753	3006	3546	12929	1710	692	242	854
BREMER	16523.32	986432	124	315	534	732	1171	1750	3002	3537	12916	1708	692	242	854
BREMER	16963.97	986873	124	315	532	731	1166	1746	2997	3528	12902	1706	691	242	851
BREMER	17577.40	987486	121	314	532	730	1161	1742	2992	3522	12887	1704	690	242	850
BREMER	18165.94	988075	121	314	531	729	1160	1738	2989	3516	12867	1702	690	242	849
BREMER	18724.87	988634	121	314	531	727	1157	1726	2983	3505	12828	1699	688	242	849
BREMER	19205.47	989114	121	314	530	726	1152	1718	2978	3496	12782	1695	688	242	848
BREMER	19399.74	989309	121	314	530	726	1151	1717	2978	3494	12768	1695	688	241	848
BREMER	19952.52	989861	121	313	530	726	1148	1715	2976	3491	12727	1693	688	241	847
BREMER	20681.11	990590	121	313	529	726	1145	1702	2966	3464	12484	1682	688	242	847
BREMER	21221.26	991130	121	323	543	751	1174	1749	3070	3572	13297	1754	733	268	915
BREMER	21708.59	991618	121	323	543	751	1172	1743	3063	3565	13131	1744	733	268	915
BREMER	22130.95	992040	121	324	545	754	1174	1750	3073	3580	13183	1754	740	272	925
BREMER	22670.96	992580	120	324	544	753	1171	1744	3062	3565	12914	1741	740	272	925
BREMER	23153.61	993063	122	324	544	753	1170	1741	3054	3556	12725	1732	740	272	924
BREMER	23672.13	993581	126	324	544	753	1169	1734	3032	3536	12414	1718	739	272	924
BREMER	24176.44	994085	126	324	544	754	1167	1723	3012	3520	12291	1714	770	274	930
BREMER	24637.92	994547	127	324	544	753	1166	1716	2998	3505	11966	1707	769	274	929
BREMER	25131.42	995040	126	323	543	753	1165	1712	2984	3484	11573	1697	769	274	929
BREMER	25626.87	995536	126	323	543	753	1162	1703	2957	3444	11110	1684	769	274	927
BREMER	26073.64	995983	126	323	543	752	1160	1696	2922	3395	10752	1668	768	274	926
BREMER	26303.28	996212	126	323	542	751	1158	1687	2890	3350	10533	1655	768	274	924
BREMER	26557.59	996467	126	323	542	751	1156	1680	2854	3297	10287	1641	767	274	923
BREMER	26914.87	996824	126	323	542	750	1153	1668	2792	3210	9953	1620	766	273	921
BREMER	27227.41	997136	126	323	541	748	1150	1658	2720	3110	9645	1597	765	273	918
BREMER	27494.98	997404	126	323	541	748	1148	1648	2639	3018	9386	1573	763	273	916
BREMER	27715.24	997624	126	323	539	745	1139	1616	2568	2936	9132	1553	759	273	909
BREMER	27945.54	997855	126	323	539	744	1137	1602	2521	2874	8905	1538	757	272	908

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	28194.94	998104	126	323	538	743	1133	1588	2467	2805	8805	1522	754	272	904
BREMER	28603.16	998512	126	324	537	743	1130	1573	2379	2711	8778	1517	785	274	909
BREMER	28997.60	998907	126	325	535	741	1125	1553	2283	2618	8706	1489	778	272	905
BREMER	29299.83	999209	126	326	535	740	1121	1533	2209	2544	8654	1466	775	271	903
BREMER	29493.87	999403	126	326	534	739	1118	1519	2169	2498	8620	1450	772	271	901
BREMER	29556.70	999466	126	326	534	739	1117	1513	2157	2484	8610	1448	771	270	900
BREMER	29734.71	999644	127	327	533	737	1110	1493	2130	2447	8585	1442	764	269	895
BREMER	29991.04	999900	127	327	533	736	1103	1468	2096	2389	8552	1437	761	269	892
BREMER	30441.04	1000350	193	703	1145	1641	2485	2916	5717	6693	24525	4479	1411	802	1892
BREMER-BOONAHNEW	568.44	941265	1	46	74	95	176	257	486	572	1480	162	50	14	101
BREMER-BOONAHNEW	1705.32	942402	1	45	73	94	175	256	483	566	1477	162	50	13	99
BREMER-BOONAHNEW	2858.19	943555	1	45	73	94	174	257	486	570	1474	161	50	13	99
BREMER-BOONAHNEW	4027.06	944723	1	45	73	94	175	253	481	566	1475	161	50	13	98
BREMER-BOONAHNEW	5268.59	945965	1	45	73	94	174	260	488	572	1471	162	50	13	98
BREMER-BOONAHNEW	6582.79	947279	1	68	73	94	174	259	481	566	1470	166	50	13	98
BREMER-BOONAHNEW	7814.42	948511	1	45	73	94	174	253	478	564	1464	162	49	13	97
BREMER-BOONAHNEW	9129.15	949826	1	45	73	94	178	251	488	578	1470	163	50	13	97
BREMER-BOONAHNEW	10167.89	950864	1	45	72	94	171	246	479	565	1457	162	49	13	97
BREMER-BOONAHNEW	11191.66	951888	1	68	111	145	295	395	693	818	2135	283	76	20	125
BREMER-BOONAHNEW	12218.44	952915	1	68	111	144	269	378	691	817	2133	266	76	20	124
BREMER-BOONAHNEW	12952.70	953649	1	68	110	143	265	374	688	813	2127	266	76	20	125

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER-BOONAHNEW	13667.81	954364	1	93	146	192	340	529	934	1108	2928	387	105	23	182
BREMER-BOONAHNEW	14163.44	954860	1	92	145	192	337	516	932	1107	2922	387	103	23	181
BREMER-BOONAHNEW	14918.01	955614	1	92	148	192	335	514	937	1109	2932	387	101	23	181
BREMER-BOONAHNEW	15976.71	956673	1	92	146	191	330	504	928	1097	2912	386	101	23	183
BREMER-BOONAHNEW	17342.28	958039	1	118	180	235	421	632	1210	1434	3868	516	109	29	236
BREMER-BOONAHNEW	18630.11	959326	1	117	180	242	431	598	1201	1426	3863	510	109	29	246
BREMER-BOONAHNEW	19908.51	960605	1	117	172	232	437	598	1201	1428	3864	510	109	29	227
BREMER-BOONAHNEW	21357.51	962054	9	117	172	211	428	595	1191	1418	3857	508	108	29	211
BREMER-BOONAHNEW	22910.31	963607	10	143	204	262	495	711	1439	1713	4961	633	173	39	268
BREMER-BOONAHNEW	24164.46	964861	10	143	204	262	496	710	1435	1707	4960	633	173	39	268
BREMER-BOONAHNEW	24523.35	965220	10	143	204	261	493	708	1435	1706	4960	633	173	39	268
BREMER-BOONAHNEW	24578.35	965275	10	143	204	261	493	707	1435	1706	4960	633	173	39	268
BREMER-BOONAHNEW	25550.36	966247	10	143	204	261	492	716	1436	1709	4960	631	173	39	268
BREMER-BOONAHNEW	27042.52	967739	18	142	204	261	488	696	1425	1694	4955	604	172	38	268
BREMER-BOONAHNEW	28398.45	969095	24	167	250	315	554	770	1671	1968	6064	747	234	79	318
FRANKLINVALE	2.36		1	24	37	51	100	147	196	230	558	90	27	8	58
FRANKLINVALE	215.35		1	25	38	51	101	148	196	231	558	91	28	9	59
FRANKLINVALE	655.82		1	25	38	51	100	148	195	230	557	91	28	9	59
FRANKLINVALE	1125.48		1	25	38	51	100	147	195	230	556	91	28	9	59

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	1567.12		1	25	38	51	100	147	195	230	556	91	28	9	59
FRANKLINVALE	2010.40		1	25	38	51	100	147	195	229	555	91	28	9	59
FRANKLINVALE	2476.41		1	25	38	51	100	148	195	230	554	91	28	9	59
FRANKLINVALE	2848.49		1	60	91	127	244	361	475	560	1321	218	66	20	142
FRANKLINVALE	3272.45		1	60	91	127	243	361	472	559	1321	218	66	20	142
FRANKLINVALE	3805.40		1	60	91	127	243	358	467	556	1319	218	66	20	142
FRANKLINVALE	4255.61		1	60	90	127	243	360	466	555	1319	217	66	20	142
FRANKLINVALE	4641.44		1	60	90	126	242	359	465	554	1318	217	66	20	142
FRANKLINVALE	4973.05		1	60	90	126	242	359	465	555	1318	217	66	20	142
FRANKLINVALE	5366.59		1	60	90	126	240	358	463	553	1317	217	66	20	142
FRANKLINVALE	5829.00		1	60	90	126	240	358	463	553	1316	217	66	20	141
FRANKLINVALE	6251.44		1	60	90	125	240	358	463	552	1316	217	66	20	138
FRANKLINVALE	6721.82		1	60	90	125	241	357	462	551	1315	217	66	20	138
FRANKLINVALE	7109.93		1	60	90	125	238	357	461	550	1314	216	66	20	138
FRANKLINVALE	7387.69		1	60	90	125	237	357	462	550	1314	216	66	20	138
FRANKLINVALE	7657.85		1	60	90	125	237	356	461	549	1313	216	66	20	138
FRANKLINVALE	8053.98		1	60	89	124	236	355	460	547	1311	215	66	20	137
FRANKLINVALE	8574.08		1	60	89	123	237	355	459	546	1310	216	66	20	138
FRANKLINVALE	9082.44		1	60	89	122	240	355	460	546	1310	218	66	20	138
FRANKLINVALE	9517.19		1	60	89	122	236	353	459	541	1316	215	66	20	138
FRANKLINVALE	10106.67		1	94	146	192	373	567	720	847	2178	359	129	31	225
FRANKLINVALE	10730.88		1	94	146	192	371	566	712	842	2176	357	129	31	225
FRANKLINVALE	11208.58		1	94	146	192	371	566	711	843	2176	358	129	31	225
FRANKLINVALE	11664.60		1	94	146	192	369	565	706	841	2175	356	129	31	225
FRANKLINVALE	12100.87		1	94	146	192	369	566	706	841	2174	357	129	31	224
FRANKLINVALE	12535.39		1	94	146	191	368	564	703	838	2174	356	129	31	224
FRANKLINVALE	12942.11		1	94	146	191	368	562	702	837	2173	356	129	31	224
FRANKLINVALE	13360.25		1	94	145	191	366	561	700	835	2171	355	128	31	224
FRANKLINVALE	13811.20		1	92	145	190	365	561	698	834	2170	355	128	31	223
FRANKLINVALE	14284.28		1	92	145	191	365	560	697	833	2169	355	128	31	224

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	14763.33		1	92	143	189	362	558	694	829	2163	353	128	31	222
FRANKLINVALE	15237.53		1	461	176	228	427	558	693	830	2164	464	144	31	245
FRANKLINVALE	15711.66		1	92	141	188	359	556	691	826	2161	351	127	31	222
FRANKLINVALE	16175.25		1	106	161	212	399	629	774	931	2524	415	131	38	234
FRANKLINVALE	16638.88		1	105	161	211	398	628	773	929	2524	414	131	38	234
FRANKLINVALE	16953.78		1	116	176	228	427	680	844	1005	2868	464	144	43	246
FRANKLINVALE	17184.33		1	116	176	228	426	680	844	1005	2868	464	143	43	245
FRANKLINVALE	17531.85		1	116	176	227	426	680	844	1004	2868	464	142	43	246
FRANKLINVALE	17949.53		1	116	176	229	426	678	842	1002	2867	463	142	43	246
FRANKLINVALE	18368.20		1	116	175	227	424	676	841	999	2867	463	142	42	245
FRANKLINVALE	19176.70		1	116	175	226	420	671	799	903	2098	463	142	42	245
FRANKLINVALE	19937.44		1	117	178	226	417	674	811	909	2306	477	151	43	247
PURGA	672.90	80841	44	68	82	109	150	185	242	307	1028	124	53	29	62
PURGA	1629.05	81797	44	67	82	107	145	178	241	304	1025	123	53	29	61
PURGA	2449.18	82618	79	120	146	192	259	314	426	545	1794	123	52	29	61
PURGA	3175.88	83344	216	263	347	453	621	755	909	1166	3963	666	242	145	360
PURGA	3924.06	84093	216	258	341	446	616	750	902	1154	3931	665	237	145	357
PURGA	4753.46	84922	215	257	340	444	614	749	899	1151	3922	665	236	144	356
PURGA	5239.53	85408	215	257	339	442	613	746	895	1145	3913	664	237	145	355
PURGA	5706.76	85875	215	254	336	433	591	742	890	1138	3903	663	236	144	352
PURGA	6194.88	86363	215	254	336	434	593	742	889	1137	3899	663	236	144	353
PURGA	6724.26	86893	212	252	333	432	587	739	887	1134	3894	663	235	144	350
PURGA	7244.66	87413	208	252	333	430	587	739	885	1133	3891	663	237	144	350
PURGA	7718.59	87887	176	252	332	430	586	739	885	1133	3889	663	237	144	350
PURGA	8197.92	88366	175	250	330	429	583	737	884	1131	3889	663	233	144	349
PURGA	8714.52	88883	176	250	330	430	583	738	883	1131	3875	662	233	144	349
PURGA	9747.02	89915	200	275	360	465	641	815	992	1279	4476	738	262	160	388
PURGA	10751.71	90920	199	275	357	463	637	811	987	1268	4445	738	260	160	386
PURGA	11166.55	91335	209	284	370	481	662	845	1030	1318	4770	773	270	165	410
PURGA	11563.04	91731	207	283	369	479	658	839	1023	1309	4755	772	267	165	409

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
PURGA	12072.24	92241	205	283	368	478	656	835	1018	1301	4743	771	264	164	409
PURGA	12574.79	92743	204	282	367	477	654	832	1016	1297	4736	770	261	164	408
PURGA	13043.95	93212	202	282	367	476	653	832	1015	1295	4733	770	261	164	408
PURGA	13425.37	93594	200	282	367	475	653	830	1013	1291	4728	770	261	164	408
PURGA	13818.94	93987	199	282	366	474	651	828	1011	1289	4724	770	261	164	408
PURGA	14264.46	94433	198	281	366	474	651	827	1011	1288	4721	770	260	164	408
PURGA	14629.61	94798	197	280	366	473	651	827	1010	1287	4715	769	260	163	408
PURGA	15053.80	95222	196	278	366	472	651	826	1009	1286	4702	769	259	163	407
PURGA	15639.79	95808	196	275	364	468	642	821	1004	1280	4666	769	258	163	406
PURGA	16267.20	96436	195	270	358	465	638	818	1002	1278	4631	769	255	163	405
PURGA	16866.56	97035	195	269	358	465	640	819	1002	1280	4612	769	255	163	405
PURGA	17498.04	97666	195	269	357	451	633	814	994	1265	4359	737	255	163	403
PURGA	17983.50	98152	190	267	348	445	629	808	1217	1541	11051	1018	253	162	400
PURGA	18385.25	98554	190	267	345	445	628	806	1168	1471	10535	990	253	162	400
PURGA	18935.86	99104	244	276	346	460	642	828	1122	1464	10533	978	264	168	426
PURGA	19586.24	99755	245	276	340	449	606	790	1069	1412	10456	905	263	168	422
PURGA	20452.56	100621	197	276	339	443	594	771	1033	1396	10387	833	263	168	417
PURGA	21320.56	101489	197	276	338	442	583	749	1480	1699	9372	1290	264	168	413
PURGA	22015.06	102184	197	275	337	437	565	713	1886	2183	9846	1629	266	168	407
PURGA_2	10.00		112	175	215	275	375	465	524	675	2270	566	179	134	308
PURGA_2	1464.35		111	196	237	294	377	461	524	671	2248	566	206	131	307
PURGA_2	3771.20		111	181	232	281	375	459	521	668	2236	565	197	123	303
RAILBRIDGE1	2.00		0	0	0	0	0	0	1	12	9	0	0	0	0
RAILBRIDGE1	18.00		0	0	0	0	0	0	4	6	8	0	0	0	1
RAILBRIDGE2	2.00		10	32	51	62	95	113	151	163	247	95	75	18	78
RAILBRIDGE2	18.00		10	32	51	62	95	113	151	163	247	95	74	18	78
RAILBRIDGE3	2.00		0	0	0	0	0	0	0	0	0	0	0	0	0
RAILBRIDGE3	18.00		0	0	0	0	0	0	0	0	0	0	0	0	0
RAILBRIDGE4	2.00		0	0	0	0	0	0	59	66	201	0	0	0	0
RAILBRIDGE4	18.00		0	0	0	0	0	0	59	66	201	0	0	0	0

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILBRIDGE5	2.00		10	34	62	83	138	180	244	289	749	136	97	19	102
RAILBRIDGE5	18.00		10	34	62	84	138	180	237	289	749	136	97	19	102
RAILBRIDGE6	2.00		0	0	0	0	0	0	0	0	0	0	1	0	9
RAILBRIDGE6	18.00		0	0	0	0	0	0	0	0	0	0	1	0	9
RAILBRIDGE7	2.00		0	0	0	0	0	0	0	0	65	0	0	0	0
RAILBRIDGE7	18.00		0	0	0	0	0	0	0	0	65	0	0	0	0
RAILBRIDGE8	2.00		1	5	10	9	11	10	9	11	120	8	8	0	9
RAILBRIDGE8	18.00		1	5	10	9	11	10	9	11	81	8	8	0	9
RAILBRIDGE9	2.00		0	0	0	0	0	0	0	2	0	0	0	0	0
RAILBRIDGE9	18.00		0	0	0	0	0	0	0	0	394	0	0	0	0
RAILNORTH	949.40		0	1	1	6	78	106	202	278	637	75	11	0	15
RAILNORTH	1214.90		0	1	1	6	36	60	140	174	465	35	11	0	13
RAILNORTH	1453.14		10	32	52	68	130	173	287	322	712	127	85	18	90
RAILNORTH	1810.80		10	32	52	68	130	173	287	321	712	127	85	18	90
RAILNORTH	2354.20		0	1	2	8	52	77	176	196	532	49	16	1	19
RAILNORTH	2973.38		0	1	2	8	52	77	177	196	532	49	16	1	19
RAILNORTH	3574.97		0	1	2	8	50	77	176	195	532	49	16	1	19
RAILNORTH	4040.72		0	1	2	8	50	77	176	195	532	49	16	1	19
RAILNORTH	4333.15		0	1	1	2	25	66	235	261	730	24	3	1	3
RAILNORTH	4469.68		0	1	1	2	25	66	235	261	730	24	2	1	3
RAILNORTH	4819.92		1	35	64	85	160	246	472	550	1478	162	100	19	105
RAILNORTH	7127.67		0	8	28	46	98	172	305	440	1039	116	66	5	68
RAILNORTH	7689.53		0	8	28	46	98	170	299	379	1036	115	65	5	68
RAILNORTH	8410.92		0	8	27	42	95	163	292	349	911	114	62	5	64
RAILNORTH	8909.14		0	8	27	42	95	163	292	349	911	114	62	4	64
RAILNORTH	9149.17		0	4	15	31	82	145	271	328	892	99	45	3	51
RAILNORTH	9520.53		0	3	17	31	82	145	271	328	892	99	45	2	51
RAILNORTH	9781.72		0	3	15	30	82	145	271	328	892	99	45	2	50
RAILNORTH	10084.53		1	3	15	31	82	145	271	328	891	99	45	2	50
RAILNORTH	10586.71		1	3	15	30	82	145	271	328	1103	99	45	2	50

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILNORTH	11087.73		1	3	14	30	82	144	270	326	1102	99	45	2	50
RAILNORTH	11671.45		1	5	21	39	103	170	299	359	1350	122	51	1	61
RAILNORTH	12176.77		1	5	19	39	103	169	299	358	1350	122	51	1	61
RAILNORTH	12400.00		1	6	18	33	83	139	255	308	1258	99	44	1	51
RAILNORTH	12939.00		1	3	5	8	26	65	142	182	1029	32	8	0	10
RAILNORTH	13668.00		0	1	3	4	19	55	119	152	922	24	4	0	5
RAILNORTH	14248.00		0	0	0	0	0	1	10	21	456	0	0	0	0
RAILNORTH	14678.00		0	0	0	0	0	2	10	20	415	1	0	0	0
RAILNORTH	14783.00		0	0	0	0	0	3	5	9	228	2	0	0	0
RAILNORTH	14848.00		0	0	0	0	0	3	5	8	221	2	0	0	0
RAILNORTH	15543.00		0	0	0	0	0	0	0	0	199	0	0	0	0
RAILSOUTH	949.40		11	34	63	79	101	141	290	349	849	100	89	19	93
RAILSOUTH	1214.90		11	34	63	79	132	187	341	404	1021	132	89	19	96
RAILSOUTH	1453.14		1	2	12	19	37	74	190	240	774	37	18	1	20
RAILSOUTH	1810.80		1	2	12	18	37	74	190	239	773	37	18	1	18
RAILSOUTH	2354.20		10	34	62	77	114	170	298	360	960	112	84	19	87
RAILSOUTH	2973.38		10	33	62	77	114	169	298	360	955	112	84	19	87
RAILSOUTH	3574.97		10	33	62	77	114	169	301	356	956	112	84	19	87
RAILSOUTH	4040.72		10	33	62	77	114	169	297	355	956	112	84	19	86
RAILSOUTH	4333.15		10	34	63	83	138	180	237	289	750	136	98	19	102
RAILSOUTH	4469.68		10	34	63	83	138	180	237	289	749	136	97	19	102
RAILSOUTH	7127.67		10	39	54	64	86	114	208	329	1019	93	74	36	75
RAILSOUTH	7689.53		10	39	54	64	86	116	216	323	1664	94	74	36	75
RAILSOUTH	8178.28		10	39	54	64	86	118	216	323	1569	94	74	36	75
RAILSOUTH	8556.64		55	154	230	285	500	783	1025	1180	3874	569	224	74	311
RAILSOUTH	8909.14		55	154	229	284	500	781	1024	1180	3873	568	223	74	311
RAILSOUTH	9149.17		55	445	239	278	502	781	1044	1199	3890	582	239	74	311
RAILSOUTH	9520.53		55	158	236	294	512	795	1043	1199	3890	582	236	75	324
RAILSOUTH	10084.53		55	158	232	293	511	794	1043	1199	3890	580	234	75	324
RAILSOUTH	10586.71		55	158	232	295	510	794	1043	1198	3657	579	234	75	324

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILSOUTH	11087.73		55	158	231	293	510	792	1043	1198	3656	579	233	75	324
RAILSOUTH	11671.45		55	154	224	278	487	763	1008	1161	3396	555	227	75	310
RAILSOUTH	12063.54		55	154	224	125	487	762	1007	1160	1545	555	227	74	135
RAILSOUTH	12276.77		55	107	116	123	183	260	309	359	1462	200	114	75	121
RAILSOUTH	12939.00		55	110	121	142	252	338	435	499	1769	281	127	76	165
RAILSOUTH	13668.00		55	111	122	145	258	348	457	525	1862	289	130	76	170
RAILSOUTH	14248.00		55	88	95	106	158	193	215	239	1389	170	99	66	118
RAILSOUTH	14678.00		55	88	92	93	131	188	193	195	895	138	92	66	99
RAILSOUTH	14783.00		55	88	95	106	157	185	186	194	1068	168	99	66	118
RAILSOUTH	15543.00		55	88	95	106	157	185	185	200	1069	168	99	66	118
RAILWEIR1	2.50		0	0	0	0	0	0	1	4	8	0	0	0	0
RAILWEIR1	17.50		0	0	0	0	0	0	1	4	8	0	0	0	0
RAILWEIR2	2.50		0	0	0	0	0	0	1	1	4	0	0	0	0
RAILWEIR2	10.00		0	0	0	0	0	0	0	0	0	0	0	0	0
RAILWEIR2	17.50		0	0	0	0	0	0	1	1	1	0	0	0	0
RAILWEIR3	2.50		0	0	0	0	0	1	1	1	233	0	0	0	0
RAILWEIR3	10.00		0	0	0	0	0	0	0	0	233	0	0	0	0
RAILWEIR3	17.50		0	0	0	0	0	0	0	0	233	0	0	0	0
RAILWEIR4	2.50		1	4	7	10	22	28	34	37	260	24	7	0	13
RAILWEIR4	17.50		1	4	7	10	22	28	34	37	260	24	7	0	13
RAILWEIR5	2.00		0	0	0	0	0	0	0	0	0	0	0	0	0
RAILWEIR5	18.00		0	0	0	0	0	0	0	0	0	0	0	0	0
RAILWEIR6	2.00		0	0	0	0	0	6	8	10	47	4	0	0	0
RAILWEIR6	18.00		0	0	0	0	0	6	8	9	46	4	0	0	0
WARPURWEIR1	2.50		0	0	0	0	0	1	1	1	3463	0	0	0	0
WARPURWEIR1	10.00		0	0	0	0	0	0	0	0	3461	0	0	0	0
WARPURWEIR1	17.50		0	0	0	0	0	1	1	1	3458	1	0	0	0
WARPURWEIR2	2.50		0	0	0	0	0	1	1	1	2	0	0	0	0
WARPURWEIR2	10.00		0	0	0	0	0	0	0	0	0	0	0	0	0
WARPURWEIR2	17.50		0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARPURWEIR3	2.50		0	0	0	0	7	72	827	1096	10795	475	0	0	0
WARPURWEIR3	10.00		0	0	0	0	7	72	827	1096	11288	475	0	0	0
WARPURWEIR3	17.50		0	0	1	1	7	72	825	1093	10768	475	0	0	0
WARRILL	516.72	74796	127	283	448	720	1144	1399	2586	2989	9506	1676	400	430	493
WARRILL	1728.77	76008	127	283	448	720	1144	1399	2586	2989	9506	1676	400	430	493
WARRILL	2966.30	77246	127	282	439	715	1135	1393	2571	2978	9484	1676	395	419	492
WARRILL	3590.99	77871	127	278	433	713	1121	1392	2572	2978	9486	1676	388	410	492
WARRILL	4231.19	78511	127	275	428	717	1110	1392	2577	2978	9472	1677	387	408	492
WARRILL	5597.98	79878	144	285	479	843	1345	1584	3530	4160	14333	2148	471	438	529
WARRILL	6759.17	81039	143	285	479	837	1329	1562	3517	4150	14330	2146	471	438	529
WARRILL	7822.70	82102	143	285	478	838	1329	1561	3512	4146	14329	2146	471	437	528
WARRILL	9205.55	83485	143	284	475	827	1311	1547	3493	4134	14322	2145	468	434	524
WARRILL	10419.36	84699	141	284	474	817	1306	1547	3490	4129	14311	2144	467	433	523
WARRILL	11260.87	85541	141	284	474	813	1303	1541	3479	4122	14305	2144	467	433	522
WARRILL	11956.24	86236	153	284	474	813	1301	1541	3481	4122	14302	2144	466	433	521
WARRILL	12625.38	86905	152	284	472	813	1300	1538	3446	4081	14286	2144	464	431	519
WARRILL	13199.09	87479	152	284	472	811	1295	1533	3422	4055	14279	2143	463	429	516
WARRILL	13588.18	87868	149	284	471	810	1294	1533	3416	4048	14277	2143	463	428	516
WARRILL	13933.74	88213	148	283	471	810	1294	1532	3414	4045	14275	2143	463	428	516
WARRILL	14685.00	88965	148	283	470	809	1294	1533	3411	4041	14271	2143	461	426	515
WARRILL	15464.29	89744	148	283	468	805	1289	1531	3395	4019	14276	2143	459	425	515
WARRILL	16008.97	90289	148	283	468	805	1288	1531	3387	4009	14292	2144	460	425	515
WARRILL	16755.14	91035	147	289	483	842	1345	1661	3666	4345	17490	2772	601	432	593
WARRILL	17710.47	91990	147	289	483	842	1345	1662	3665	4343	17469	2772	602	432	593
WARRILL	18471.75	92751	146	289	482	841	1342	1658	3649	4312	17418	2768	601	432	592
WARRILL	18939.93	93220	146	289	482	839	1340	1654	3642	4298	17391	2767	600	431	591
WARRILL	19446.27	93726	146	289	481	838	1338	1651	3636	4288	17354	2767	598	428	590
WARRILL	19953.37	94233	146	289	480	837	1337	1648	3631	4279	17319	2766	597	426	589
WARRILL	20436.06	94716	146	289	480	836	1336	1646	3627	4272	17280	2766	597	426	589
WARRILL	20836.16	95116	148	289	480	835	1335	1644	3622	4264	17225	2766	597	426	589

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	21408.97	95689	151	289	480	835	1334	1641	3614	4252	17101	2765	597	426	589
WARRILL	22522.48	96802	150	289	480	835	1333	1639	3608	4244	16873	2765	597	426	589
WARRILL	23449.07	97729	150	290	480	830	1324	1633	3669	4292	16609	2799	614	426	605
WARRILL	23914.04	98194	150	290	480	826	1311	1556	2846	3219	7160	2323	613	425	604
WARRILL	24353.37	98633	149	290	480	824	1305	1549	2841	3203	7016	2321	612	425	604
WARRILL	24814.29	99094	149	290	480	823	1304	1548	2837	3197	6878	2320	612	425	604
WARRILL	25379.46	99659	149	290	480	819	1299	1542	2829	3185	6671	2316	611	425	604
WARRILL	25974.85	100255	149	291	481	823	1306	1556	2945	3325	7427	2371	638	426	639
WARRILL	26456.35	100736	149	291	481	822	1305	1554	2938	3314	7311	2368	638	426	639
WARRILL	27004.35	101284	149	291	481	822	1303	1550	2926	3297	7133	2365	637	426	638
WARRILL	27594.35	101874	149	291	481	821	1302	1545	2887	3239	6631	2355	637	425	637
WARRILL	28180.35	102460	148	291	482	822	1301	1535	2819	3153	6093	2340	637	425	635
WARRILL	28869.85	103150	148	291	482	823	1301	1522	2757	3105	6057	2327	636	425	631
WARRILL	29550.85	103831	148	291	483	825	1302	1515	2699	3057	6031	2315	636	425	633
WARRILL	30006.85	104287	147	292	485	828	1305	1428	2217	2646	7007	1827	636	425	635
WARRILL	30525.35	104805	147	292	486	830	1273	1267	1781	2143	6485	1608	636	425	637
WARRILL	31029.85	105310	195	419	627	955	1510	1787	3656	4322	16315	3051	897	540	1013
WARRILL	31349.85	105630	195	419	626	956	1513	1797	3654	4321	16311	3049	898	540	1012
WARRILL	31774.85	106055	195	416	623	957	1517	1812	3652	4320	16308	3048	899	540	1012
WARRILL	32153.85	106434	194	415	622	958	1521	1825	3651	4320	16305	3047	900	540	1012
WARRILL	32459.35	106739	194	414	620	958	1524	1834	3649	4319	16302	3046	901	540	1012
WARRILL	32942.35	107222	194	412	618	960	1529	1851	3648	4319	16299	3046	902	540	1012
WARRILL	33555.35	107835	192	400	613	966	1541	1883	3646	4319	16294	3045	909	547	1014
WARRILL-BOONAH	881.95	44347	24	79	140	190	300	449	862	1028	2996	386	103	112	180
WARRILL-BOONAH	2267.55	45732	24	79	140	192	303	440	861	1025	2990	385	103	112	179
WARRILL-BOONAH	3078.10	46543	24	79	140	191	292	452	858	1024	2986	385	103	112	178
WARRILL-BOONAH	3950.52	47415	24	79	140	191	288	440	860	1022	2987	385	103	112	178
WARRILL-BOONAH	5122.33	48587	39	79	140	191	287	435	861	1022	2978	384	103	112	178
WARRILL-BOONAH	6096.17	49561	40	79	139	191	287	435	846	1015	2974	384	103	112	177
WARRILL-BOONAH	6871.93	50337	24	79	140	191	287	435	844	1014	2969	384	103	112	177

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	7759.10	51224	24	79	139	190	287	435	843	1017	2969	384	103	112	177
WARRILL-BOONAH	8660.16	52125	24	79	139	191	287	435	845	1025	2965	384	103	112	177
WARRILL-BOONAH	9855.94	53321	24	79	139	190	287	435	840	1013	2987	383	103	111	177
WARRILL-BOONAH	11335.75	54801	24	79	140	191	287	435	848	1000	2936	384	103	112	177
WARRILL-BOONAH	12618.46	56083	24	79	139	187	286	434	808	997	2935	383	103	111	173
WARRILL-BOONAH	13821.96	57287	24	79	139	187	286	434	808	998	2925	383	103	111	173
WARRILL-BOONAH	14671.40	58136	23	79	138	187	286	432	812	993	2911	382	103	111	173
WARRILL-BOONAH	15431.91	58897	24	79	139	187	286	432	867	991	2904	383	103	111	173
WARRILL-BOONAH	16606.35	60071	27	79	138	187	286	432	894	1073	2905	385	102	111	173
WARRILL-BOONAH	17763.03	61228	34	79	137	186	285	430	801	974	2891	383	102	111	172
WARRILL-BOONAH	18604.66	62069	34	79	135	181	293	436	807	993	2989	387	102	108	170
WARRILL-BOONAH	19171.36	62636	34	303	428	639	1040	1364	2021	2348	8088	1607	357	409	494
WARRILL-BOONAH	20226.62	63691	34	303	428	639	1041	1363	2019	2343	8086	1607	357	409	498
WARRILL-BOONAH	21731.54	65196	34	293	425	636	1036	1356	2002	2317	8063	1605	350	408	485
WARRILL-BOONAH	22767.29	66232	34	293	425	633	1035	1354	2001	2315	8059	1604	350	408	485
WARRILL-BOONAH	23556.68	67021	34	293	425	632	1034	1354	2000	2313	8057	1604	350	408	485
WARRILL-BOONAH	24590.68	68055	34	291	424	632	1033	1352	1999	2320	8052	1602	351	407	481
WARRILL-BOONAH	25718.40	69183	34	294	446	719	1156	1503	2624	3034	9545	1677	418	437	497
WARRILL-BOONAH	27226.09	70691	34	284	450	720	1155	1466	2629	3037	9538	1677	409	438	495
WARRILL-BOONAH	28624.97	72090	36	284	448	718	1145	1401	2589	2996	9510	1676	405	434	494
WARRILL-BOONAH	29954.18	73419	38	284	449	718	1142	1400	2585	2993	9510	1676	404	433	493
WESTBREM1	2.50		0	47	112	166	309	503	701	802	1935	356	143	0	190
WESTBREM1	10.00		0	47	112	166	309	503	701	802	1935	356	143	0	190
WESTBREM1	17.50		0	47	112	166	309	503	700	801	1934	356	143	0	189
WESTBREM2	2.50		0	24	30	43	118	218	351	417	1480	151	35	11	56
WESTBREM2	10.00		0	24	30	43	118	218	351	417	1480	151	35	11	56
WESTBREM2	17.50		0	24	30	43	118	217	351	416	1477	151	35	11	56
WESTBREM3	2.50		0	0	0	0	0	4	39	62	525	0	0	0	0
WESTBREM3	10.00		0	0	0	0	0	4	39	62	525	0	0	0	0
WESTBREM3	17.50		0	0	0	1	1	4	39	62	525	0	0	0	1

Table A.2 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WESTERN	247.01		11	35	64	86	169	248	478	561	1486	165	100	20	106
WESTERN	671.49		11	35	64	86	168	248	477	561	1486	165	100	20	106
WESTERN	5374.25		11	35	64	85	156	246	470	550	1478	160	100	19	105
WESTERN	5906.90		11	35	64	84	156	246	470	549	1477	161	100	19	105
WESTERN	6517.88		15	47	82	111	184	287	513	632	2059	209	140	40	143

Table A.3 Model results—Peak water velocity (m/s)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	0.00	969909	0.70	1.00	1.04	1.05	1.06	1.08	1.11	1.13	1.36	1.07	1.02	0.78	1.05
BREMER	182.40	970091	0.90	1.17	1.21	1.24	1.26	1.30	1.34	1.35	1.45	1.20	1.19	1.00	1.19
BREMER	364.80	970274	1.74	1.75	1.76	1.82	1.91	2.07	2.08	2.11	2.27	1.78	1.75	1.75	1.76
BREMER	989.17	970898	0.84	1.05	1.19	1.27	1.43	1.46	1.48	1.49	1.60	1.45	1.18	0.93	1.26
BREMER	1613.53	971522	0.62	0.84	1.09	1.28	1.74	1.98	2.06	2.08	2.17	1.98	1.08	0.70	1.26
BREMER	1910.60	971820	0.48	0.58	0.63	0.70	0.88	1.01	1.20	1.26	1.92	1.02	0.63	0.54	0.69
BREMER	2207.67	972117	0.40	0.44	0.44	0.49	0.59	0.68	0.97	1.05	1.86	0.68	0.44	0.43	0.48
BREMER	2339.84	972249	0.57	0.61	0.60	0.63	0.75	0.84	1.10	1.15	1.80	0.84	0.60	0.60	0.63
BREMER	2472.00	972381	1.06	1.06	1.07	1.04	1.06	1.10	1.28	1.29	1.91	1.10	1.06	1.04	1.07
BREMER	2492.00	972401	1.09	1.08	1.09	1.10	1.11	1.12	1.29	1.30	1.87	1.12	1.09	1.10	1.09
BREMER	2507.43	972416	1.10	1.11	1.11	1.13	1.13	1.15	1.32	1.33	1.83	1.15	1.11	1.12	1.11
BREMER	2522.86	972432	1.12	1.14	1.14	1.16	1.16	1.18	1.35	1.37	1.87	1.18	1.13	1.15	1.14
BREMER	2785.83	972695	1.11	1.03	1.08	1.04	1.01	1.09	1.24	1.26	1.48	1.09	1.12	1.00	1.12
BREMER	3048.80	972958	1.13	1.14	1.14	1.14	1.14	1.14	1.18	1.18	1.28	1.14	1.14	1.14	1.14
BREMER	3314.30	973223	1.06	1.06	1.04	1.03	1.03	1.07	1.13	1.14	1.21	1.04	1.03	1.08	1.04
BREMER	3579.79	973489	1.06	1.00	1.00	0.99	0.99	0.99	1.09	1.10	1.15	1.01	1.00	1.02	1.03
BREMER	3848.74	973758	1.05	1.02	1.03	1.02	1.02	1.02	1.02	1.02	1.14	1.05	1.03	1.04	1.06
BREMER	4117.69	974027	1.18	1.09	1.11	1.08	1.08	1.08	1.08	1.08	1.22	1.16	1.18	1.11	1.19
BREMER	4388.20	974297	1.39	1.42	1.40	1.43	1.45	1.47	1.48	1.47	1.62	1.38	1.38	1.38	1.37
BREMER	4658.71	974568	1.69	1.72	1.71	1.74	1.80	1.83	1.85	1.87	2.29	1.66	1.69	1.71	1.70
BREMER	5062.58	974972	0.83	1.05	1.07	1.08	1.13	1.21	1.23	1.25	1.48	1.05	1.04	0.99	1.05
BREMER	5466.45	975375	0.61	0.94	0.95	0.97	1.02	1.09	1.11	1.15	1.25	0.94	0.93	0.81	0.94
BREMER	5801.86	975711	0.64	0.89	0.90	0.91	0.97	1.04	1.06	1.09	1.20	0.89	0.88	0.79	0.89
BREMER	6137.27	976046	0.94	1.05	1.09	1.11	1.22	1.32	1.30	1.34	1.41	0.95	0.98	0.94	0.97
BREMER	6520.13	976429	0.79	0.81	0.83	0.85	0.90	0.95	1.04	1.09	1.50	0.92	0.83	0.79	0.82
BREMER	6902.98	976812	0.87	0.90	0.99	1.18	1.46	1.67	1.86	1.94	2.21	1.69	1.08	0.87	1.14
BREMER	7250.02	977159	0.89	0.91	0.90	0.92	0.94	0.97	0.98	0.99	1.10	0.89	0.88	0.89	0.89
BREMER	7597.07	977506	0.97	0.98	0.98	0.97	1.00	1.04	1.07	1.06	1.07	0.96	0.95	0.96	0.96
BREMER	7913.27	977822	0.95	0.90	0.91	0.89	0.88	0.83	0.86	0.84	1.13	0.84	0.84	0.84	0.87

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	8229.47	978138	0.96	0.86	0.90	0.86	0.84	0.83	0.99	1.04	1.43	0.83	0.80	0.82	0.86
BREMER	8617.83	978527	0.75	0.67	0.69	0.67	0.72	0.77	0.90	0.95	1.37	0.73	0.65	0.65	0.71
BREMER	9006.19	978915	0.76	0.67	0.68	0.66	0.68	0.71	0.82	0.87	1.31	0.74	0.65	0.66	0.74
BREMER	9394.93	979304	0.58	0.52	0.52	0.52	0.53	0.54	0.67	0.72	1.15	0.58	0.53	0.49	0.56
BREMER	9783.66	979693	0.55	0.56	0.56	0.63	0.67	0.77	0.77	0.79	1.10	0.53	0.53	0.55	0.48
BREMER	9803.66	979713	0.55	0.57	0.57	0.66	0.71	0.79	0.81	0.83	1.11	0.58	0.54	0.57	0.52
BREMER	9870.22	979769	0.54	0.58	0.57	0.63	0.67	0.79	0.80	0.82	1.10	0.52	0.53	0.51	0.47
BREMER	9936.78	979846	0.55	0.58	0.58	0.63	0.69	0.73	0.75	0.78	1.09	0.52	0.53	0.52	0.47
BREMER	10164.14	980073	0.49	0.52	0.52	0.53	0.54	0.56	0.59	0.64	1.08	0.53	0.49	0.47	0.46
BREMER	10391.51	980300	0.58	0.61	0.60	0.60	0.62	0.64	0.66	0.66	0.99	0.65	0.60	0.59	0.57
BREMER	10642.58	980552	0.30	0.38	0.38	0.39	0.43	0.50	0.69	0.75	1.30	0.48	0.38	0.35	0.39
BREMER	10893.66	980803	0.28	0.53	0.64	0.65	0.66	0.72	0.96	1.04	1.75	0.69	0.61	0.39	0.65
BREMER	11104.67	981014	0.57	0.81	0.92	0.93	0.97	1.04	1.25	1.34	2.31	1.03	0.93	0.72	0.94
BREMER	11315.68	981225	0.75	0.89	1.05	1.13	1.25	1.33	1.54	1.63	2.53	1.33	1.11	0.81	1.18
BREMER	11396.65	981306	0.90	1.03	1.12	1.16	1.21	1.22	1.39	1.47	2.33	1.21	1.15	0.92	1.20
BREMER	11477.63	981387	1.18	1.22	1.30	1.30	1.35	1.44	1.45	1.47	2.16	1.29	1.30	1.14	1.30
BREMER	11487.63	981397	1.20	1.43	1.61	1.62	1.64	1.64	1.66	1.67	2.29	1.63	1.62	1.31	1.62
BREMER	11681.07	981590	0.69	0.74	0.82	0.90	0.97	1.07	1.28	1.36	2.20	1.06	0.89	0.70	0.92
BREMER	11874.52	981783	0.50	0.53	0.56	0.65	0.74	0.87	1.08	1.17	2.11	0.86	0.64	0.51	0.68
BREMER	12052.72	981962	0.54	0.61	0.67	0.73	0.77	0.85	1.00	1.06	1.65	0.84	0.72	0.57	0.74
BREMER	12230.92	982140	0.66	0.78	0.84	0.85	0.86	0.88	0.94	0.97	1.36	0.86	0.84	0.74	0.85
BREMER	12462.76	982372	0.80	0.82	0.87	0.88	0.89	0.91	0.98	1.00	1.30	0.90	0.87	0.81	0.88
BREMER	12694.60	982604	1.05	1.07	1.07	1.11	1.13	1.15	1.17	1.17	1.24	1.04	1.07	1.06	1.07
BREMER	12981.75	982891	1.16	1.19	1.19	1.23	1.25	1.27	1.28	1.27	1.31	1.15	1.17	1.16	1.18
BREMER	13268.91	983178	1.37	1.41	1.40	1.46	1.54	1.59	1.63	1.63	1.75	1.34	1.37	1.34	1.39
BREMER	13569.55	983479	0.91	0.97	0.99	1.05	1.10	1.18	1.21	1.22	1.33	0.90	0.94	0.96	0.96
BREMER	13870.20	983779	0.71	0.78	0.79	0.84	0.89	0.96	0.99	0.99	1.11	0.72	0.75	0.77	0.77
BREMER	14130.01	984039	0.75	0.85	0.86	0.88	0.92	0.95	0.97	0.98	1.13	0.83	0.83	0.84	0.84
BREMER	14389.82	984299	0.79	1.07	1.08	1.10	1.15	1.19	1.24	1.24	1.30	1.06	1.05	1.05	1.05

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	14394.91	984304	0.79	1.07	1.08	1.10	1.15	1.19	1.24	1.24	1.30	1.06	1.05	1.06	1.06
BREMER	14400.00	984309	0.79	1.07	1.08	1.10	1.15	1.19	1.24	1.25	1.30	1.06	1.05	1.06	1.06
BREMER	14420.00	984329	0.80	1.07	1.09	1.11	1.16	1.19	1.24	1.25	1.31	1.06	1.06	1.07	1.07
BREMER	14625.61	984535	0.47	0.63	0.64	0.65	0.68	0.69	0.71	0.72	1.13	0.63	0.63	0.62	0.62
BREMER	14831.22	984740	0.33	0.48	0.48	0.48	0.50	0.51	0.52	0.55	1.05	0.48	0.48	0.47	0.48
BREMER	14945.61	984855	0.51	0.71	0.71	0.71	0.72	0.73	0.74	0.74	1.23	0.70	0.70	0.70	0.70
BREMER	15060.00	984969	1.11	1.41	1.42	1.45	1.42	1.46	1.43	1.49	1.51	1.43	1.41	1.43	1.43
BREMER	15080.00	984989	1.12	1.42	1.44	1.46	1.44	1.47	1.44	1.50	1.51	1.44	1.42	1.44	1.44
BREMER	15195.94	985105	1.22	1.54	1.55	1.55	1.56	1.57	1.58	1.59	1.62	1.54	1.54	1.53	1.54
BREMER	15311.88	985221	1.39	1.75	1.75	1.76	1.77	1.78	1.80	1.81	1.84	1.75	1.75	1.73	1.74
BREMER	15529.86	985439	1.16	1.42	1.43	1.44	1.45	1.46	1.47	1.48	1.86	1.43	1.43	1.40	1.42
BREMER	15747.83	985657	1.16	1.24	1.27	1.27	1.29	1.29	1.38	1.46	2.22	1.27	1.26	1.18	1.25
BREMER	16044.13	985953	1.11	1.22	1.25	1.25	1.27	1.27	1.38	1.44	2.04	1.25	1.25	1.18	1.24
BREMER	16340.42	986249	1.35	1.40	1.40	1.42	1.48	1.53	1.57	1.57	1.89	1.39	1.37	1.34	1.39
BREMER	16523.32	986432	1.02	1.13	1.14	1.14	1.18	1.23	1.25	1.26	1.53	1.13	1.13	1.11	1.13
BREMER	16706.22	986615	0.93	1.10	1.10	1.11	1.13	1.14	1.17	1.18	1.29	1.10	1.09	1.07	1.09
BREMER	16963.97	986873	0.80	0.97	0.98	0.98	1.00	1.01	1.04	1.05	1.46	0.97	0.97	0.95	0.97
BREMER	17221.72	987131	0.71	0.94	0.97	0.97	0.99	1.00	1.03	1.05	1.68	0.98	0.97	0.85	0.96
BREMER	17577.40	987486	0.77	1.01	1.05	1.06	1.09	1.10	1.11	1.13	1.87	1.07	1.06	0.95	1.07
BREMER	17933.08	987842	0.85	1.12	1.18	1.30	1.34	1.37	1.40	1.42	2.12	1.32	1.29	1.06	1.31
BREMER	18165.94	988075	0.81	1.05	1.10	1.12	1.16	1.19	1.23	1.24	1.71	1.14	1.12	0.99	1.13
BREMER	18398.80	988308	0.79	0.98	1.07	1.08	1.10	1.12	1.14	1.14	1.43	1.09	1.07	0.93	1.08
BREMER	18724.87	988634	0.90	1.07	1.08	1.09	1.11	1.11	1.12	1.12	1.31	1.10	1.09	1.04	1.09
BREMER	19050.94	988960	1.05	1.21	1.21	1.21	1.21	1.20	1.20	1.20	1.20	1.20	1.20	1.19	1.20
BREMER	19205.47	989114	0.93	0.99	1.05	1.06	1.07	1.07	1.08	1.07	1.49	1.06	1.05	0.97	1.05
BREMER	19360.00	989269	0.87	0.94	1.00	1.01	1.04	1.07	1.12	1.18	1.96	1.02	1.00	0.85	1.00
BREMER	19380.00	989289	0.88	1.03	1.15	1.17	1.18	1.18	1.19	1.19	1.97	1.15	1.14	0.96	1.14
BREMER	19399.74	989309	0.88	1.04	1.15	1.17	1.18	1.18	1.19	1.20	1.98	1.15	1.14	0.98	1.14
BREMER	19419.49	989328	0.91	1.05	1.16	1.17	1.17	1.19	1.20	1.21	2.00	1.15	1.14	0.99	1.14

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	19952.52	989861	0.86	1.06	1.16	1.17	1.21	1.22	1.24	1.23	1.46	1.15	1.14	0.98	1.16
BREMER	20485.54	990395	0.85	1.07	1.20	1.24	1.36	1.37	1.43	1.43	1.19	1.25	1.21	0.97	1.24
BREMER	20681.11	990590	1.14	1.15	1.17	1.17	1.15	1.14	1.13	1.12	1.11	1.15	1.17	1.14	1.17
BREMER	20876.67	990786	1.83	1.83	1.83	1.83	1.83	1.83	1.81	1.78	1.64	1.85	1.83	1.84	1.84
BREMER	21221.26	991130	0.96	1.27	1.37	1.39	1.39	1.38	1.38	1.36	1.33	1.36	1.37	1.21	1.38
BREMER	21565.85	991475	0.74	1.26	1.64	1.93	2.15	2.17	2.17	2.13	1.78	2.08	1.90	1.13	2.09
BREMER	21708.59	991618	0.96	1.47	1.73	1.89	1.99	2.00	2.00	1.97	1.59	1.91	1.86	1.34	1.92
BREMER	21851.32	991760	1.39	1.76	1.84	1.85	1.90	1.89	1.87	1.84	1.59	1.85	1.83	1.66	1.83
BREMER	22130.95	992040	1.07	1.25	1.32	1.38	1.44	1.46	1.47	1.47	1.57	1.43	1.37	1.20	1.41
BREMER	22410.57	992320	1.28	1.29	1.32	1.34	1.39	1.38	1.37	1.36	1.48	1.28	1.28	1.28	1.28
BREMER	22670.96	992580	0.97	1.17	1.28	1.39	1.51	1.53	1.55	1.55	1.56	1.50	1.38	1.12	1.46
BREMER	22931.36	992840	1.13	1.50	1.73	1.89	2.13	2.17	2.19	2.17	2.06	2.10	1.87	1.40	2.02
BREMER	23153.61	993063	1.20	1.50	1.70	1.83	2.07	2.11	2.14	2.12	1.97	2.04	1.81	1.42	1.96
BREMER	23375.87	993285	1.29	1.49	1.67	1.78	2.01	2.13	2.23	2.23	2.05	1.97	1.75	1.44	1.90
BREMER	23672.13	993581	0.64	0.84	0.96	1.01	1.09	1.11	1.17	1.17	1.27	1.07	0.99	0.80	1.04
BREMER	23968.39	993877	0.43	0.59	0.67	0.71	0.74	0.75	0.78	0.77	1.19	0.74	0.70	0.56	0.72
BREMER	24176.44	994085	0.61	0.78	0.88	0.93	0.99	1.00	1.01	1.01	1.28	1.00	0.94	0.75	0.96
BREMER	24384.48	994293	1.36	1.40	1.44	1.47	1.50	1.58	1.53	1.56	1.65	1.51	1.42	1.34	1.46
BREMER	24637.92	994547	1.04	1.18	1.27	1.36	1.50	1.53	1.54	1.54	1.65	1.52	1.38	1.16	1.45
BREMER	24891.36	994800	1.00	1.22	1.25	1.32	1.52	1.69	1.78	1.78	1.90	1.59	1.35	1.21	1.43
BREMER	25131.42	995040	1.07	1.35	1.44	1.47	1.56	1.60	1.61	1.61	1.78	1.59	1.50	1.32	1.52
BREMER	25371.48	995280	1.15	1.54	1.73	1.75	1.77	1.81	1.82	1.85	2.05	1.76	1.76	1.47	1.76
BREMER	25626.87	995536	0.81	1.12	1.31	1.37	1.46	1.46	1.45	1.48	1.67	1.48	1.43	1.05	1.42
BREMER	25882.25	995791	0.63	0.88	1.07	1.17	1.29	1.35	1.39	1.39	1.57	1.36	1.23	0.82	1.25
BREMER	26073.64	995983	0.70	0.98	1.16	1.20	1.27	1.27	1.29	1.32	1.47	1.28	1.28	0.90	1.24
BREMER	26265.02	996174	0.79	1.09	1.28	1.31	1.33	1.39	1.40	1.42	1.49	1.31	1.40	1.00	1.36
BREMER	26303.28	996212	1.01	1.27	1.42	1.44	1.46	1.53	1.55	1.57	1.67	1.44	1.54	1.21	1.51
BREMER	26341.55	996251	1.39	1.54	1.61	1.61	1.67	1.71	1.73	1.78	1.93	1.66	1.74	1.52	1.70
BREMER	26557.59	996467	0.99	1.37	1.58	1.58	1.73	1.73	1.76	1.82	2.10	1.74	1.79	1.29	1.71

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	26773.64	996683	0.77	1.24	1.55	1.60	1.81	1.77	1.78	1.87	2.33	1.85	1.84	1.13	1.74
BREMER	26914.87	996824	0.90	1.16	1.27	1.27	1.36	1.44	1.46	1.51	1.80	1.39	1.48	1.07	1.44
BREMER	27056.11	996965	1.14	1.18	1.17	1.23	1.27	1.29	1.29	1.32	1.46	1.16	1.25	1.16	1.24
BREMER	27227.41	997136	0.97	1.13	1.17	1.20	1.26	1.38	1.38	1.43	1.65	1.25	1.41	1.06	1.38
BREMER	27398.71	997308	0.87	1.18	1.29	1.28	1.35	1.54	1.54	1.62	1.92	1.41	1.60	1.04	1.55
BREMER	27494.98	997404	0.99	1.02	1.06	1.07	1.10	1.15	1.14	1.15	1.20	1.06	1.09	1.06	1.09
BREMER	27591.25	997500	1.15	1.16	1.20	1.23	1.25	1.24	1.26	1.27	1.25	1.22	1.24	1.21	1.23
BREMER	27715.24	997624	1.03	1.03	1.07	1.09	1.10	1.10	1.10	1.11	1.10	1.10	1.11	1.08	1.11
BREMER	27839.23	997748	0.93	1.18	1.22	1.19	1.35	1.53	1.52	1.57	1.84	1.45	1.58	1.04	1.55
BREMER	27945.54	997855	1.04	1.14	1.09	1.15	1.33	1.47	1.46	1.50	1.53	1.12	1.46	1.07	1.48
BREMER	28051.84	997961	1.18	1.10	1.11	1.19	1.33	1.41	1.40	1.42	1.38	1.24	1.39	1.16	1.45
BREMER	28194.94	998104	1.21	1.10	1.11	1.20	1.29	1.39	1.38	1.39	1.32	1.29	1.36	1.15	1.46
BREMER	28338.03	998247	1.29	1.20	1.24	1.31	1.38	1.51	1.51	1.52	1.57	1.43	1.45	1.27	1.48
BREMER	28603.16	998512	0.63	0.67	0.73	0.88	0.97	1.13	1.11	1.16	1.39	0.74	0.84	0.71	0.87
BREMER	28868.29	998777	0.42	0.41	0.47	0.60	0.66	0.80	0.77	0.81	0.99	0.56	0.60	0.46	0.61
BREMER	28997.60	998907	0.61	0.60	0.69	0.85	0.93	1.08	1.05	1.09	1.30	0.74	0.84	0.67	0.83
BREMER	29126.92	999036	1.17	1.19	1.38	1.54	1.61	1.75	1.72	1.76	2.01	1.48	1.52	1.32	1.38
BREMER	29299.83	999209	1.05	1.24	1.43	1.75	1.81	1.95	1.94	1.97	2.17	1.49	1.72	1.27	1.34
BREMER	29472.75	999382	1.32	1.57	1.68	2.03	2.12	2.32	2.28	2.32	2.47	1.69	2.08	1.33	1.63
BREMER	29493.87	999403	1.13	1.24	1.41	1.73	1.89	2.06	2.03	2.06	2.20	1.43	1.81	1.10	1.35
BREMER	29515.00	999424	1.02	1.10	1.21	1.50	1.69	1.85	1.82	1.85	2.01	1.25	1.55	0.93	1.14
BREMER	29535.00	999444	1.03	1.16	1.22	1.52	1.71	1.88	1.85	1.87	2.05	1.26	1.53	0.94	1.16
BREMER	29556.70	999466	0.97	1.15	1.30	1.56	1.75	1.90	1.86	1.89	2.08	1.36	1.56	0.97	1.20
BREMER	29578.39	999487	0.91	1.15	1.39	1.61	1.79	1.92	1.88	1.91	2.11	1.48	1.61	1.10	1.23
BREMER	29734.71	999644	0.83	1.01	1.40	1.82	2.04	2.22	2.18	2.21	2.44	1.57	1.66	1.14	1.15
BREMER	29891.04	999800	1.05	1.17	1.77	2.34	2.49	2.72	2.68	2.74	3.02	2.10	2.09	1.36	1.30
BREMER	29991.04	999900	0.34	0.43	0.73	0.96	1.16	1.39	1.31	1.36	1.67	0.73	0.84	0.53	0.69
BREMER	30091.04	1000000	0.22	0.29	0.45	0.61	0.74	0.90	0.84	0.88	1.11	0.52	0.56	0.32	0.47
BREMER	30441.04	1000350	0.45	0.56	0.65	0.70	0.74	0.74	0.75	0.75	1.19	0.74	0.68	0.59	0.71

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER	30791.04	1000700	0.38	0.51	0.60	0.62	0.64	0.64	0.68	0.71	1.31	0.64	0.61	0.54	0.63
BREMER-BOONAHNEW	0.00	940696	0.33	0.33	0.33	0.33	0.33	0.30	0.32	0.32	0.32	0.33	0.33	0.33	0.33
BREMER-BOONAHNEW	568.44	941265	1.28	1.67	1.79	1.92	2.40	2.73	3.36	3.55	4.84	2.31	1.54	1.15	1.97
BREMER-BOONAHNEW	1136.88	941833	0.81	0.84	0.93	1.01	1.30	1.52	1.90	2.01	2.71	1.26	0.84	0.73	1.04
BREMER-BOONAHNEW	1705.32	942402	1.58	1.74	1.83	1.96	2.44	2.79	3.42	3.59	4.85	2.37	1.75	1.42	1.99
BREMER-BOONAHNEW	2273.76	942970	0.91	1.16	1.22	1.25	1.26	1.38	1.68	1.76	2.26	1.17	1.18	0.84	1.22
BREMER-BOONAHNEW	2858.19	943555	1.53	1.92	2.00	2.11	2.54	2.92	3.27	3.39	4.39	2.48	1.93	1.38	2.14
BREMER-BOONAHNEW	3442.63	944139	0.77	1.03	1.15	1.24	1.51	1.75	2.06	2.10	2.30	1.43	1.06	0.74	1.26
BREMER-BOONAHNEW	4027.06	944723	1.71	2.27	2.64	2.83	2.89	2.95	3.08	3.07	4.16	2.88	2.35	1.56	2.81
BREMER-BOONAHNEW	4611.50	945308	1.29	1.72	1.96	2.08	2.24	2.23	2.23	2.21	2.22	2.06	1.80	1.17	2.08
BREMER-BOONAHNEW	5268.59	945965	2.09	2.45	2.47	2.66	2.74	2.79	3.00	3.07	3.48	2.62	2.25	1.80	2.64
BREMER-BOONAHNEW	5925.69	946622	1.13	1.29	1.31	1.33	1.47	1.62	1.71	1.71	1.80	1.28	1.28	0.95	1.28
BREMER-BOONAHNEW	6582.79	947279	1.80	2.08	2.32	2.51	2.85	2.82	2.71	2.71	3.09	2.85	2.10	1.60	2.53
BREMER-BOONAHNEW	7239.89	947936	0.97	1.35	1.57	1.71	2.06	2.04	2.03	2.02	2.03	1.84	1.43	0.89	1.73
BREMER-BOONAHNEW	7814.42	948511	1.17	1.18	1.29	1.42	1.64	1.79	1.95	2.03	2.31	1.49	1.10	0.92	1.39
BREMER-BOONAHNEW	8388.95	949085	0.59	0.59	0.59	0.59	0.71	0.76	0.82	0.83	1.09	0.60	0.59	0.58	0.58
BREMER-BOONAHNEW	9129.15	949826	1.12	0.99	1.13	1.15	1.26	1.24	1.34	1.39	1.70	1.22	1.01	0.94	1.11

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER-BOONAHNEW	9869.34	950566	0.80	0.83	0.90	0.94	0.97	0.98	0.99	0.99	1.00	0.79	0.83	0.79	1.03
BREMER-BOONAHNEW	10167.89	950864	1.06	1.27	1.30	1.30	1.32	1.31	1.37	1.38	1.46	1.24	1.27	0.97	1.25
BREMER-BOONAHNEW	10466.43	951163	0.80	1.04	1.10	1.11	1.14	1.14	1.21	1.23	1.29	0.99	1.05	0.72	1.03
BREMER-BOONAHNEW	11191.66	951888	1.55	1.72	1.71	1.76	1.77	1.82	1.96	2.05	2.22	1.72	1.72	1.38	1.72
BREMER-BOONAHNEW	11916.88	952613	1.04	1.15	1.24	1.21	1.35	1.33	1.35	1.91	1.56	1.70	1.60	0.97	1.40
BREMER-BOONAHNEW	11936.88	952633	1.91	1.95	2.07	1.99	2.12	2.13	2.16	2.59	2.24	2.59	2.55	1.83	2.03
BREMER-BOONAHNEW	12218.44	952915	1.62	1.76	1.71	1.81	1.92	1.96	2.05	2.07	2.15	1.78	1.68	1.43	1.69
BREMER-BOONAHNEW	12500.00	953196	1.12	1.12	1.14	1.16	1.17	1.17	1.17	1.17	1.44	1.17	1.12	0.99	1.31
BREMER-BOONAHNEW	12952.70	953649	1.55	1.75	1.82	1.83	1.84	1.85	1.84	1.84	1.84	1.78	1.77	1.42	1.86
BREMER-BOONAHNEW	13405.41	954102	1.55	2.36	2.49	2.51	2.54	2.55	2.56	2.55	2.56	2.43	2.42	1.32	2.59
BREMER-BOONAHNEW	13667.81	954364	1.27	1.33	1.31	1.36	1.53	1.66	1.68	1.72	1.71	1.28	1.28	1.09	1.29
BREMER-BOONAHNEW	13930.22	954627	0.53	0.59	0.58	0.57	0.57	0.56	0.60	0.61	0.68	0.51	0.59	0.56	0.70
BREMER-BOONAHNEW	13938.22	954635	0.90	0.93	0.92	0.94	1.00	1.09	1.12	1.16	1.16	0.91	0.92	0.77	0.92
BREMER-BOONAHNEW	14163.44	954860	1.07	1.08	1.07	1.07	1.14	1.27	1.35	1.35	1.39	1.07	1.09	1.00	1.08
BREMER-BOONAHNEW	14388.66	955085	1.26	1.42	1.42	1.44	1.43	1.43	1.43	1.43	1.43	1.42	1.46	1.25	1.43
BREMER-BOONAHNEW	14918.01	955614	1.31	1.50	1.50	1.52	1.56	1.60	1.63	1.66	1.78	1.49	1.50	1.23	1.49
BREMER-BOONAHNEW	15447.36	956144	1.05	1.21	1.30	1.30	1.31	1.32	1.34	1.34	1.34	1.28	1.18	0.94	1.39

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER-BOONAHNEW	15976.71	956673	1.24	1.36	1.41	1.41	1.41	1.41	1.41	1.41	1.42	1.39	1.42	1.08	1.40
BREMER-BOONAHNEW	16506.06	957202	1.21	1.38	1.42	1.46	1.48	1.51	1.52	1.53	1.70	1.42	1.49	1.11	1.58
BREMER-BOONAHNEW	16518.06	957214	1.68	1.91	1.92	1.96	1.99	2.12	2.12	2.14	2.74	1.96	1.89	1.35	1.92
BREMER-BOONAHNEW	17342.28	958039	1.51	1.71	1.77	1.79	1.80	1.82	1.84	1.85	1.90	1.75	1.69	1.28	1.75
BREMER-BOONAHNEW	18166.50	958863	1.21	1.47	1.75	2.07	2.23	2.27	2.31	2.27	2.30	2.16	1.48	1.04	2.22
BREMER-BOONAHNEW	18630.11	959326	1.30	1.62	1.65	1.67	1.69	1.91	2.02	2.05	2.31	1.62	1.59	1.07	1.62
BREMER-BOONAHNEW	19093.71	959790	1.03	1.28	1.33	1.34	1.38	1.38	1.37	1.37	1.40	1.31	1.30	0.82	1.36
BREMER-BOONAHNEW	19908.51	960605	1.28	1.64	1.66	1.67	1.69	1.73	1.81	1.87	2.18	1.65	1.69	1.06	1.67
BREMER-BOONAHNEW	20723.30	961420	1.21	1.68	1.84	1.85	1.86	1.85	1.86	1.85	1.72	1.80	1.76	1.05	1.98
BREMER-BOONAHNEW	21357.51	962054	0.93	0.95	0.96	0.97	0.96	0.96	1.02	1.06	1.31	1.01	1.01	0.79	0.95
BREMER-BOONAHNEW	21991.71	962688	0.69	0.69	0.69	0.73	0.74	0.74	0.81	0.83	1.02	0.71	0.71	0.70	0.70
BREMER-BOONAHNEW	22910.31	963607	1.07	1.07	1.10	1.11	1.14	1.23	1.41	1.45	1.82	1.20	1.08	0.98	1.11
BREMER-BOONAHNEW	23828.91	964525	1.37	1.56	1.64	1.75	1.82	2.01	2.24	2.29	2.66	1.85	1.61	1.25	1.81
BREMER-BOONAHNEW	24164.46	964861	0.75	1.12	1.30	1.45	1.75	1.79	1.90	1.95	2.59	1.74	1.21	0.63	1.46
BREMER-BOONAHNEW	24500.00	965196	0.48	0.66	0.85	0.96	1.34	1.31	1.33	1.36	1.81	1.25	0.76	0.47	1.10
BREMER-BOONAHNEW	24523.35	965220	0.60	0.82	1.02	1.18	1.57	1.61	1.63	1.66	2.24	1.55	0.92	0.61	1.20
BREMER-BOONAHNEW	24546.71	965243	0.54	0.69	0.89	1.00	1.40	1.37	1.40	1.43	1.92	1.32	0.80	0.55	1.14

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
BREMER-BOONAHNEW	24556.71	965253	0.89	1.03	1.17	1.25	1.57	1.57	1.63	1.71	2.38	1.55	1.13	0.99	1.30
BREMER-BOONAHNEW	24578.35	965275	1.36	1.21	1.58	1.68	1.85	2.05	2.10	2.20	2.59	1.67	1.23	1.10	1.35
BREMER-BOONAHNEW	24600.00	965296	1.63	1.41	2.04	2.01	2.45	2.86	3.12	3.29	4.40	1.71	1.34	1.28	1.37
BREMER-BOONAHNEW	25550.36	966247	0.91	1.08	1.19	1.30	1.59	1.69	1.76	1.78	2.24	1.63	1.13	0.80	1.31
BREMER-BOONAHNEW	26500.72	967197	0.72	0.89	1.02	1.11	1.43	1.40	1.40	1.40	1.68	1.36	0.94	0.68	1.19
BREMER-BOONAHNEW	27042.52	967739	1.09	1.16	1.20	1.24	1.24	1.22	1.22	1.25	1.76	1.25	1.17	1.01	1.19
BREMER-BOONAHNEW	27584.32	968281	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.65	1.62	1.63	1.57	1.59
BREMER-BOONAHNEW	28398.45	969095	0.98	1.19	1.21	1.22	1.21	1.21	1.21	1.22	1.58	1.21	1.19	0.95	1.22
BREMER-BOONAHNEW	29212.58	969909	0.70	0.98	1.04	1.04	1.05	1.06	1.10	1.12	1.36	1.05	1.02	0.77	1.04
FRANK_WEST_WEIR1	0.00		0.00	0.01	0.01	0.01	0.01	0.01	0.07	0.14	0.73	0.00	0.01	0.00	0.01
FRANK_WEST_WEIR1	2.50		0.00	0.01	0.01	0.01	0.01	0.01	0.07	0.14	0.73	0.00	0.00	0.00	0.01
FRANK_WEST_WEIR1	5.00		0.00	0.00	0.01	0.01	0.01	0.01	0.07	0.14	0.73	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR1	10.00		0.00	0.00	0.00	0.00	0.00	0.64	0.92	1.19	2.33	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR1	15.00		0.00	0.00	0.00	0.00	0.00	0.09	0.29	0.39	0.57	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR1	17.50		0.00	0.00	0.00	0.00	0.00	0.09	0.29	0.39	0.57	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR1	20.00		0.00	0.00	0.00	0.00	0.00	0.09	0.29	0.39	0.57	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR2	0.00		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANK_WEST_WEIR2	2.50		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR2	5.00		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR2	10.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR2	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR2	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
FRANK_WEST_WEIR2	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
FRANKLINVALE	0.00		1.02	1.53	1.80	1.84	1.86	1.91	1.90	1.92	2.09	1.83	1.61	0.96	1.83
FRANKLINVALE	2.36		1.05	1.55	1.82	1.86	1.89	1.93	1.92	1.94	2.12	1.85	1.63	0.99	1.86
FRANKLINVALE	4.73		1.20	1.64	1.89	1.93	1.96	1.98	1.99	2.01	2.18	1.92	1.71	1.16	1.93
FRANKLINVALE	215.35		1.36	1.80	2.04	2.09	2.09	2.12	2.12	2.12	2.20	2.09	1.87	1.31	2.09
FRANKLINVALE	425.97		1.64	2.03	2.25	2.40	2.44	2.52	2.56	2.56	2.68	2.42	2.10	1.60	2.44
FRANKLINVALE	655.82		1.58	2.03	2.28	2.44	2.49	2.51	2.52	2.52	2.55	2.49	2.11	1.54	2.47
FRANKLINVALE	885.68		1.70	2.12	2.37	2.56	2.72	2.82	2.86	2.85	2.95	2.72	2.20	1.65	2.66
FRANKLINVALE	1125.48		1.75	2.22	2.48	2.68	2.82	2.85	2.86	2.86	2.90	2.83	2.30	1.70	2.78
FRANKLINVALE	1365.29		2.00	2.44	2.68	2.87	3.34	3.64	3.96	4.18	4.42	3.27	2.51	1.96	2.96
FRANKLINVALE	1567.12		1.72	2.27	2.59	2.83	3.43	3.82	3.96	3.97	4.05	3.34	2.37	1.66	2.95
FRANKLINVALE	1768.94		1.64	2.21	2.57	2.85	3.57	4.03	4.19	4.20	4.27	3.45	2.32	1.59	2.99
FRANKLINVALE	2010.40		1.52	1.83	2.02	2.18	2.52	2.65	2.84	2.90	3.03	2.48	1.89	1.50	2.25
FRANKLINVALE	2251.85		1.69	1.67	1.74	1.79	1.96	2.02	2.28	2.29	2.38	1.95	1.65	1.69	1.83
FRANKLINVALE	2476.41		0.70	0.88	0.92	0.99	1.14	1.24	1.51	1.53	1.85	1.12	0.90	0.67	1.05
FRANKLINVALE	2700.97		0.85	1.10	1.18	1.26	1.47	1.64	1.84	1.98	2.46	1.43	1.13	0.80	1.30
FRANKLINVALE	2848.49		1.32	1.65	1.79	1.92	2.05	2.13	2.18	2.27	2.55	2.01	1.68	1.27	1.97
FRANKLINVALE	2996.01		1.80	1.97	2.18	2.31	2.40	2.45	2.49	2.51	2.59	2.40	2.01	1.80	2.36
FRANKLINVALE	3272.45		1.17	1.40	1.52	1.59	1.70	1.84	1.85	1.88	2.07	1.67	1.41	1.16	1.61
FRANKLINVALE	3548.88		0.90	1.10	1.16	1.20	1.39	1.45	1.46	1.48	1.58	1.34	1.10	0.87	1.22

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	3805.40		1.15	1.42	1.48	1.49	1.55	1.61	1.61	1.63	1.74	1.47	1.43	1.11	1.49
FRANKLINVALE	4061.92		1.70	2.08	2.16	2.16	2.24	2.29	2.28	2.29	2.41	2.15	2.11	1.64	2.17
FRANKLINVALE	4255.61		1.29	1.80	1.92	1.92	1.96	1.99	1.98	2.00	2.06	1.91	1.85	1.22	1.93
FRANKLINVALE	4449.29		1.07	1.61	1.81	1.82	1.84	1.91	1.91	1.94	2.03	1.82	1.67	1.00	1.81
FRANKLINVALE	4641.44		1.37	1.93	2.12	2.13	2.19	2.27	2.27	2.30	2.37	2.18	1.99	1.29	2.15
FRANKLINVALE	4833.58		2.00	2.46	2.61	2.72	2.77	2.86	2.87	2.89	2.98	2.73	2.50	1.94	2.72
FRANKLINVALE	4973.05		1.62	1.93	2.03	2.07	2.14	2.27	2.28	2.31	2.46	2.07	1.96	1.55	2.07
FRANKLINVALE	5112.51		1.41	1.63	1.68	1.69	1.77	1.85	1.86	1.89	2.02	1.67	1.63	1.35	1.70
FRANKLINVALE	5366.59		1.54	1.95	2.02	2.03	2.06	2.09	2.09	2.10	2.18	2.01	1.99	1.47	2.03
FRANKLINVALE	5620.66		2.92	3.23	3.22	3.22	3.22	3.16	3.23	3.22	3.22	3.20	3.20	2.70	3.23
FRANKLINVALE	5625.69		3.06	3.27	3.23	3.33	3.25	3.21	3.25	3.27	3.28	3.32	3.23	2.78	3.26
FRANKLINVALE	5829.00		1.56	2.17	2.35	2.37	2.39	2.44	2.44	2.45	2.49	2.35	2.24	1.48	2.36
FRANKLINVALE	6032.32		1.42	1.91	2.13	2.15	2.18	2.22	2.22	2.24	2.29	2.14	1.96	1.35	2.15
FRANKLINVALE	6251.44		1.10	1.48	1.67	1.76	1.78	1.81	1.81	1.82	1.90	1.77	1.52	1.08	1.76
FRANKLINVALE	6470.57		1.09	1.22	1.39	1.54	1.56	1.58	1.58	1.58	1.63	1.54	1.26	0.98	1.54
FRANKLINVALE	6721.82		1.02	1.27	1.35	1.37	1.41	1.47	1.49	1.50	1.56	1.36	1.29	0.99	1.38
FRANKLINVALE	6973.07		1.20	1.36	1.37	1.39	1.43	1.46	1.46	1.47	1.51	1.36	1.36	1.19	1.37
FRANKLINVALE	7109.93		1.00	1.23	1.30	1.30	1.32	1.34	1.35	1.36	1.60	1.30	1.25	0.97	1.31
FRANKLINVALE	7246.79		0.89	1.16	1.29	1.38	1.51	1.52	1.52	1.52	1.75	1.50	1.20	0.85	1.45
FRANKLINVALE	7387.69		1.06	1.33	1.45	1.47	1.51	1.54	1.54	1.55	1.58	1.46	1.36	1.00	1.47
FRANKLINVALE	7528.59		1.37	1.58	1.69	1.71	1.77	1.83	1.82	1.83	1.87	1.70	1.61	1.31	1.72
FRANKLINVALE	7657.85		0.92	1.12	1.20	1.21	1.34	1.45	1.45	1.48	1.59	1.19	1.13	0.88	1.22
FRANKLINVALE	7787.11		0.73	0.88	0.94	0.95	1.10	1.23	1.23	1.26	1.38	0.93	0.89	0.69	0.95
FRANKLINVALE	8053.98		0.90	1.10	1.18	1.18	1.22	1.29	1.28	1.29	1.35	1.18	1.14	0.86	1.18
FRANKLINVALE	8320.85		1.30	1.58	1.73	1.73	1.74	1.76	1.79	1.78	1.86	1.75	1.62	1.25	1.74
FRANKLINVALE	8574.08		0.93	1.08	1.10	1.11	1.23	1.28	1.33	1.33	1.48	1.08	1.08	0.89	1.11
FRANKLINVALE	8827.31		0.73	0.82	0.82	0.82	0.82	0.83	0.83	0.89	1.35	0.83	0.83	0.70	0.83
FRANKLINVALE	8843.31		1.28	1.75	1.88	1.90	1.94	1.97	2.04	2.07	2.53	1.92	1.79	1.21	1.90
FRANKLINVALE	9082.44		1.29	1.70	1.79	1.79	1.79	1.80	1.78	1.77	1.73	1.79	1.73	1.23	1.79

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	9321.57		1.38	1.69	1.76	1.78	1.75	1.74	1.76	1.76	1.73	1.78	1.70	1.35	1.76
FRANKLINVALE	9517.19		1.04	1.37	1.50	1.59	1.61	1.61	1.62	1.62	1.62	1.59	1.33	0.96	1.53
FRANKLINVALE	9712.81		1.00	1.39	1.62	1.83	2.00	2.06	2.19	2.20	2.19	1.88	1.42	0.94	1.85
FRANKLINVALE	10106.67		1.02	1.40	1.57	1.66	1.81	2.02	2.13	2.15	2.10	1.80	1.51	1.01	1.70
FRANKLINVALE	10500.52		0.88	1.14	1.23	1.27	1.42	1.59	1.64	1.65	1.67	1.41	1.20	0.86	1.30
FRANKLINVALE	10730.88		0.91	1.19	1.32	1.40	1.69	1.90	1.93	1.93	1.92	1.67	1.29	0.90	1.47
FRANKLINVALE	10961.24		0.99	1.27	1.45	1.57	2.10	2.49	2.50	2.50	2.50	2.06	1.41	0.97	1.71
FRANKLINVALE	11208.58		1.09	1.30	1.41	1.44	1.50	1.53	1.56	1.56	1.90	1.44	1.39	1.08	1.44
FRANKLINVALE	11455.91		1.29	1.34	1.41	1.43	1.48	1.46	1.49	1.49	1.64	1.41	1.40	1.28	1.41
FRANKLINVALE	11664.60		1.24	1.36	1.43	1.43	1.46	1.46	1.46	1.48	1.98	1.43	1.43	1.23	1.43
FRANKLINVALE	11873.29		1.22	1.39	1.48	1.48	1.49	1.61	1.73	1.83	2.49	1.48	1.48	1.21	1.48
FRANKLINVALE	12100.87		1.58	1.60	1.61	1.60	1.62	1.65	1.66	1.67	2.04	1.59	1.59	1.55	1.59
FRANKLINVALE	12328.45		2.34	2.34	2.36	2.35	2.37	2.39	2.41	2.41	2.42	2.34	2.34	2.28	2.35
FRANKLINVALE	12535.39		1.15	1.35	1.38	1.40	1.41	1.42	1.42	1.44	1.90	1.35	1.35	1.10	1.36
FRANKLINVALE	12742.32		0.78	1.17	1.23	1.36	1.67	1.78	1.78	1.78	2.12	1.65	1.20	0.74	1.45
FRANKLINVALE	12942.11		0.77	0.85	0.84	0.88	1.00	1.11	1.15	1.19	1.52	0.99	0.75	0.75	0.85
FRANKLINVALE	13141.89		0.96	0.95	0.96	1.01	1.06	1.15	1.12	1.16	1.25	0.94	0.95	0.95	0.96
FRANKLINVALE	13360.25		0.91	0.91	0.93	0.94	1.01	1.05	1.03	1.05	1.35	0.90	0.90	0.90	0.92
FRANKLINVALE	13578.62		1.05	1.12	1.13	1.13	1.17	1.24	1.22	1.26	1.57	1.10	1.10	1.04	1.11
FRANKLINVALE	13811.20		1.41	1.47	1.47	1.46	1.48	1.48	1.49	1.49	1.68	1.46	1.46	1.38	1.46
FRANKLINVALE	14043.78		2.22	2.65	2.67	2.75	2.72	2.77	2.81	2.85	2.90	2.65	2.62	2.19	2.66
FRANKLINVALE	14284.28		1.09	1.51	1.52	1.63	1.63	1.69	1.71	1.76	1.81	1.50	1.47	1.06	1.52
FRANKLINVALE	14524.77		0.74	1.04	1.04	1.11	1.13	1.18	1.17	1.21	1.23	1.03	1.02	0.71	1.04
FRANKLINVALE	14763.33		0.81	1.00	1.00	1.06	1.08	1.14	1.14	1.17	1.24	0.96	0.95	0.79	0.99
FRANKLINVALE	15001.90		0.94	1.04	1.03	1.03	1.10	1.11	1.09	1.09	1.59	1.00	0.98	0.93	1.01
FRANKLINVALE	15237.53		1.21	1.29	1.30	1.28	1.29	1.25	1.26	1.25	1.36	1.28	1.27	1.20	1.28
FRANKLINVALE	15473.17		1.81	1.95	1.97	1.95	1.93	1.84	1.86	1.85	1.84	1.95	1.90	1.78	1.95
FRANKLINVALE	15711.66		1.26	1.19	1.21	1.21	1.23	1.23	1.23	1.24	1.24	1.20	1.26	1.15	1.29
FRANKLINVALE	15950.15		1.13	1.10	1.07	1.07	1.08	1.07	1.07	1.07	1.08	1.10	1.12	1.08	1.15

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
FRANKLINVALE	16175.25		1.05	1.27	1.25	1.26	1.28	1.26	1.27	1.28	1.32	1.26	1.25	1.00	1.27
FRANKLINVALE	16400.35		1.04	1.50	1.49	1.50	1.50	1.48	1.50	1.50	1.59	1.50	1.48	1.03	1.50
FRANKLINVALE	16638.88		0.63	0.78	0.77	0.79	0.94	1.06	1.13	1.19	1.63	0.94	0.82	0.57	0.82
FRANKLINVALE	16877.42		0.49	0.60	0.64	0.71	0.88	1.04	1.13	1.21	1.80	0.90	0.62	0.48	0.73
FRANKLINVALE	16953.78		0.72	0.73	0.72	0.73	0.88	1.05	1.15	1.23	1.87	0.91	0.71	0.72	0.73
FRANKLINVALE	17030.13		1.32	1.32	1.31	1.32	1.84	1.37	1.34	1.73	1.92	1.72	1.32	1.81	1.33
FRANKLINVALE	17033.13		1.52	1.52	1.54	1.56	1.94	1.59	1.60	1.84	2.01	1.81	1.53	1.89	1.54
FRANKLINVALE	17184.33		1.13	1.15	1.14	1.17	1.23	1.30	1.30	1.26	1.78	1.13	1.12	1.13	1.15
FRANKLINVALE	17335.54		1.12	1.21	1.21	1.23	1.24	1.32	1.30	1.32	1.68	1.20	1.20	1.13	1.20
FRANKLINVALE	17531.85		1.12	1.21	1.21	1.23	1.24	1.26	1.25	1.26	1.70	1.21	1.21	1.14	1.21
FRANKLINVALE	17728.16		1.16	1.27	1.28	1.29	1.29	1.32	1.32	1.33	1.73	1.28	1.27	1.17	1.27
FRANKLINVALE	17949.53		1.01	1.12	1.11	1.14	1.17	1.20	1.20	1.21	1.43	1.10	1.10	1.02	1.10
FRANKLINVALE	18170.90		0.91	1.15	1.22	1.23	1.23	1.25	1.26	1.27	1.33	1.23	1.22	0.92	1.24
FRANKLINVALE	18368.20		0.92	1.25	1.34	1.34	1.35	1.35	1.37	1.38	1.68	1.34	1.34	0.92	1.34
FRANKLINVALE	18565.51		1.17	1.39	1.56	1.63	1.93	1.97	1.99	2.03	2.71	1.62	1.48	1.03	1.63
FRANKLINVALE	19176.70		1.17	1.27	1.34	1.44	1.49	1.50	1.46	1.46	1.45	1.46	1.29	1.18	1.51
FRANKLINVALE	19787.88		1.76	1.70	1.73	1.70	1.69	1.73	1.62	1.64	1.74	1.64	1.77	1.80	1.81
FRANKLINVALE	19937.44		1.13	1.08	1.14	1.10	1.05	1.00	0.89	0.90	1.20	1.00	1.23	1.19	1.25
FRANKLINVALE	20087.00		0.83	0.89	0.94	0.90	0.87	0.81	0.66	0.67	1.28	0.77	1.06	0.89	1.05
PURGA	0.00	80168	0.72	0.97	0.70	0.83	1.14	1.18	0.99	1.12	2.57	0.58	0.56	0.57	0.57
PURGA	672.90	80841	0.95	1.05	1.11	1.02	1.02	1.09	1.11	1.11	1.30	0.88	0.86	0.85	0.96
PURGA	1345.80	81514	1.57	1.55	1.50	1.56	1.56	1.55	1.66	1.68	1.93	1.43	1.42	1.40	1.48
PURGA	1629.05	81797	1.38	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.57	1.57	1.53	1.57
PURGA	1912.30	82081	1.72	1.74	1.75	1.77	1.78	1.80	1.80	1.81	1.82	2.17	2.18	1.80	2.16
PURGA	2449.18	82618	0.80	0.85	0.86	0.90	0.92	0.97	0.99	1.00	1.12	0.38	0.32	0.29	0.23
PURGA	2986.06	83155	0.25	0.39	0.38	0.48	0.48	0.57	0.60	0.63	0.75	0.20	0.32	0.14	0.14
PURGA	3006.06	83175	0.56	0.63	0.69	0.79	0.84	0.88	0.92	0.96	1.22	0.83	0.62	0.50	0.69
PURGA	3175.88	83344	0.56	0.65	0.62	0.70	0.76	0.80	0.83	0.88	1.10	0.74	0.57	0.51	0.62
PURGA	3345.71	83514	0.83	1.14	1.09	1.41	1.39	1.42	1.46	1.47	1.66	0.68	0.52	0.68	0.56

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
PURGA	3924.06	84093	0.70	0.68	0.73	0.79	0.85	0.90	0.93	0.96	1.33	0.87	0.66	0.63	0.74
PURGA	4502.41	84671	1.21	1.21	1.23	1.21	1.24	1.28	1.29	1.29	1.74	1.22	1.21	1.21	1.21
PURGA	4753.46	84922	1.16	1.18	1.18	1.14	1.18	1.21	1.19	1.19	1.51	1.13	1.13	1.13	1.13
PURGA	5004.51	85173	1.21	1.37	1.23	1.19	1.32	1.41	1.40	1.37	1.43	1.15	1.17	1.15	1.15
PURGA	5239.53	85408	1.24	1.31	1.32	1.33	1.37	1.43	1.39	1.42	1.44	1.23	1.24	1.26	1.22
PURGA	5474.54	85643	1.36	1.42	1.53	1.55	1.60	1.73	1.65	1.71	1.75	1.36	1.34	1.39	1.34
PURGA	5706.76	85875	1.08	1.09	1.07	1.13	1.12	1.12	1.15	1.17	1.23	1.03	1.04	1.05	1.05
PURGA	5938.99	86107	1.69	2.13	2.30	2.29	2.32	2.33	2.34	2.34	2.36	2.29	2.04	1.43	2.29
PURGA	6194.88	86363	1.30	1.35	1.36	1.36	1.39	1.40	1.41	1.42	1.49	1.24	1.26	1.27	1.27
PURGA	6450.77	86619	1.36	1.36	1.40	1.40	1.44	1.45	1.47	1.47	1.53	1.33	1.34	1.33	1.35
PURGA	6724.26	86893	1.26	1.25	1.28	1.25	1.29	1.28	1.30	1.29	1.38	1.25	1.26	1.25	1.26
PURGA	6997.75	87166	1.47	1.54	1.52	1.52	1.56	1.61	1.62	1.61	1.71	1.48	1.50	1.48	1.50
PURGA	7244.66	87413	0.82	0.82	0.82	0.82	0.88	0.94	0.99	1.07	1.62	0.92	0.81	0.81	0.81
PURGA	7491.57	87660	0.64	0.66	0.71	0.78	0.86	0.93	0.99	1.07	1.66	0.90	0.65	0.57	0.73
PURGA	7718.59	87887	0.52	0.58	0.63	0.69	0.76	0.82	0.88	0.96	1.54	0.79	0.58	0.49	0.64
PURGA	7945.62	88114	0.68	0.73	0.77	0.81	0.84	0.89	0.89	0.93	1.44	0.71	0.50	0.53	0.57
PURGA	8197.92	88366	0.76	0.78	0.78	0.79	0.84	0.89	0.93	1.00	1.51	0.87	0.68	0.65	0.75
PURGA	8450.21	88619	1.33	1.44	1.40	1.56	1.58	1.76	1.99	2.10	2.71	1.18	1.09	1.12	1.14
PURGA	8714.52	88883	0.69	0.69	0.69	0.69	0.69	0.70	0.74	0.76	1.02	0.70	0.69	0.69	0.73
PURGA	8978.82	89147	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.75	0.71	0.69	0.70	1.01
PURGA	9747.02	89915	0.70	0.70	0.70	0.69	0.69	0.68	0.71	0.76	1.07	0.69	0.69	0.69	0.69
PURGA	10515.22	90684	0.97	0.98	0.97	0.98	0.98	1.02	1.08	1.15	1.58	0.98	0.97	1.04	1.04
PURGA	10751.71	90920	0.77	0.77	0.77	0.77	0.77	0.82	0.87	0.92	1.27	0.79	0.77	0.78	0.82
PURGA	10988.20	91157	0.81	0.81	0.81	0.81	0.80	0.80	0.81	0.81	1.10	0.82	0.82	0.83	0.89
PURGA	11166.55	91335	1.06	1.06	1.06	1.07	1.06	1.06	1.06	1.07	1.12	1.06	1.06	1.06	1.06
PURGA	11344.89	91513	1.44	1.45	1.45	1.45	1.46	1.47	1.48	1.48	1.55	1.43	1.43	1.43	1.43
PURGA	11563.04	91731	1.27	1.28	1.27	1.29	1.30	1.30	1.32	1.31	1.38	1.26	1.26	1.26	1.26
PURGA	11781.18	91950	1.20	1.21	1.20	1.22	1.23	1.24	1.27	1.27	1.38	1.19	1.19	1.18	1.20
PURGA	12072.24	92241	1.43	1.43	1.42	1.44	1.45	1.46	1.49	1.50	1.54	1.42	1.43	1.42	1.43

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
PURGA	12363.30	92532	1.83	1.83	1.81	1.80	1.84	1.86	1.88	1.91	2.00	1.81	1.80	1.81	1.81
PURGA	12574.79	92743	1.42	1.55	1.45	1.44	1.62	1.61	1.64	1.61	1.79	1.43	1.43	1.43	1.43
PURGA	12786.29	92955	2.69	2.27	2.27	2.27	2.28	2.28	2.75	3.20	2.28	2.70	2.27	2.27	2.27
PURGA	12806.29	92975	2.73	2.28	2.28	2.28	2.29	2.29	2.77	3.17	2.28	2.74	2.28	2.28	2.28
PURGA	13043.95	93212	1.52	1.51	1.50	1.49	1.51	1.50	1.55	1.58	1.84	1.55	1.49	1.48	1.48
PURGA	13281.62	93450	1.80	1.81	1.81	1.81	1.84	1.83	1.86	1.86	1.90	1.80	1.80	1.78	1.80
PURGA	13425.37	93594	1.81	1.82	1.82	1.82	1.83	1.83	1.84	1.84	1.88	1.79	1.81	1.79	1.81
PURGA	13569.12	93738	1.86	1.87	1.86	1.87	1.88	1.88	1.90	1.90	1.93	1.83	1.86	1.84	1.85
PURGA	13818.94	93987	1.93	1.94	1.93	1.94	1.95	1.95	1.97	1.97	2.01	1.89	1.92	1.90	1.91
PURGA	14068.76	94237	2.09	2.13	2.15	2.16	2.18	2.18	2.21	2.23	2.32	2.02	2.09	1.98	2.13
PURGA	14264.46	94433	1.33	1.35	1.35	1.36	1.37	1.40	1.49	1.60	2.01	1.36	1.32	1.31	1.32
PURGA	14460.16	94629	1.11	1.15	1.18	1.21	1.23	1.29	1.28	1.39	1.87	1.17	1.07	1.06	1.07
PURGA	14629.61	94798	1.35	1.35	1.35	1.36	1.37	1.38	1.39	1.43	1.91	1.33	1.33	1.33	1.34
PURGA	14799.07	94968	2.06	2.08	2.09	2.10	2.13	2.15	2.16	2.17	2.24	2.01	2.05	2.01	2.05
PURGA	15053.80	95222	1.37	1.38	1.39	1.43	1.48	1.57	1.57	1.59	1.70	1.32	1.33	1.33	1.35
PURGA	15308.54	95477	1.08	1.12	1.16	1.19	1.22	1.30	1.27	1.31	1.52	1.04	1.03	1.04	1.06
PURGA	15639.79	95808	1.05	1.07	1.10	1.12	1.13	1.14	1.15	1.15	1.26	1.02	1.02	1.02	1.04
PURGA	15971.04	96139	1.10	1.11	1.12	1.12	1.12	1.13	1.14	1.13	1.22	1.10	1.10	1.10	1.11
PURGA	16267.20	96436	1.15	1.16	1.16	1.16	1.16	1.15	1.16	1.16	1.78	1.14	1.15	1.14	1.16
PURGA	16563.37	96732	1.22	1.21	1.21	1.37	1.51	1.72	1.92	2.18	3.37	1.76	1.20	1.20	1.31
PURGA	16866.56	97035	1.50	1.56	1.64	1.66	1.67	1.67	1.67	1.67	1.81	1.50	1.52	1.45	1.60
PURGA	17169.76	97338	2.07	2.34	2.64	2.68	2.72	2.71	2.71	2.70	2.23	2.31	2.27	1.89	2.56
PURGA	17498.04	97666	0.93	0.92	0.90	0.89	0.86	0.81	0.80	0.75	0.83	0.88	0.93	0.96	1.02
PURGA	17826.32	97995	1.00	1.00	1.00	0.95	0.67	0.53	0.54	0.51	0.61	0.81	0.98	1.04	1.07
PURGA	17983.50	98152	1.04	1.04	1.04	0.95	0.69	0.63	0.64	0.71	0.98	0.79	1.01	1.09	1.13
PURGA	18140.67	98309	1.46	1.45	1.44	1.41	1.37	1.35	1.34	1.30	1.30	1.35	1.43	1.45	1.48
PURGA	18385.25	98554	1.27	1.30	1.29	1.24	1.10	1.08	0.93	0.85	1.08	1.13	1.27	1.26	1.26
PURGA	18629.82	98798	1.15	1.22	1.21	1.15	1.07	1.06	0.96	0.91	0.95	1.01	1.17	1.12	1.14
PURGA	18935.86	99104	1.31	1.39	1.41	1.40	1.39	1.43	1.43	1.46	1.56	1.14	1.31	1.27	1.38

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
PURGA	19241.91	99410	1.58	1.60	1.66	1.64	1.65	1.71	1.72	1.76	1.95	1.38	1.50	1.52	1.59
PURGA	19586.24	99755	1.05	1.15	1.21	1.19	1.25	1.34	1.31	1.35	1.55	0.74	1.01	0.95	1.15
PURGA	19930.56	100099	0.90	0.94	1.01	1.05	1.06	1.17	1.17	1.15	1.51	0.67	0.78	0.71	0.92
PURGA	19950.56	100119	0.90	1.01	1.01	1.05	1.14	1.22	1.17	1.18	1.55	0.68	0.78	0.72	0.92
PURGA	20452.56	100621	0.94	1.03	1.06	1.13	1.12	1.02	1.00	1.06	1.27	0.58	0.83	0.85	0.96
PURGA	20954.56	101123	1.16	1.19	1.20	1.24	1.21	1.19	1.17	1.19	1.63	0.61	0.89	1.04	1.14
PURGA	21320.56	101489	1.40	1.42	1.38	1.37	1.36	1.36	1.26	1.33	1.56	0.46	0.96	0.97	1.31
PURGA	21686.56	101855	1.78	1.77	1.74	1.71	1.67	1.65	1.47	1.57	1.97	0.54	1.17	1.18	1.59
PURGA	22015.06	102184	1.21	1.26	1.15	1.02	0.93	0.91	0.73	0.82	1.42	0.42	0.53	0.54	0.93
PURGA	22343.56	102512	0.92	0.99	0.85	0.73	0.60	0.55	0.46	0.55	0.98	0.40	0.37	0.36	0.65
PURGA_2	0.00		1.64	1.92	1.92	1.94	1.94	1.94	1.94	1.94	2.26	1.91	1.92	1.88	1.94
PURGA_2	10.00		1.58	1.81	1.81	1.81	1.81	1.81	1.82	1.81	2.29	1.81	1.81	1.77	1.81
PURGA_2	20.00		1.53	1.73	1.72	1.74	1.74	1.74	1.75	1.74	2.31	1.74	1.74	1.71	1.74
PURGA_2	42.25		3.20	5.03	3.23	4.93	5.79	5.11	5.35	4.57	9.10	2.26	2.20	2.35	2.28
PURGA_2	1464.35		1.96	1.99	1.97	1.98	2.02	2.03	2.06	2.05	2.25	1.97	1.96	1.98	1.98
PURGA_2	2886.45		2.75	2.77	2.76	2.76	2.77	2.77	2.77	2.77	2.76	2.76	2.76	2.76	2.76
PURGA_2	2890.12		2.99	3.39	3.44	3.47	3.50	3.51	3.91	5.19	5.15	3.21	3.24	3.04	3.19
PURGA_2	3771.20		0.60	0.86	0.89	0.80	0.92	0.97	0.96	1.01	1.04	0.98	0.92	0.73	0.98
PURGA_2	4652.28		0.33	0.51	0.53	0.48	0.55	0.57	0.57	0.60	0.72	0.69	0.56	0.45	0.59
RAILBRIDGE1	0.00		0.02	0.02	0.03	0.03	0.05	1.06	0.07	0.18	0.13	2.13	0.01	0.02	0.02
RAILBRIDGE1	2.00		0.00	0.00	0.00	0.00	0.01	2.43	0.01	6.70	0.08	0.00	0.00	0.00	0.09
RAILBRIDGE1	4.00		0.00	0.00	0.00	0.00	0.00	0.90	0.01	0.20	0.08	0.06	0.00	0.00	0.00
RAILBRIDGE1	16.00		0.00	0.00	0.00	0.00	0.03	0.04	0.06	0.15	0.07	0.03	0.01	0.00	0.09
RAILBRIDGE1	18.00		0.00	0.00	0.00	0.00	0.04	0.06	0.07	0.05	0.08	0.03	0.02	0.00	0.11
RAILBRIDGE1	20.00		0.02	0.00	0.01	0.01	0.04	0.06	0.08	0.10	0.09	0.03	0.02	0.02	0.11
RAILBRIDGE2	0.00		1.10	1.40	1.58	1.74	2.37	2.52	2.78	2.84	3.30	2.37	2.17	1.25	2.20
RAILBRIDGE2	2.00		1.12	1.42	1.59	1.76	2.40	2.55	2.81	2.87	3.31	2.40	2.23	1.26	2.23
RAILBRIDGE2	4.00		1.14	1.44	1.61	1.77	2.43	2.57	2.83	2.90	3.32	2.43	2.23	1.28	2.26
RAILBRIDGE2	16.00		3.88	4.73	4.98	4.97	5.00	5.04	5.04	5.04	5.20	4.97	4.96	4.32	4.96

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILBRIDGE3	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE3	2.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE3	4.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE3	16.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE3	18.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE3	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE4	0.00		0.00	0.01	0.01	0.01	0.01	0.02	1.39	1.56	4.60	0.00	0.00	0.00	0.00
RAILBRIDGE4	2.00		0.00	0.00	0.00	0.00	0.00	0.00	1.33	1.46	3.54	0.00	0.00	0.00	0.00
RAILBRIDGE4	4.00		0.00	0.00	0.00	0.00	0.00	0.00	1.27	1.36	2.87	0.00	0.00	0.00	0.00
RAILBRIDGE4	16.00		0.00	0.00	0.00	0.00	0.00	0.00	1.32	1.43	3.30	0.00	0.00	0.00	0.00
RAILBRIDGE4	18.00		0.00	0.00	0.00	0.00	0.00	0.00	1.32	1.43	3.32	0.00	0.00	0.00	0.00
RAILBRIDGE4	20.00		0.00	0.00	0.00	0.00	0.00	0.00	1.33	1.44	3.34	0.00	0.00	0.00	0.00
RAILBRIDGE5	0.00		0.50	0.87	1.38	1.68	2.22	2.53	2.79	3.21	6.20	2.21	1.88	0.62	1.92
RAILBRIDGE5	2.00		0.50	0.87	1.38	1.69	2.23	2.54	2.80	3.22	4.93	2.22	1.88	0.62	1.93
RAILBRIDGE5	4.00		0.50	0.87	1.39	1.69	2.24	2.55	2.81	3.24	4.09	2.23	1.89	0.62	1.93
RAILBRIDGE5	16.00		0.51	0.88	1.41	1.71	2.28	2.61	2.88	3.35	6.21	2.27	1.92	0.62	1.96
RAILBRIDGE5	18.00		0.51	0.88	1.41	1.73	2.29	2.62	2.89	3.37	6.27	2.28	1.92	0.62	1.97
RAILBRIDGE5	20.00		0.51	0.88	1.42	1.73	2.30	2.63	2.90	3.38	6.34	2.29	1.94	0.62	1.98
RAILBRIDGE6	0.00		0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.04
RAILBRIDGE6	2.00		0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.04
RAILBRIDGE6	4.00		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.04
RAILBRIDGE6	16.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.82
RAILBRIDGE6	18.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.82
RAILBRIDGE6	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.83
RAILBRIDGE7	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
RAILBRIDGE7	2.00		-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	-0.01	0.00
RAILBRIDGE7	4.00		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	2.17	0.00	0.00	0.00	0.00
RAILBRIDGE7	16.00		0.00	0.00	0.07	0.07	0.12	0.07	0.07	0.07	2.28	0.07	0.07	0.00	0.00
RAILBRIDGE7	18.00		0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.37	0.49	0.24	0.24	0.24	0.24

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILBRIDGE7	20.00		0.00	0.00	0.17	0.18	0.18	0.18	0.18	0.18	0.29	0.19	0.19	0.00	0.00
RAILBRIDGE8	0.00		-0.01	0.05	0.09	0.08	0.10	0.08	0.09	0.10	0.22	0.07	0.08	-0.01	0.08
RAILBRIDGE8	2.00		-0.01	0.07	0.13	0.12	0.14	0.12	0.12	0.14	0.37	0.11	0.11	-0.01	0.12
RAILBRIDGE8	4.00		-0.06	0.13	0.22	0.21	0.25	0.21	0.22	0.25	1.59	0.18	0.19	-0.04	0.20
RAILBRIDGE8	16.00		-0.07	0.13	0.22	0.21	0.25	0.21	0.22	0.25	1.37	0.18	0.19	-0.05	0.20
RAILBRIDGE8	18.00		-0.13	0.22	0.37	0.36	0.42	0.34	0.36	0.40	0.41	0.30	0.31	-0.09	0.33
RAILBRIDGE8	20.00		-3.18	0.87	0.98	1.10	1.23	1.01	1.16	1.18	1.04	0.77	0.99	-1.75	0.94
RAILBRIDGE9	0.00		0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00
RAILBRIDGE9	2.00		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00
RAILBRIDGE9	4.00		0.03	0.03	0.03	0.23	0.07	0.21	0.40	0.47	0.28	0.03	0.08	0.09	0.26
RAILBRIDGE9	16.00		0.00	0.00	0.00	0.05	0.00	0.03	0.09	0.09	0.05	0.01	0.02	0.02	0.06
RAILBRIDGE9	18.00		0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.24	0.00	0.00	0.00	0.00
RAILBRIDGE9	20.00		0.32	0.20	0.32	0.32	0.30	0.32	0.36	0.61	0.62	0.32	0.20	0.32	0.32
RAILNORTH	868.96		0.01	0.02	0.02	0.11	0.99	1.24	1.89	2.32	2.70	0.97	0.18	0.02	0.25
RAILNORTH	949.40		0.02	0.04	0.05	0.20	1.53	1.74	2.21	2.63	2.94	1.51	0.31	0.03	0.42
RAILNORTH	1029.84		0.79	1.05	1.21	1.24	1.54	1.66	2.05	2.34	2.71	1.54	1.24	0.90	1.30
RAILNORTH	1214.90		0.09	0.09	0.09	0.21	0.51	0.62	0.87	0.99	1.51	0.51	0.25	0.09	0.29
RAILNORTH	1399.96		0.25	0.23	0.17	0.23	0.30	0.38	0.53	0.58	1.04	0.30	0.20	0.17	0.15
RAILNORTH	1453.14		0.77	1.12	1.24	1.27	1.35	1.36	1.38	1.41	1.73	1.33	1.30	0.93	1.33
RAILNORTH	1506.31		0.81	1.25	1.38	1.42	1.59	1.61	1.60	1.61	1.90	1.52	1.49	1.00	1.53
RAILNORTH	1810.80		0.77	1.10	1.15	1.17	1.29	1.32	1.39	1.40	1.53	1.28	1.25	0.95	1.27
RAILNORTH	2115.29		0.15	0.17	0.18	0.20	0.47	0.55	0.69	0.71	0.95	0.45	0.21	0.15	0.24
RAILNORTH	2354.20		0.17	0.17	0.17	0.19	0.58	0.69	0.88	0.91	1.28	0.57	0.30	0.16	0.34
RAILNORTH	2593.10		0.29	0.33	0.37	0.50	0.78	0.94	1.29	1.34	1.98	0.79	0.57	0.31	0.58
RAILNORTH	2973.38		0.31	0.35	0.40	0.46	0.70	0.79	1.04	1.08	1.53	0.68	0.52	0.33	0.55
RAILNORTH	3353.67		0.33	0.38	0.43	0.55	0.64	0.66	0.86	0.89	1.24	0.60	0.51	0.36	0.53
RAILNORTH	3574.97		0.36	0.41	0.44	0.53	0.75	0.88	1.15	1.18	1.61	0.74	0.59	0.38	0.61
RAILNORTH	3796.28		0.39	0.45	0.46	0.74	1.02	1.34	1.72	1.76	2.28	1.01	0.80	0.42	0.82
RAILNORTH	4040.72		0.40	0.48	0.51	0.97	1.27	1.29	1.29	1.29	1.44	1.28	1.14	0.44	1.19

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILNORTH	4285.17		0.41	0.41	0.43	0.43	0.57	0.76	1.01	1.03	1.37	0.56	0.43	0.41	0.43
RAILNORTH	4333.15		0.51	0.51	0.55	0.55	0.77	1.00	1.31	1.34	1.68	0.77	0.55	0.51	0.55
RAILNORTH	4381.13		0.67	0.68	0.76	1.00	1.22	1.47	1.87	1.91	2.18	1.23	1.22	0.68	1.22
RAILNORTH	4469.68		0.38	0.38	0.38	0.38	0.38	0.57	1.14	1.15	1.51	0.38	0.38	0.38	0.38
RAILNORTH	4558.22		1.19	1.19	1.20	1.20	1.26	1.39	1.65	1.73	2.34	1.25	1.20	1.19	1.21
RAILNORTH	4819.92		1.20	1.21	1.30	1.36	1.50	1.52	1.50	1.50	1.73	1.50	1.41	1.21	1.42
RAILNORTH	5081.62		1.23	1.62	1.68	1.70	1.89	1.90	1.88	1.88	1.90	1.88	1.73	1.45	1.75
RAILNORTH	6908.85		0.58	0.57	0.66	0.91	1.46	2.02	2.69	3.56	4.10	1.61	1.14	0.58	1.16
RAILNORTH	7127.67		0.34	0.36	0.44	0.52	0.64	0.81	0.95	1.11	1.32	0.69	0.57	0.31	0.57
RAILNORTH	7346.49		0.27	0.29	0.35	0.37	0.51	0.60	0.67	0.68	0.84	0.43	0.38	0.29	0.38
RAILNORTH	7689.53		0.29	0.32	0.32	0.34	0.39	0.45	0.53	0.54	0.65	0.38	0.34	0.32	0.34
RAILNORTH	8032.56		0.32	0.47	0.48	0.44	0.54	0.60	0.85	0.71	0.84	0.51	0.52	0.46	0.44
RAILNORTH	8410.92		0.26	0.39	0.39	0.41	0.44	0.47	0.50	0.52	0.70	0.45	0.43	0.38	0.43
RAILNORTH	8789.28		0.22	0.59	0.76	0.87	1.20	1.39	1.72	1.87	2.90	1.26	1.02	0.44	1.03
RAILNORTH	8909.14		0.25	0.74	1.12	1.22	1.55	1.81	2.21	2.38	3.58	1.64	1.39	0.55	1.38
RAILNORTH	9029.00		0.31	1.02	2.19	2.31	2.33	2.61	3.11	3.28	4.67	2.33	2.30	0.71	2.28
RAILNORTH	9149.17		0.30	0.52	0.73	0.77	1.05	1.18	1.33	1.42	2.07	0.95	0.79	0.42	0.77
RAILNORTH	9269.34		0.29	0.45	0.60	0.62	0.89	1.09	1.32	1.39	1.64	0.62	0.62	0.37	0.59
RAILNORTH	9520.53		0.25	0.26	0.35	0.38	0.46	0.56	0.72	0.78	1.14	0.48	0.38	0.25	0.38
RAILNORTH	9771.72		0.26	0.26	0.38	0.41	0.54	0.60	0.68	0.69	0.98	0.43	0.42	0.26	0.37
RAILNORTH	9781.72		0.26	0.27	0.42	0.45	0.69	0.83	0.97	0.97	1.16	0.50	0.46	0.26	0.41
RAILNORTH	9791.72		0.26	0.27	0.47	0.55	0.94	1.31	1.67	1.77	2.30	0.73	0.61	0.26	0.46
RAILNORTH	10084.53		0.30	0.30	0.32	0.36	0.46	0.57	0.73	0.78	1.05	0.50	0.40	0.30	0.41
RAILNORTH	10377.33		0.45	0.57	0.58	0.58	0.58	0.68	0.83	0.88	1.13	0.60	0.58	0.57	0.58
RAILNORTH	10586.71		0.23	0.30	0.33	0.39	0.50	0.57	0.66	0.67	0.91	0.51	0.42	0.21	0.43
RAILNORTH	10796.10		0.14	0.33	0.41	0.46	0.55	0.63	0.97	0.91	1.36	0.47	0.37	0.12	0.39
RAILNORTH	11087.73		0.16	0.17	0.20	0.25	0.36	0.42	0.51	0.54	0.71	0.37	0.30	0.16	0.30
RAILNORTH	11379.36		0.36	0.37	0.37	0.37	0.37	0.38	0.51	0.55	0.73	0.38	0.41	0.38	0.37
RAILNORTH	11671.45		0.25	0.29	0.32	0.30	0.42	0.50	0.62	0.66	1.00	0.45	0.33	0.25	0.35

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILNORTH	11963.54		0.30	0.63	0.72	0.66	0.84	0.86	0.81	0.88	1.14	0.61	0.59	0.38	0.64
RAILNORTH	12176.77		0.40	0.65	0.69	0.69	0.69	0.74	0.90	0.94	1.34	0.70	0.65	0.52	0.68
RAILNORTH	12390.00		0.76	1.18	1.85	1.87	1.97	2.03	2.10	2.11	2.13	1.56	1.51	0.95	1.85
RAILNORTH	12400.00		1.27	1.59	2.38	2.56	2.81	2.92	3.05	3.06	3.10	1.83	1.82	1.52	2.38
RAILNORTH	12410.00		3.74	4.17	4.81	4.95	5.35	5.58	5.86	5.87	5.93	4.17	4.15	4.20	4.58
RAILNORTH	12939.00		0.21	0.58	0.64	0.67	0.74	0.80	0.79	0.81	1.26	0.70	0.65	0.26	0.66
RAILNORTH	13468.00		0.21	0.99	0.95	1.04	1.15	1.25	1.23	1.27	1.62	0.92	0.92	0.23	0.94
RAILNORTH	13668.00		0.22	0.68	0.73	0.74	0.94	1.22	1.39	1.38	1.67	1.00	0.74	0.25	0.74
RAILNORTH	13868.00		0.10	2.39	3.41	4.49	24.42	53.80	56.23	56.64	57.32	19.80	7.00	0.21	5.09
RAILNORTH	14248.00		0.12	0.12	0.12	0.13	0.14	0.14	0.35	0.40	0.57	0.12	0.12	0.12	0.12
RAILNORTH	14628.00		0.09	0.09	0.09	0.10	0.11	0.14	0.33	0.33	0.34	0.09	0.09	0.09	0.09
RAILNORTH	14678.00		0.09	0.09	0.09	0.10	0.12	0.20	0.38	0.38	0.39	0.12	0.09	0.09	0.09
RAILNORTH	14728.00		0.09	0.09	0.09	0.10	0.18	0.34	0.98	1.01	0.95	0.18	0.09	0.09	0.09
RAILNORTH	14783.00		0.00	0.00	0.00	0.03	0.07	0.21	0.24	0.25	0.60	0.14	0.01	0.00	0.02
RAILNORTH	14838.00		0.00	0.00	0.00	0.03	0.07	0.22	0.27	0.29	0.92	0.15	0.01	0.00	0.02
RAILNORTH	14848.00		0.00	0.00	0.00	0.03	0.07	0.23	0.29	0.31	1.24	0.15	0.01	0.00	0.02
RAILNORTH	14858.00		0.00	0.00	0.00	0.02	0.07	0.24	0.31	0.35	2.09	0.15	0.01	0.00	0.02
RAILNORTH	15543.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.39	0.00	0.00	0.00	0.00
RAILNORTH	16228.00		0.05	0.11	0.11	0.15	0.19	0.26	0.28	0.31	0.50	0.14	0.09	0.07	0.09
RAILSOUTH	868.96		0.51	0.87	1.21	1.35	1.53	1.65	2.93	3.47	3.75	1.50	1.44	0.67	1.48
RAILSOUTH	949.40		0.65	1.02	1.38	1.52	1.67	1.70	1.70	1.79	1.86	1.66	1.63	0.82	1.65
RAILSOUTH	1029.84		0.91	1.24	1.62	1.75	1.87	1.87	1.86	1.86	1.92	1.87	1.86	1.07	1.87
RAILSOUTH	1214.90		1.25	1.55	1.69	1.69	1.86	1.85	1.86	1.86	2.13	1.85	1.85	1.45	1.86
RAILSOUTH	1399.96		2.03	2.45	2.46	2.44	2.47	2.46	2.46	2.47	2.46	2.46	2.46	2.28	2.45
RAILSOUTH	1453.14		0.38	0.38	0.44	0.45	0.53	0.71	1.02	1.14	1.91	0.53	0.46	0.39	0.47
RAILSOUTH	1506.31		0.81	0.91	0.92	0.94	0.95	1.15	1.16	1.27	2.04	0.90	0.92	0.88	0.91
RAILSOUTH	1810.80		0.58	0.58	0.67	0.76	0.95	1.10	1.21	1.23	1.52	0.94	0.76	0.58	0.77
RAILSOUTH	2115.29		0.65	0.65	0.65	0.79	1.28	1.62	1.69	1.70	1.98	1.28	0.79	0.65	0.81
RAILSOUTH	2354.20		1.52	1.90	1.89	1.93	2.09	2.23	2.28	2.25	2.41	2.07	1.96	1.77	1.98

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILSOUTH	2593.10		1.31	1.60	1.59	1.61	1.63	1.65	1.99	2.20	2.96	1.54	1.55	1.50	1.57
RAILSOUTH	2973.38		1.20	1.47	1.49	1.55	1.67	1.91	2.16	2.17	2.21	1.66	1.56	1.40	1.58
RAILSOUTH	3353.67		1.11	1.50	1.77	1.84	2.03	2.42	2.63	2.69	2.85	2.01	1.87	1.30	1.89
RAILSOUTH	3574.97		1.33	1.74	1.98	2.02	2.05	2.07	2.08	2.09	2.15	2.03	2.02	1.53	2.04
RAILSOUTH	3796.28		1.64	2.06	2.25	2.26	2.27	2.28	2.31	2.32	2.37	2.27	2.26	1.86	2.26
RAILSOUTH	4040.72		0.89	1.45	1.90	1.99	2.01	2.01	2.02	2.02	2.03	1.99	1.98	1.14	2.00
RAILSOUTH	4285.17		0.61	1.12	1.65	1.80	1.95	2.42	2.56	2.52	2.83	1.93	1.80	0.81	1.81
RAILSOUTH	4333.15		0.60	1.13	1.70	1.97	2.36	2.51	2.59	2.58	2.61	2.35	2.11	0.81	2.15
RAILSOUTH	4381.13		0.59	1.14	1.73	2.03	2.38	2.47	2.57	2.57	2.59	2.37	2.17	0.80	2.21
RAILSOUTH	4469.68		0.80	1.48	2.27	2.66	3.21	3.33	3.34	3.34	3.46	3.20	2.88	1.04	2.94
RAILSOUTH	4558.22		1.27	2.14	3.28	3.88	4.96	5.22	5.23	5.24	5.52	4.94	4.31	1.52	4.38
RAILSOUTH	6908.85		1.18	1.22	1.26	1.26	1.29	1.34	1.84	2.80	3.48	1.30	1.28	1.20	1.27
RAILSOUTH	7127.67		1.20	1.43	1.48	1.50	1.56	1.62	1.70	1.71	1.84	1.56	1.54	1.36	1.53
RAILSOUTH	7346.49		1.22	1.72	1.81	1.84	1.96	2.06	2.19	2.19	2.28	1.98	1.94	1.56	1.93
RAILSOUTH	7689.53		1.33	1.59	1.65	1.77	1.87	1.95	2.15	2.19	2.35	1.87	1.78	1.77	1.76
RAILSOUTH	8032.56		1.68	1.89	1.95	2.06	2.24	2.31	2.45	2.47	2.58	2.13	2.13	2.09	1.97
RAILSOUTH	8178.28		0.47	0.68	0.76	0.87	1.03	1.09	1.29	1.31	1.42	1.00	1.00	0.95	0.84
RAILSOUTH	8324.00		0.28	0.42	0.47	0.53	0.62	0.66	0.82	0.83	0.90	0.65	0.65	0.61	0.53
RAILSOUTH	8556.64		1.20	1.37	1.37	1.38	1.39	1.43	1.43	1.44	1.52	1.32	1.36	1.31	1.36
RAILSOUTH	8789.28		1.33	1.61	1.62	1.63	1.62	1.63	1.60	1.61	1.67	1.57	1.61	1.46	1.61
RAILSOUTH	8909.14		1.49	1.78	1.79	1.78	1.78	1.76	1.73	1.73	1.80	1.73	1.78	1.61	1.76
RAILSOUTH	9029.00		1.68	2.03	2.02	2.02	2.01	1.97	1.93	1.93	2.00	1.99	2.01	1.79	1.99
RAILSOUTH	9149.17		1.72	2.00	2.03	2.05	2.08	2.10	2.11	2.11	2.16	2.00	1.99	1.85	2.00
RAILSOUTH	9269.34		1.76	1.97	2.02	2.03	2.06	2.08	2.09	2.10	2.15	2.03	2.03	1.89	2.03
RAILSOUTH	9520.53		1.67	1.92	1.95	2.00	2.03	2.05	2.07	2.07	2.13	1.96	1.95	1.79	1.95
RAILSOUTH	9771.72		1.70	2.05	2.00	2.06	2.12	2.13	2.13	2.08	2.48	2.02	2.04	1.75	2.05
RAILSOUTH	9791.72		1.72	2.08	2.06	2.08	2.15	2.17	2.16	2.14	2.53	2.05	2.06	1.77	2.08
RAILSOUTH	10084.53		1.28	1.54	1.65	1.65	1.66	1.68	1.68	1.70	2.20	1.65	1.65	1.36	1.66
RAILSOUTH	10377.33		1.06	1.31	1.55	1.59	1.65	1.68	1.70	1.71	1.95	1.61	1.54	1.12	1.59

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILSOUTH	10586.71		1.24	1.41	1.45	1.46	1.50	1.54	1.55	1.56	1.86	1.45	1.44	1.32	1.46
RAILSOUTH	10796.10		1.49	1.68	1.67	1.74	1.78	1.82	1.83	1.84	1.94	1.66	1.64	1.59	1.66
RAILSOUTH	11087.73		1.35	1.60	1.60	1.64	1.67	1.70	1.71	1.72	1.87	1.58	1.57	1.50	1.59
RAILSOUTH	11379.36		1.23	1.53	1.53	1.56	1.57	1.58	1.59	1.60	1.85	1.51	1.51	1.42	1.53
RAILSOUTH	11671.45		1.35	1.71	1.71	1.73	1.73	1.73	1.73	1.73	2.12	1.70	1.69	1.61	1.71
RAILSOUTH	11963.54		1.50	2.56	3.13	3.44	3.41	3.38	3.45	3.45	3.47	3.39	3.12	1.84	3.41
RAILSOUTH	12063.54		1.59	1.65	1.64	1.70	1.74	1.79	1.81	1.81	2.45	1.61	1.61	1.62	1.64
RAILSOUTH	12163.54		1.70	1.76	1.74	1.81	1.89	1.94	1.98	1.99	2.19	1.71	1.71	1.72	1.75
RAILSOUTH	12276.77		1.45	1.48	1.49	1.56	1.66	1.78	1.80	1.83	1.95	1.44	1.45	1.44	1.45
RAILSOUTH	12390.00		1.36	1.31	1.33	1.79	1.79	1.79	2.00	2.60	2.20	1.86	1.30	1.72	1.79
RAILSOUTH	12410.00		1.37	1.30	1.34	1.83	1.85	1.86	2.03	2.62	2.26	1.91	1.32	1.76	1.83
RAILSOUTH	12939.00		1.30	1.42	1.42	1.43	1.48	1.55	1.54	1.58	1.63	1.42	1.42	1.38	1.42
RAILSOUTH	13468.00		1.38	1.69	1.69	1.69	1.69	1.72	1.72	1.72	1.73	1.69	1.69	1.60	1.69
RAILSOUTH	13668.00		1.55	1.59	1.59	1.63	1.71	1.74	1.76	1.77	2.34	1.55	1.56	1.57	1.58
RAILSOUTH	13868.00		1.91	1.94	1.95	1.98	2.10	2.14	2.16	2.19	3.72	1.91	1.92	1.93	1.94
RAILSOUTH	14248.00		1.66	1.67	1.68	1.67	1.71	1.75	1.73	1.73	1.71	1.60	1.65	1.67	1.69
RAILSOUTH	14628.00		1.50	1.76	1.72	1.75	1.95	1.97	1.95	1.94	1.62	1.76	1.73	1.55	1.82
RAILSOUTH	14678.00		1.57	1.84	1.79	1.83	2.02	2.04	2.01	2.00	1.65	1.81	1.80	1.61	1.90
RAILSOUTH	14728.00		1.64	1.93	1.88	1.92	2.15	2.19	2.19	2.14	1.76	1.90	1.89	1.67	2.00
RAILSOUTH	14783.00		1.77	2.07	2.00	2.05	2.25	2.29	2.29	2.23	1.81	1.97	2.01	1.79	2.14
RAILSOUTH	14838.00		1.93	2.29	2.17	2.20	2.38	2.54	2.58	2.55	2.13	2.19	2.14	1.93	2.30
RAILSOUTH	14858.00		2.01	2.43	2.31	2.26	2.41	2.58	2.62	2.58	2.15	2.22	2.28	1.99	2.34
RAILSOUTH	15543.00		0.56	0.51	0.51	0.50	0.47	0.40	0.43	0.42	0.31	0.30	0.45	0.69	0.69
RAILSOUTH	16228.00		0.28	0.27	0.28	0.31	0.36	0.40	0.42	0.44	0.59	0.27	0.27	0.39	0.42
RAILWEIR1	0.00		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00
RAILWEIR1	2.50		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00
RAILWEIR1	5.00		0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
RAILWEIR1	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
RAILWEIR1	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILWEIR1	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
RAILWEIR2	0.00		0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.00	0.01	0.00	0.00
RAILWEIR2	2.50		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.00	0.00
RAILWEIR2	5.00		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00
RAILWEIR2	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR2	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR2	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR3	0.00		0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.12	0.00	0.00	0.00	0.00
RAILWEIR3	2.50		0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.12	0.00	0.00	0.00	0.00
RAILWEIR3	5.00		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.12	0.00	0.00	0.00	0.00
RAILWEIR3	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00
RAILWEIR3	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00
RAILWEIR3	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00
RAILWEIR4	0.00		0.00	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.13	0.04	0.03	0.00	0.04
RAILWEIR4	2.50		0.00	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.13	0.04	0.03	0.00	0.04
RAILWEIR4	5.00		0.00	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.13	0.04	0.03	0.00	0.04
RAILWEIR4	15.00		0.00	0.15	0.17	0.19	0.35	0.40	0.53	0.58	1.09	0.10	0.12	0.00	0.17
RAILWEIR4	17.50		0.00	0.21	0.17	0.30	0.35	0.40	0.54	0.63	0.67	0.10	0.12	0.00	0.22
RAILWEIR4	20.00		0.00	0.35	0.17	0.63	0.35	0.41	0.72	0.90	1.20	0.10	0.12	0.00	0.30
RAILWEIR5	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR5	2.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR5	4.00		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
RAILWEIR5	16.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR5	18.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR5	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RAILWEIR6	0.00		0.00	0.00	0.00	0.00	0.01	0.04	0.06	0.07	0.11	0.03	0.00	0.00	0.00
RAILWEIR6	2.00		0.00	0.00	0.00	0.00	0.01	0.07	0.10	0.11	0.15	0.05	0.00	0.00	0.00
RAILWEIR6	4.00		-0.09	-0.10	-0.10	-0.01	0.04	0.26	0.36	0.42	0.45	0.17	0.00	-0.09	0.00
RAILWEIR6	16.00		-0.03	-0.03	-0.03	-0.02	0.03	0.26	0.36	0.41	0.45	0.17	-0.03	-0.02	-0.01

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
RAILWEIR6	18.00		-0.02	-0.02	-0.02	-0.02	0.05	0.30	0.42	0.48	0.52	0.20	-0.02	-0.02	-0.02
RAILWEIR6	20.00		-0.02	-0.02	-0.02	-0.02	0.09	0.36	0.52	0.58	0.72	0.25	-0.02	-0.02	-0.02
WARPURWEIR1	0.00		0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.66	0.00	0.00	0.00	0.00
WARPURWEIR1	2.50		0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.66	0.00	0.00	0.00	0.00
WARPURWEIR1	5.00		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.66	0.00	0.00	0.00	0.00
WARPURWEIR1	10.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	0.00	0.00
WARPURWEIR1	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00
WARPURWEIR1	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00
WARPURWEIR1	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00
WARPURWEIR2	0.00		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
WARPURWEIR2	2.50		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
WARPURWEIR2	5.00		0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
WARPURWEIR2	10.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WARPURWEIR2	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WARPURWEIR2	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WARPURWEIR2	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WARPURWEIR3	0.00		0.00	0.00	0.00	0.01	0.01	0.03	0.15	0.18	1.00	0.10	0.00	0.00	0.00
WARPURWEIR3	2.50		0.00	0.00	0.00	0.01	0.01	0.03	0.15	0.18	1.00	0.10	0.00	0.00	0.00
WARPURWEIR3	5.00		0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.18	1.00	0.10	0.00	0.00	0.00
WARPURWEIR3	10.00		0.00	0.00	0.00	0.00	0.97	1.63	3.00	3.18	3.85	2.64	0.00	0.00	0.00
WARPURWEIR3	15.00		0.00	0.00	0.00	0.00	0.01	0.04	0.21	0.25	0.36	0.12	0.00	0.00	0.00
WARPURWEIR3	17.50		0.00	0.00	0.00	0.00	0.01	0.04	0.21	0.24	0.55	0.11	0.00	0.00	0.00
WARPURWEIR3	20.00		0.00	0.00	0.00	0.00	0.01	0.04	0.21	0.23	2.03	0.11	0.00	0.00	0.00
WARRILL	0.00	74280	1.31	1.33	1.32	1.36	1.32	1.27	1.32	1.35	1.97	1.31	1.32	1.30	1.32
WARRILL	516.72	74796	0.99	0.99	1.00	1.01	1.06	1.10	1.35	1.41	1.72	1.09	0.99	0.99	1.00
WARRILL	1033.45	75313	1.23	1.22	1.34	1.32	1.39	1.43	1.70	1.79	2.05	1.06	1.10	1.06	1.09
WARRILL	1728.77	76008	1.09	1.09	1.13	1.10	1.12	1.12	1.16	1.18	1.56	1.07	1.06	1.07	1.07
WARRILL	2424.10	76704	1.50	1.49	1.55	1.48	1.61	1.64	1.44	1.63	1.80	1.48	1.55	1.50	1.62
WARRILL	2444.10	76724	1.52	1.51	1.56	1.51	1.65	1.68	1.59	1.66	1.82	1.51	1.57	1.53	1.67

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	2966.30	77246	0.95	1.00	1.00	1.00	1.07	1.18	1.26	1.25	1.67	0.97	1.00	1.00	1.01
WARRILL	3488.49	77768	0.85	0.95	0.95	0.94	1.10	1.01	1.09	1.12	2.08	1.00	0.96	0.96	0.96
WARRILL	3498.49	77778	0.85	0.96	0.96	0.95	1.07	1.01	1.26	1.32	2.09	1.08	0.97	0.96	0.97
WARRILL	3590.99	77871	0.82	0.91	0.91	0.90	1.05	1.11	1.40	1.47	1.96	1.20	0.91	0.91	0.92
WARRILL	3683.49	77963	0.78	0.94	1.08	1.21	1.41	1.53	1.73	1.73	2.16	1.36	1.11	1.03	1.11
WARRILL	4231.19	78511	0.62	0.65	0.67	0.65	0.70	0.76	0.85	0.92	1.10	0.79	0.62	0.63	0.69
WARRILL	4778.90	79059	0.96	0.95	0.98	0.97	0.97	0.98	0.98	0.99	0.99	0.82	0.94	0.98	0.99
WARRILL	4798.90	79079	0.98	0.99	0.99	0.99	0.99	0.99	0.99	1.01	1.01	0.83	0.96	0.99	1.00
WARRILL	5597.98	79878	1.22	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.22	1.22	1.23	1.22
WARRILL	6397.07	80677	1.69	1.68	1.76	2.05	1.74	1.88	1.89	1.90	1.96	1.73	1.64	1.78	1.66
WARRILL	6407.07	80687	1.83	1.78	1.92	2.18	1.89	2.00	2.09	2.07	2.15	1.89	1.78	1.84	1.78
WARRILL	6759.17	81039	1.06	1.16	1.31	1.46	1.52	1.53	1.62	1.67	1.88	1.52	1.30	1.27	1.35
WARRILL	7111.27	81391	0.79	0.88	1.06	1.32	1.70	1.80	2.11	2.11	2.28	2.04	1.05	1.71	1.09
WARRILL	7131.27	81411	0.79	0.88	1.06	1.33	1.73	1.89	2.34	2.36	2.79	2.14	1.06	1.72	1.10
WARRILL	7822.70	82102	0.76	0.81	0.89	0.95	0.99	1.08	1.33	1.38	2.19	1.16	0.86	0.85	0.87
WARRILL	8514.13	82794	0.75	0.82	0.81	0.90	0.96	1.07	1.18	1.21	1.81	0.80	0.77	0.76	0.77
WARRILL	9205.55	83485	0.82	0.85	0.87	0.89	0.92	1.01	1.07	1.11	1.81	0.85	0.85	0.84	0.85
WARRILL	9896.98	84177	1.00	1.01	1.03	1.05	1.09	1.15	1.29	1.30	1.82	1.00	1.00	1.01	1.02
WARRILL	10419.36	84699	1.21	1.22	1.23	1.27	1.27	1.27	1.32	1.33	1.76	1.27	1.23	1.23	1.23
WARRILL	10941.75	85221	1.77	1.77	1.78	1.82	1.86	1.91	1.93	1.94	2.01	1.84	1.75	1.76	1.75
WARRILL	11260.87	85541	1.22	1.43	1.58	1.60	1.62	1.61	1.63	1.63	2.06	1.62	1.58	1.57	1.60
WARRILL	11579.99	85860	1.01	1.27	1.45	1.47	1.49	1.49	1.48	1.48	2.60	1.49	1.45	1.43	1.47
WARRILL	11599.99	85880	1.44	1.49	1.55	1.57	1.59	1.63	1.88	2.00	2.84	1.64	1.54	1.54	1.56
WARRILL	11956.24	86236	1.15	1.19	1.21	1.23	1.28	1.33	1.45	1.46	1.80	1.17	1.16	1.17	1.19
WARRILL	12312.49	86592	0.95	1.01	1.02	1.03	1.07	1.14	1.25	1.26	1.31	0.99	0.98	0.98	1.01
WARRILL	12625.38	86905	0.89	0.95	0.96	0.96	1.00	1.05	1.14	1.14	1.32	0.92	0.92	0.92	0.95
WARRILL	12938.26	87218	0.84	0.89	0.90	0.90	0.93	0.97	1.04	1.04	1.32	0.87	0.87	0.86	0.89
WARRILL	13199.09	87479	0.92	0.94	0.94	0.94	0.95	0.97	1.02	1.02	1.51	0.91	0.93	0.93	0.93
WARRILL	13459.92	87740	1.57	1.56	1.58	1.56	1.54	1.54	1.54	1.54	1.77	1.56	1.55	1.55	1.55

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	13588.18	87868	1.70	1.67	1.71	1.65	1.62	1.62	1.62	1.62	2.00	1.67	1.67	1.65	1.65
WARRILL	13716.44	87996	1.98	1.96	1.95	1.90	1.90	1.90	1.90	1.90	2.30	1.91	1.96	1.97	1.97
WARRILL	13933.74	88213	1.46	1.45	1.44	1.43	1.41	1.36	1.47	1.49	2.14	1.41	1.45	1.46	1.46
WARRILL	14151.04	88431	1.35	1.36	1.37	1.35	1.29	1.25	1.44	1.47	2.00	1.32	1.38	1.39	1.38
WARRILL	14685.00	88965	1.38	1.36	1.36	1.30	1.23	1.23	1.22	1.22	1.65	1.28	1.39	1.40	1.37
WARRILL	15218.95	89499	1.43	1.36	1.37	1.29	1.29	1.29	1.29	1.28	1.41	1.33	1.43	1.42	1.39
WARRILL	15464.29	89744	1.39	1.31	1.33	1.26	1.26	1.26	1.26	1.26	1.43	1.24	1.34	1.32	1.33
WARRILL	15709.63	89989	1.35	1.37	1.36	1.40	1.44	1.45	1.42	1.42	1.47	1.45	1.34	1.31	1.36
WARRILL	16008.97	90289	1.04	1.01	1.05	0.97	0.97	0.97	0.97	0.97	1.16	0.96	0.99	1.00	1.03
WARRILL	16308.32	90588	0.98	1.00	0.98	0.98	0.98	0.98	0.98	0.98	1.04	0.94	0.98	0.98	1.00
WARRILL	16755.14	91035	1.10	1.10	1.12	1.16	1.27	1.37	1.40	1.41	1.57	1.10	1.08	1.10	1.10
WARRILL	17201.96	91482	1.24	1.25	1.29	1.43	1.75	1.81	1.83	1.83	2.41	1.82	1.26	1.25	1.26
WARRILL	17710.47	91990	1.27	1.28	1.31	1.35	1.45	1.54	1.59	1.62	1.86	1.38	1.26	1.27	1.28
WARRILL	18218.98	92499	1.30	1.31	1.36	1.40	1.49	1.57	1.63	1.65	1.78	1.32	1.29	1.30	1.33
WARRILL	18471.75	92751	1.31	1.32	1.35	1.40	1.54	1.62	1.68	1.71	1.77	1.32	1.30	1.31	1.32
WARRILL	18724.52	93004	1.32	1.34	1.35	1.43	1.60	1.69	1.76	1.78	1.86	1.33	1.31	1.31	1.32
WARRILL	18939.93	93220	1.17	1.19	1.20	1.25	1.40	1.51	1.57	1.58	1.68	1.19	1.17	1.17	1.17
WARRILL	19155.35	93435	1.05	1.06	1.07	1.11	1.21	1.31	1.36	1.38	1.50	1.06	1.05	1.05	1.05
WARRILL	19446.27	93726	1.20	1.20	1.22	1.23	1.30	1.38	1.44	1.45	1.58	1.20	1.20	1.20	1.21
WARRILL	19737.18	94017	1.53	1.57	1.62	1.62	1.66	1.70	1.74	1.76	1.79	1.58	1.56	1.57	1.59
WARRILL	19953.37	94233	1.50	1.54	1.59	1.60	1.64	1.68	1.71	1.72	1.86	1.52	1.52	1.53	1.54
WARRILL	20169.55	94449	1.48	1.52	1.57	1.57	1.64	1.68	1.72	1.73	1.95	1.49	1.50	1.51	1.52
WARRILL	20436.06	94716	1.23	1.27	1.32	1.33	1.40	1.48	1.53	1.55	2.04	1.26	1.25	1.26	1.27
WARRILL	20702.56	94982	1.05	1.15	1.21	1.44	1.55	1.58	1.66	1.70	2.14	1.56	1.27	1.18	1.26
WARRILL	20836.16	95116	1.04	1.10	1.14	1.17	1.32	1.45	1.50	1.52	1.69	1.17	1.16	1.13	1.17
WARRILL	20969.75	95249	1.04	1.10	1.16	1.18	1.39	1.47	1.65	1.70	1.74	1.18	1.17	1.15	1.19
WARRILL	21408.97	95689	1.16	1.20	1.23	1.24	1.29	1.31	1.34	1.35	1.87	1.23	1.25	1.22	1.27
WARRILL	21848.19	96128	1.33	1.35	1.46	1.84	2.17	2.32	2.42	2.44	2.83	2.38	1.62	1.38	1.61
WARRILL	22522.48	96802	1.23	1.23	1.22	1.17	1.14	1.14	1.17	1.19	1.70	1.24	1.22	1.20	1.25

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	23196.78	97476	1.15	1.24	1.23	1.21	1.18	1.19	1.23	1.23	1.23	1.25	1.24	1.20	1.24
WARRILL	23449.07	97729	0.81	0.92	0.93	0.96	1.02	1.08	1.14	1.16	1.36	0.93	0.91	0.92	0.93
WARRILL	23701.37	97981	0.62	0.75	0.82	0.82	0.82	0.82	0.87	0.87	1.53	0.84	0.81	0.82	0.83
WARRILL	23914.04	98194	0.65	0.79	0.87	0.86	0.85	0.85	0.86	0.86	0.87	0.88	0.86	0.87	0.87
WARRILL	24126.72	98406	0.68	0.83	0.93	0.93	0.91	0.90	0.92	0.91	0.85	0.92	0.93	0.92	0.93
WARRILL	24353.37	98633	0.76	0.96	1.10	1.16	1.15	1.11	1.13	1.13	0.95	1.13	1.15	1.09	1.13
WARRILL	24580.02	98860	0.90	1.13	1.39	1.70	1.83	1.92	1.99	1.97	1.76	1.85	1.51	1.34	1.48
WARRILL	24814.29	99094	0.93	0.94	0.90	0.89	0.89	0.89	0.89	0.89	0.88	0.98	0.91	0.93	0.91
WARRILL	25048.56	99328	1.04	1.05	1.01	0.99	0.99	0.99	0.99	0.99	0.97	1.10	1.02	1.04	1.03
WARRILL	25379.46	99659	0.89	0.92	0.91	0.88	0.87	0.87	0.87	0.86	0.96	0.97	0.90	0.91	0.91
WARRILL	25710.35	99990	0.92	1.11	1.43	1.74	2.08	2.10	2.06	2.03	2.41	2.19	1.55	1.35	1.51
WARRILL	25730.35	100010	0.95	1.14	1.43	1.79	2.16	2.26	2.30	2.29	2.44	2.20	1.55	1.36	1.52
WARRILL	25974.85	100255	0.94	1.08	1.30	1.50	1.55	1.59	1.74	1.76	2.25	1.67	1.41	1.25	1.41
WARRILL	26219.35	100499	0.92	1.02	1.19	1.28	1.32	1.35	1.43	1.45	2.06	1.33	1.26	1.15	1.27
WARRILL	26456.35	100736	0.90	1.05	1.23	1.31	1.35	1.38	1.44	1.46	1.87	1.33	1.28	1.19	1.30
WARRILL	26693.35	100973	0.89	1.08	1.27	1.35	1.39	1.43	1.50	1.52	1.71	1.38	1.31	1.22	1.33
WARRILL	27004.35	101284	0.97	1.10	1.31	1.39	1.43	1.48	1.57	1.58	1.70	1.43	1.35	1.25	1.36
WARRILL	27315.35	101595	1.10	1.13	1.34	1.43	1.48	1.55	1.68	1.71	1.82	1.49	1.39	1.29	1.40
WARRILL	27594.35	101874	1.04	1.07	1.17	1.22	1.25	1.34	1.41	1.43	1.56	1.28	1.18	1.14	1.20
WARRILL	27873.35	102153	0.99	1.01	1.04	1.10	1.15	1.25	1.27	1.30	1.43	1.12	1.03	1.02	1.05
WARRILL	28180.35	102460	0.95	1.04	1.19	1.21	1.24	1.29	1.38	1.40	1.50	1.27	1.18	1.16	1.19
WARRILL	28487.35	102767	0.98	1.15	1.39	1.41	1.44	1.50	1.60	1.62	1.73	1.48	1.38	1.36	1.38
WARRILL	28869.85	103150	1.02	1.13	1.28	1.30	1.32	1.40	1.47	1.50	1.62	1.36	1.26	1.27	1.25
WARRILL	29252.35	103532	1.07	1.11	1.19	1.20	1.22	1.29	1.37	1.40	1.51	1.27	1.16	1.19	1.15
WARRILL	29550.85	103831	1.20	1.22	1.21	1.22	1.28	1.39	1.47	1.49	1.58	1.28	1.21	1.24	1.20
WARRILL	29849.35	104129	1.45	1.68	1.68	1.69	1.87	1.92	1.91	1.92	2.02	1.72	1.68	1.72	1.68
WARRILL	30006.85	104287	1.36	1.46	1.45	1.46	1.59	1.74	1.75	1.77	1.84	1.52	1.44	1.49	1.43
WARRILL	30164.35	104444	1.37	1.58	1.74	1.79	1.92	1.92	2.10	2.12	2.11	1.87	1.69	1.75	1.64
WARRILL	30525.35	104805	0.95	1.19	1.34	1.39	1.49	1.51	1.59	1.60	1.60	1.46	1.30	1.36	1.26

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL	30886.35	105166	0.73	0.96	1.10	1.14	1.22	1.25	1.27	1.27	1.26	1.19	1.06	1.11	1.02
WARRILL	31029.85	105310	0.83	1.03	1.12	1.23	1.27	1.34	1.46	1.50	1.64	1.18	1.13	1.08	1.13
WARRILL	31173.35	105453	0.76	0.95	1.04	1.15	1.18	1.23	1.37	1.40	1.65	1.09	1.05	0.99	1.05
WARRILL	31349.85	105630	0.81	0.98	1.05	1.08	1.17	1.22	1.31	1.35	1.63	1.04	0.97	1.02	0.95
WARRILL	31526.35	105806	0.86	1.01	1.09	1.11	1.19	1.23	1.33	1.36	1.61	1.03	1.00	1.05	0.98
WARRILL	31774.85	106055	0.82	0.97	1.05	1.06	1.12	1.14	1.24	1.27	1.70	1.01	0.97	1.02	0.94
WARRILL	32023.35	106303	0.77	0.94	1.03	1.03	1.09	1.15	1.27	1.34	1.80	1.10	0.98	1.00	0.92
WARRILL	32153.85	106434	0.91	1.07	1.17	1.17	1.24	1.31	1.45	1.51	1.91	1.23	1.11	1.14	1.04
WARRILL	32284.35	106564	1.12	1.26	1.35	1.37	1.44	1.53	1.71	1.75	2.03	1.40	1.28	1.33	1.22
WARRILL	32459.35	106739	1.11	1.24	1.35	1.35	1.41	1.40	1.61	1.65	1.99	1.31	1.27	1.33	1.20
WARRILL	32634.35	106914	1.10	1.22	1.34	1.36	1.42	1.41	1.63	1.67	1.96	1.31	1.27	1.32	1.18
WARRILL	32942.35	107222	1.10	1.12	1.13	1.04	0.97	0.85	0.97	0.98	1.47	0.85	0.90	1.01	1.07
WARRILL	33250.35	107530	1.24	1.27	1.24	1.14	1.05	0.95	0.96	0.94	1.26	0.92	0.99	1.12	1.19
WARRILL	33555.35	107835	1.11	1.16	1.02	0.91	0.71	0.71	0.68	0.72	1.55	0.69	0.77	0.89	0.99
WARRILL	33860.35	108140	1.07	1.12	0.85	0.84	0.89	0.93	0.99	1.08	2.01	0.92	0.81	0.86	0.82
WARRILL-BOONAH	0.00	43465	0.41	0.41	0.41	0.41	0.41	0.30	0.32	0.31	0.30	0.41	0.41	0.41	0.41
WARRILL-BOONAH	881.95	44347	0.94	1.29	1.55	1.66	1.94	2.15	2.15	2.28	3.33	2.09	1.40	1.44	1.64
WARRILL-BOONAH	1763.90	45229	0.42	0.57	0.80	0.88	1.25	1.34	1.50	1.49	1.52	1.29	0.67	0.70	0.86
WARRILL-BOONAH	2267.55	45732	1.25	1.50	1.56	1.59	1.61	1.72	1.86	1.98	2.26	1.59	1.53	1.54	1.58
WARRILL-BOONAH	2771.21	46236	0.69	0.72	0.74	0.74	0.75	0.76	0.77	0.77	0.77	0.72	0.72	0.73	0.72
WARRILL-BOONAH	3078.10	46543	1.38	1.60	1.59	1.61	1.61	1.65	1.79	1.81	1.86	1.59	1.59	1.60	1.59
WARRILL-BOONAH	3385.00	46850	0.32	0.32	0.32	0.39	0.41	0.43	0.45	0.52	0.53	0.32	0.33	0.34	0.35
WARRILL-BOONAH	3400.00	46865	1.37	1.83	2.02	2.12	2.37	2.78	2.63	2.72	2.88	2.12	1.89	1.89	2.12

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	3950.52	47415	1.68	2.19	2.56	2.70	2.70	2.71	2.71	2.71	2.90	2.69	2.35	2.41	2.69
WARRILL-BOONAH	4501.05	47966	1.35	1.60	1.87	2.08	2.47	2.61	2.66	2.66	2.67	2.40	1.72	1.76	2.04
WARRILL-BOONAH	5122.33	48587	1.26	1.77	2.17	2.41	2.72	2.85	2.99	3.03	3.20	2.80	1.95	2.01	2.35
WARRILL-BOONAH	5743.62	49208	0.37	0.50	0.62	0.71	1.06	1.29	1.46	1.47	1.49	1.07	0.55	0.56	0.69
WARRILL-BOONAH	6096.17	49561	0.99	1.40	1.77	1.98	2.29	2.68	2.82	2.82	2.89	2.56	1.56	1.62	1.93
WARRILL-BOONAH	6448.72	49914	0.69	0.89	1.13	1.30	1.68	1.89	2.30	2.34	2.44	1.70	1.00	1.03	1.27
WARRILL-BOONAH	6871.93	50337	0.91	1.28	1.54	1.72	1.96	2.23	2.67	2.73	2.92	2.14	1.39	1.43	1.68
WARRILL-BOONAH	7295.14	50760	0.41	0.59	0.69	0.77	1.01	1.15	1.36	1.39	1.48	1.02	0.63	0.64	0.75
WARRILL-BOONAH	7759.10	51224	0.98	1.40	1.66	1.82	2.08	2.35	2.84	2.90	2.95	2.26	1.51	1.55	1.78
WARRILL-BOONAH	8223.07	51688	0.84	1.10	1.29	1.43	1.90	2.16	2.57	2.71	3.11	1.88	1.17	1.20	1.40
WARRILL-BOONAH	8660.16	52125	1.50	2.01	2.36	2.56	2.82	3.13	3.35	3.36	3.55	3.01	2.16	2.21	2.52
WARRILL-BOONAH	9097.24	52562	1.01	1.32	1.48	1.63	1.92	2.08	2.17	2.17	2.18	1.91	1.38	1.40	1.62
WARRILL-BOONAH	9855.94	53321	1.28	1.76	2.14	2.37	2.71	3.09	3.14	3.14	3.21	3.01	1.93	1.98	2.31
WARRILL-BOONAH	10614.64	54079	0.63	0.85	1.10	1.28	1.80	2.12	3.19	3.26	3.25	1.78	0.96	0.99	1.24
WARRILL-BOONAH	11335.75	54801	1.28	1.60	1.77	1.85	1.94	2.10	2.37	2.41	2.86	1.96	1.67	1.70	1.84
WARRILL-BOONAH	12056.87	55522	0.83	1.07	1.10	1.11	1.12	1.13	1.14	1.14	1.29	1.05	1.07	1.09	1.06
WARRILL-BOONAH	12618.46	56083	1.46	1.73	1.77	1.78	1.79	1.90	1.95	2.03	2.13	1.86	1.75	1.75	1.78

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	13180.04	56645	0.87	1.14	1.28	1.46	1.80	2.25	2.91	3.04	3.65	1.87	1.17	1.20	1.41
WARRILL-BOONAH	13821.96	57287	1.13	1.57	1.87	2.06	2.32	2.39	2.72	2.80	2.87	2.39	1.70	1.75	2.01
WARRILL-BOONAH	14463.88	57929	0.42	0.59	0.64	0.76	1.09	1.32	1.39	1.40	1.41	0.98	0.60	0.61	0.71
WARRILL-BOONAH	14671.40	58136	1.19	1.66	1.96	2.16	2.43	2.46	2.73	2.88	3.05	2.47	1.79	1.84	2.11
WARRILL-BOONAH	14878.92	58344	1.26	1.61	1.87	2.06	2.38	2.59	3.68	3.68	3.76	2.36	1.72	1.76	2.01
WARRILL-BOONAH	15431.91	58897	1.61	2.07	2.37	2.54	2.91	3.34	3.42	3.43	3.45	3.20	2.23	2.25	2.48
WARRILL-BOONAH	15984.89	59450	0.51	0.71	0.78	0.83	1.15	1.55	2.11	2.62	2.67	0.91	0.76	0.74	0.68
WARRILL-BOONAH	15994.89	59460	1.65	2.08	2.49	2.46	2.94	3.56	5.81	5.74	6.06	3.38	2.22	2.30	2.38
WARRILL-BOONAH	16606.35	60071	1.34	1.84	2.22	2.20	2.28	2.24	2.81	3.09	3.08	2.20	2.07	2.12	2.21
WARRILL-BOONAH	17217.81	60683	0.73	0.98	1.24	1.24	1.23	1.12	1.45	1.48	1.53	0.99	1.08	1.12	1.28
WARRILL-BOONAH	17763.03	61228	1.00	1.28	1.19	1.24	1.20	1.23	0.77	0.76	0.96	1.11	1.13	1.13	1.24
WARRILL-BOONAH	18308.24	61773	0.43	0.45	0.49	0.47	0.37	0.33	0.38	0.37	0.60	0.38	0.42	0.36	0.44
WARRILL-BOONAH	18604.66	62069	0.82	0.90	0.86	0.91	0.80	0.67	0.60	0.60	0.87	0.73	0.73	0.73	0.99
WARRILL-BOONAH	18901.08	62366	1.02	1.15	1.20	1.22	1.22	1.23	1.24	1.24	1.25	1.19	1.19	1.19	1.21
WARRILL-BOONAH	19171.36	62636	2.07	2.64	2.70	2.74	2.73	2.72	2.72	2.73	2.73	2.71	2.74	2.74	2.74
WARRILL-BOONAH	19441.64	62906	2.30	3.34	3.52	3.59	3.58	3.61	3.63	3.64	3.69	3.33	3.23	3.46	3.41
WARRILL-BOONAH	19461.64	62926	2.54	3.68	4.03	4.11	4.26	4.31	4.33	4.34	4.35	4.05	3.98	4.19	4.09

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	20226.62	63691	1.67	1.70	1.70	1.74	1.86	1.96	2.08	2.05	2.23	1.68	1.68	1.67	1.69
WARRILL-BOONAH	20991.60	64456	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.92	1.92	1.93	1.92
WARRILL-BOONAH	21731.54	65196	1.55	1.63	1.59	1.67	1.74	1.75	1.78	1.78	1.94	1.57	1.53	1.54	1.55
WARRILL-BOONAH	22471.48	65936	1.68	2.35	2.66	2.67	2.64	2.63	2.64	2.64	2.59	2.54	2.37	2.60	2.60
WARRILL-BOONAH	22767.29	66232	1.97	2.76	3.08	3.08	3.05	3.03	3.07	3.07	3.22	3.07	3.00	3.07	3.07
WARRILL-BOONAH	23063.09	66528	2.13	3.10	3.62	3.95	3.88	3.82	3.92	3.86	3.87	3.91	3.23	3.50	3.79
WARRILL-BOONAH	23556.68	67021	1.02	1.39	1.29	1.49	1.73	1.87	1.98	2.06	2.35	1.20	1.06	0.98	1.02
WARRILL-BOONAH	24050.26	67515	0.86	0.95	0.86	0.85	0.86	0.86	0.88	0.92	1.21	0.85	0.86	0.87	0.89
WARRILL-BOONAH	24590.68	68055	0.97	1.00	0.98	0.97	0.98	0.98	0.97	0.98	1.34	0.94	0.97	0.97	1.04
WARRILL-BOONAH	25131.10	68596	1.10	1.31	1.10	1.10	1.10	1.10	1.10	1.10	1.41	1.07	1.10	1.15	1.17
WARRILL-BOONAH	25718.40	69183	1.21	1.28	1.32	1.37	1.46	1.55	1.68	1.71	1.81	1.16	1.23	1.21	1.23
WARRILL-BOONAH	26305.71	69771	1.15	1.24	1.22	1.04	1.02	1.04	1.04	1.05	1.54	1.09	1.09	1.08	1.08
WARRILL-BOONAH	26315.71	69781	1.31	1.34	1.36	1.37	1.48	1.70	2.04	1.99	2.42	1.25	1.24	1.23	1.31
WARRILL-BOONAH	27226.09	70691	1.61	1.67	1.65	1.68	1.62	1.64	1.66	1.75	1.99	1.66	1.66	1.65	1.67
WARRILL-BOONAH	28136.46	71601	2.48	2.79	2.73	2.88	2.67	2.80	2.92	2.85	2.82	2.84	2.82	2.89	2.83
WARRILL-BOONAH	28624.97	72090	1.53	1.54	1.55	1.63	1.75	1.82	1.98	2.05	2.39	1.51	1.55	1.55	1.56
WARRILL-BOONAH	29113.49	72578	1.27	1.39	1.27	1.27	1.27	1.27	1.47	1.56	2.70	1.40	1.27	1.38	1.30

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WARRILL-BOONAH	29954.18	73419	1.10	1.14	1.22	1.21	1.38	1.41	1.48	1.50	2.27	1.24	1.02	1.01	1.02
WARRILL-BOONAH	30794.86	74260	1.21	1.22	1.23	1.15	1.19	1.18	1.18	1.21	1.78	1.22	1.21	1.17	1.18
WARRILL-BOONAH	30814.86	74280	1.31	1.33	1.32	1.36	1.32	1.27	1.32	1.35	1.97	1.31	1.32	1.30	1.32
WESTBREM1	0.00		0.00	0.20	0.34	0.42	0.57	0.73	0.83	0.87	1.27	0.61	0.39	0.00	0.45
WESTBREM1	2.50		0.00	0.20	0.34	0.42	0.57	0.73	0.83	0.87	1.26	0.61	0.39	0.00	0.45
WESTBREM1	5.00		0.00	0.20	0.34	0.42	0.57	0.74	0.83	0.87	1.25	0.62	0.39	0.00	0.45
WESTBREM1	10.00		0.00	1.62	2.01	2.22	2.58	2.90	3.13	3.22	4.00	2.67	2.14	0.00	2.30
WESTBREM1	15.00		0.00	0.17	0.19	0.24	0.24	0.24	0.23	0.23	0.28	0.17	0.23	0.00	0.54
WESTBREM1	17.50		0.00	0.17	0.19	0.24	0.24	0.24	0.23	0.23	0.28	0.17	0.23	0.00	0.54
WESTBREM1	20.00		0.00	0.17	0.19	0.24	0.24	0.24	0.23	0.23	0.28	0.17	0.23	0.00	0.54
WESTBREM2	0.00		0.00	0.19	0.24	0.31	0.58	0.85	1.17	1.33	3.87	0.67	0.27	0.10	0.36
WESTBREM2	2.50		0.00	0.19	0.24	0.31	0.58	0.85	1.18	1.33	4.00	0.67	0.27	0.10	0.37
WESTBREM2	5.00		0.00	0.19	0.24	0.31	0.58	0.85	1.18	1.34	4.13	0.68	0.27	0.10	0.37
WESTBREM2	10.00		0.00	1.34	1.42	1.54	1.95	2.22	2.42	2.49	5.45	2.06	1.47	1.10	1.65
WESTBREM2	15.00		0.00	0.05	0.05	0.05	0.05	0.07	0.09	0.10	0.22	0.05	0.06	0.02	0.11
WESTBREM2	17.50		0.00	0.05	0.05	0.05	0.05	0.07	0.09	0.10	0.22	0.05	0.06	0.02	0.11
WESTBREM2	20.00		0.00	0.05	0.05	0.05	0.05	0.07	0.09	0.10	0.22	0.05	0.06	0.02	0.11
WESTBREM3	0.00		0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.20	0.70	0.00	0.00	0.00	0.00
WESTBREM3	2.50		0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.20	0.61	0.00	0.00	0.00	0.00
WESTBREM3	5.00		0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.20	0.55	0.00	0.00	0.00	0.00
WESTBREM3	10.00		0.00	0.00	0.00	0.00	0.00	0.77	1.48	1.70	2.21	0.49	0.00	0.00	0.00
WESTBREM3	15.00		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.00
WESTBREM3	17.50		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.00
WESTBREM3	20.00		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.00
WESTERN	0.00		1.25	1.87	2.05	2.07	2.09	2.10	2.12	2.13	2.27	2.07	2.05	1.56	2.08
WESTERN	247.01		1.68	2.31	2.52	2.52	2.53	2.54	2.55	2.56	2.60	2.52	2.52	1.99	2.53
WESTERN	494.03		2.07	2.86	3.21	3.26	3.30	3.32	3.33	3.35	3.41	3.30	3.28	2.47	3.30

Table A.3 (continued)

Branch	Chainage (m)	AMTD (m)	2yr	5yr	10yr	20yr	50yr	100yr	200yr	500yr	PMP	1974	1983	1989	1996
WESTERN	671.49		0.84	1.36	1.77	2.01	2.24	2.25	2.25	2.25	2.27	2.24	2.16	1.07	2.22
WESTERN	848.96		0.47	0.86	1.20	1.43	2.16	2.68	3.20	3.21	3.21	2.15	1.59	0.65	1.67
WESTERN	868.96		0.52	0.89	1.23	1.46	2.21	2.89	4.80	5.77	6.29	2.20	1.62	0.68	1.70
WESTERN	5081.62		1.40	1.73	1.73	1.75	1.96	1.97	1.95	1.96	1.97	1.94	1.78	1.56	1.80
WESTERN	5374.25		1.18	1.68	1.85	1.93	2.19	2.17	2.15	2.16	2.16	2.17	1.99	1.40	2.02
WESTERN	5666.88		1.01	1.65	2.02	2.19	2.56	2.87	2.95	2.87	2.73	2.56	2.27	1.28	2.31
WESTERN	5906.90		0.83	1.28	1.58	1.74	2.18	2.46	2.38	2.39	2.35	2.10	1.77	0.88	1.86
WESTERN	6146.92		0.81	1.18	1.43	1.58	1.98	2.27	2.23	2.23	2.21	1.94	1.63	0.92	1.70
WESTERN	6517.88		1.07	1.41	1.65	1.77	2.06	2.33	2.31	2.31	2.27	2.13	1.90	1.33	1.91
WESTERN	6888.85		1.28	1.42	1.65	1.74	1.98	2.20	2.23	2.81	5.06	2.03	1.86	1.31	1.87
WESTERN	6908.85		1.50	1.54	1.92	2.17	2.73	3.36	4.52	6.36	7.57	2.90	2.42	1.53	2.43

Ipswich Rivers
Improvement Trust

Ipswich Rivers Improvement Trust

Bremer River Catchment Flood Risk Management Study

FINAL REPORT

September 2004

Queensland Risk Management Consultants Pty Ltd in association with Kellogg Brown & Root Pty Ltd

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EXECUTIVE SUMMARY

Queensland Risk Management Consultants (QRMC) in association with Kellogg Brown & Root (KBR) has carried out a Flood Risk Management Study for the Bremer River Catchment for the Ipswich Rivers Improvement Trust.

Previous Natural Disaster Risk Management Studies for Ipswich City Council have identified that flooding is one of the most significant hazards for the city and this report builds on the technical flood studies and other reports to provide this risk management study.

Risk is defined in the Australian Standard as the chance of something happening that will have an impact upon objectives, and is measured in terms of likelihood and consequences. There are three components, namely hazard, elements at risk (or exposure to hazard) and vulnerability (of the elements at risk). Risk analysis needs to estimate the level of the risk and to provide input for risk evaluation and development of treatment options.

This report therefore provides a critical component of this important aspect of the risk management process for the City of Ipswich.

Previous reports have been prepared covering technical flood studies, natural disaster management and flood risk assessments. This report consolidates these previous reports and provides recommendations for implementation.

The flood processes included are:

- Flash flooding, localised storm events
- Local catchments, major river tributaries
- Bremer River, the main catchment considered in this report
- Brisbane River, affects the lower reaches of other rivers.

As part of this project, consultation has been held with government agencies and the community as well as the Study Advisory Group. Contributions to the project have been obtained from a range of organisations.

The investigations have included an assessment of flood risk and vulnerability and developed a risk rating for each of the sub-catchments in the project area. The risk assessment considered the risk and likelihood. The vulnerable elements considered were:

- People
- Residential property
- Business
- Agriculture
- Environment

- Lifelines
- Critical facilities
- Special facilities.

The risk rating was developed for each of these elements for the urban and rural sections of each sub-catchment and then summarised for the catchment overall, with this summary listed below.

Element	**Consequences**		**Risk rating**	
	Urban	**Rural**	**Urban**	**Rural**
Bremer River	Major	Moderate	High	Moderate
Bundamba Creek	Major	Minor	High	Low
Ironpot Creek	Minor	Minor	Low	Low
Deebing Creek	Minor	Minor	Low	Low
Warrill Creek	Minor	Moderate	Low	Moderate
Purga Creek	Minor	Moderate	Low	Moderate
Western Creek	Minor	Moderate	Low	Moderate
Woogaroo Creek	Moderate	Minor	Moderate	Low
Goodna Creek	Moderate	Minor	Moderate	Low
Six Mile Creek	Minor	Minor	Low	Low

Following this assessment and in association with the consultation programme, risk treatment (flood management) options were considered. A number of specific measures were recommended as follows.

FLOOD MANAGEMENT STRATEGIES

The classification of flood events is important in the community understanding of flood risk and the measures that are needed to respond to events. This classification is a responsibility of both the Bureau of Meteorology and the Ipswich City Council.

It was recommended therefore that the flood classification for the Bremer River be reviewed, which will involve reconsideration of the flood behaviour at each gauging location in the catchment requiring consultation between the Council and the Bureau.

NON-STRUCTURAL MEASURES

There are several recommendations that are relevant for the consideration of non-structural measures. These involve the main non-structural measures of floodplain planning and management and flood forecasting and warning.

Floodplain mapping is an important part of implementation of non-structural flood management measures. It was noted that the accuracy of the flood inundation maps is limited in some parts of the floodplain because of the accuracy of the topographic mapping. It was therefore recommended that additional survey be undertaken to improve the accuracy of the flood inundation maps and therefore the reliability of the floodplain management measures.

Flood forecasting and warning has been identified as an important component of mitigating the flood risk in the Bremer River catchment. There is already a flood forecasting and warning system in the catchment, but there are several issues that have been noted. Enhancement of the system is recommended particularly in the improvement in dissemination of information and in the provision of more complete warnings in the upper parts of the catchment.

STRUCTURAL MEASURES

There is a place for structural flood mitigation measures where there are high value existing flood prone assets. While much of the study area has relatively limited opportunity for implementation of structural measures, several opportunities have been identified, and details of these are as follows.

Where future development is possible, future flood mitigation measures are recommended to ensure that future development does not have an adverse impact on downstream flooding, so no additional property or assets are placed at risk.

Wivenhoe Dam (including the associated Somerset Dam) is an important flood mitigation measure in the Brisbane River catchment and has an impact on the rivers in this study area by affecting the backwater from the Brisbane River. This report recommended that the operational procedures for Wivenhoe and Somerset Dams should be reconsidered and impacts on flood risk implemented in the Bremer River catchment study area where backwater has an impact.

The urban parts of the lower reaches of Woogaroo Creek have been identified as an area of particular flood hazard. Because of the high risk to residential and commercial property identified in this study, further assessment was recommended.

TRANSPORT LINKS

The consultation and reviews of this project have clearly noted that the flood immunity of many of the roads in the study area is low. These low flood immunities include those for major roads including national highways. It is recommended that upgrading of the roads should ensure that the flood immunity is improved (also considering other constraints such as flood afflux impacts) to improve access and evacuation during emergency events. This will need a review of emergency access and assessment of the required level of access during flood events.

Queensland Rail is currently upgrading the railway lines located in the study area to replace the old timber bridges. The rail bridges generally have a higher standard of flood immunity than the road bridges and are not as critical for evacuation. However the replacement of the old bridges must ensure that the waterway areas of the new bridges do not worsen flood impacts. It is therefore recommended that further investigation be completed in association with Queensland Railways to ensure that benefits can be gained from the railway bridge upgrading programme.

1. INTRODUCTION

This report provides the final report for the Bremer River Catchment Flood Risk Management Study. It consolidates the previous progress reports prepared during the project.

Previous Natural Disaster Risk Management Studies for Ipswich City Council identified that flooding is one of the most important hazards for the City and the Bremer River catchment is the main catchment of concern.

Risk is defined in the Australian Standard as the chance of something happening that will have an impact upon objectives, and is measured in terms of likelihood and consequences. There are three components, namely hazard, elements at risk (or exposure to hazard) and vulnerability (of the elements at risk).

Risk analysis needs to estimate the level of the risk and to provide input for risk evaluation and development of treatment options.

This definition can be applied to all types of hazard, but this report is concerned only with flood hazards.

This report therefore provides a critical component of this important aspect of the risk management process for the City of Ipswich.

2. BACKGROUND REPORTS

2.1. INTRODUCTION

This project relies on previous reports that have been prepared on flooding for the Bremer River catchment and other streams in the City. These previous reports allow a good understanding of the issues and have been used throughout the current project to provide the technical basis for the studies.

2.2. TECHNICAL FLOOD STUDIES

Flood studies have been completed for the main rivers of the City. These studies have been completed in recent years and have used extensive data and survey in the analysis. They therefore provide a sound technical basis for the risk management study.

The first study was the "Ipswich Rivers Flood Study - Phase One and Phase Two", prepared by Sinclair Knight Merz in 2000. This report included the development of hydrology and hydraulic models for the Brisbane and Bremer Rivers as well as major tributaries in the urban areas of the city. The models were used to analyse the floods in the rivers and prepare flood inundation maps for the range of flood probability up to the average recurrence interval (ARI) 100 year flood event.

Following the completion of the Phase One and Phase Two report, the "Ipswich Rivers Flood Study - Phase Three" was completed by Halliburton KBR in September 2002. This report continued on from the previous phases and provided similar results for the upstream reaches of the rivers in the city, and particularly covered the rural portions. The approach and methodology for this report was similar to the Phases One and Two report. In particular the hydrology analysis, which provided the design flood inflows, was adopted from the Phase One and Phase Two report. The Phase Three project area was mainly located upstream of the Phase One and Phase Two river reaches, and the water levels from the Phase One and Phase Two model provided the downstream control for the Phase Three hydraulic model.

As part of the Phase Three project, a supplementary report was prepared on the local flood events, that is the floods that occur in the tributaries without associated flooding in the Brisbane and Bremer Rivers that affect the backwater levels in the lower reaches of the tributaries. This report was produced by Halliburton KBR in May 2002. The local catchment flood events result in lower flood levels in the downstream reaches of the creek, where there is a backwater effect, but have higher flow velocities. It is possible for local catchment flood events to occur independently of the main river flooding, particularly for the smaller catchments. The findings from this report provide information to assist in assessment of flood hazard by locating areas of higher flow velocity.

Flood inundation maps were prepared by the Ipswich City Council for the flood levels calculated by each of these projects. The maps have been prepared in the Council Geographic Information System. These maps are valuable for risk assessment study, and are discussed further below.

2.3. FLOOD RISK ASSESSMENTS

As well as the technical flood studies, a number of studies have been carried out covering risk and hazard assessments.

The Australian Geological Survey Organisation produced a report covering a multi-hazard risk assessment for the Ipswich City Council (as well as other south-east Queensland local authorities) in May 2001 (AGSO, 2001). Chapter 8 of this report included a comprehensive report on flood hazards for the City of Ipswich.

This report demonstrated extensive potential flood damage for the city, as well as extensive damage that had occurred in historical flood events.

Halliburton KBR produced a "Flood Vulnerability Analysis" in February 2002, which provided background data and information for subsequent studies by the Council on flood risk. This report recommended further investigations which have since been carried out and some completed.

The first component of the risk assessment for the City was the "Preliminary Natural Disaster Risk Management Report" prepared for Ipswich City Council by Fisher Stewart in November 2001. This plan was prepared following the guidelines of the Department of Emergency Services (Stage 1) and covered all natural disasters, not just flooding. Flooding received a high rating in respect of all elements, hence Stages 2b and 3 of the programme were recommended.

Fisher Stewart prepared a subsequent report in August 2002, which provided the final "Natural Disaster Mitigation Plan", summarising the three stage process. Flooding was identified as the greatest of the risks assessed for the city.

The report included a summary of risk treatment strategies for consideration by the Council.

Council officers summarised the findings of the different studies in a memo presented to the Council in May 2002 (Ipswich City Council Works Department, 2002). This memo recommended that the Council accept the findings of the two reports by Fisher Stewart and continue implementation of the strategy.

The current project is a part of this on-going strategy.

3. FLOODPLAIN MAPPING

3.1. INTRODUCTION

Floodplain mapping is a critical part of the current project and is also important for planning for the Council. The floodplain inundation maps were prepared from the results of the hydraulic modelling. This section contains some details of the approach that has been applied and the accuracy of the maps.

The accuracy of the maps is important since the maps can be used to determine the location of specific flood prone properties.

Hydraulic modelling for the flood studies using the MIKE 11 hydraulic model relied on cross sections that were obtained from ground survey. The results therefore provide calculated water levels for each cross section for each design flood event. These flood levels were also presented as inundation maps to allow easy incorporation of the flood levels into the Council planning schemes and for presentation to the public.

3.2. INUNDATION EXTENT PROCEDURE

The Council provided two types of survey data for use in the flood study project. These were a detailed field survey comprising channel and floodplain sections, and a 20m square grid Digital Elevation Model (DEM) produced from photogrammetry.

The hydraulic modelling was mainly derived from the detailed field surveyed cross sections. Where this information was insufficient the sections were extended using elevations from the 20m grid DEM. This situation applied in only a few locations and the extension did not seriously affect the results.

The surveyed cross sections were regarded as accurate and the results of application to the hydraulic modelling showed the conclusions to be consistent and acceptable throughout the study area.

The inundation maps were then prepared from the DEM, which provided the topography for the regional floodplain information. The results from the hydraulic model, calculated for the surveyed cross sections were combined with the ground surface from the DEM to provide the extent of inundation.

The approach was to use a civil engineering computer program (12D Model by 4D solutions) to compute the extent of inundation. To do this, two surfaces were required, a natural ground surface and a water elevation surface. The surfaces were represented in the computer program as a series of connecting triangles referred to as a TIN. The natural surface TIN was generated from the 20m grid DEM data. The water surface TIN was created using a combination of the horizontal location of the field survey cross section data and the water level elevations generated by the hydraulic model at these locations.

A function exists in the computer package to compute the intersection between the two TINs. The resulting lines are the extent of inundation.

This approach provides a simple, accurate and automated procedure for generating inundation maps and has been used successfully in a number of applications.

3.3. GENERATION OF THE DEM

There were primarily two main sources of photogrammetry relevant to the generation of the DEM needed for the preparation of the inundation maps for the study. Photogrammetry was supplied from both Ipswich City Council and the Department of Natural Resources, Mines and Energy (NRM&E) (through the Council), both of which had different contour intervals and accuracy limits.

The Ipswich City Council photogrammetric information was supplied at 0.5m contour intervals and predominantly covers the area of the Phase 1 and Phase 2 project. The accuracy disclaimer on the ICC photogrammetry information has been claimed to be less than 90% of the half contour interval. This suggests that the levels obtained in this location are accurate to less than ±0.25m. Comparisons between the field survey and DEM levels have indicated that the disclaimer on the accuracy limits appear to be acceptable.

The photogrammetric information supplied by NRM&E covered most of the Phase 3 study area. Unlike the ICC photogrammetric information, the contour interval used in preparation of this data was 5m. Again, the disclaimer on this information is stated to be less than 90% of the half contour information (i.e. 2.5m). However analysis on the accuracy between the DEM and the field survey has indicated that the difference in elevation is closer to 5m. This is a larger than expected difference in elevation. It may have been caused by the fact that, even though 5m contours were used in the generation of the surface TIN, the 20m grid used to extract elevations may be introducing additional error into elevations in addition to the errors resulting from the basic data.

In this region therefore, there is a significant difference between the relatively accurate field survey and the DEM generated from the photogrammetry. It was expected that the NRM&E contours would be relatively less accurate. What was not expected was the extent of this inaccuracy. In addition, the difference in level between the surveyed cross sections and the DEM is not a random difference, with the levels in the cross sections generally lower than the DEM. There are regions however where the difference is in the opposite direction.

3.4. ACCURACY OF INUNDATION MAPPING

The water courses used in the hydraulic model have been represented mainly by the detailed field survey cross sections, and as noted above, these are believed to be accurate. Where these cross sections were compared with the 20 m grid DEM, there was a significant inconsistency in elevation. One particular issue is that the 20 m grid DEM has failed to define the low flow channels. This is related to the question of the size of the grid where the channel is relatively narrow. More concerning though in the generation of the inundation lines is that the DEM elevations are generally a few metres higher than those from the field survey, though there are a smaller number of locations where the DEM shows lower ground levels than the ground survey. This is related to the accuracy of the DEM itself. As a result, this has affected the accuracy of the horizontal location of the inundation lines significantly. These large differences in elevation were envisaged not to be especially critical in producing the inundation lines in the higher reaches of the study area due to the steepness of the terrain and the closeness of the ground contours. However, direct comparison between the extent of inundation produced manually from the field survey to the inundation lines produced automatically from the DEM has produced substantial horizontal differences in inundation lines.

There are two issues involved in the inconsistency between the field survey and the DEM.

Firstly the difference in the levels results in problems in determining the extent of inundation because of the difficulty in relating the levels from the hydraulic model to the floodplain extent. The second problem is related to the relatively narrow extent of the main channel of the water courses. The narrow channel is represented adequately in the ground survey of the cross section, but is too small to be represented in the terrain model, which relies on a grid of elevation points.

In addition, these elevation differences have produced inconsistencies between the flow patterns generated from the hydraulic model and the extent of inundation generated from the 20 m grid DEM. As an example, this is most apparent when looking at the inundation produced along Western Creek. The Ipswich to Rosewood railway line, which runs parallel to Western Creek has several hydraulic structures under its embankment allowing flow to pass between the northern and southern sides. Flow patterns adjacent to the railway line are extremely complex in this area and have been difficult to accurately represent given the limited number of field survey sections taken here. Incorporating additional ground level information in this area using the 20 m grid DEM was not possible due to the large level differences.

Storm events where flow is contained within the low flow channels are especially susceptible to these survey inconsistencies and as a result, the inundation process produces "pools" with no interconnection along the flow path. Where applicable, manual modifications to the inundation lines created from the DEM could connect these 'pools', however such corrections would be based upon DEM contour information where the accuracy is considered questionable.

Modifications can only be considered feasible for the larger events where there is sufficient inundation outside the low flow channels in the study area. For the smaller events, no correction to the inundation lines was considered appropriate due to the lack of inundation produced from the inundation procedure.

3.5. CONCLUSION

The general procedure for the preparation of the flood inundation maps followed the reasonably automated procedure descried above. However because of the accuracy limitations noted, some adjustments were made to the maps. These adjustments provided some final details considered by manual analysis. This manual analysis relied on assessment of the local conditions including local knowledge gained in the field. The ultimate maps adopted by the Council therefore included the best knowledge from these different sources.

If more complete survey data is obtained in the future, the detailed flood inundation may be revised to incorporate this additional information.

4. FLOODING ISSUES

4.1. DESCRIPTION OF CATCHMENTS

A number of rivers are of concern for flooding in the City of Ipswich. The most significant of these is the Brisbane River, which is the largest river in the region with a catchment area of 13,000 km^2. This river flows through the northern part of the city and forms the boundary between Ipswich and Brisbane for some distance. The Brisbane River, being such a significant river affecting the main urban centres in south-east Queensland has extensive information on flooding. The catchment has two major dams, which operate as flood mitigation works as well as water supply dams. These are Wivenhoe Dam on the Brisbane River and Somerset Dam on the Stanley River. The combined operation of these two dams will have a significant impact on flood levels in the Brisbane River downstream.

The Bremer River catchment constitutes a major tributary of the Brisbane River catchment. The Bremer River flows from the south west and joins the Brisbane River in the City of Ipswich at AMTD 73 km. (AMTD is Adopted Middle Thread Distance and is the distance from the mouth of the river). The total area of the catchment is about 1,500 km^2, though Warrill Creek, the major tributary of the Bremer River, makes up more than half of this total catchment area. Other tributaries are Western Creek in the western part of the catchment and Purga Creek, a tributary of Warrill Creek. Bundamba Creek flows into the lower reaches of the Bremer River. Moogerah Dam is located on Reynolds Creek, a tributary of Warrill Creek. It supplies water to irrigation areas in the Warrill Valley, cooling water to Swanbank Power Station and some urban water supplies in Boonah Shire and small towns in Ipswich City. Much of the catchment is hilly and lightly forested, though the headwaters are mountainous and there are alluvial river flats in parts of the lower reaches. Land use includes forest, grazing, agriculture, urban and some mining.

While the Bremer River is the most important tributary of the Brisbane River in this area, there are a number of other tributaries which also affect urban areas in the City. The most important of these streams are Six Mile, Goodna and Woogaroo Creeks and Sandy Creek which flows out of Ipswich City before ultimately joining the Brisbane River.

The upper reaches of Warrill Creek and the Bremer River are located in Boonah Shire. The Brisbane River catchment includes a number of local authorities upstream of where it flows into Ipswich City.

4.2. FLOODING PROCESSES

Floods affecting the city are complex and can be produced by rainfall in any one of a number of tributaries. The major tributary of the Brisbane River upstream of Ipswich is Lockyer Creek, which flows into the river immediately downstream of Wivenhoe Dam. Runoff from upstream of Wivenhoe Dam is routed through the dam, which is operated to provide flood mitigation benefits. However because of the large catchment area and the operation of the flood mitigation dams, floods in the Brisbane River generally rise and fall slowly. There is a flood warning system in the catchment and this helps in mitigating damages.

Flooding in the Bremer River and its tributaries is particularly important for flood concerns in Ipswich. Warrill, Purga and Bundamba Creeks are particularly important. There are also a number of smaller tributaries of the Bremer River that are more minor for the consideration of major flood impacts. The flooding in this catchment is the most complex and because of the large catchment size, is of the most importance for Ipswich City.

Flooding processes in the main urban areas of the catchment are complex with flooding contributions from a number of sources including:

- ***Flash flooding:*** Very localised intense storm events can cause local inundation in small catchments and drainage systems. These events affect minor and poorly defined water courses, especially in urban areas. Inundation in this type of event is very difficult to analyse and is not normally considered in flood assessments.

- ***Local catchments:*** Flooding in the main tributaries can arise from local catchment rainfall. This type of flooding is normally produced from relatively short duration intense rainfall events and is generally of relatively short duration. These are catchments such as Warrill Creek and the Brisbane River tributaries.

- ***Bremer River:*** Flooding in the Bremer River not only affects the river itself but also affects the tributaries through backwater effects where water backs up tributaries. This is a particular issue for Bundamba Creek and other smaller tributaries.

- ***Brisbane River:*** In the same way, backwater from the Brisbane River affects the lower reaches of the Bremer River and its tributaries. Because of the relatively large size of the Brisbane River, with a total catchment area of over 13,000 km^2, the flood response is much slower and major floods are produced from longer duration rainfall events. Flood waters in these events rise and fall more slowly than in other flood events noted above. The construction of Wivenhoe Dam, which operates in conjunction with Somerset Dam for flood mitigation, has reduced the risk of flooding in the Brisbane River to some degree. The benefits of this flood mitigation system should be included in the floodplain planning process for the city.

- ***Combination:*** All four flood types can occur in various combinations. However due to the large catchment size, it is unlikely that major flood events will occur in the whole of the catchment completely simultaneously, though the flood types will often be associated with each other, as they were in January 1974.

The lower reaches of the Bremer River and the Brisbane River up to Mt Crosby are tidal and while tidal levels would not be expected to have a significant effect on large floods, there may be some impact on smaller events.

The typical flooding pattern in the lower reaches of the Bremer River was experienced during the significant event that occurred in January 1974. Flooding occurred firstly in the smaller catchments. The slower responding catchments of the Bremer River and Warrill Creek then rose and finally backwater from the Brisbane River increased water levels. Brisbane River backwater will either slow the outflow of water from the Bremer River or if it is sufficiently delayed could even allow flow upstream in the Bremer River. A point on the lower reaches of one of the smaller tributaries could therefore have three separate flood peaks (local runoff, Bremer River and Brisbane River) from a single major event.

The determination of the ARI 100 year flood (or any other large flood event) level for locations in the major rivers of Ipswich City is not easy. The actual level in various locations depends on the flooding in the Brisbane and Bremer Rivers, as well as in any one of a number of smaller tributaries. The risk of flooding depends on the combination of risks from the different locations, and consideration needs to be made of the catchment areas, timing of floods and combinations of events.

The Bremer River has had flood records observed for just over 100 years at the City's flood warning gauge at the David Trumpy Bridge. The most significant floods on record with a gauge height of greater than 10 m are listed in Table 4.1.

Table 4.1 Major floods—Bremer River at Ipswich

Date	Gauge height (m)
4 February 1893	24.50
12 January 1898	17.48
27 January 1927	12.98
7 February 1931	15.47
26 January 1947	15.19
31 January 1951	11.69
29 March 1955	13.82
12 June 1967	11.99
14 January 1968	11.69
4 February 1971	11.71
27 January 1974	20.70
28 January 1974	20.70
11 February 1976	13.65
23 June 1983	10.65
4 April 1988	11.20
12 December 1991	13.10
3 May 1996	11.31

There are four tributaries of the Brisbane River in the city. Three of these flow directly into the Brisbane River, namely Six Mile, Goodna and Woogaroo Creeks and another creek, Sandy Creek flows into Brisbane City before ultimately flowing into the Brisbane River. Because these creeks are all much smaller than the Bremer River, backwater from the Brisbane River is of greater significance, though flooding is produced from both local catchment events as well as backwater from the Brisbane River.

Backwater flooding and local catchment flooding have different impacts in these relatively small tributaries. In the most downstream reaches, the flood levels produced by backwater will have higher flood levels than the local catchment floods, but the flow velocity will be very low. Local catchment runoff on the other hand will have higher velocities which could actually cause damage as occurred in Woogaroo Creek in January 1974.

The largest flood on record in Ipswich occurred in 1893, over 100 years ago. This flood was about 13 m higher at the gauge than the most recent significant flood that occurred in May 1996.

5. FLOOD RISK AND HAZARD BACKGROUND

5.1. INTRODUCTION

Since flooding has been recognised as one of the most important hazards affecting the City of Ipswich, a detailed assessment of the hazard is necessary, and this comprises the principal outcome of this project.

This section of the report includes background information, which is developed further below.

5.2. FLOOD RISK

Introduction

The flood reports and flood inundation maps provide a good indication of the extent of flooding in the City of Ipswich and this information has been incorporated into the previously completed natural disaster risk management programmes and will be used in the current project as well.

The costs of flood damage have been estimated in Ipswich as part of the flooding experienced in January 1974 and general information on the calculation of flood damage has been provided by the Bureau of Transport Economics (2001).

Residential and commercial property

Risk of flood damage to residential and commercial property is a critical issue for the city with a very large number of flood prone properties. Property at risk is located in both urban and rural regions.

The AGSO (2001) report provides an estimate of the properties at risk from flooding throughout the urban portions of the city. Additional properties will also be affected in rural areas, but there will be a smaller number. The number of properties is listed in Table 5.1 for the range of average exceedance probability (AEP) events studied.

Table 5.1 Properties affected by flooding

Flood probability (AEP)	Number of properties
1:20	1,190
1:50	2,090
1:100	3,380
1:200	4,030
1:500	5,400
Probable Maximum Flood[1]	17,690

Source: AGSO (2001)

[1] **Defined as the maximum event that can occur**

Transport

Flooding affects many road and rail links in the City, and the disruption to transport is an important risk.

The New South Wales Floodplain Management Manual (1999) has a graph that indicates the velocities and depths where vehicles become unstable. This indicates that vehicles become unstable at depths greater than 0.3 m and velocities greater than 2.0 m/s. The type of vehicle was not mentioned, but it would seem to apply to cars and other small vehicles.

There is a similar relationship in the SCARM Best Practice Principles and Guidelines for Floodplain Management in Australia (1998). This report indicates that 4WDs are safe for water depths up to 0.5 m and small cars for water depths up to 0.3 m.

The report by AGSO (2001) has some details on the extent of roads and railways in the urban parts of the city that are inundated by flooding. In addition to these, there are extensive lengths of rural and minor roads that are flood prone. The lengths of urban roads are plotted on Figure 5.1.

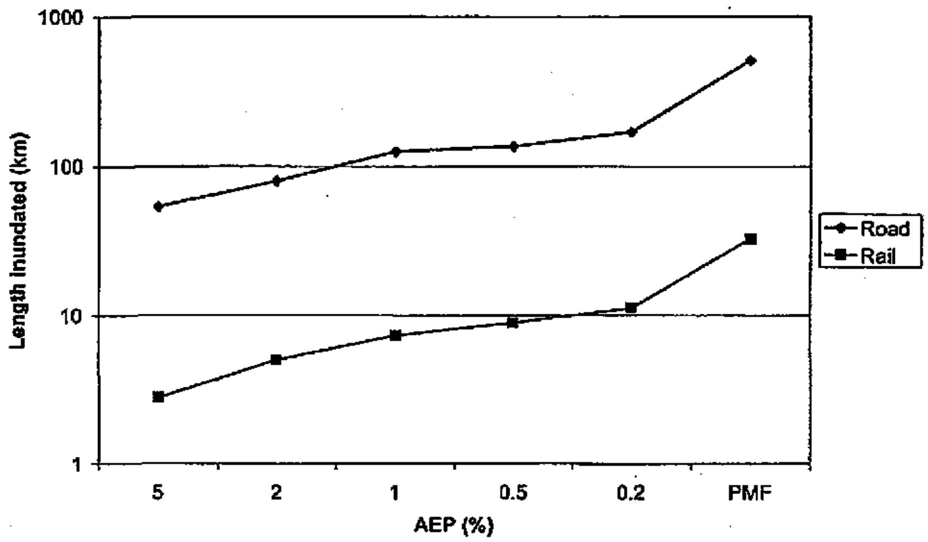

Figure 5.1 Length of road and rail inundated (Source: AGSO, 2001)

Inundation of roads causes a disruption to transport as well as damage to the infrastructure itself. The Bureau of Transport Economics (2001) has details of the costs of both of these aspects, which are difficult to quantify.

It is noted that the roads that are closed by flooding include major arterial roads that carry significant traffic volumes.

Government infrastructure

As well as the roads and rail infrastructure, there are other government facilities located in the floodplains. These are owned by all branches of government and include critical community resources.

Agriculture

There is extensive and high value agriculture carried out on floodplains throughout the rural areas of the city. Agriculture is practiced on the floodplains because of the high quality land and the proximity to irrigation water. However these features lead to potential flood damage.

Damage to agriculture includes damage to crops, livestock, farm equipment, irrigation equipment and fences as well as buildings. The time of occurrence of the flood may influence the extent of damage depending on the susceptibility of the crop at the stage of growth for example.

The Bureau of Transport Economics (2001) has estimated flood damage for agricultural areas.

Other infrastructure

There are individual facilities that are potentially affected. These have not been completely identified, however there are several known high value facilities.

For example, the Amberley RAAF Base is one such facility. The flood inundation maps indicate that part of the base, including the runways, are inundated in the AEP 1:100 flood, with the buildings of the base inundated in larger floods. The aircraft were relocated during the 1974 flood off the site. Inundation of the aircraft at the base would be an extremely high damage event.

As well, there are mines located in the lower reaches of the Bremer River. These mines are protected by levees but floods in excess of the design floods for the levees would be a potential large damage. This would not only cause damage to the mine itself but could potentially cause environmental harm by the release of poor quality water from the mine pit.

Special facilities include museums and other sites that sometimes have irreplaceable contents.

6. COMMUNITY VULNERABILITY

6.1. BACKGROUND

Introduction

The issues of vulnerability in the context of flood hazards have been described and analysed previously in a number of reports prepared for the Council. These reports allow a good background understanding of the issues and can assist in the current project.

Halliburton KBR Report

A report entitled "Community Vulnerability" was prepared by Halliburton KBR in February 2002. This report described the background to flooding in the city of Ipswich and then covered the main issues of community vulnerability concerning flood hazards.

This vulnerability report was a component of the Ipswich Rivers Flood Study Phase 3 though it did consider the whole of the Ipswich City area, and not just the streams included in the Phase 3 report.

It introduced the main topics that are now considered in more detail in the current report.

Fisher Stewart report

The Stage 1 Preliminary Natural Disaster Risk Management Report prepared by Fisher Stewart in November 2001 covered all aspects of all natural disasters, including the consideration of the vulnerability of the community to flood hazards.

This was an important report that formed the basis for the current project.

Flooding was identified as the greatest of the risks assessed for the city. Based on a population of 126,853 in the 1996 census, 9,300 people (about 7% of the total population) would be affected by the ARI 100 year flood and approximately 54,000 people (about 43% of the total population) in the Probable Maximum Flood. The largest flood of the twentieth century occurred in January 1974 when there were 2,000 properties affected. With further development since that time, it was estimated that there would be 4,700 properties now affected if another flood the same size as the 1974 flood were to occur again today. As well, many roads were affected by flooding including a number of major connections inundated by the ARI 20 year flood.

AGSO Report

The *Australian Geological Survey Organisation* produced a report covering all natural hazards for the City in May 2001.

Chapter 3 of this report provided details of the community and its vulnerability based on an assessment of the factors that affect vulnerability and the distribution in the City of Ipswich.

6.2. COMMUNITY VULNERABILITY

Introduction

Vulnerability is defined (in Fisher Stewart, 2001) as a measure of the exposure of a person or group to the effects of hazards and the degree to which that person or group can anticipate, cope with, resist and recover from the impacts of hazards. It therefore relates to both susceptibility to a hazard and the resilience to coping with the hazard.

It is not possible to measure it directly, but relevant factors are described.

Vulnerability Factors

The assessment of flood risk and hazard has shown significant levels of risk and hazard with extensive areas of inundation and large numbers of properties affected.

This assessment must be considered in relation to the vulnerability of the community. The vulnerability of the community includes consideration of not only the actual risk and damage but also the impact of the hazard on the community and the effectiveness of measures to cope with the hazard and to recover from the event.

Factors of concern are described below.

Population Characteristics

The characteristics of the population at risk provide an indication of the vulnerability of the community.

In the Bremer River catchment, there are both rural and urban communities, with the urban communities including large urban areas such as the main Ipswich suburbs as well as smaller urban communities, such as the town of Rosewood. These different communities have different responses to flood hazards and damage to their property. Obviously there are different risk and damage factors for the two different community types.

The difference between the rural (assumed to include the smaller urban centres) and the urban populations is important in the assessment of vulnerability.

Rural residents are often better prepared for isolation (when roads are closed) and have equipment to help in mitigating damage and recovering from the flood than the residents in urban areas. As well rural residents are often a more stable population and have been resident in the area for longer so are more experienced with floods, especially important in the Bremer River where major floods occur infrequently.

On the other hand, education programmes for improving people's response to flood disasters can be targeted more easily to urban residents and the smaller areas make response easier. The more concentrated population density in urban areas also means that structural flood mitigation measures may be easier to justify on economic grounds.

Critical Facilities

The vulnerability of different community assets depends on the type of asset. For example, while the consequences of flood damage to residential property are of concern, the consequences of damage to important community facilities such as water treatment plants are greater. The Vulnerability Analysis must identify these critical facilities and make specific recommendations for planning of these.

The critical facilities that need to be identified will include water and sewerage treatment plants, police, ambulance, fire and rescue services, telecommunications facilities, hospitals and government infrastructure. Locations where important archives are stored should also be considered specifically. These include museums as well as storage locations of government and private archives. In addition transport links, discussed further below, will also be included in the critical facilities.

Facilities for vulnerable members of the community, such as nursing homes and hospitals, would also need specific consideration as critical facilities.

It is often accepted in Ipswich and elsewhere that the defined flood event for general planning should be set at the flood with an average recurrence interval of 100 years. However the defined flood event for critical facilities could be set at a higher standard to reduce the risk of damage or disruption. The actual standard adopted should be set at a particular level after reviewing the importance of the facility and the level of risk considered acceptable.

The defined flood event could possibly be set as high as the Probable Maximum Flood for particularly important and sensitive facilities, such as the most important hospitals and the emergency centre used for the management of the flood emergency response.

Communications

Floods can cause severe disruption to communications. In particular, the most obvious disruption is the closure or damage of roads and railways. There are however other communication facilities that can be closed such as telecommunications or airports.

Roads and railways are the most important communication facilities that need careful review. The road network in particular is the most important means of evacuating residents and moving property during the flood event. It is known that there are extensive parts of the road network that are affected by flooding.

While it is impossible to make every road flood free, it is important to have vital links flood free, particularly where they are the only access to large concentrations of population and evacuation may be necessary. In addition, where roads have a lower flood immunity, it is important to know the actual flood immunity and the timing of closure for the point where the roads are closed. In locations where population centres may be isolated by flood water, the level where the access is initially closed is important. It is especially important where a community first becomes isolated and is later inundated. In this case, evacuation has to occur by boat or helicopter, a hazardous activity during a flood emergency.

As well as the local concerns, which are important, there are a number of important national communication links that run through Ipswich. Disruption to these roads and railways affects the broader economy as well as the local community.

Evacuation and Protection of Property

The issue of evacuation and protection of property is closely related to the question on communication, but is somewhat broader. It depends not only on the timing and probability of flood inundation of property and the closure of roads and other evacuation routes, but also on the preparation of the community and the effectiveness of warning systems.

This important aspect of the vulnerability of the community is concerned with the effectiveness of evacuation of residents and the protection of property before the flood reaches a critical level. Evacuation and protection of property can significantly reduce the potential damage to the community and development of effective measures can reduce the vulnerability of the community and help in more rapid recovery.

The effectiveness of evacuation and protection of property depends on the timing. Flood events can occur during the night, at weekends or during holidays and this timing influences the effectiveness of the measures. It is especially important for commercial properties. For example the major flood event that occurred in parts of Brisbane in March 2001 occurred on a Friday evening after many businesses had closed. Those business operators who knew about the event were unable to return to their property because roads were closed, and many were not even aware their property had been inundated and damaged until the following Monday morning. In any case the flood rose and fell very rapidly with most affected properties inundated less than an hour after the beginning of the heavy rainfall. Because of these factors, very little property was generally saved from the flood water. However there were some businesses where considerable property was saved even with the very short warning time. High value property, such as computers for example, were especially important.

It has been noted in a number of studies that well prepared communities where evacuation and protection of property is well managed can reduce the damage significantly. For example, communities such as Ingham, where flooding is a relatively frequent occurrence suffer relatively small damage since the community can prepare for the event. On the other hand, the community in Townsville was unprepared for the flood that occurred in the city in January 1998 and relatively small amounts of property were saved before houses were inundated. Research has shown that where even very short term warnings, say less than an hour, are heeded, considerable property can be saved.

Effective evacuation and protection of property depend on a number of factors. The technical factors are important, but the warning times and systems as well as the effectiveness of communications for evacuation are also important. This question is described further in the following section.

Flood Forecasting and Warning

Effective flood forecasting and warning systems are important for reducing the vulnerability of the community and this has been recognised in Ipswich.

While flood forecasting and warning systems do not have any impact on the potential damages in a flood event, they can have a significant impact on the actual damages that occur in a particular event. Surveys of actual flood events have shown that a well prepared community with adequate warning can reduce the damage by a significant extent.

The effective implementation of flood forecasting and warning systems requires both technical performance of the system itself as well as an appropriate social setting. The technical performance requires that the system be reliable and accurate. The forecasts need to be accurate in both the forecast water levels and the timing. As well there should be no major events that are missed and there should be no "false alarms". Both of these lead to a lack of confidence in the system and will cause the community to fail to respond to warnings.

The social context means that the community must be aware of the forecasting system and educated in the correct response needed for a particular event. In addition the warnings must be distributed to the community efficiently and in a format that can be readily understood by the community. The warnings must also be in a context that can be applied to the individual community members. In locations where the community is familiar with flood events, a warning stating that a flood will reach a certain gauge height on the flood warning gauge may be completely adequate, but this type of warning may not be suitable for many locations. In Ipswich, warnings based on flood gauge heights may be suitable for rural areas, but not for urban areas.

Community Awareness

The development of awareness of the risk of flooding is an important part of the management of community vulnerability. This project, with its associated public meetings and consultation programme, is one means of increasing the awareness of the community to flood risks. The vulnerability of the community, that is the ability of the community to respond to flood events, is improved by improving the community understanding of the events and the most appropriate response.

7. MEETINGS AND CONSULTATION

7.1. COMMUNITY MEETINGS

There have been two community meetings as part of the project, where input was sought for this report. These were public meetings held in the CWA Hall in Rosewood on 11 May 2004 and at the School of Arts Hall in Harrisville on 15 September 2004.

There were a number of issues raised at the public meetings, with the main ones being:

- It was noted that even though the 1974 flood was the largest event on record in the Ipswich City area and the downstream part of the catchment, other events have been larger in localised regions of the catchment
- Performance of the flood warning system was seen as critical to residents in both urban and rural areas
- The warning system is however better developed for the more downstream urban areas
- The main issue with the improvement of warning systems is to improve the social and communications components rather than the technical aspects
- Additional community awareness campaigns to ensure that the community is aware of flood risk and can take precautions before events (such as having battery operated radios available) are valuable
- Road networks are at risk in even quite small flood events
- Houses in rural areas seem to be generally built with a lower risk of flooding, even though there are significant areas of floodplain inundated
- Council has improved its information distribution and property owners can determine whether their property is below the level of the ARI 100 year flood line and a town planning search will indicate the risk
- Roads and railways as well as other linear features can affect flood flow distribution in areas of shallow sheet flow
- River revegetation may have environmental benefits, but the impact on flooding needs to be considered
- There are well established existing levees in some floodplain areas and local land owners may be concerned about recommendations to change these, because of possible adverse impacts
- Urban growth and development may affect flooding downstream without mitigation measures, though it was noted that development approvals generally require such measures to be implemented
- The Council is implementing flood management processes.

7.2. GOVERNMENT AGENCY CONSULTATION

Introduction

Discussions have been held with government agencies with an interest in flood risk in the Bremer River catchment and this section of the report contains details of this consultation and relevant input to the development of the risk assessment for the Bremer River as it concerns the Ipswich Rivers Improvement Trust.

Department of Natural Resources, Mines and Energy

A discussion was held with Mr Russell Cuerel, Principal Policy Officer in the Water Use Group, Water Management and Use of the Department of Natural Resources, Mines and Energy (NRM&E), the Department officer concerned with flood management in the Department.

There is no specific role for NRM&E in floodplain management at present and the Department can provide 'encouragement' to local authorities only.

The State Flood Risk Management Policy is not yet enacted. A discussion paper has been prepared and community consultation completed, but there was little significant interest shown by public. The Department is working towards building up to 'requiring' floodplain management policies, but as yet has no legislative powers.

Works on floodplains can be an issue for flood impacts, but licensing of levees and other structures is not a responsibility or authority of NRM&E unless connected to a water abstraction structure, though there has been some consideration in some locations.

The State Planning Policy Guideline—Mitigating the Adverse Impacts of Flood, Bushfire and Landslide was released in June 2003. The current status of this policy is that it applies to assessable development, chiefly through IPA Planning Schemes.

The most realistic outcome likely is to require Councils to introduce floodplain management and risk assessments by the use of the policy when necessary amendments have been made to the Water Act, but this is not envisaged to occur in the near future.

Nothing specific has been done by NRM&E in respect of the Bremer River catchment.

Copies of the following documents were provided:

- State Flood Risk Management Policy—Discussion Paper
- State Flood Risk Management Policy—Summary Discussion Paper

- State Planning Policy—Mitigating the Adverse Impacts of Flood, Bushfire and Landslide
- State Planning Policy Guideline—Mitigating the Adverse Impacts of Flood, Bushfire and Landslide.

These provide general information on the state government approach to floodplain management, but have no specific data for the Bremer River or Ipswich.

Bureau of Meteorology

A meeting was held with Mr Terry Malone, Senior Engineer, Hydrology and Flood Warning. Mr Malone is responsible for implementing flood forecasting systems throughout Queensland, including the Bremer River.

There were a number of general issues discussed as well as specific concerns for the Bremer River and tributaries.

The Bureau has a forecasting system for the Bremer River, focussed specifically on the City of Ipswich but also on the remainder of the catchment to a lesser extent.

The Bureau distinguishes between flash flooding (that resulting in floods occurring less than 6 hours from rainfall peak) and non-flash flooding (resulting in floods occurring more than 6 hours from rainfall peak). Only very generalised advice can be given in respect of flash flooding because of the lack of cover of gauges and short response times. Non-flash flooding is of greater significance in rural catchments, because the catchments are larger and floods occur more slowly.

Different parts of the Bremer River catchment and tributaries include both types of flood occurrence.

The Bureau's role concentrates on warning procedures, which involves the issue of flood warnings and river height bulletins. Following this, responsibility for specific warnings is with local authorities. The Bureau's role is to forecast height and then the Council's role is forecast the areal extent of flooding and likely impacts. The levels of warning type are set by Council. Flood severity is classified as minor, moderate and major. These definitions are defined for all flood warning stations in the catchment, with the specific flood gauge heights listed in the Bureau's website.

Details of relevant information for the Bremer River Flood Warning System were supplied by the Bureau.

The warning system defines flood sizes, defined as:

- ***Major flooding:*** This causes inundation of large areas, isolating towns and cities. Major disruptions occur to road and rail links. Evacuation of many houses and business premises may be required. In rural areas widespread flooding of farmland is likely.

- ***Moderate flooding:*** This causes the inundation of low lying areas requiring the removal of stock and/or the evacuation of some houses. Main traffic bridges may be closed by floodwaters.
- ***Minor flooding:*** This causes inconvenience such as closing of minor roads and the submergence of low level bridges and makes the removal of pumps located adjacent to the river necessary.

Figure 7.1 illustrates the flood sizes for the gauge at the David Trumpy Bridge in Ipswich.

Figure 7.1 Flood Classification, Bremer River at Ipswich

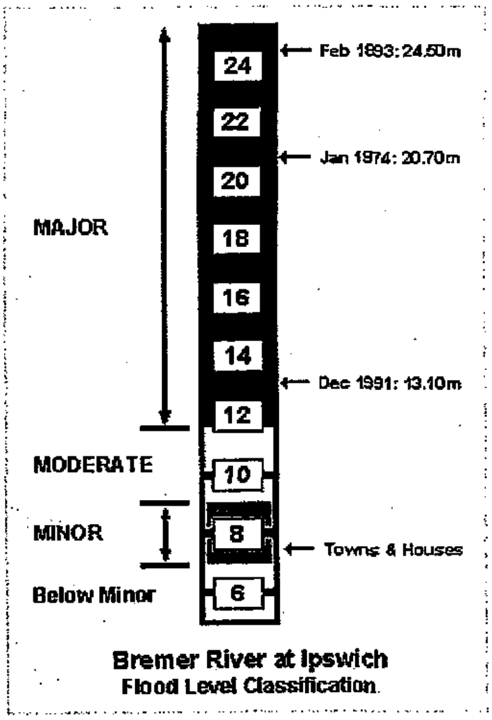

Table 7.1 shows the flood classifications for selected river height stations in the Bremer River catchment to Ipswich.

Table 7.1 Flood classifications for Bremer River—river height stations

River height station	First report height	Crossing height	Minor flood level	Crops and grazing	Moderate flood level	Towns and houses	Major flood level
Kalbar	4.0	7.0 (B)	6.0	7.0	7.0		9.0
Harrisville	3.0	5.5 (B)	3.0	5.0	4.0 (d/s)		5.0
Amberley			4.0		5.5		6.5
Kuss Road	4.0	7.6 (B)	6.0		7.0		8.0
Rosewood	2.0	5.2 (B)	4.0	5.0	5.0		6.0
Walloon			3.5		5.5		7.0
Ipswich (David Trumpy Bridge)	4.0		7.0	7.0	9.0	7.4	11.7

All heights are in metres on flood gauges.
(B) = Bridge (d/s) = Downstream

The Bureau maintains a network of flood warning gauges in association with other agencies, including the Council.

There are three types of station that are maintained by the Bureau. These are rainfall, rainfall/river level and manual observations. These are equipped with radio or telephone telemetry while gauges are maintained by SEQ Water or Ipswich City Council.

Other gauges are the ALERT (Automated Local Evaluation in Real Time) gauges. Every event (1 mm of rain or 50 mm change in water level) is radioed to Ipswich City Council Base Station and the Bureau of Meteorology office. The Bureau runs a model and decides whether to issue a warning. For minor flooding, there may not even be a prediction issued.

In Ipswich, warnings are issued when the gauge height reaches 7 m at the David Trumpy Bridge. The Bureau tries to achieve 6 to 24-hour warning times. The forecast is complicated by backwater from Brisbane River including Wivenhoe discharges by SEQ Water in the lower reaches near the Brisbane River.

Warnings are issued in four modes of communication:

1. fax to service agencies/ABC/commercial stations
2. email
3. web
4. recorded telephone service.

There is a code of conduct for radio/TV stations, but commercial stations are often not responsive and warnings are often not distributed as well as possible. The ABC is reported to be more reliable.

In conclusion, the Bureau consider that the station network cover is quite adequate, further stations would not improve adequacy of warnings and additional effort would be best applied to improving dissemination of warnings.

Copies of the following documents were provided:

- Brisbane and Bremer River Basin warning procedures
- Flood warning system for the Bremer River to Ipswich
- Bremer River to Ipswich Flood Warning Network Map
- Bremer River, Warrill and Lockyer Creeks Flood Warning Network Map
- Brisbane, Bremer and Stanley Rivers Flood Warning Network Map
- Metropolitan Brisbane, Ipswich, Logan, Pine and Caboolture Rivers Flood Warning Network Map.

Main Roads Department

Discussions were held with Mr John Barff, Principal Engineer (Hydraulics) with Main Roads Department. Main Roads Department owns the state controlled roads throughout Queensland including a number of roads in the Bremer River catchment. The flood immunity of these roads is important from a flood risk perspective since they are concerned with evacuation and communication during flood events.

The Department has no specific information on the roads in the Bremer River catchment except to refer to the flood immunity standard of ARI 50 year flood immunity. It was recognised that many of the roads in the Bremer River catchment have a flood immunity much lower than this level and these include many important transport links.

Other agencies

Other government agencies including the Environmental Protection Agency and the Department of Primary Industries had no specific concerns about floodplain risk assessment in the Bremer River catchment.

8. RISK ASSESSMENT BACKGROUND

8.1. DEFINITION

Risk is defined in the Australian Standard as the chance of something happening that will have an impact upon objectives, and is measured in terms of likelihood and consequences. There are three components, namely hazard, elements at risk (or exposure to hazard) and vulnerability (of the elements at risk).

Risk analysis needs to estimate the level of the risk and to provide input for risk evaluation and development of treatment options.

This definition can be applied to all types of hazard, but this report is concerned only with flood hazards.

The Natural Disaster Risk Management Studies Programme for the Council identified that flooding is one of the most important hazards for the City of Ipswich and the Bremer River catchment is the main catchment of concern.

8.2. LIKELIHOOD

The likelihood of occurrence of a flood event in a defined period of time can be calculated from the statistics of flooding. The flood with an average recurrence interval of 100 years (ARI 100 years) is normally adopted for floodplain management (as it is in Ipswich City), though flood risk assessment requires a consideration of other flood events up to the Probable Maximum Flood, defined as the largest flood that can occur. The flood studies for the Ipswich Rivers Flood Study have only calculated floods up to ARI 100 years.

Adopting a period of 50 years, Figure 8.1 shows the likelihood of occurrence of floods of different probabilities during a 50 year period.

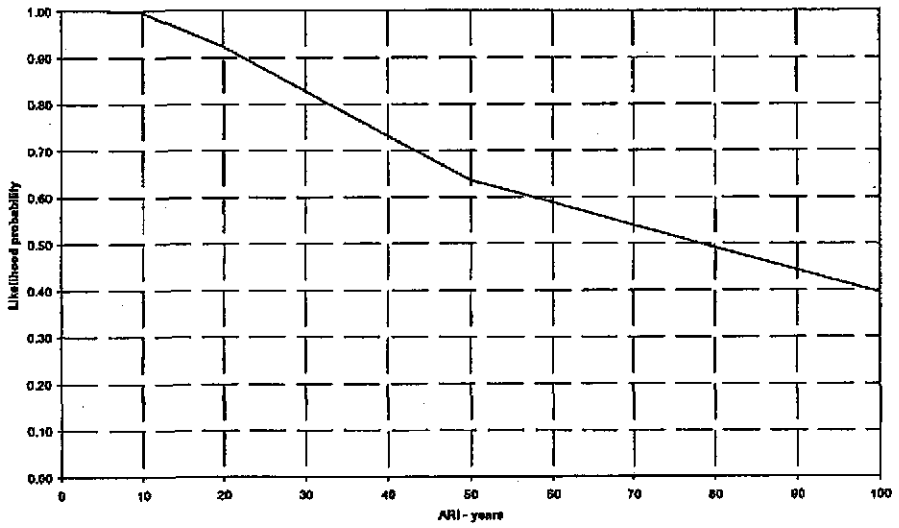

Figure 8.1 Likelihood of Occurrence in a 50-year Period

This figure shows that there is an approximately 40% probability of occurrence of the ARI 100 year flood in any 50 year period, while a flood with an average recurrence interval of 20 years is very likely with a likelihood probability of over 90%.

The likelihood ratings for floods of different average recurrence intervals are listed in Table 8.1.

Table 8.2 Likelihood of floods

Likelihood	Likelihood probability	Approximate ARI - years
Rare	<10%	500
Unlikely	<50%	100
Possible	<75%	50
Likely	<90%	20
Almost certain	>90%	10

8.3. CONSEQUENCES

The consequence is the impact of the hazard, and is defined on a scale from insignificant to catastrophic. The consequences of flood events can be established with several different criteria.

The information provided in the presentation for the first SAG meeting for this project listed consequences in six criteria as follows:

- Financial (revenue and costs)
- Information and data
- Property
- People
- Provision of services and performance
- Environment.

Depending on specific conditions, a range of criteria could be analysed as well as these.

The consequences are illustrated in Table 8.2, which lists consequences for property. There are similar categories for a range of other criteria, though property is an important criterion for flood hazards and indicates the type of issues for other criteria.

Table 8.3 Consequences – property

Consequence	Issue
1. Insignificant	Negligible damage to or loss of assets
2. Minor	Minor loss / damage. Some repairs may be required
3. Moderate	Moderate to high damage requiring specialist/contractor equipment to repair or replace
4. Major	Significant / permanent damage to assets and / or infrastructure
5. Catastrophic	Widespread, substantial / permanent damage to assets and/or infrastructure

8.4. VULNERABILITY

The third aspect of the risk assessment analysis is vulnerability. This was described in the section of this report on Community Vulnerability.

Vulnerability is a measure of the exposure of the community to hazards and the degree to which the community can cope with the hazard and then recover from the disaster afterwards.

There is insufficient information to provide a quantitative assessment of community vulnerability, however a number of issues are relevant.

Population Characteristics

The characteristics of the population at risk provide an indication of the vulnerability of the community. In the Bremer River catchment, there are both rural and urban communities, with the urban communities including large urban areas such as the main Ipswich suburbs as well as smaller urban communities, such as the town of Rosewood. These different communities have different responses to flood hazards and damage to their property.

Critical Facilities

The vulnerability of different community assets depends on the type of asset. For example, while the consequences of flood damage to residential property are of concern, the consequences of damage to important community facilities such as water treatment plants for example are greater.

Communications

Floods can cause severe disruption to communications. In particular, the most obvious disruption is the closure or damage of roads and railways. There are however other communication facilities that can be closed such as telecommunications or airports.

Evacuation and Protection of Property

The issue of evacuation and protection of property is closely related to the question above on communication, but is somewhat broader. It depends not only on the timing and probability of flood inundation of property and the closure of roads and other evacuation routes, but also on the preparation of the community and the effectiveness of warning systems.

Flood Forecasting and Warning

Effective flood forecasting and warning systems are important for reducing the vulnerability of the community and this has been recognised in Ipswich including the first public meeting for this project. While flood forecasting and warning systems do not have any impact on the potential damages in a flood event, they can have a significant impact on the actual damages that occur in a particular event. Surveys of actual flood events have shown that a well prepared community with adequate warning can reduce the damage to a significant extent.

Community Awareness

The development of awareness of the risk of flooding is an important part of the management of community vulnerability. This project, with its associated public meetings and consultation programme, is one means of increasing the awareness of the community to flood risks. The vulnerability of the community, that is the ability of the community to respond to flood events, is improved by improving the community understanding of the events and the most appropriate response.

8.5. RISK ANALYSIS

The risk analysis is prepared primarily from the combination of the likelihood and consequences with the vulnerability providing another factor.

The risk analysis can be expressed as a matrix as shown in Table 8.3.

Table 8.4 Risk analysis matrix

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Moderate	High	Extreme	Extreme	Extreme
Likely	Moderate	High	High	Extreme	Extreme
Possible	Low	Moderate	High	Extreme	Extreme
Unlikely	Low	Low	Moderate	High	Extreme
Rare	Low	Low	Moderate	High	High

8.6. CONCLUSION

The three issues involved in flood risk assessment have been introduced here and are described further below and implemented in this specific context.

9. FLOOD CHARACTERISTICS

9.1. INTRODUCTION

This section includes details of the data used for the assessment of flood risk, based on the flood studies and the flood map data provided by the Council.

9.2. FLOOD INUNDATION

The Bremer River is a major tributary of the Brisbane River and is the primary focus of this study. The catchment location map is shown in Figure 9.1. For the purpose of this report, the Bremer River floodplain has been divided into the following main tributaries.

- ***Bremer River:*** The Bremer River floodplain includes significant urban areas in the lower reaches in the main centre of the City of Ipswich, but much of the upper reaches are rural. Large areas of the floodplain are used for agricultural production.
- ***Bundamba Creek:*** This tributary flows from the south and joins the Bremer River in the Ipswich suburbs of Bundamba and North Booval. There are significant urban areas in the lower reaches, with rural land in the upper reaches.
- ***Ironpot Creek:*** This tributary flows from the north-west and joins the Bremer River in the Ipswich suburb of Brassall. There is relatively limited urban development in the floodplain, but most of the floodplain area is close to urban areas.
- ***Deebing Creek:*** This tributary flows from the south and joins the Bremer River in the Ipswich suburbs of Churchill and West Ipswich. There is considerable urban development particularly in the lower reaches.
- ***Warrill Creek:*** This is the most significant tributary of the Bremer River, and has a similar catchment area (including the tributary Purga Creek, noted below) to the remainder of the Bremer River catchment. It flows from the south and joins the Bremer River near Amberley. Except for some small urban areas in the lower reaches, the floodplain of Warrill Creek is mainly rural, with intensive agricultural production, including irrigation, over large areas. Moogerah Dam is a source for irrigation water and is located on the upper reaches of the catchment, outside the Ipswich City area.

- ***Purga Creek:*** This creek is a tributary of Warrill Creek, also flowing from the south. The floodplain of Purga Creek is also mainly rural with agricultural production on large areas of floodplain.
- ***Western Creek (including Franklin Vale Creek):*** This stream is a tributary of the Bremer River, flowing from the west and joining the Bremer River near the town of Rosewood. Most of the floodplain of this creek, including Franklin Vale Creek is rural.
- ***Brisbane River tributaries:*** There are three relatively minor tributaries that flow into the Brisbane River downstream of the Bremer River junction. These are Six Mile, Goodna and Woogaroo Creeks.

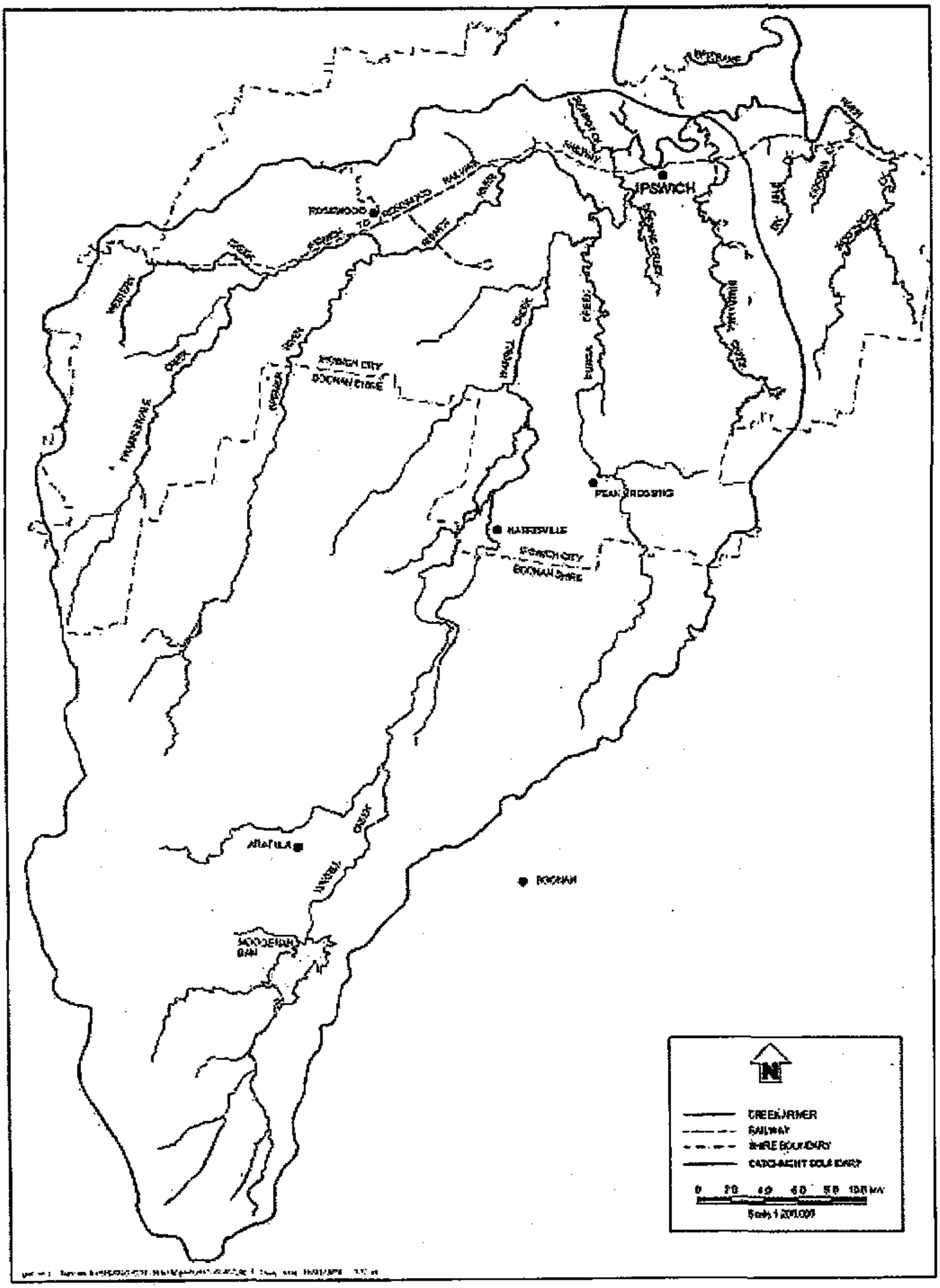

Figure 9.1 Catchment location map

9.3. FLOOD INUNDATION DATA

Ipswich City Council supplied flood inundation maps for the Bremer River and tributaries that had resulted from the previous flood studies.

Flood maps were supplied for floods with average recurrence intervals of 20 and 100 years as well as for the 1974 flood, the largest historical flood with significant observations of levels and inundation.

Flood maps for the ARI 100 year flood are plotted in Figures 9.2 to 9.7.

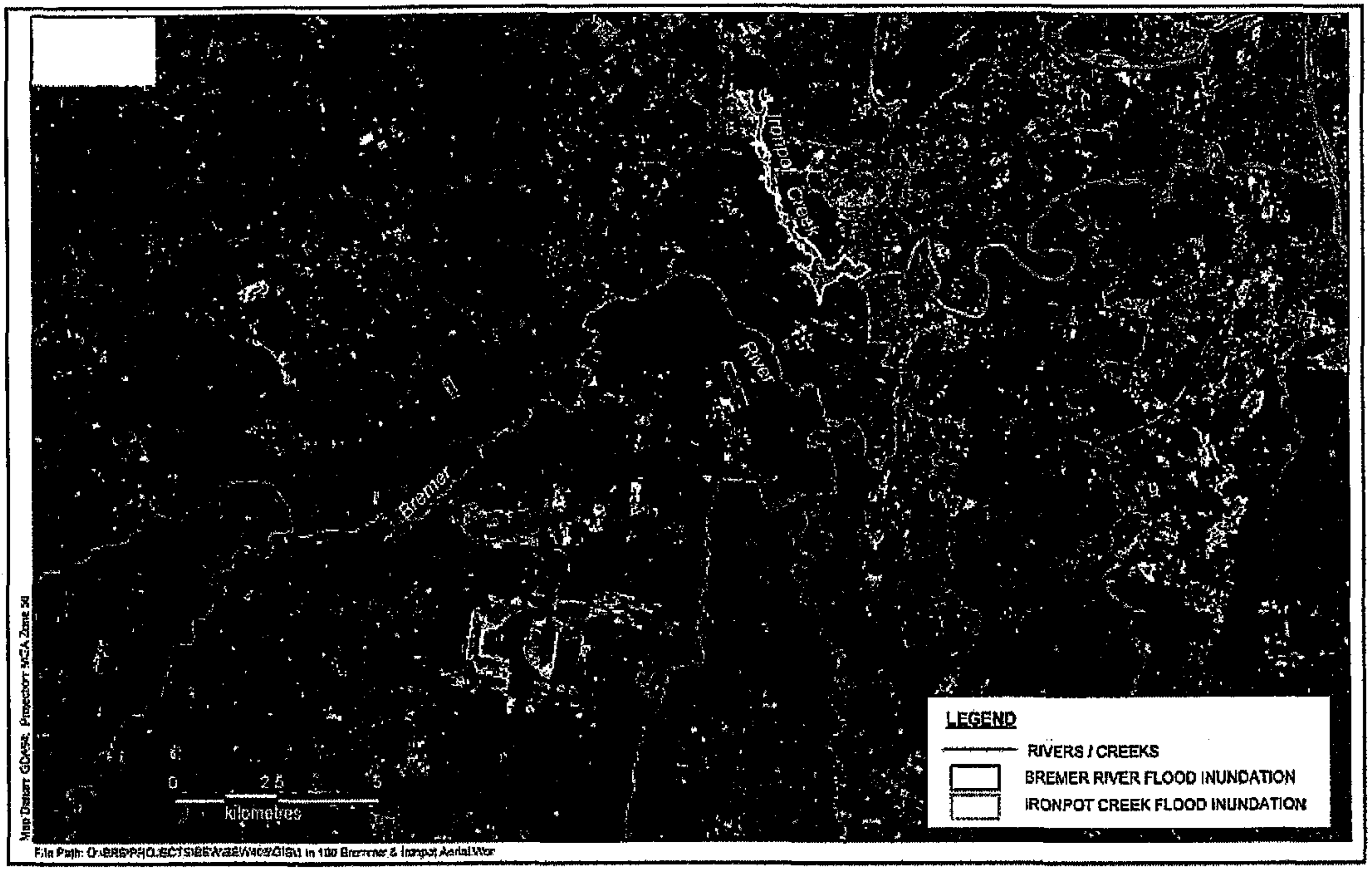

Figure 9.2 Flood map for the ARI 100 year flood – Bremer River and Ironpot Creek Catchments

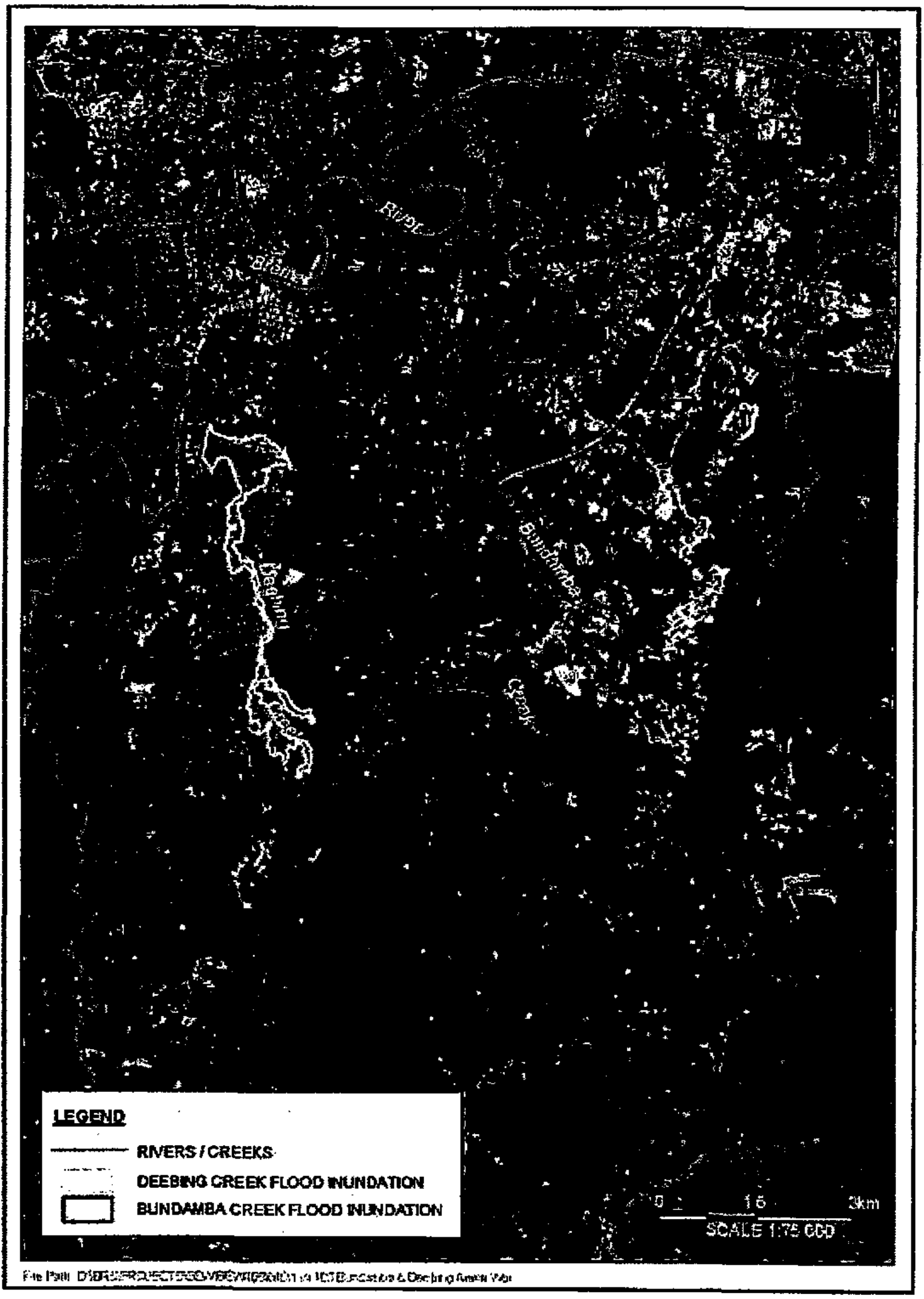

Figure 9.3 **Flood map for the ARI 100 year flood – Bundamba Creek and Deebing Creek Catchments**

Figure 9.4 **Flood map for the ARI 100 year flood – Warrill Creek and Purga Creek Catchments**

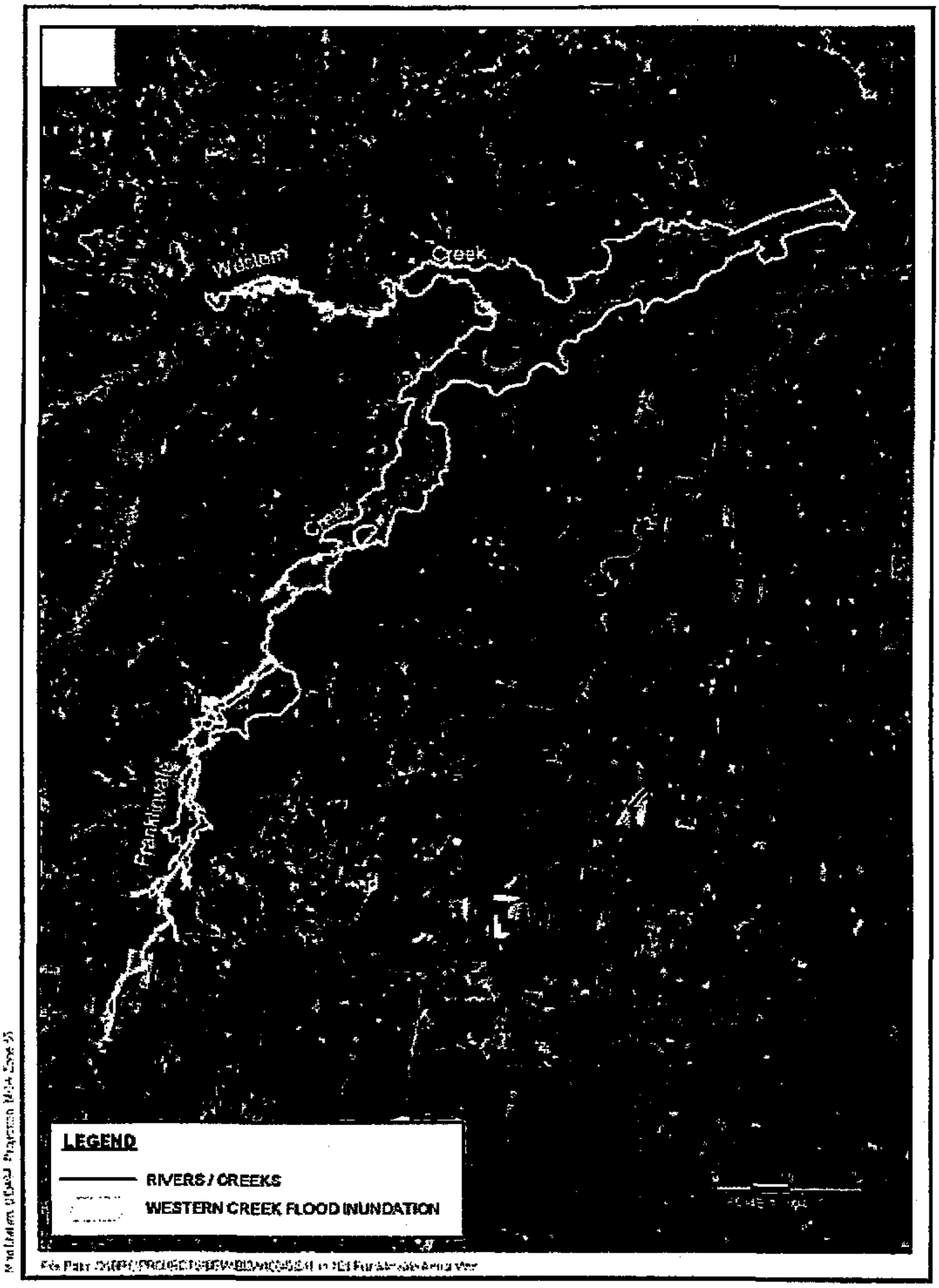

Figure 9.5 Flood map for the ARI 100 year flood – Western Creek Catchment

Figure 9.6 Flood map for the ARI 100 year flood – Six Mile and Goodna Creeks Catchment

Figure 9.7 Flood map for the ARI 100 year flood – Woogaroo Creek Catchment

9.4. FLOOD ASSESSMENT

The AGSO report referred to in previous reports of this project provided data for the urban areas of Ipswich City. This report provides data for the whole of the Bremer River catchment, with results subdivided into the sub-catchments referred to above.

The data supplied by Ipswich City Council on flood inundation included data for three flood events, the ARI 100 and 20 year events and the 1974 flood. The 1974 flood data appeared to be based on backwater from the Brisbane River so it did not include reliable data for the upper reaches of any of the tributaries. The data for the ARI 20 year flood also appeared incomplete, but the reason for this was not clear. The ARI 100 year flood inundation, which was the principal concern in the original flood mapping project and also for this project, appeared to be acceptable.

The total areas of inundation in each of the sub-catchments are listed in Table 9.1.

Table 9.1 Area of inundation (area in ha)

Sub-catchment	ARI 100 year flood
Bremer River	5,760
Bundamba Creek	618
Ironpot Creek	142
Deebing Creek	151
Warrill Creek	3,027
Purga Creek	2,038
Western Creek	1,915
Six Mile Creek	211
Goodna Creek	122
Woogaroo Creek	238
Total	14,094

The number of lots affected by flooding in each sub-catchment is listed in Table 9.2.

Table 9.2 Number of lots inundated

Sub-catchment	ARI 100 year flood
Bremer River	2,907
Bundamba Creek	725
Ironpot Creek	126
Deebing Creek	239
Warrill Creek	261
Purga Creek	153
Western Creek	253
Six Mile Creek	146
Goodna Creek	105
Woogaroo Creek	633
Total	5,548

There was 197 km of road inundated in the ARI 100 year flood event.

9.5. OTHER ISSUES

Other aspects of the assessment of flood risk need to consider flood mitigation and flood warning systems, which provide means of mitigating the risk.

There are some flood mitigation works already existing in the catchment, and further assessment is suggested. As well, there are also some flood forecasting and warning systems in the catchment and comment on the effectiveness of these systems has been received in the consultation process.

9.6. REVIEW

The flood data supplied shows considerable impact on the community from floods, for both likely and unlikely design floods and the largest historical flood event in recent years. The implications of these results for the flood risk assessment are discussed further below.

10. RISK ASSESSMENT

10.1. BASIS OF ASSESSMENT

The approach to risk assessment has been discussed in previous reports for this project.

The risk rating resulting from the flood hazards is based on an analysis of the combination of the likelihood and consequences as listed in Table 10.1.

Table 10.1 Risk analysis matrix

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Moderate	High	Extreme	Extreme	Extreme
Likely	Moderate	High	High	Extreme	Extreme
Possible	Low	Moderate	High	Extreme	Extreme
Unlikely	Low	Low	Moderate	High	Extreme
Rare	Low	Low	Moderate	High	High

The assessment in this report reviews the range of flood hazards and evaluates the risk rating for each sub-catchment of the project area for each vulnerable element. The list of risk ratings indicates the key locations and elements that are relevant for consideration of mitigation measures.

10.2. RISK REGISTER

Introduction

The main issues described in this report are the two risk register components, Part A (Risk Description) and Part B (Risk Evaluation). These concepts were introduced in the previous report, but the current report provides more detailed assessment.

Catchment Subdivision

For the purposes of this assessment the Bremer River catchment has been subdivided into eight sub-catchments as follows.

- ***Bremer River:*** The Bremer River floodplain includes significant urban areas in the lower reaches in the main centre of the City of Ipswich, but much of the upper reaches are rural. Large areas of the floodplain are used for agricultural production. There are coal mines located on the floodplain.
- ***Bundamba Creek:*** This tributary flows from the south and joins the Bremer River in the Ipswich suburbs of Bundamba and North Booval. There are significant urban areas in the lower reaches, with rural land and some industrial development (including Swanbank power Station) in the upper reaches.
- ***Ironpot Creek:*** This tributary flows from the north-west and joins the Bremer River in the Ipswich suburb of Brassall. There is relatively limited urban development in the floodplain, but most of the floodplain area is close to urban areas.
- ***Deebing Creek:*** This tributary flows from the south and joins the Bremer River in the Ipswich suburbs of Churchill and West Ipswich. There is considerable urban development particularly in the lower reaches.
- ***Warrill Creek:*** This is the most significant tributary of the Bremer River, and has a similar catchment area (including the tributary Purga Creek, noted below) to the remainder of the Bremer River catchment. It flows from the south and joins the Bremer River near Amberley. Except for some minor urban areas mainly in the lower reaches, the floodplain of Warrill Creek is mainly rural, with intensive agricultural production, including irrigation, over large areas of floodplain. Moogerah Dam is a source for irrigation water and is located on the upper reaches of the catchment, outside the Ipswich City area.
- ***Purga Creek:*** This creek is a tributary of Warrill Creek, also flowing from the south. The floodplain of Purga Creek is similar to Warrill Creek and is also mainly rural with agricultural production on large areas of floodplain.
- ***Western Creek (including Franklin Vale Creek):*** This stream is a tributary of the Bremer River, flowing from the west and joining the Bremer River near the town of Rosewood. Most of the floodplain of this creek, including the tributary Franklin Vale Creek is rural.
- ***Woogaroo, Goodna and Six Mile Creeks:*** These streams are tributaries of the Brisbane River flowing from the south and joining the river downstream of the junction with the Brisbane River. There are some areas of development affected by inundation.

This subdivision has been adopted since it is a convenient means of separating out the components of the study.

The information is not adequate to allow any more detailed subdivision of the data so these sub-catchments have been analysed.

Vulnerable Elements

The first consideration is to look at the consequences for flood hazard on vulnerable elements. The presentations early in this project have outlined the range of consequences. As well, the Natural Disaster Risk Management Report produced by Fisher Stewart in 2001 provides discussion of flood risks as well as other natural disaster risk assessments.

This information has been reviewed and the range of vulnerable elements considered relevant in the current study is listed as follows:

- ***People:*** The population at risk or affected by flooding is clearly one of the most significant elements. The risk for people covers both damage to property, losses of possessions and possible loss of life. Lives have been lost in previous flood events in the catchment. There will be a major disruption to the lives of many people, including possible loss of life. Loss of life is especially an issue when motorists drive across flooded bridges and floodplains. Even though the population density is higher in the urban parts of the catchment, there is still disruption to the population in rural areas as well. Clearly the potential impact on people is an important element.
- ***Residential property:*** This includes houses in the flood prone regions. This is expected to be the most significant financial loss, because of the large number of residential properties in the catchment. As with the significant impact on people, there are many residential properties inundated. While there is a concentration of residential properties in the lower urban reaches, there is a scatter of residential properties in the rural areas as well. Floor levels are not surveyed for the residential properties, but anecdotal evidence is that there are relatively few residential properties in the rural areas that are inundated in even major floods. The total number of residential properties affected in the rural areas is less than in the urban areas.
- ***Business:*** This includes a range of commercial and industrial facilities. There are many businesses in urban and rural parts of the catchment, and many industries are represented. Most business in the catchment is located in the lower urban reaches and this business includes the Central Business District of Ipswich. There are smaller concentrations of businesses in the smaller urban centres. There is limited business located in the upper rural areas.
- ***Agriculture:*** This is an important industry in many floodplains of the rural parts of the project catchments, and includes crops, livestock and agricultural infrastructure such as fences. Agriculture is concentrated in the rural areas. Floods in rural areas will cause damage to crops and livestock as well as farm infrastructure, particularly fences which are vulnerable to flood damage. Many of the floodplains throughout the Bremer River catchment are used for intensive agriculture.

- ***Environment:*** Flooding can cause damage by scour and other 'natural' processes and this damage is possible in all parts of the catchment. As well floods may overtop levees or cause damage to water quality control facilities or industry and cause the discharge of contaminated water. For example discharge of contaminated water from mines or waste water treatment facilities during large flood events would be a significant risk because of the poor water quality in mine pits. These events will occur in specific locations where these facilities are located.
- ***Lifelines:*** Communication links, especially roads needed for evacuation during flood events and telecommunication links needed for dissemination of information during emergencies, are critical lifelines. Others include infrastructure supplies of water, sewerage, gas and electricity. Roads are the vital links throughout the whole catchment, while other lifelines are more concentrated in the urban areas. Because of the importance of roads, the flood immunity of all roads crossing the main water courses are listed in Section 11.
- ***Critical facilities:*** These include other facilities in addition to those noted above as lifelines, such as emergency centres and hospitals. Most of the critical facilities are located in the urban areas, though there are some in other regions, such as water treatment or sewage facilities.
- ***Special facilities:*** These cover individual facilities such as museums that may have irreplaceable contents or the RAAF facility at Amberley. These are individual high value facilities that are outside the normal categories listed above. Other special facilities include a number of mines, several of which are located on the floodplain.

Risk Register Parts A and B

Introduction

The risk rating for each sub-catchment has been calculated from the assessment of the consequences and likelihood of flood events for each sub-catchment. The issues are discussed and the risk weighting developed for each sub-catchment in the following sections.

General

The first part of this section provides background information for all of the sub-catchments and this is subsequently analysed in detail for each and results provided.

Assessment of each of the vulnerable elements particularly considers the ARI 100 year flood, noting that the likelihood of the ARI 100 year flood is classified as unlikely.

Where appropriate, there is some discussion of other flood events.

Bremer River

The Bremer River floodplain included in this analysis covers the main river channel excluding the tributaries described below. The lower reaches include major urban areas such as the City Centre of Ipswich while the upper reaches are predominantly rural with important agricultural land on the floodplain. There are a total of 5,760 ha and 2,907 lots inundated in the ARI 100 year flood event. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of main concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.2.

Table 10.2 Bremer River—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Major	Major	High	High
Residential property	Major	Minor	High	Low
Business	Major	Minor	High	Low
Agriculture	Minor	Major	Low	High
Environment	Moderate	Moderate	Moderate	Moderate
Lifelines	Major	Moderate	High	Moderate
Critical facilities	Major	Major	High	High
Special facilities	Major	Minor	High	Low
Overall	Major	Moderate	High	Moderate

Bundamba Creek

The Bundamba Creek floodplain included in this analysis covers a creek section where the creek flows into the Bremer River. The lower reaches include significant urban areas as well as industrial and commercial zones while the upper reaches are predominantly rural with some agriculture on the floodplain, though the land use seems to be mainly grazing. There is a limited extent of inundation in the upper rural floodplains. The Swanbank Power Station is located in the catchment, though it appears to be outside the extent of the ARI 100 year flood. There are major arterial roads crossing the creek in the Cunningham Highway and Brisbane Road, both of which are inundated by the ARI 100 year flood. There are a total of 618 ha and 725 lots inundated in the ARI 100 year flood event. This is a smaller number than are inundated in the Bremer River catchment, but the floodplain and catchment areas are both significantly smaller than the Bremer River. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.3.

Table 10.3 Bundamba Creek—consequences and risk rating

Element	**Consequences**		**Risk rating**	
	Urban	**Rural**	**Urban**	**Rural**
People	Major	Minor	High	Low
Residential property	Major	Minor	High	Low
Business	Major	Minor	High	Low
Agriculture	Minor	Minor	Low	Low
Environment	Major	Minor	High	Low
Lifelines	Major	Moderate	High	Moderate
Critical facilities	Major	Minor	High	Low
Special facilities	Major	Minor	High	Low
Overall	Major	Minor	High	Low

Ironpot Creek

The Ironpot Creek floodplain included in this analysis covers a relatively minor creek section where the creek flows into the Bremer River from the north-west. There are some urban areas, though these are minor. Much of the floodplain is predominantly rural with some agriculture on the floodplain, though the land use seems to be mainly grazing. There is one major arterial road, the Warrego Highway, crossing the creek and this appears to be inundated by the ARI 100 year flood. There are a total of 142 ha and 126 lots inundated in the ARI 100 year flood event. This is a relatively small number, but the floodplain and catchment areas are both small. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.4.

Table 10.4 Ironpot Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	**Rural**	**Urban**	**Rural**
People	Minor	Minor	Low	Low
Residential property	Minor	Minor	Low	Low
Business	Minor	Minor	Low	Low
Agriculture	Minor	Minor	Low	Low
Environment	Minor	Minor	Low	Low
Lifelines	Moderate	Minor	Moderate	Low
Critical facilities	Minor	Minor	Low	Low
Special facilities	Minor	Minor	Low	Low
Overall	Minor	Minor	Low	Low

Deebing Creek

The Deebing Creek floodplain included in this analysis covers a relatively minor creek section where the creek flows into the Bremer River from the south. There are some urban areas, though these are minor. Much of the floodplain is predominantly rural with some agriculture on the floodplain, though the land use seems to be mainly grazing. The extent of flooding is narrow for most of the length of the floodplain except for a small area in the lower reaches. There is one major arterial road, the Cunningham Highway, crossing the creek and this appears to be inundated by the ARI 100 year flood. There are a total of 151 ha and 239 lots inundated in the ARI 100 year flood event. This is a relatively small number, but the floodplain and catchment areas are both small. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.5.

Table 10.5 Deebing Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Minor	Minor	Low	Low
Residential property	Minor	Minor	Low	Low
Business	Minor	Minor	Low	Low
Agriculture	Minor	Minor	Low	Low
Environment	Minor	Minor	Low	Low
Lifelines	Moderate	Minor	Moderate	Low
Critical facilities	Minor	Minor	Low	Low
Special facilities	Minor	Minor	Low	Low
Overall	Minor	Minor	Low	Low

Warrill Creek

The Warrill Creek floodplain included in this analysis covers a major tributary of the Bremer River flowing from the south. There are essentially no urban areas. Much of the floodplain is predominantly rural with extensive agriculture on the floodplain. There is a wide extent of flood inundation over much of the length of floodplain. There is one major arterial road, the Cunningham Highway, crossing the creek and this appears to be inundated by the ARI 100 year flood and there are many other connecting roads, most of which have low flood immunity at creek crossings. There are a total of 3,027 ha and 261 lots inundated in the ARI 100 year flood event. The relatively small number of lots for the large area of inundation indicates the mainly rural nature of the floodplain. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.6.

Table 10.6 Warrill Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Minor	Moderate	Low	Moderate
Residential property	Minor	Minor	Low	Low
Business	Minor	Minor	Low	Low
Agriculture	Minor	Major	Low	High
Environment	Minor	Moderate	Low	Moderate
Lifelines	Minor	Moderate	Low	Moderate
Critical facilities	Minor	Minor	Low	Low
Special facilities	Minor	Minor	Low	Low
Overall	Minor	Moderate	Low	Moderate

Purga Creek

The Purga Creek floodplain included in this analysis covers a major tributary of Warrill Creek, joining the creek just before it reaches the Bremer River, flowing from the south. It is very similar to Warrill Creek and there are essentially no urban areas. Much of the floodplain is predominantly rural with extensive agriculture on the floodplain. There is a wide extent of flood inundation over much of the length of floodplain. There is one major arterial road, the Cunningham Highway, crossing the creek and this appears to be inundated by the ARI 100 year flood and there are many other connecting roads, most of which have low flood immunity at creek crossings. There are a total of 2,038 ha and 153 lots inundated in the ARI 100 year flood event. As with Warrill Creek, the relatively small number of lots for the large area of inundation indicates the mainly rural nature of the floodplain. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.7.

Table 10.7 Purga Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Minor	Moderate	Low	Moderate
Residential property	Minor	Minor	Low	Low
Business	Minor	Minor	Low	Low
Agriculture	Minor	Major	Low	High
Environment	Minor	Moderate	Low	Moderate
Lifelines	Minor	Moderate	Low	Moderate
Critical facilities	Minor	Minor	Low	Low
Special facilities	Minor	Minor	Low	Low
Overall	Minor	Moderate	Low	Moderate

Western Creek (including Franklin Vale Creek)

The Western Creek floodplain (with Franklin Vale Creek) included in this analysis covers a major tributary of the Bremer River. It is similar to Warrill and Purga Creeks. There are essentially no urban areas. Much of the floodplain is predominantly rural with extensive agriculture on the floodplain. There is a wide extent of flood inundation over much of the length of floodplain, though there are some areas of relatively narrow inundation. There are many connecting roads, though no major highways. There are a total of 1,915 ha and 253 lots inundated in the ARI 100 year flood event. As with Warrill and Purga Creeks, the relatively small number of lots for the large area of inundation indicates the mainly rural nature of the floodplain, though there are some smaller lots in this catchment. There are rural residences that are in the area of inundation, though the extent of damage in floods is not known. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.8.

Table 10.8 Western (and Franklin Vale) Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Minor	Moderate	Low	Moderate
Residential property	Minor	Minor	Low	Low
Business	Minor	Minor	Low	Low
Agriculture	Minor	Major	Low	High
Environment	Minor	Moderate	Low	Moderate
Lifelines	Minor	Moderate	Low	Moderate
Critical facilities	Minor	Minor	Low	Low
Special facilities	Minor	Minor	Low	Low
Overall	Minor	Moderate	Low	Moderate

Woogaroo Creek

The Woogaroo Creek catchment is a tributary of the Brisbane River flowing from the south and joining the river in the suburb of Gailes. The upper parts of the creek are mainly rural but there are areas of residential and commercial development in the lower reaches. There are important transport links crossing the creek in the lower reaches with the Ipswich Motorway and the Ipswich Railway crossing the creek. The lower reaches of the creek are affected by backwater from the Brisbane River as well as by flooding from the local catchment. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.9.

Table 10.9 Woogaroo Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Major	Minor	High	Low
Residential property	Major	Minor	High	Low
Business	Major	Minor	High	Low
Agriculture	Minor	Minor	Low	Low
Environment	Moderate	Moderate	Moderate	Moderate
Lifelines	Major	Minor	High	Low
Critical facilities	Moderate	Minor	Moderate	Low
Special facilities	Moderate	Minor	Moderate	Low
Overall	Moderate	Minor	Moderate	Low

Goodna Creek

Goodna Creek is a tributary of the Brisbane River, flowing from the south and joining the river in the suburb of Goodna. It has similarities to Woogaroo Creek. The upper reaches of the creek are mainly rural, but there are some areas of residential and commercial development in the lower reaches. The Ipswich Motorway and the Ipswich Railway cross the creek in the lower reaches. Flooding in the creek is affected by both backwater from the Brisbane River and local catchment flooding. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.10.

Table 10.10 Goodna Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Minor	Minor	Low	Low
Residential property	Minor	Minor	Low	Low
Business	Moderate	Minor	Moderate	Low
Agriculture	Minor	Minor	Low	Low
Environment	Moderate	Moderate	Moderate	Moderate
Lifelines	Moderate	Minor	Moderate	Low
Critical facilities	Moderate	Minor	Moderate	Low
Special facilities	Moderate	Minor	Moderate	Low
Overall	Moderate	Minor	Moderate	Low

Six Mile Creek

Six Mile Creek is a tributary of the Brisbane River, flowing from the south and joining the river between Redbank and Riverview. It has similarities to Woogaroo and Goodna Creeks. The upper reaches of the creek are mainly rural, but there are some areas of residential and commercial development in the lower reaches. The inundation maps however do not indicate any residential or commercial properties that are actually inundated. The Ipswich Motorway and the Ipswich Railway cross the creek in the lower reaches. Flooding in the creek is affected by both backwater from the Brisbane River and local catchment flooding. The likelihood of occurrence of the ARI 100 year flood is classified as unlikely. The smaller floods that would be classified as possible with an ARI of the order of 10 years have more limited impacts. The floods of concern in this assessment therefore are classified as unlikely.

The consequences and risk rating for each of the vulnerable elements are listed in Table 10.11.

Table 10.11 Six Mile Creek—consequences and risk rating

Element	Consequences		Risk rating	
	Urban	Rural	Urban	Rural
People	Minor	Minor	Low	Low
Residential property	Minor	Minor	Low	Low
Business	Minor	Minor	Low	Low
Agriculture	Minor	Minor	Low	Low
Environment	Moderate	Moderate	Moderate	Moderate
Lifelines	Moderate	Minor	Moderate	Low
Critical facilities	Minor	Minor	Low	Low
Special facilities	Minor	Minor	Low	Low
Overall	Minor	Minor	Low	Low

Flood Risk Overview

The assessment of flood risk discussed above indicates that the flood risk is higher in the catchments with more intense development, particularly the Bremer River and Bundamba Creek. The flood risk is lower in the smaller tributaries, partly because of the smaller extent of development but also because of the relatively small extent of flood inundation in many areas. The rural areas of Warrill and Purga Creeks however have a higher risk rating for the rural areas because of the higher value agricultural development in these catchments and the wide extent of inundation.

The flood risk therefore would indicate that higher value treatment measures would be more justified in the areas of higher risk rating, while more general flood risk measures will be justified throughout the whole Bremer River because of the generally widespread distribution of risk, though at a lower level in parts.

11. BRIDGE FLOOD IMMUNITY

The Ipswich Rivers Flood Study Phase 3 included details of the flood immunity of all of the bridges in that region of the Bremer River flood study, essentially the rural areas of Ipswich City and the Bremer River catchment. The flood immunity of all bridges is listed in Table 11.1.

Table 11.1 Summary of flood immunity for all hydraulic structures

Reach	Chainage (m)	Controlling weir level (m AHD)	Structure Flood Immunity (ARI)	Crossing name
Bremer	2482.00	46.73	2	Mt. Walker West
Bremer	9793.63	38.74	2 - 5	Rosewood–Warill View Road
Bremer	11482.63	37.08	<2	Keane's Road
Bremer	14410.00	34.78	5	Jeebropilly
Bremer	15070.00	34.05	2	7 Mile Creek
Bremer	19370.00	27.52	2	5 Mile Creek
Bremer	29525.00	17.50	2	3 Mile Creek
Bremer-Boonah	11926.89	96.45	20	Unknown
Bremer-Boonah	13934.22	86.73	5	Unknown
Bremer-Boonah	16512.06	80.03	10	Unknown
Bremer-Boonah	24551.71	57.78	<2	Unknown
Franklinvale	5623.15	96.29	<2	Franlinvale Road
Franklinvale	8835.62	85.32	2	Meadow Flat Road
Franklinvale	17032.00	59.96	<2	Cummings Road
Purga	2996.06	49.92	<2	Ipswich-Boonah Road
Purga	12796.29	29.47	<2	Purga School Road
Purga	19940.56	22.19	10	Cunningham Hway
Purga_2	30.85	60.33	<2	Washpool Road
Purga_2	2888.285	53.71	2	Dwyers Road Bridge

Reach	Chainage (m)	Controlling weir level (m AHD)	Structure Flood Immunity (ARI)	Crossing name
RailBridge	10.00	Various	>100	Ipswich-Rosewood R'way
RailSouth	9781.72	50.70	2	Kuss Road
RailSouth	12400.00	44.05	2	Strongs Bridge
RailSouth	14848.00	41.14	<2	Warrill View Road
Warrill	2434.10	49.26	<2	Private Rd
Warrill	3493.49	46.18	<2	Unknown
Warrill	4788.90	49.22	>100	Fresser's Bridge
Warrill	6402.07	42.29	<2	Unknown
Warrill	7121.27	38.63	<2	Private Rd
Warrill	11589.99	37.40	<2	Mutdapilly-Churchbank Rd
Warrill	25720.35	26.84	20	Cunningham Road
Warrill-Boonah	3392.50	137.54	10	Villis Bridge
Warrill-Boonah	15989.89	88.06	>100	Maclean Bridge
Warrill-Boonah	19454.64	75.08	5	Kalbar Bridge
Warrill-Boonah	26310.71	64.92	2	Unknown
Warrill-Boonah	30804.86	57.58	<2	Walter Harsant Bridge
Warrill-Boonah	30804.86	57.58	<2	Radford Rd
Warrill-Boonah	30804.86	57.58	<2	Wilsons Plains
Western	858.96	85.74	>100	Rosewood-Laidley Road
Western	858.96	85.74	>100	Grandchester-Mt Mort Road
Western	6898.85	59.96	>100	Hiddenvale Road

This indicates that a large number of bridges, especially roads, rather than rail, have relatively low flood immunity, which is important for the consideration of lifelines for flood evacuation.

The details of flood immunity of the bridges in the area covered by the Ipswich River Flood Study Phases 1 and 2 were not included in the report, but the general level of flood immunity is believed to be similar to that in the Phase 3 region.

12. TREATMENT OPTIONS (FLOOD MITIGATION)

12.1. INTRODUCTION

Preliminary assessment of flood mitigation measures was carried out in all phases of the Ipswich Rivers Flood Study. More detailed analysis would be needed to determine the real feasibility, but preliminary issues have been considered.

There are non-structural flood mitigation measures, including floodplain zoning and planning as well as flood forecasting and warning. Flood inundation maps and the design flood levels produced in the flood studies provide suitable material to develop these measures.

Where there are existing flood prone properties (especially high value facilities), structural flood mitigation measures may be more appropriate. These include measures such as flood mitigation dams and retention basins, channel works and levees. A number of such measures have been suggested over the years for several locations throughout the catchment.

As well as the potential damage to property, many of the bridges in the catchment have a low flood immunity and upgrading of the bridges would be useful to improve the evacuation of residents and communication during flood events.

These measures are discussed here and details of specific issues are also included.

12.2. GENERIC TREATMENT MEASURES

The risk register prepared previously allows the relative assessment of each sub-catchment.

This section gives an overview of generic measures, while specific measures and recommendations are described in the following section. The specific measures were developed from analysis of the issues and consultation with the Study Advisory Group, government agencies and the community.

Treatment measures are the flood mitigation measures that are appropriate for each flood risk and location. These treatment measures have been discussed previously in the flood risk and hazard report of this project.

The flood mitigation measures are classified as either structural or non-structural. An overview of potential mitigation measures is provided.

Non-Structural

Non-structural measures are a means of managing flood risk and are valuable because of the relatively low cost and potential high benefits. Non-structural measures can provide benefits throughout the catchment, including the rural areas where the risk rating is lower, because of the lower density of development, even though there are assets at risk.

The two principal means of non-structural flood mitigation are floodplain planning and zoning, and flood forecasting and warning.

Floodplain planning and zoning

Floodplain planning and zoning is a critical measure and is one that can clearly reduce the vulnerability of the community. Future development in the catchment is regulated but there are many properties that were developed before the current floodplain zoning was established and are currently at risk.

However the flood studies that have been carried out provide detailed flood inundation extents as well as details on floodways and areas of high flood hazard (high flow velocities and depths). These maps have been prepared in the Council GIS and allow an excellent picture of flooding with technical details as well as map overlays on aerial photographs.

Responsibility for floodplain planning and zoning lies with the Council. The Council has provided overlays within the 2004 Ipswich Planning Scheme that relate to flooding issues.

Floodplain planning not only includes the planning for development though this is important. Other aspects include community awareness and information programmes to ensure that the community is aware of flood risks and of actions necessary during flood disasters to minimise their losses and disruption. Because of the infrequent occurrence of floods, community education programmes are often difficult to implement and there may often be little interest in the community.

A number of agencies have an interest in community awareness campaigns. These include the Department of Natural Resources, Mines and Energy, the Bureau of Meteorology and the Department of Emergency Services as well as the Council. There is some material available, however this material requires both effective distribution and on-going reinforcement.

Flood forecasting and warning

Flood forecasting and warning is an important measure, and one that has been identified in the community consultation process for this project. It has also been discussed with the Bureau of Meteorology as part of the government agency consultation.

The process is a consultative one between several government agencies, with the Bureau providing the higher level technical inputs and the Council interpreting these to provide detailed and useful information of the community. Good technical input is critical and perhaps the easier component of the process, while the community aspects are more difficult, but probably more important.

Forecasting and warning systems do not affect the size of the flood or the extent of inundation, but they can reduce the vulnerability of the community and the actual damage by a significant extent.

In the case of the Bremer River, two different approaches are appropriate. The urban areas of the catchment, especially the Bremer River, but to a lesser extent Bundamba Creek and other smaller tributaries, are areas of high risk rating and are located in the lower reaches of the two catchments. Detailed flood forecasting and warning systems are appropriate in these locations and are already operating.

In the rural portions of the whole catchment, the risk rating is lower because of the lower concentration of vulnerable elements and more general flood forecasting and warning systems are appropriate in these regions. Again this system is operating in these parts of the catchment.

As with the consideration of community awareness and education programmes, infrequent occurrences of floods and the considerable period of time since the last major flood means that the community is inexperienced and are not aware of the interpretation of flood warnings and appropriate actions during a flood. Awareness and information programmes are also important to ensure that flood forecasting and warning systems operate effectively.

This project therefore sees flood forecasting and warning systems as an important means of reducing the community flood vulnerability and flood risk. The existing systems appear to be good technically but the dissemination of information may not be as effective as it could be.

Upgrading of the systems is a responsibility of the Bureau of Meteorology and the Council with lesser inputs from other agencies.

Structural

Structural measures provide works to reduce the impact of floods on the community.

<u>Flood storages</u>

Flood storages include flood mitigation dams as well as smaller flood detention basins. The effectiveness of flood mitigation storages depends on the volume of storage available as well as the location of the storage in relation to the flood prone property. The reduction of flood peak produced by the storage is related to the volume of the storage in relation to the volume of the flood and the storage should be located as close (upstream) as possible to the flood prone property.

In the case of these streams, the catchments are all relatively large so the required volume of any flood mitigation storage must also be large. As well, there are limited dam sites available in the catchments.

Small flood detention basins may be of value in some specific locations in small sub-catchments and these are easier to implement where the volume of flood storage required is relatively small.

There is a high cost in the construction of dams, and there are considerable social and environmental concerns so it is difficult to gain approvals for dam construction.

Because of the high costs and sometimes limited benefits from construction of flood mitigation storages, they are also difficult to justify economically, though there may be opportunities for small detention basins in specific locations.

Channel works

Channel works for flood mitigation are constructed by widening and straightening of stream channels to allow the flood flows to pass through the flood prone regions more quickly to reduce flood levels. Channel works require earth works and sometimes extensive clearing of vegetation.

Channel works are generally expensive and also often have considerable environmental impacts. There is also the possibility that the channel works may transfer flood problems to another more downstream part of the catchment by increasing the rate of flow through the channel. There are also technical problems since channel works require relatively steep channel slopes, to limit the extent of works. Where the channel is relatively flat, the widening of the channel may not provide sufficient benefits to justify the cost, because the channel must extend for a considerable distance downstream.

In the case of this catchment, the floodplains are generally relatively flat and there is a considerable discharge spread over a wide and flat floodplain. In addition, many of the potential flood prone areas are located downstream in the catchment. Both of these lead to a relatively low benefit from channel works, though there may be opportunities in some locations.

Levees

Levees could be a valuable option for particular locations where there is an existing area of flood prone property. In addition, because levees constrict the width of flow paths, the area to be protected by levees must be in a reach of the water course where these problems are relatively limited. Levees have been used in this study area, for example, for the flood protection of coal mines on the lower reaches of the Bremer River.

Levees therefore could be the most applicable structural flood mitigation measure for existing flood prone properties in the project area, especially where there is a concentration of properties at risk.

Levees are possible for flood mitigation for events in the main streams, and therefore are designed to limit the inundation from the main stream. However, they must also consider the issue of run-off from inside the levee as well as the flow in the main water course. This means that there must be an allowance for diversion of water from inside the levee.

Levees must also meet the requirements for economic performance of any flood mitigation project, before the scheme can be approved.

Overview

Because of the high costs, structural measures are often difficult to justify. In the case of the Bremer River, locations where structural measures could possibly be justified are in the more intensely developed parts of the catchment.

12.3. SPECIFIC TREATMENT MEASURES

Introduction

Specific treatment measures or flood mitigation options have been developed during the progress of the project from the review of relevant information and the consultation programme with the Study Advisory Group, Ipswich City Council, government agencies and the community.

The programme identified a number of appropriate measures. These were primarily in the area of non-structural and planning measures, though there were several structural measures identified for specific locations.

The flood mitigation measures described in this report have been divided into four categories with details of specific flood mitigation measures described in this section.

Flood Management Strategies

Flood management strategies include a group of non-structural measures. The main non-structural measures are described further below. The strategies are separated out in this report since they are more strategic issues than the direct management measures.

The strategies were raised in particular by the Council, but some related issues were discussed in consultation with the Bureau of Meteorology.

The classification of flood events is important in the community understanding of flood risk and the measures that are needed to respond to events. This classification is a responsibility of both the Bureau of Meteorology and the Ipswich City Council.

The Bureau has a forecasting system for the Bremer River, focussed specifically on the City of Ipswich but also on the remainder of the catchment to a lesser extent.

The Bureau distinguishes between flash flooding (resulting in floods occurring less than 6 hours from rainfall peak) and non-flash flooding (resulting in floods occurring more than 6 hours from rainfall peak). Only very generalised advice can be given in respect of flash flooding because of the lack of cover of gauges and short response times. Non-flash flooding is of greater significance in rural catchments, because the catchments are larger and floods occur more slowly.

Different parts of the Bremer River catchment and tributaries include both types of flood occurrence.

Flood severity is classified as minor, moderate and major. These definitions are defined for all flood warning stations in the catchment, with the specific flood gauge heights listed in the Bureau's website.

- ***Major flooding:*** This causes inundation of large areas, isolating towns and cities. Major disruptions occur to road and rail links. Evacuation of many houses and business premises may be required. In rural areas widespread flooding of farmland is likely.

- ***Moderate flooding:*** This causes the inundation of low lying areas requiring the removal of stock and/or the evacuation of some houses. Main traffic bridges may be closed by floodwaters.

- ***Minor flooding:*** This causes inconvenience such as closing of minor roads and the submergence of low level bridges and makes the removal of pumps located adjacent to the river necessary.

Table 7.1 in Section 7 shows the flood classifications for selected river height stations in the Bremer River catchment to Ipswich.

The classification of flood severity is defined by the Council and the Bureau in consultation. In this case the issues are complicated by the fact that the classification needs to consider the Brisbane and Bremer Rivers as well as other major tributaries and more minor catchments. There are also different issues between the downstream mainly urban portions and the mainly rural upstream portions of the catchments. The issues are quite different in these different flooding conditions. The consultation has indicated that there are inconsistencies in the classifications.

The classification of floods into the three categories has been identified as a possible issue and one where a review of the classification may improve the understanding of the community. The understanding of the classification by the community is critical to ensure that the community makes the best response to flood conditions during emergency events.

It is recommended therefore that this classification be reviewed, which will involve reconsideration of the flood behaviour at each gauging location in the catchment requiring consultation between the Council and the Bureau. The successful reassessment of the flood classifications therefore needs to include technical studies of specific flood risks at defined points in the catchment as well as consultation between the Council and the Bureau as well as possibly other agencies.

Non-Structural Measures

There are several recommendations that are relevant for the consideration of non-structural measures. These involve the main non-structural measures of floodplain planning and management and flood forecasting and warning.

Floodplain management, including the definition of areas where development is allowed and setting floor levels of buildings, must be a critical part of appropriate treatment measures. It is recognised that there is a large number of existing flood prone properties in the catchment but new development can be managed. The Council is already implementing floodplain management measures and this must continue.

Floodplain mapping is an important part of implementation of non-structural flood management measures. There are flood inundation maps available for the catchment that have been prepared as part of the technical flood studies undertaken in the past. These maps depend on the accuracy of topographic mapping and this issue is discussed in Section 3.4 of this report. It is noted that the accuracy of the flood inundation maps is limited in some parts of the floodplain because of the accuracy of the topographic mapping. It is therefore recommended that additional survey be undertaken to improve the accuracy of the flood inundation maps and therefore the reliability of the floodplain management measures.

Flood forecasting and warning has been identified as an important component of mitigating the flood risk in the Bremer River catchment. There is already a flood forecasting and warning system in the catchment, but there are several issues that have been noted.

- The community sometimes has difficulty in interpreting the warnings and applying them to their own circumstances. This difficulty can be overcome by additional explanation and community information programmes, and this is recommended.

- There are also some technical problems in the application of warnings in the more upstream reaches of the tributaries since the forecasting and warning system is focussed more closely on the downstream reaches where the greatest concentration of residential and commercial property is found.

It is understood that the Council has made a submission for funding under the Natural Disaster Mitigation Programme to enhance the flood forecasting and warning system. Details of this submission have not been reviewed during the preparation of this report, but this submission is supported and the findings of the current project indicate that additional support to this programme would be valuable in mitigation of flood risk.

The findings of this report therefore recommend upgrading of the flood forecasting and warning system involving the two aspects described above.

Structural Measures

There is a place for structural flood mitigation measures where there are high value existing flood prone assets. While much of the study area has relatively limited opportunity for implementation of structural measures, several opportunities have been identified, and details of these are as follows.

One specific measure that can be implemented in the smaller sub-catchments where future development is possible is the recommendation for future flood mitigation measures to ensure that future development does not have an adverse impact on downstream flooding, which therefore does not place any additional property or assets at risk. Specific portions of the study area where impacts of future development is seen as having a potential impact on flooding are located in the catchments of Bundamba, Woogaroo, Deebing and Ripley Creeks and in the Walloon and Rosewood corridor.

Wivenhoe Dam (including the associated Somerset Dam) is an important flood mitigation measure in the Brisbane River catchment and has an impact on the rivers in this study area by affecting the backwater from the Brisbane River. The dams are operated by SEQWater for both flood mitigation and water supply. The operation of the dams therefore has an important impact on the flood risk for the lower reaches of this study area. Ipswich City Council is working with other agencies including SEQWater, Brisbane City Council, Department of Natural Resources, Mines and Energy, Sunwater and the Bureau of Meteorology to ensure that the operation of the dams is as effective as possible for flood mitigation in this study area.

It is understood that the operational procedures for the dams have been adopted for some time. Possible changes in the operational procedures could have a significant impact on the flood risk in the Bremer River and other tributaries of the Brisbane River. In addition design flood procedures for the Brisbane River have been under reconsideration and these may be revised.

This report therefore recommends that the operational procedures for Wivenhoe and Somerset Dams should be reconsidered and impacts on flood risk implemented in the Bremer River catchment study area where backwater has an impact.

The urban parts of the lower reaches of Woogaroo Creek have been identified as an area of particular flood hazard. The Council has made a submission to the Natural Disaster Risk Management Programme to investigate structural flood mitigation measures for this creek. Because of the high risk to residential and commercial property identified in this study, this further assessment is recommended.

Transport Links

The consultation and reviews of this project have clearly noted that the flood immunity of many of the roads in the study area is relatively low. These low flood immunities include those for major roads including national highways (managed by Main Roads Department). Many of these roads do not meet the normal standard of the Main Roads Department of an average recurrence interval of 50 years flood immunity.

Many of these roads are critical for emergency access and evacuation during flood events. Some of the roads under the control of the Main Roads Department are under consideration for upgrading. It is recommended that part of the upgrading should ensure that the flood immunity is improved (also considering other constraints such as flood afflux impacts) to improve access and evacuation during emergency events. This will need a review of emergency access and assessment of the required level of access during flood events.

Queensland Rail is currently upgrading the railway lines located in the study area to replace the old timber bridges. The rail bridges generally have a higher standard of flood immunity than the road bridges and are not as critical for evacuation, so the flood immunity is not as critical for this flood risk report. However the replacement of the old bridges must ensure that the waterway areas of the new bridges do not worsen flood impacts. There is also an opportunity during the design of the bridges to consider locations where there may be existing adverse flood impacts from the railway bridges. While Queensland Railways would not be obliged to improve flood impacts beyond the current situation, funding for an improvement in flood impacts could be sought from the Natural Disaster Risk Management Programme to provide an improvement in these locations. It is therefore recommended that further investigation be completed in association with Queensland Railways to ensure that benefits can be gained from the railway bridge upgrading programme.

13. CONCLUSION

This report provides a component of the risk management strategy for the City of Ipswich, with flooding recognised as an important hazard for the city.

The review of risk, vulnerability and hazard has confirmed this importance and identified and categorised the risk and hazards for each sub-catchment in the project area.

Following the analysis of the available information and consultation with members of the Study Advisory Group, government agencies and the community, a number of mitigation measures have been recommended.

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Ipswich City Council – Works Department

Brief Review of Flood Frequency Analysis and Discharge Rating Curve for Brisbane River at Moggill Gauge

1. Executive Summary

This paper has been prepared to review the flood modelling of the Brisbane and Bremer Rivers in respect of the Moggill Gauge on the Brisbane River, in order to shed some light on an apparent anomaly between modelled and historic flood levels.

The main outcomes of this review are summarised below:

1.1. Hydrology

The **design peak flows** are based on a flood frequency analysis for Moggill using an incomplete series of recorded levels, and using a rating curve (not included in report) to convert levels to discharges.

Design hydrographs for input to MIKE11 are derived from a RAFTS model, calibrated for historic floods and with rainfall loss rates adjusted so that peak flows coincide with those from the flood frequency analysis.

Some aspects of the RAFTS model parameters and inputs lead me to suspect that the **flows are being overestimated** and that too much weight has been given to the flood frequency analysis.

Recommendations

I recommend the following:

☐ That the flood frequency analysis for Moggill be critically reviewed. In order to do this, the basic data used in the analysis will need to be obtained from SKM, BoM or BCC as they have not been provided in the report. This includes a critical review of the stage – discharge rating curve used to convert between water levels and flows.

☐ That the RAFTS model design flows be recomputed, if the outcome of the above shows this to be necessary.

☐ In any event, that a sensitivity analysis be undertaken to evaluate the sensitivity of the design hydrographs to the model parameters and to the design rainfall distribution (spatial and temporal), in order that some assessment may be made of likely errors, in flows and subsequently in flood levels.

☐ That this analysis be refined to account for the revised flood operating rules for Wivenhoe Dam when they become available.

1.2 Hydraulic Modelling

The major factor in the anomalously high 20 Year ARI flood levels in the Moggill to Goodna reach of the Brisbane River is undoubtedly the relatively high values of Manning's n which have been adopted for the design runs of MIKE11.

In calibrating the model, SKM found that it was necessary to use higher roughness values in some reaches to replicate the 1974 flood levels, than in the other floods, which were all substantially smaller. This was necessary in order to account for head losses at the meander bends. In the Moggill area the ratio of n values used to model the 1974 flood was up to twice that used for the smaller floods.

These higher roughness values were subsequently applied to all of the design events, from 2 year ARI upwards.

The peak flows in the 1974 flood in this reach were about 30 -35 Year ARI in the pre-Wivenhoe conditions of that time, but are about 100 Year ARI for current conditions. The result is that **the model is conservative in respect of floods smaller than 1974, and possibly non-conservative in relation to larger floods.**

The MIKE 11 model was run with the lower roughness set and with the 20 Year ARI design flows, in order to estimate the potential overestimation, with the following difference in peak water levels between 2 runs, identical except for the roughness parameters:

☐ **1.88m** for Brisbane River at Moggill;
☐ **1.92m** for Brisbane River at Goodna Creek confluence; and
☐ **1.99m** for Bremer River at David Trumpy Bridge.

These are **upper limits** to the difference resulting from the assumed roughness, as the 20 year ARI would be expected to require roughness values intermediate between the 2 calibration sets.

The current version of MIKE11 (v 2001b) has the facility to compute roughness as a power law function of velocity, depth or (velocity * hydraulic radius). This option was not available in the version used in 1999 by SKM (v 4.03). Recalibration of the model using this approach (based on velocity head) would overcome the major problem outlined above.

Recommendations

In order to improve the performance of the hydraulic model, I recommend the following:

- convert the model to the current version of MIKE 11;
- check the bridge, culvert and weir definitions and refine as necessary;
- recalibrate the MIKE11 model using one of the functional forms for roughness which incorporate variations due to velocity and/or depth;
- refine the floodplain roughness elements using the "triple zone" function available in M11 v2001b;
- re-run the design runs with modified design discharges;
- undertake sensitivity testing to identify likely error bands in predicted water levels;
- revise the flood mapping.

2. Background

This paper has been prepared in response to a request from Andrew Underwood to David Sargent to briefly review the flood modelling of the Brisbane and Bremer Rivers in respect of the Moggill Gauge on the Brisbane River, just downstream of the Brisbane/Bremer River confluence, in order to shed some light on an apparent anomaly between modelled and historic flood levels. This anomaly relates to small to medium level floods (up to about 20 Year ARI).

ICC is concerned that modelled flood levels in the Goodna to Moggill reach of the Brisbane River, in particular, are too high in this range of flood events, which also results in excessive backwater effects in the Bremer River up to One Mile Creek for these events.

3. Approach

The approach taken has been to consider the factors which may give rise to this anomaly, and how they have been dealt with in the hydrologic (RAFTS) and hydraulic (MIKE 11) models developed by SKM for this study.

The review has been based on the SKM report and on MIKE11 model files, results files and some additional model runs.

This paper outlines and comments on these factors, and makes recommendations regarding the further work which would be required to rectify the anomalies.

4. Summary of Factors

The factors influencing the modelling of floods of a given ARI, and the corresponding flood levels, at the Moggill Gauge fall into two categories, namely hydrologic and hydraulic. The main factors are:

4.1. Hydrologic

- The adopted flow frequency relationship from the flood frequency analysis and the RAFTS model, and utilised in the MIKE 11 Model;

- The stage discharge (rating) curve for Brisbane River at Moggill;

- The relative magnitude and timing of peak flows in the Brisbane and Bremer Rivers; and

- The assumed discharge hydrographs at the upstream boundary of the hydraulic model representing Wivenhoe Dam discharge combined with Lockyer Creek flows.

4.2. Hydraulic

- Adopted values of hydraulic roughness (Manning's n) from the MIKE 11 calibration process;
- Adequacy of lateral extent of modelled cross-sections at Moggill Gauge and in the reaches downstream;
- Adequacy of modelling of hydraulic structures (bridges, culverts and weirs), particularly those downstream of Moggill.

These are considered in the following paragraphs.

5. Hydrologic Factors

5.1. Flow Frequency Curve at Moggill

The following process was followed by SKM in developing the flow frequency relationship for Brisbane River at Moggill, as quoted in **Table 7.5** (page 87 of SKM's report):

a) Flood Frequency Analysis

The basic data used were:

- Incomplete flood level records from BoM's flood warning gauge at Moggill, converted to discharge using a rating curve produced by SKM (from previous modelling?);
- Additional floods added to the Moggill records by correlation with Port Office Gauge for the period prior to 1893 and between 1983 and 1996;
- Discharges below 2,000 m^3/s were excluded due to tidal influence. SKM noted that discharges above 10,000 m^3/s are to be used with caution;
- A flood frequency curve was derived on the adjusted data using a Log Pearson Type 3 distribution;
- Adjustment was made to the pre-dam situation using an analysis by Brisbane City Council (BCC).

Comment:

- The basic data are not included in the report, so it is not possible to comment on the detail of this analysis;

- The results of the analysis are very dependant upon:
  - The rating curve used;
  - The statistical distribution used (Log Pearson Type 3) although recommended in ARR can severely overestimate flows particularly when used with an incomplete series, as in this case.

- Given the importance of this relationship to the modelling in the Bremer River (as it sets the tailwater for the Bremer), the incomplete nature of the record, and its not being a flow measuring station, I don't believe this should have been adopted as the primary relationship without further work, or at least by sensitivity testing.

- The uncertainty in the flows as indicated by the 95% confidence limits are quite wide, as given in **Table 7.5** and **Figure 7.3)** of SKM report (p87 and 89 respectively.). For example, the central estimate of the 20 Year ARI peak flow at Moggill is 7886 m^3/s, but the 90% confidence band (ie between the 5% and 95% confidence limits) is from 4668 m^3/s to 13,322 m^3/s. Incidentally, quoting such values to 4 or 5 places gives them a spurious precision. Really this is saying - *the best estimate is 8,000 m^3/s, and we are 90% confident that the real value lies between 4,500 m^3/s and 13,000 m^3/s.*

b) Stage Discharge Rating Curve

The discharge rating curve for the Moggill Gauge location in the MiIKE 11 model is shown in **Figure 1**.

This curve shows a "loop" rating or hysteresis effect which is common in channels with flat gradients, at which the flow for a given water level is greater during rising water levels than it is during receding levels, as the corresponding water surface slopes are greater and lesser respectively.

For example, a flow of 4,000 m^3/s occurs at a stage of 11m on a rising flood, but at 13m on the falling limb. Conversely, the flow at 13m rising is 5,400 m^3/s, compared to 4,000 m^3/s on a falling stage.

It is not known whether this effect was taken into account when converting observed water levels into flows.

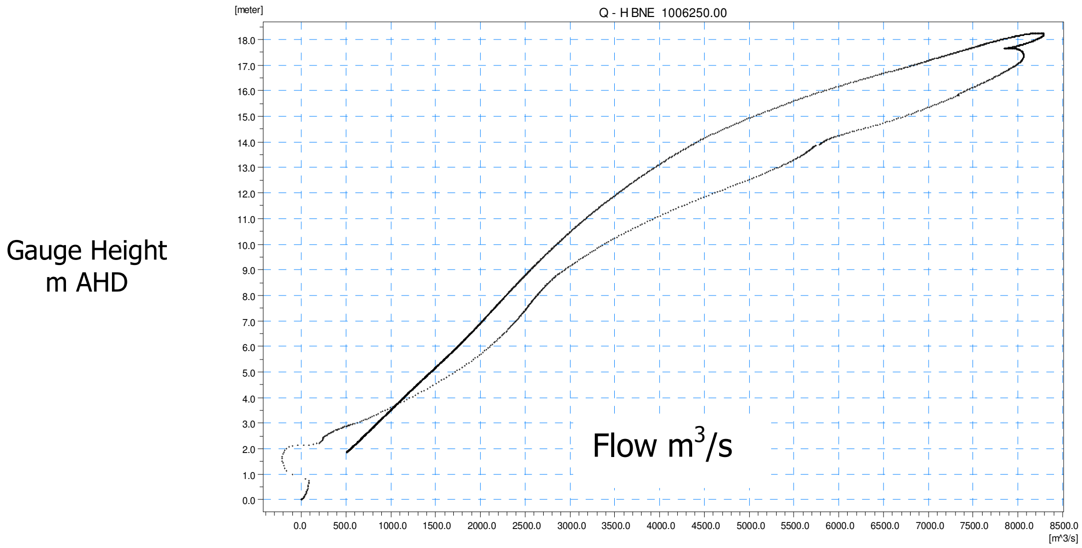

Figure 1
Discharge Rating Curve from MIKE11 for Brisbane River at 1006.250

Also, if the stage-discharge curve used in the initial estimation of flows was from the MIKE 11 model of the Brisbane River (BCC or ICC study), then the flows used are not independent of the MIKE11 model, and depend upon the model parameters eg roughness, which as discussed in section 6 are not well defined.

c) RAFTS modelling

A comprehensive RAFTS model was developed for the Brisbane and Bremer River catchments and was calibrated using data from Jan 1974, Jun 1983, Apr 1989, Dec 1991 (Bundamba Ck only) and May 1996. Calibration included simultaneous or "in tandem" calibration of both RAFTS and MIKE11 models to ensure consistency between models, such as flows at various points, roughness and storage. Also, an iterative process was necessary due to tidal and backwater influences at a number of the gauge locations;

Model loss rates derived for the calibration events were:

Event	Peak flow at Moggill m^3/s	Initial Loss mm	Continuing loss mm/hr
1974	9,346	0	0 – 2.5 (mostly 2.5)
1983	1,457	0	0.4 – 2.5 (mostly 2.5)
1989	1,200	0 – 30 (mostly 30)	0 – 2.5 (mostly 2.5)
1996	2,792	100 - 150	0.8 – 2.5

For the design floods, the RAFTS model loss rates were modified to give agreement with the peak flows from the flood frequency analysis, resulting in the loss rates given in Table 7.10 of SKM's report (p95) and summarised below:

ARI Years	Peak flow at Moggill m^3/s	Initial Loss mm	Continuing loss mm/hr
100	13,843	0	0.5
50	11,145	0	1.0
20	7,886	0	1.5
10	5,522	25	2.5
5	2,595	70	3.0
2	1,187	70	3.0
NOTE: Peak Flow/ARI relationship in this table is pre-dam construction			

SKM accounted for spatial variability in design rainfall by estimating the point rainfall at 130 locations and interpolating these to the 450 sub areas in the RAFTS model, as an alternative to applying a traditional areal reduction factor citing findings by DNR that areal reduction factors in large storms under cyclonic rainfalls are close to 1.

Comment:

- Although the RAFTS model calibration was comprehensive, there was no "split record" testing to validate the model ie. running the model with historic events not used in calibration to check on performance outside the range of calibration events;

- The calibration values of initial loss of zero obtained in some of the floods are very low, and would only apply on an already saturated catchment (which could have been the case), the dominant value of continuing loss of 2.5mm/hr is typical for SE Qld and is the median value given in ARR.

- For floods of >= 20 Year ARI, the design initial loss was zero and the continuing loss was reduced below that found in calibration. Whilst the initial loss varies between events, the continuing loss is more consistent as it represents those soil properties determining the infiltration rate once saturation is achieved. Its variation from the median value biases the frequency relationship of rainfall frequency equalling runoff frequency which is inherent in rainfall-runoff event modelling. The fact that these values were reduced (as initial loss could not be reduced further) suggests that the higher ARI flows may be overestimated. SKM do not present any results of sensitivity testing to quantify the change in peak flows resulting from this modification.

- Whereas historic point rainfalls used for model calibration have their own temporal patterns, and exhibit spatial variability, the use of an areal reduction factor of 98% (ie only 2% reduction) over the whole Brisbane River catchment together with the design temporal rainfall patterns from ARR, would result, I believe, in overestimation of the catchment rainfall and the coincidence of that rainfall, which would lead in turn, other factors being equal, to overestimation of the design flood discharges.

- **The combination of smaller than expected design rainfall loss rates, and higher than expected catchment rainfall totals, with the same temporal distribution throughout, would lead, in my view to overestimation of the design discharges.**

- Also, given the relatively large degree of uncertainty in respect of the flows determined from the flood frequency analysis, it is unclear why the latter were used as the primary data, and the RAFTS results adjusted to match, even though that results in bias to the RAFTS model.

- I would have thought that the flood frequency analysis should have been critically reviewed, possibly with it being modified to match the RAFTS results with unbiased loss rates and spatial/temporal rainfall distribution, or some compromise reached between the two.

- **The implication of this is that the peak flows used for the various ARIs may be conservative, especially at the higher ARIs (>= 20 year ARI).**

- This anomaly is apparent in the flood frequency curves for Brisbane River at Moggill (**Figure 7.8** p103), which shows a distinct bump in the curve between 10 and 100 Year ARIs, which is not present in any of the other curves (**Figures 7.9 to 7.20**).

5.2. Relative Timing of Peaks

There is some difference between the relative timing of peaks from the RAFTS model derived design flows, and that in the main calibration event (1974 flood), but this is unlikely to be significantly affecting the flood frequency curves.

5.3. Upstream Discharges at Model Boundary

SKM have incorporated Wivenhoe and Somerset Dams into the RAFTS model and taken account of reservoir operation as advised by DNR in determining design flows.

The peak flows at the upstream boundary of the Brisbane River MIKE11 model, which represents Wivenhoe Dam outflow plus Lockyer Creek flows are given below:

Flood Event	**Peak Discharge (m^3/s) Brisbane River at**	
	Upstream Boundary	**Moggill Gauge**
2 Year ARI	368	584
5 Year ARI	942	1230
10 Year ARI	2112	2238
20 Year ARI	5578	5283
50 Year ARI	7147	6866
100 Year ARI	8814	8293

Comment

The effect of Wivenhoe Dam operation on the design flows should be checked once the new operating rules are established.

6. Hydraulic factors

SKM developed a MIKE11 model of the Brisbane/Bremer river system for the modelling of design floods ranging from 2 Year ARI to PMF throughout Ipswich, primarily in respect of the urban areas.

The model was calibrated using historic flood flow and level data from the major flood of 1974, and for small floods in 1983, 1989 and 1996.

Design flood flows were produced using the fitted RAFTS model (see section 5.1), and input to MIKE 11 as upstream and tributary hydrographs.

6.1. Adopted Hydraulic Roughness

One of the main functions of the model calibration phase is to determine the hydraulic roughness (Manning's **n**) of the waterway. In MIKE11 the roughness may be varied along and between model reaches, and between the river channel and floodplain (specified either horizontally or vertically).

SKM's approach was to vary the model roughness to maximise the agreement between modelled and observed flood levels at a number of points for which flood levels were recorded(or surveyed after the event). Each reach was allocated a channel roughness and a floodplain roughness (defined by factoring up the channel roughness).

SKM found that larger roughness values were necessary to replicate the 1974 flood, than the smaller floods in some reaches. From their **Figures 6.1 to 6.13** (following page 61), this can be seen to apply to the following reaches and tributaries: Brisbane River (downstream of Bremer River confluence); Bremer River; and Bundamba Creek.

In **Figures 2 and 3**, these roughness values are plotted as a ratio of:

Roughness for 1974 calibration: Average roughness for small floods

for the channel and floodplain respectively for the Brisbane River part of the model only.

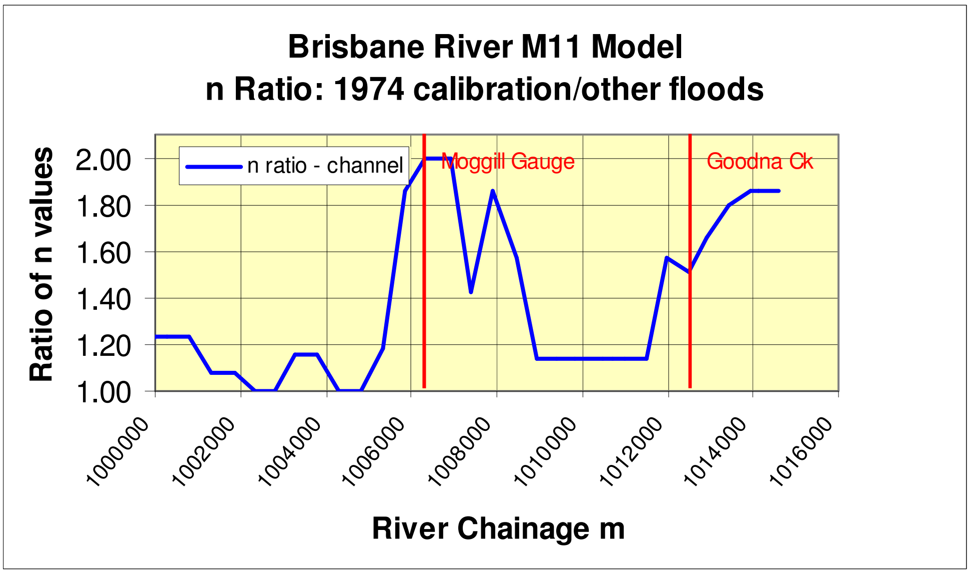

Figure 2

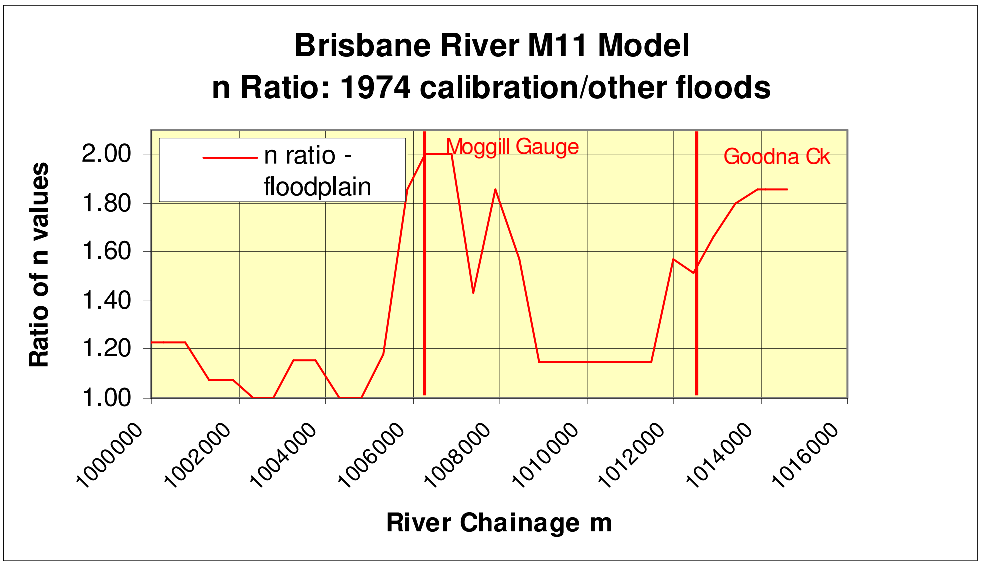

Figure 3

These figures show:

- ❑ The maximum roughness ratio between these calibration events was 2.0, and this occurred in the reach downstream from the Moggill Gauge, with a ratio of 1.85 also in the Goodna reach; and
- ❑ The channel and floodplain ratios are identical.

The actual values used in the Moggill to Goodna reach are shown in **Figure 4.**

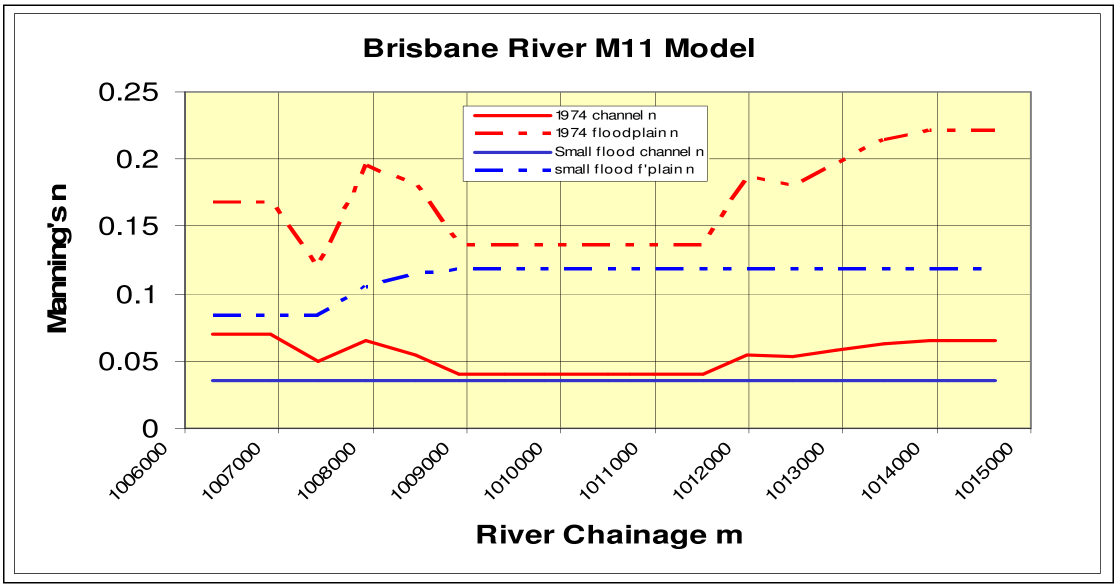

Figure 4 **Model Roughness - Brisbane River Moggill to Goodna**

SKM attributed the additional roughness to energy loss at bends, which is not specifically modelled in MIKE11 and has to be included by factoring the roughness. Chow (1973) quotes a maximum factor of 1.3 for highly meandering streams. SKM argue correctly that this bend loss increases as velocity increases (as a function of the velocity head) according to

$$H_b = C_L.\ V^2/2g$$

Where H_b is the bend energy loss
C_L. is the energy loss coefficient and
C_L. = 2b/r where
b = flow width and r = radius of the bend (in plan).

As both b and V increase with increasing flood magnitude, a significant increase in head loss can occur. SKM's **Table 6.2** (p68) compares the loss around one of the bends in the Brisbane River for the 1996 and 1974 floods and shows that the head loss would be 0.06 and 0.39m respectively. The device of increasing roughness to account for this is reasonable.

SKM subsequently adopted the roughness values from the 1974 flood calibration for **all of the design events** (Section 8.2 p 114), thereby biasing the model to floods or around that magnitude, and **making the model conservative in respect of the smaller floods, and possibly non-conservative in relation to floods of larger than 100 Year ARI.**

The small floods were in the range of 1,200 to 2,800 m^3/s at Moggill, about 2 to 5 year ARI. Hence the 20 Year ARI would be expected to require roughness values between these 2 extremes.

In order to try to quantify the degree of overestimation of flood levels, which would have resulted from the adoption of the 1974 roughness values, the MIKE11 model was run for 20 Year ARI existing conditions, but with the "small" flood roughness values. Unfortunately, these results are not directly comparable to the SKM results as a more recent version of MIKE11 (version 2001b) compared to that used by SKM (version 4.03). This resulted in higher water levels probably due to changes to the hydraulic structure routines. Also, a number of minor errors in the model setup were identified in running the current version, which presumably were not apparent in version 4.03.

To overcome this, the 20 Year ARI run was repeated (in version 2001b) with the 1974 calibration roughness values. It was possible then to calculate the differences between these runs, as an indication of the differences expected in comparable runs of version 4.03, although it should be noted that these differences will not be identical.

The difference between peak levels for the v2001b runs was:

- ☐ **1.88m** for Brisbane River at Moggill;
- ☐ **1.92m** for Brisbane River at Goodna Creek confluence; and
- ☐ **1.99m** for Bremer River at David Trumpy Bridge.

These are **upper limits** to the difference resulting from the assumed roughness, as the 20 year ARI would be expected to require roughness values intermediate between the 2 calibration sets.

6.2. Model cross sections

The river cross sections in the Moggill to Goodna reach were briefly reviewed to evaluate if their horizontal extent was adequate. Inadequate cross-section extent would result in the waterway area being constrained. Assuming that the largest of the calibration floods (1974) was within the modelled cross-sections, any inadequacy in this regard would be evident only in respect of floods larger than 1974, and would result in overestimation of flood levels.

The brief examination of the cross sections undertaken in this review did not show this to be an issue.

6.3. Hydraulic Structures

SKM checked modelled structure (bridges, culverts and weirs) afflux predicted for the 1974 flood with that given by the HEC-RAS model. This is a prudent approach, as HEC-RAS is generally regarded as having the best bridge modelling routines of any of the commercially available hydraulic model (although it appears that an old version of HEC-RAS was used, which didn’t model bridge waterway and pier geometry in detail). The approach was to vary the geometry/hydraulic parameters of the structures in MIKE 11 until there was a good level of agreement with that obtained from the HEC_RAS models which were set up separately for each structure.

For the Brisbane River downstream of Moggill, the total afflux in MIKE 11 (for 1974 flood) was 1.17m compared to 1.03m in HEC-RAS (**Table 6.3**, p73), which is adding 0.14m to the estimated levels at Moggill, presumably compensated for by reduced roughness to achieve model calibration.

The impact on this for other floods, greater and lower than the calibration flood is difficult to predict, as this will depend on the degree of submergence of each structure during the various design events.

6.4. Boundary Conditions

Boundary conditions comprise 157 input flow hydrographs and one downstream water level hydrograph.

For the design floods, the discharge hydrographs are from the appropriate RAFTS output, and the downstream water level, at the Brisbane River bar has been set at a constant value of 0.92m AHD, the mean high water spring tide level.

The lack of a tidal component would not have a significant impact in the reach of interest during flood events, as the flood suppresses the tide to only the downstream part of the river.

SKM made model runs with 100 year storm surge (plus an allowance for the Greenhouse effect) of 2.5 m AHD which resulted in a maximum flood level increase of only 80mm within Ipswich. This shows that flood levels in Ipswich are not sensitive to the downstream boundary level

No problems are apparent with the Model boundary conditions.

7. Discussion and Recommendations

7.1 Hydrology

My review of the hydrologic analysis and modelling suggests that **design discharges may be overestimated** for the following reasons:

- In the RAFTS model, the combination of smaller than expected design rainfall loss rates, and higher than expected catchment rainfall totals (due to the lack of an areal reduction factor), with the same temporal distribution throughout, would lead, in my view to overestimation of the design discharges.

- There is a relatively large degree of uncertainty in respect of the flows determined from the flood frequency analysis, so it is unclear why the latter were used as the primary data, and the RAFTS results adjusted to match, even though that results in bias to the RAFTS model.

- It would have been preferable for the flood frequency analysis to have been critically reviewed, possibly with it being modified to match the RAFTS results with unbiased loss rates and spatial/temporal rainfall distribution, or some compromise reached between the two.

- The implication of this is that the peak flows used for the various ARIs may be conservative, especially at the higher ARIs (>= 20 year ARI).

I recommend that the flood frequency analysis for Moggill be critically reviewed. In order to do this, the basic data used in the analysis will need to be obtained from SKM, BoM or BCC as they have not been provided in the report. This includes a critical review of the stage – discharge rating curve used to convert between water levels and flows.

I also recommend that the RAFTS model design flows be recomputed, if the outcome of the above shows this to be necessary.

In any event, I recommend that a sensitivity analysis be undertaken to evaluate the sensitivity of the design hydrographs to the model parameters and to the design rainfall distribution (spatial and temporal), in order that some assessment may be made of likely errors, in flows and subsequently in flood levels.

I also recommend that this analysis be refined to account for the revised flood operating rules for Wivenhoe Dam when they become available.

7.2. Hydraulic Model

The critical factor in respect of the hydraulic model has been shown to be the choice of roughness values.

The adoption of the higher roughness values derived from the 1974 flood calibration is reasonable in respect of the floods of similar magnitude to the 1974 event.

SKM's argument that the "effective" roughness increases with velocity and flow width at major bends (see section 6.1), as this is the only way in which energy loss at these bends can be introduced into the MIKE11 model is reasonable.

However, the consequences of adopting the 1974 calibration roughness values for all design floods are that:

- **for floods smaller than the 1974 event (30 – 35 Year ARI pre-Wivenhoe, about 100 Year ARI current conditions), water levels will be overestimated; and**

- **for floods larger than the 1974 event (30 – 35 Year ARI pre-Wivenhoe, about 100 Year ARI current conditions), water levels will be underestimated.**

The current model has a ratio between channel and floodplain roughness which is fixed for each reach, so if the channel roughness is doubled, for example, the floodplain roughness is also doubled. This is of no consequence for the smaller floods which are contained within the river channel (Brisbane and Bremer Rivers), it further complicates the relationships for floods in which substantial floodplain flow occurs. This is a second order problem compared to the major issue outlined above.

MIKE11 (v 2001b) has the facility to compute roughness as a power law function of velocity, depth or (velocity * hydraulic radius). Recalibration of the model using this approach (based on velocity head) would overcome the major problem outlined above.

As it will be necessary to convert the model to version 2001b to incorporate the above refinement, it will also be necessary to check/refine the bridge/culvert afflux evaluations.

In respect of floodplain roughness, the methodology outlined in the previous paragraph can be separately applied to the floodplain, although there may be insufficient data on floodplain flows to enable the model to be adequately calibrated for the floodplain component.

A further alternative would be to convert the model to a 2-dimensional model eg MIKE21. This would have the advantage of being able to model the superelevation at bends, but the current formulation of MIKE21 is constrained to fixed values of Manning’s n for each grid square. This would also be a time consuming and costly exercise, and is not considered to be warranted, considering the cost and that apart from the superelevation issue, the flow is essentially one-dimensional. This option is not recommended for further consideration.

In order to improve the performance of the hydraulic model, I recommend the following:

- ☐ Convert the model to the current version of MIKE 11;
- ☐ Check the bridge, culvert and weir definitions and refine as necessary;
- ☐ Recalibrate the MIKE11 model using one of the functional forms for roughness which incorporate variations due to velocity and/or depth;

- ☐ Refine the floodplain roughness elements using the "triple zone" function available in M11 v2001b;
- ☐ Re-run the design runs with modified design discharges;
- ☐ Undertake sensitivity testing to identify likely error bands in predicted water levels;
- ☐ Revise the flood mapping.

David Sargent
8th November 2002

FINAL REPORT
EXTREME RAINFALL ESTIMATION PROJECT

CRCFORGE AND (CRC) ARF TECHNIQUES

QUEENSLAND AND BORDER LOCATIONS

DEVELOPMENT AND APPLICATION

Gary Hargraves
Water Assessment Group
Water Assessment and Planning
Resource Sciences Centre

EXECUTIVE SUMMARY

This report covers the first application of the CRCFORGE and (CRC)ARF analytical techniques to Tropical and Sub-Tropical Regions of Australia. These techniques are designed to produce catchment rainfall estimates for use in design flood estimation (modelling). In Queensland and border locations, these analytical methods were applied to a large data set of daily rainfall stations provided by the Bureau of Meteorology.

The CRCFORGE method is a regional analytical method for developing point rainfall estimates at rare risk levels - Annual Exceedance Probability (AEP) much less than 1%, from data records of less than 100 years duration on average. The method is a development of the FORGE method (UK) by the Cooperative Research Centre for Catchment Hydrology.

Areal Reduction Factors (ARF's) are the preferred means for converting point rainfall estimates to catchment rainfall estimates. The other CRCCH partnership project successfully implemented in Queensland, was analysis to produce a mathematical model of ARF.

In this report, the sampled rainfall data set in Queensland is defined in some detail and compared generally with the Victorian set. Issues of stationarity, regional homogeneity, and appropriate probability distributions are resolved, and the issues of inter-site dependence are delineated. Tools used and developed during these analyses and data checking are described.

In both Victoria and Queensland, the raw annual maxima from the data set showed a correlation with the GEV distribution. All available evidence indicates that the Queensland data set is stationary. As the CRCFORGE method is more dependent on the extreme quantiles, there is no issue regarding split rainfall series within stations.

Because of the nature of the technique, CRCFORGE represents a fresh analysis of more up-to-date daily rainfall data for individual stations in the AEP range 1 in 50 to 1 in 100 - when compared with AR&R. For these reasons, the Queensland partners have rejected the CRCCH recommendation to base the CRCFORGE output on the existing AR&R data for AEP 1 in 50.

While there may be alternative methods of applying event independence, these were unable to be assessed within the resources available for the Queensland extension of the project. Bench-marking indicates that CRCFORGE is applicable sub-tropical areas. The precision of the method indicates that the upper order of AEP produced is in the range 0.05% - 0.02%.

The tangible outcomes are a set of design rainfall estimates at points, and a formula for generating areal reductions factors to enable transition to catchment design estimates. These results are now available with tools and documentation on a CD. The contents of the CD are in the public domain, at cost of production, and may be freely copied and distributed.

In Summary:

- New tools for estimating catchment design rainfall developed by the CRCCH, have been successfully trialled in sub-tropical Queensland, bench-marked and peer reviewed.
- The combination of CRCFORGE/ARF allows for estimates across AEP and into the rare risk domain, covering most practical durations after extension using AR&R (1987) data.
- The application of design rainfall methods (of which these techniques form a part) to catchments larger than 8,000 km^2 is a matter for professional judgement.

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1 BACKGROUND

The Extreme Rainfall Estimation Project came from a need for improved certainty and accuracy in estimates of catchment design rainfalls for flood synthesis and risk analysis - particularly for medium to large dams.

The Extreme Rainfall Estimation Project was part of an interstate partnership extending the development of techniques initiated by the Co-operative Research Centre for Catchment Hydrology (CRCCH) operating out of Monash University in Melbourne.

The developments were part of broader changes in practice for catchment design rainfalls used in flood risk analysis. These included a revision of Section 13 of Australian Rainfall and Runoff (AR&R) 1987, resulting in Book VI of AR&R 1999.

The idea for the original project came from the Australian National Council on Large Dams (ANCOLD). The extension in Queensland was established by a consortium of sponsors. The sponsors are listed in alphabetical order below by organisational name as it stood at the time:

- Cairns CC
- CS EnergyDepartment of Natural Resources
- Gladstone Area WB
- Gold Coast CC
- South East Queensland WB
- Stanwell CorpTarong Energy
- Toowoomba CC
- Townsville/Thuringowa WB

Specifically, the EREP project was to apply and develop the following two techniques in the tropical environment of Queensland and border areas:

- CRCFORGE Design Point Rainfall Estimation
- A modified Bell's method for Areal Reduction Factors (ARF's)

The FORGE technique target was to estimate design point rainfalls in the range of concern for large dams – target range: Annual Exceedence Probability (AEP) 1 in 5,000 to 1 in 10,000.

Use of an Areal Reduction Factor based on a reliable analysis of local data is the currently preferred method of converting from point rainfalls to catchment average rainfalls.

Previous to the new ARF method, the only options were those based on very limited, predominantly overseas, data analysis. These options had largely been eschewed by practising professionals – erring on the side of significant conservatism.

2 CRCFORGE POINT RAINFALL ESTIMATION

2.1 Conceptual and Theoretical Basis of CRCFORGE

The CRCFORGE method is an analytical statistical method for estimating design point rainfall. The method is a development by the Cooperative Research Centre for Catchment Hydrology (CRCCH) of the FORGE method (UK).

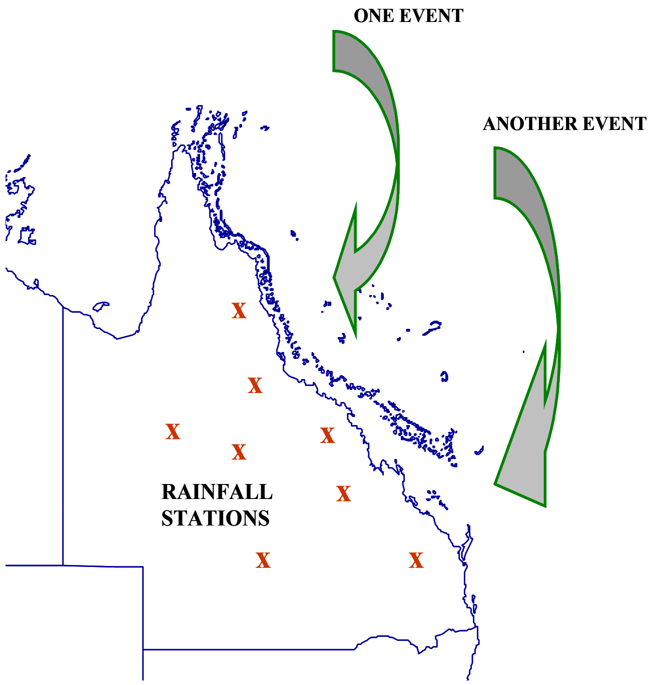


Figure 1 - Concept of Regional Sampling

The idealised diagram at left shows that, for any given event, some rainfall recording stations are affected more than others.

Therefore, if there were some legitimate way to pool station samples into an annual series, it would yield a more extreme series than that from any single station.

One objection to such pooling is that the resulting series might include samples of the same event from different stations – dependent events.

A more nagging objection is that the regional series would still be limited to the average time sample across individual stations.

The answer to the latter objection is that, while there are seasonal cyclic influences and decadal trends, there is a high degree of randomness in meteorology over longer records. This is the basis of conventional hydrological statistics - including fitting of series to station data.

Statistically, a fair sample is a set of independent events drawn from a homogeneous, random super set. An analogy is tossing a die. These statistical concepts of independence of events and homogeneity of the super set are complementary – each event must be separate (a toss or tosses of the die), but from the same type of root cause (the nature of the die, and the toss).

If one can accept that:

- meteorological events are highly random over longer time periods, and:
- the samples being combined come from the same type of meteorology, and
- the samples are corrected to remove the effects of combining dependent events;

then a regional pool can be seen statistically to represent a larger time sample or series.

CRCFORGE is a regional method based on pooling the samples of events from recording stations across a compatible region - taking account of the potential dependence of events recorded at different stations. This regional pooling allows for estimates beyond that normally expected based on the average length of individual station records.

All current hydrologic analyses rely on the premise that rainfall does not trend over long time. Whether or not there are trends in meteorology is referred to as an issue of **stationarity**.

If there were proven to be recent trends of global warming, then these might best be handled by factoring predictions that were based on the assumption of historically stationary data.

There are three pre-conditions specific to applying a regional method:

- The stations need to be subject to the same type of meteorological cause. This is an issue of **homogeneity** of meteorology and stations in regions.
- The data must be standardised or normalised to allow combination.
- The annual samples from each station should not be of the same event. This is an issue of **independence** between stations and recorded events.

In the case of CRCFORGE, the data is normalised within station by dividing by the Mean Annual Maximum for the particular duration of event being considered. This enables the combination of regional data, to which the local information (mean) may then be reapplied.

This concept of regional combination was used previously in the 'station year' method. The fundamental differences between 'station year' and the current methods are that independence is taken into account, and the current method of combining limited regional information.

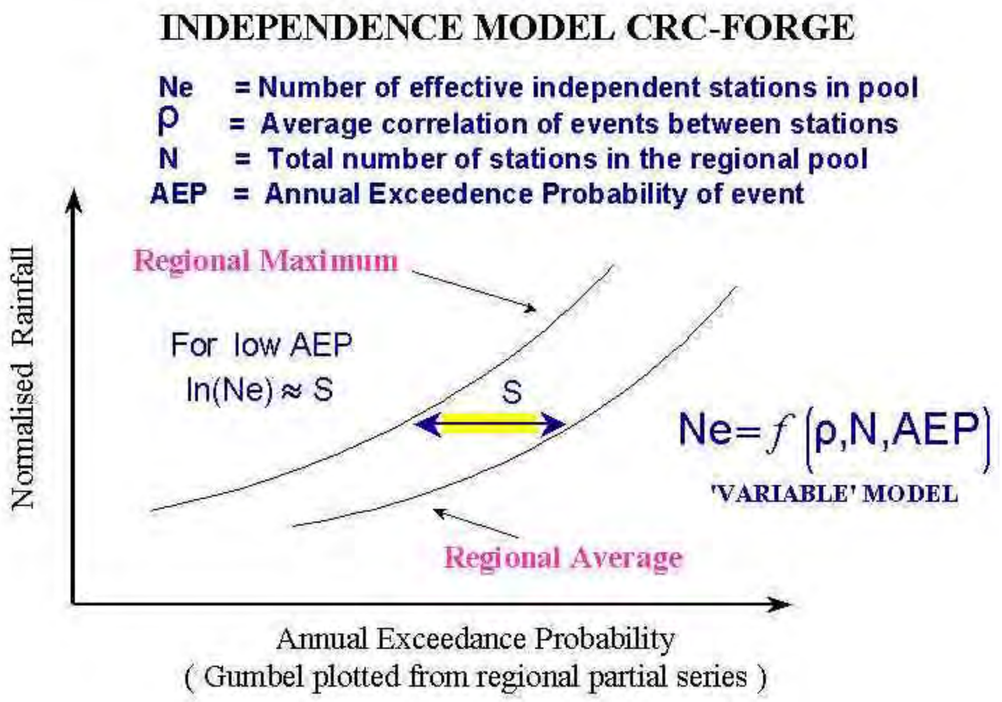
There are two stages in the CRCFORGE process:

- A model of inter-station dependence is fitted to the data set
- The regional-augmented curve for a particular focal station is grown

In the CRCFORGE method, the model of inter-station dependence is calibrated using average statistical correlation between sample pools of stations. It is the correlation between normalised station annual maxima for particular durations that is assessed.

The model calibration exploits a statistical property of regional partial series as shown below.

Figure 2 - Property Basis for Independence Model



For both FORGE and CRCFORGE, a curve is progressively plotted (or 'grown'). To a plot of the data from the focal station is successively adding data from more distant regional stations. Both the acronyms reflect the concept – as displayed in the diagram below.

FOcussed **R**ainfall **G**rowth **E**stimation.

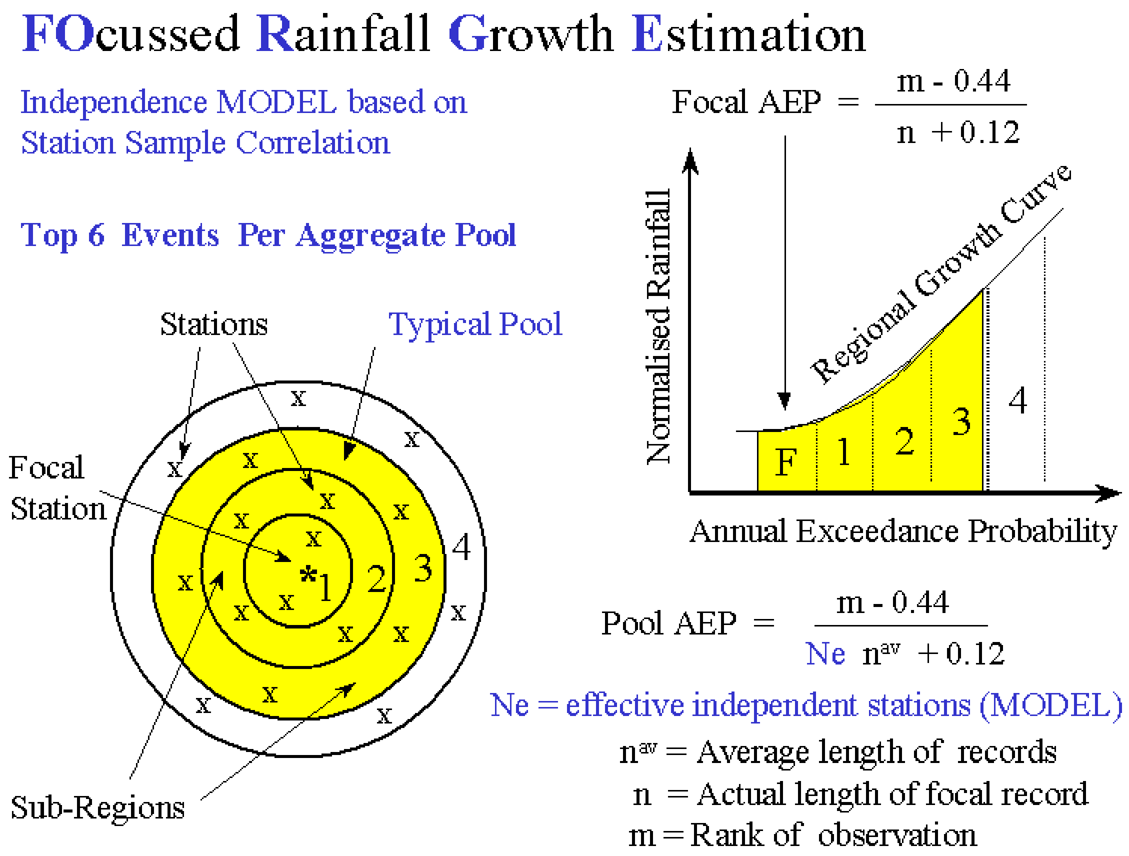


Figure 3 - Second Stage of FORGE

Important points to note are that:

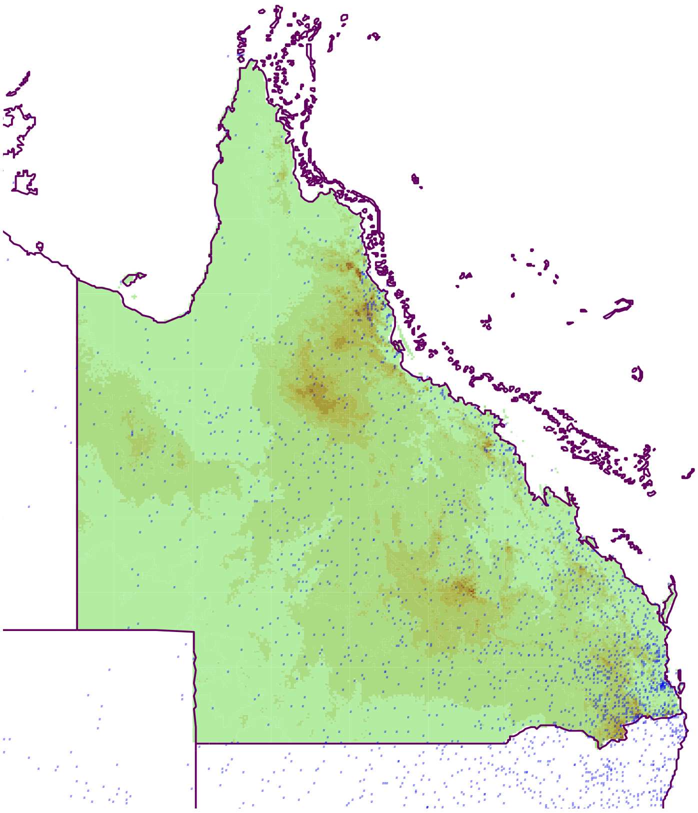
- The focal station data is plotted conventionally (no regional data / no dependency model).
- From each regional pool, only the largest six events are plotted.

As the geographic distance increases, there is an understandable general trend to less dependency between larger events in any regional pool. The degree to which this makes the procedure robust, or less dependent on the model, predominantly depends on regional size.

While the fitting of a particular probability distribution to the plotted data is not mandatory, in the CRCFORGE method in Victoria the Generalised Extreme Value (GEV) had been adopted.

The following key aspects in applying CRCFORGE are considered in subsequent sections:
Stationarity
Homogeneity
Independence
Probability Distribution
Realistic Outcomes

2.2 Data Scoping, Characterisation, and Checking



In applying the methodology, Queensland had the benefit of quite a large data set of daily rainfall stations - provided by the Bureau of Meteorology (BoM). Limited use was also made of the available digitised pluviograph stations.

The colour contour map at left shows the geographic coverage of daily rainfall stations (blue dots) with more than 30 years of available annual maxima for events of 1-5 day duration.

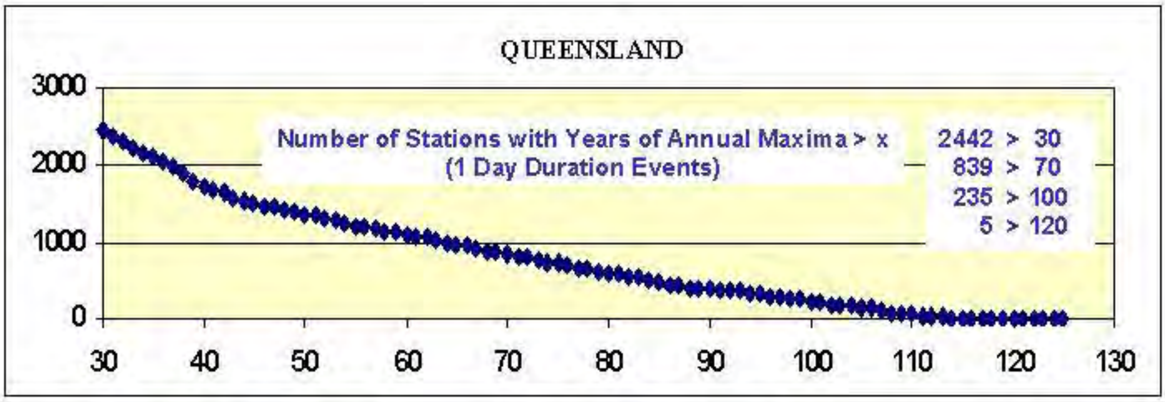
The geographic density of stations in Queensland's remote areas is clearly more sparse than elsewhere.

Figure 4 - Geographical Spread of Useful Data

For statistical analysis, a necessary prerequisite is that there is a high degree of randomness in rainfall data. Using visual inspection tools under CRCFORGE processing, 1 to 5 day duration annual maxima were formed from the daily rainfall BoM data sets. The most numerous and reliable 1 day duration maxima, were used for determinative statistical analyses in this report.

One way of examining the broad nature of the data set is to plot the number of years of available event maxima for each station in the selected base data set. For Queensland, entry to the base data set was limited to those stations with a minimum of 30 years annual maxima.

Figure 5 - Population Dynamic of Useful Data Set



Another way to examine the data set is by the spread of the event quantiles (individual rainfall events) across the stations. The data is normalised within stations by dividing by the Mean Annual Maxima, and then the number of quantiles within ranges determined.

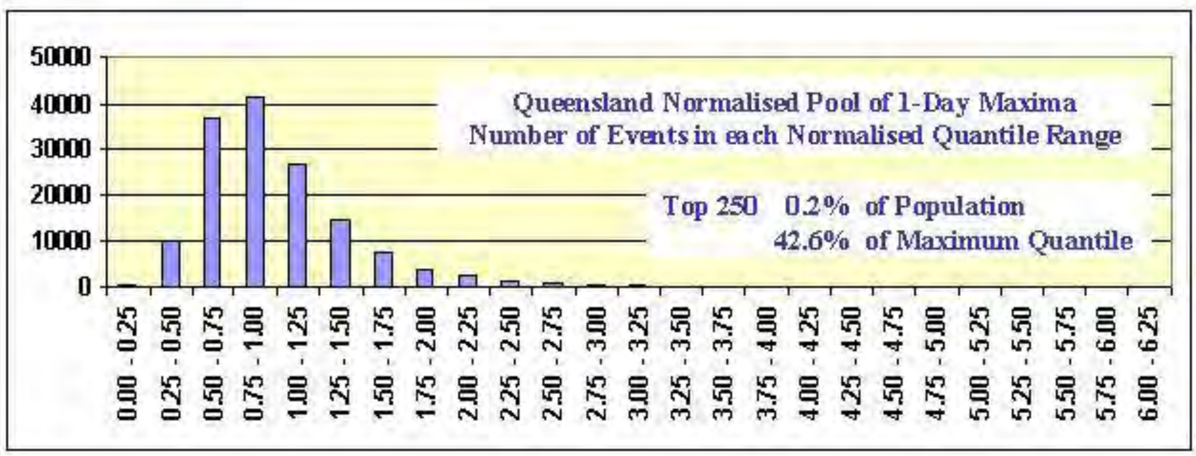


Figure 6 - Quantile Spread of Useful Data Set

One can readily see that any potential regional series will show a 'long tail' - a very small percentage by number, will form a high percentage by normalised quantile. As indicated above, the CRCFORGE method is highly dependent on the larger regional quantiles.

These population characteristics established the numbers for 'in station' raw data checking. The top 250 events from stations with more than 30 years of annual maxima were supplemented with the top 50 events from 5 nominal geographic regions – making a total of 324. Also data suspect because of its neat coincidence to whole unit numbers were identified.

These events were then subject to comparison across nearby stations and within station. The 99 events still suspect were then subjected to further checking:

- The original manual recording sheets were pulled for all events and checked
- Opinion on suspect events was sought from BoM.
- All available digitised pluviograph data was obtained.
- Finally, surface fitting of rainfall events surrounding the suspect events was conducted in Arcview / Spatial Analyst (GIS) using daily and pluviograph data.

Of the suspect 99 events – in a pool of 147,165 events across the database, 32 were rejected. They were rejected from all event durations to which they had contributed.

2.3 Probability Distributions – Statistical Insights to the Data Set

In statistical terms, a fair sample is a set of independent events drawn from a homogeneous pool. In the first instance, we make the assumption that the whole Queensland data set is affected by the same meteorological system.

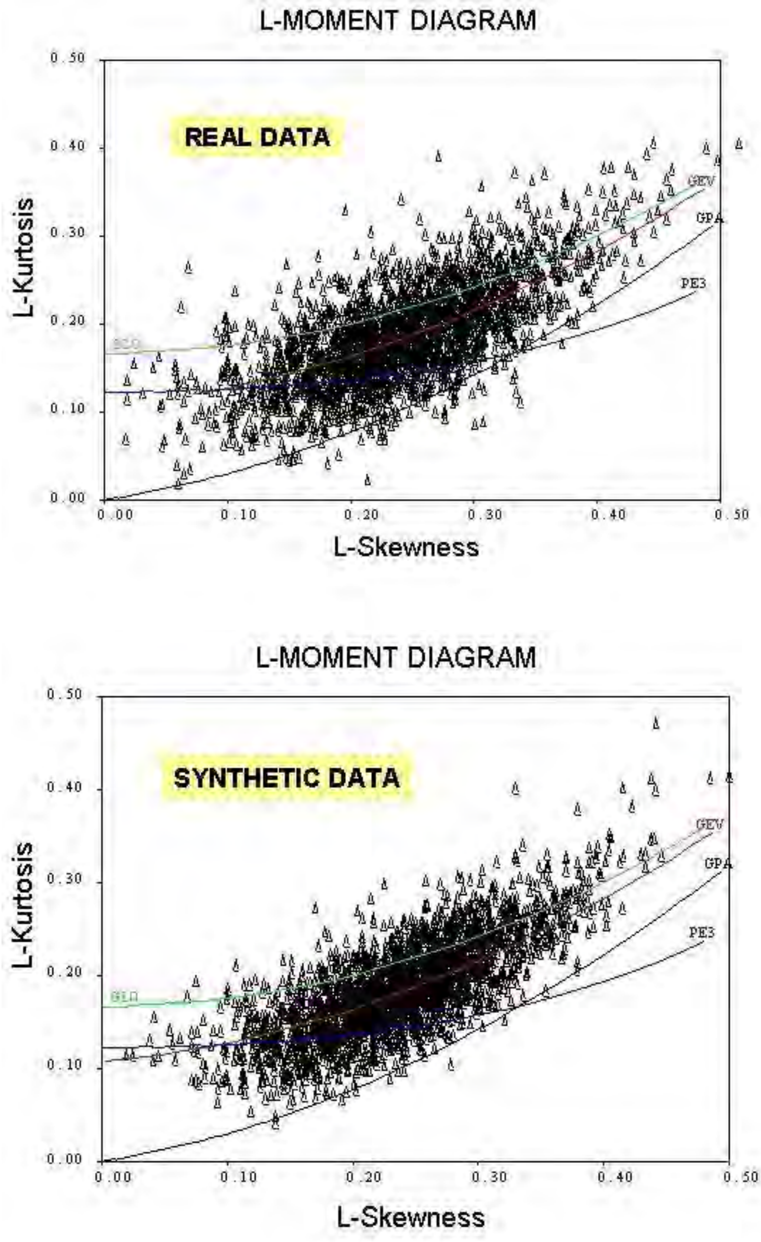
Statistical parameters are calculated to determine the form of a fair sample, by its:

- Central tendency - mean or median
- Degree of scatter – standard deviation or variance
- The shape of that scatter – skewness and kurtosis

Statistical parameters are often used to determine which distribution may be best applied to a random data set. Probability distributions may be thought of as mathematical models of randomness patterns in reality. Tests specifically addressing the randomness of these data samples and the homogeneity of the data set, are examined in the following sections.

L-moment statistics differ from the conventional statistics. Conventional statistics obtain the deviation and shape about the central tendency by using powers of the differences between the central tendency and other quantiles – a 'least squares' technique. L-moments determine the deviation and shape by using linear combinations of differences between all quantiles, to obtain information with a similar meaning. Because powers have not been used in the calculation, the parameter assessments are less biased to the large quantiles.

In the diagrams below, each point plotted represents the relevant shape parameters of the data sample contained within a single station. The first diagram is the actual Queensland data set. The family curves for four distributions – Generalised Extreme Value, Pearson 3, Generalised Pareto, and Generalised Logistic are also plotted. Note that any one point on a family curve represents a set of parameters for a particular distribution of that type.



The scatter of stations is about a point (almost circular if the data is plotted on equal scales). This suggests that the best fit distribution for the potential regional pool would be GEV.

This result is supported by results from Monte Carlo methods. Routines were commissioned to estimate best-fit parameters from real data sets for all four distributions, and to generate synthetic data sets. The generation algorithm was transformation using the Matalas multi-site method.

The synthetic data set shown at left was generated to be of the same shape and size (number of stations and average events per station) - using GEV parameters fitted from the real data set. Note the similarity of scatter for the purely random, synthetic GEV set of station data.

Figure 7 - L-Moment Plots

2.4 Stationarity – Checking Time

Trends in Station Samples

While there are irregular short term cycles in rainfall data sets (about ten year), the existence of long-term trends would contraindicate the use of conventional statistical methods of analysis. This is because a trend obviates the basic premise of an approximate randomness.

The tools supplied by the CRCCH to test the databases for stationarity were routines based on the Mann-Kendall rank correlation, and the CUSUM technique by McGilchrist and Woodyer. These were designed to be applied to the annual maxima for individual stations.

When applied to the Queensland data set of stations (more than 30 years of annual maxima):

- Mann-Kendall rejected 172 out of 2,444 stations (≈7 %) at the 5% confidence limit, and
- CUSUM rejected 194 out of 2,444 stations (≈8 %) at the 5% confidence limit.
  (Interestingly, only 58 stations - less than 1/3, were common to both reject lists.)

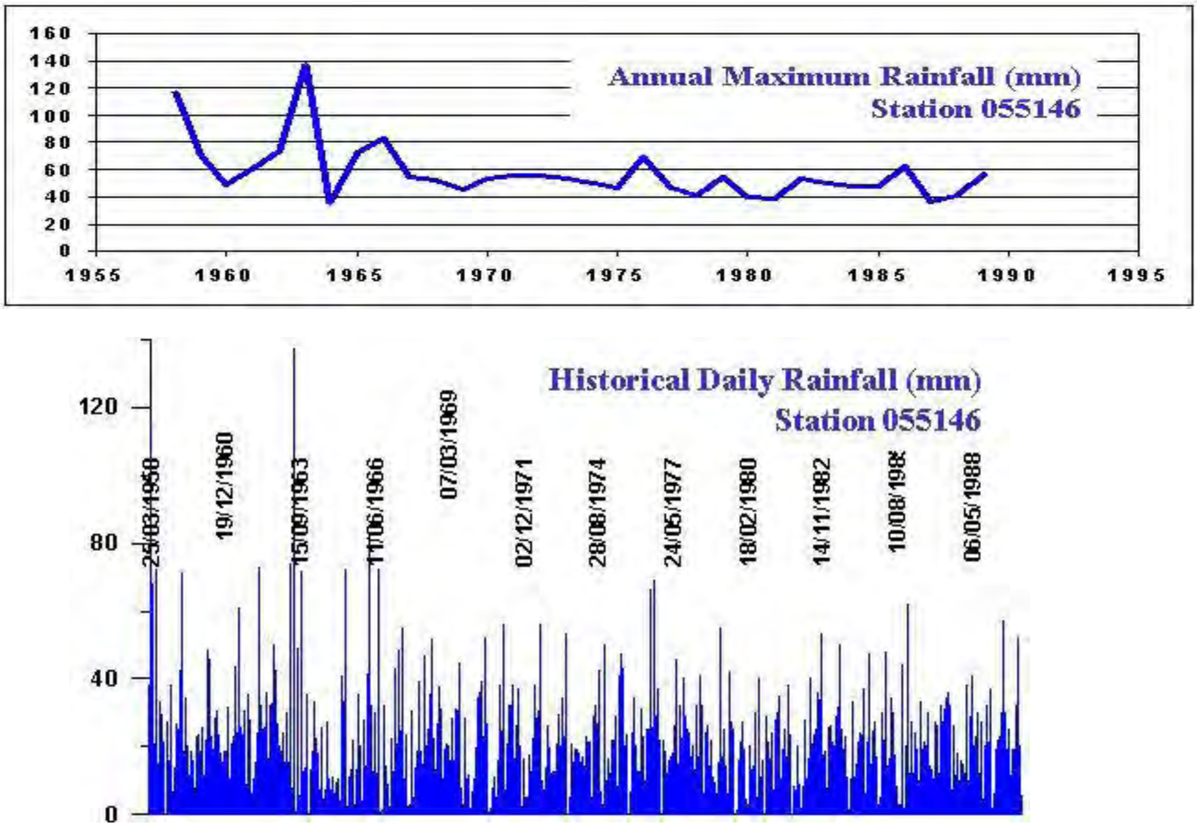
When applied to the GEV-distributed synthetic data set of similar shape and parameters:

- Mann-Kendall rejected 116 out of 2,400 stations (≈5 %) at the 5% confidence limit, and
- CUSUM rejected 113 out of 2,400 stations (≈5 %) at the 5% confidence limit.
  (Again, only 33 synthetic stations - less than 1/3, were common to both reject lists.)

As a synthetic (Monte Carlo) data set is created as random as possible, there is no real trend in the generated data set – only apparent trend in a particular random sample.

Suspect *real* station data was also visually inspected. A set of stations was formed consisting of those that failed either stationarity test by more than 30% of the nominal test parameter (62 stations). Where a plot of the annual maxima might have suggested a trend, the plot of the whole data set consistently disputed such a trend. A typical example is below.

Figure 8 - Plot of All Daily Data for a Test Station



This latter evidence suggests that annual maxima may not be the best indicator of general time trends in rainfall. While there may be alternatives to using annual maxima to determine independence between stations, this could not be tested within the resources for this project.

CSIRO analysis of the national rainfall records by Hennessy, Suppiah and Page (1998) using the Kendall-Tau test, suggested that in Queensland there was a small non-significant increase in annual total rainfall and no significant change in heavy rainfall indices.

Taking all this evidence together, it was concluded that the data set for Queensland is stationary within the limits of the current technology and length of record available. There may well have been relatively recent trends due to global warming or whatever.

2.5 Homogeneity for Queensland Regions – Meteorology vs Statistics

The fundamental premise of any statistical analysis is a high degree of randomness and the sampling of independent events. In a regional analysis, the aim of the technique is to combine data caused by the same type of meteorology into a type of mathematical model.

The data for combination should be independent - ie. not from the same meteorological event. The issue of common type of root cause (ie. type of meteorology) is called homogeneity.

Two sets of packaged tests were supplied by CRCCH as tools for testing regional homogeneity. The tests attributed to Hoskings and Wallis (1993) were acknowledged by project partners as being more stringent than those by Lu and Stedinger (1992).

In their paper, Hoskings and Wallis had postulated that the distances on an L-Moment diagram between real and simulated average parameters were normally distributed and the routines tested for coherence at a Gaussian 5% or 10% confidence level.

The packaged set of tests by Hoskings and Wallis (using the method of L-Moments) contained three tests (in order of increasing stringency):

- Between real and simulated averages of L-Skewness/L-Kurtosis
- Between real and simulated averages of L-CV/L-Skewness
- Between real and simulated (group) standard deviations of L-CV

The reader is reminded of the meanings ascribed to conventional and L-moment parameters:

- CV (Coifficient of Variation) – a measure of scatter of the whole sample range
- Skewness – a measure of where in the sample range the central tendency is located
- Kurtosis – a measure of how concentrated or peaked is the central tendency

In Victoria, decisions relating to homogeneity were based on L-moment statistics of 1-3 day duration events from all stations having more than 60 years of annual maxima. In Queensland, decisions relating to homogeneity were based on L-moment statistics of 1 day duration events from all stations having more than 30 years of annual maxima.

Although the Victorian data set of stations having more than 60 years of maxima did not pass all Hoskings and Wallace tests, the CRCCH held the view that their data set was sufficiently homogeneous for application of the CRCFORGE analysis methods.

In Queensland, in order to clarify the Hoskings and Wallace results, L-moment parameters were displayed spatially using the GIS package Arcview. No significant trend was found for L-Skewness or L-Kurtosis, but a definite spatial trend was found for L-CV.

Each of the following plots is a colour-coded display of one parameter for all stations. Each colour represents a particular range of value of the parameter being displayed. Using these methods, Queensland was divided by trial and error into 8 nominal regions – such that only 2 regions failed the most stringent Hoskings and Wallis L-CV test at the 5% level.

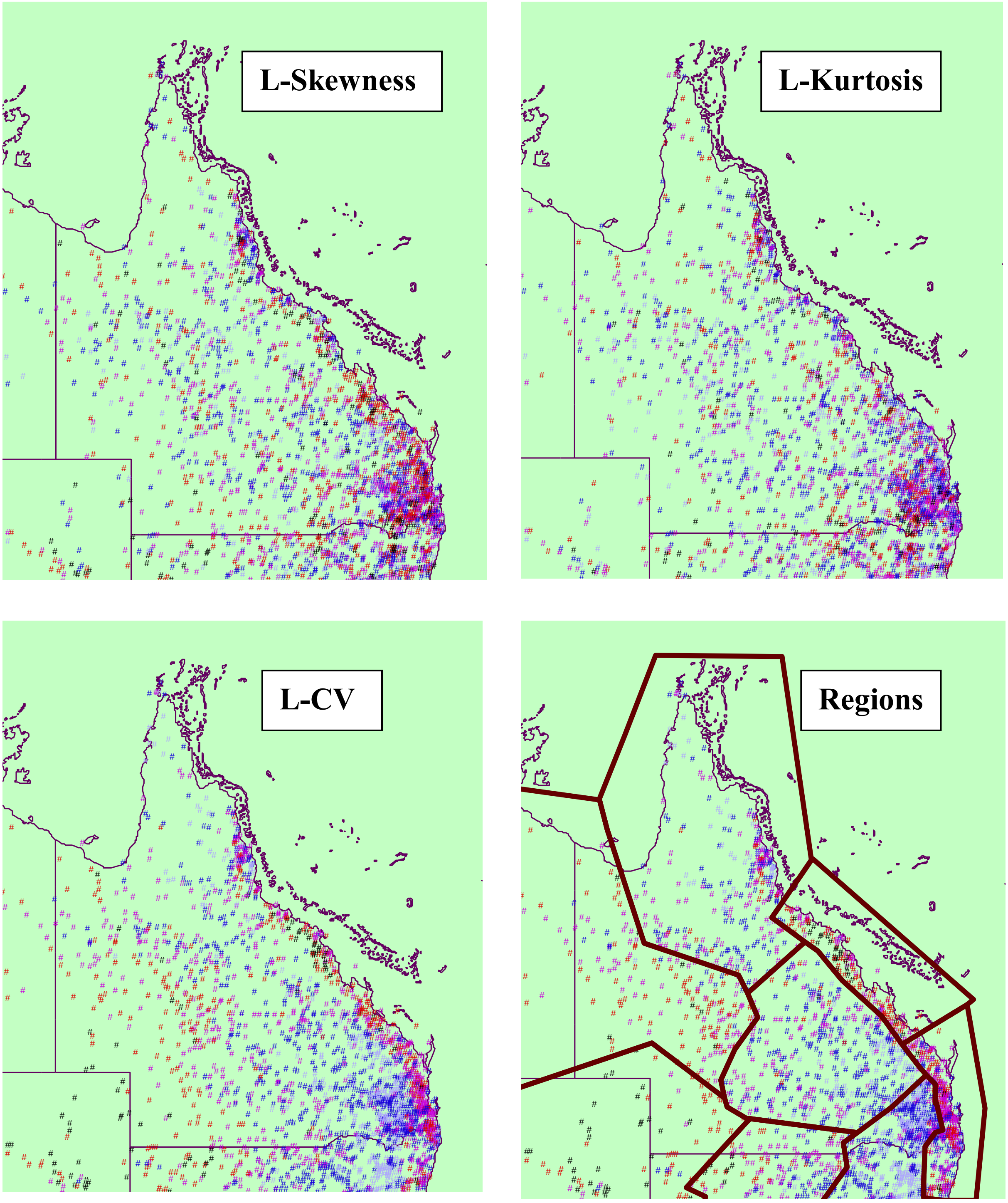


Figure 9 - GIS Display of L-Moment Parameters (for Regions)

There may be a difference between meteorological homogeneity – rainfall from predominantly the same type of cause; and statistical homogeneity – the ability to fit the one mathematical distribution to a set of rainfall recordings. In this context, 'one distribution' means an example from a type of distribution (form of equation) thought to apply to the case.

The words 'nominal regions' were used earlier because the Lcv parameter is a measure of data scatter (within station). According to these tests, it is possible to group stations in Western Queensland with those on the Northern Coast to make a *statistically* homogeneous region – that successfully meets all of the most stringent (best practice) statistical tests. However, it is not feasible to generate a set of (smaller) regions where *all regions* meet all tests individually.

There is no reason to suggest that more geographically distant stations will be more meteorologically homogeneous. Conversely, there is every reason to believe that geographically nearer stations may be more meteorologically homogeneous.

For these reasons, the evidence contradicts the use of sample scatter for determining meteorological homogeneity. The remaining statistical parameters lend support to the proposition that the whole data set in Queensland is meteorologically homogeneous.

While the evidence is not conclusive on meteorological homogeneity for the whole Queensland data set, the nominal regions selected are as *statistically* homogeneous as it is reasonable to achieve with available data and current tools. More importantly, as explored next, the CRCFORGE technique mandates its own view of homogeneity of the data set.

2.6 Homogeneity for CRCFORGE - Sensitivity Testing of Regions

To determine whether a regional division was necessary in Queensland, sensitivity testing of CRCFORGE outcomes was conducted with different regions or no regions. The effect of regions on (1) the dependence modelling step and (2) the FORGE step was tested separately.

To test the effect of the data set via the dependence model (1), three geographically diverse sub-regions were chosen and two stations were chosen from each. Outcomes for the 'whole-of-Queensland' model was slightly conservative in comparison with one tested sub-region.

To test the effect of the data set via the FORGE step (2), two Northern regions were used– a superset containing both the coast and tableland, and subset with only the coast. The superset (including tableland stations) resulted in a significant reduction in FORGE estimates.

The outcomes of the sensitivity testing suggest that the FORGE step is quite dependent on the degree of scatter in the regional data set. This is not unexpected.

The fact that the FORGE step selects only the top six events in each regional pool, also removes the concern regarding the application of the method to tropical areas where there are multiple event mechanisms and potentially dual series at recording stations.

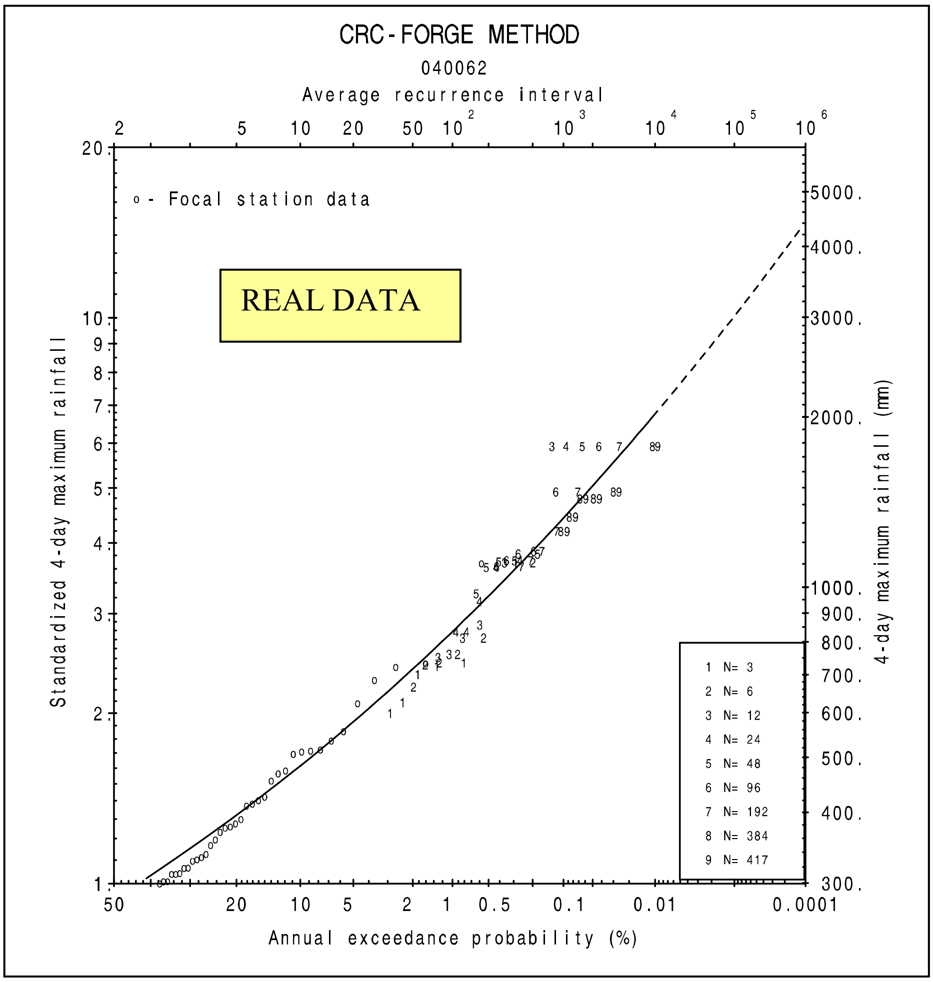
As the FORGE step uses only large regional events and only uses the focal station to tie the bottom end of the final curve, any secondary (lesser) series that might appear in the station data will not be represented in the final (regionally-augmented) curve.

2.7 Realistic AEP Limits for CRCFORGE Design Estimates

In testing the CRCFORGE method in Victoria, the CRCCH (1997) estimated the confidence limits of the output based purely on the likely Gaussian variation in the dependency model and the curve fitting procedure. The estimated error was less than 5% at AEP of 1 in 2,000. Subjective support for this finding was provided by inspection of all curves in Queensland.

It would be of benefit to have a viable alternative regional analysis method– even if this method were not sufficiently proven to be a benchmark for the current work. Preparatory work was conducted by McConachy (1996) for the CRCCH using Schaefer's method, but a full comparison with CRCFORGE outcomes was not performed.

In the absence of any better confidence estimates - and not having the resources to develop alternative methods, the writer examined the key issue of believability of the proposition that real (nominally random) data sets of the size and shape of Queensland and Victoria, might produce events that could be plotted at the order of 1 in 5,000 AEP.



The real example at left, shows the common behaviour of the plots for successive data pools in the second part of the method – where an outlier occurs at the focal station.

Note that the process of incorporating regional data returns the outlier to the estimated distribution.

Figure 10 - Example of Real Station Plot, Stage 2 CRCFORGE

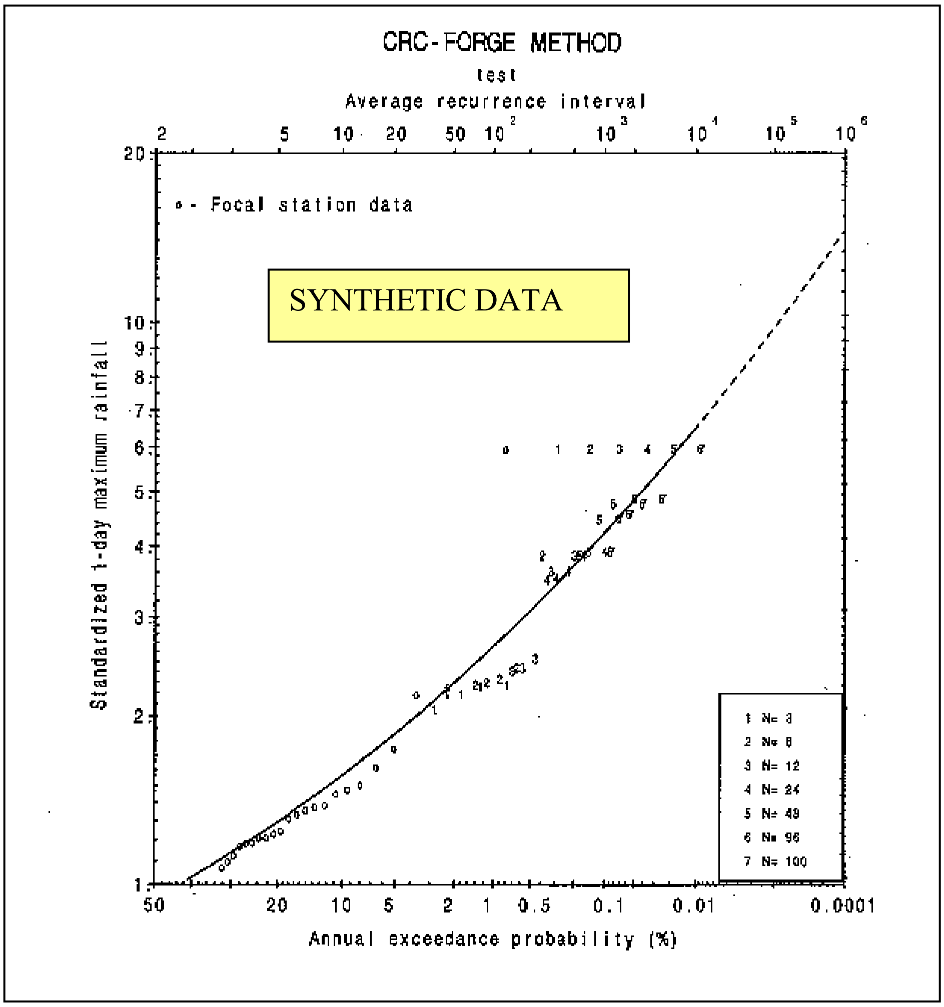


Figure 11 - Synthetic (Monte Carlo) Station Plot, Stage 2 CRCFORGE

The example at left is a synthetic station drawn from a monte carlo pool of data of the same 'size and shape' as the Queensland real data pool. As a monte carlo pool is purely random data by design, this indicates that one may expect occasional 'outlier' events of the order indicated earlier in random samples of this size and shape.

2.8 Operational Decisions for Data Analysis using CRCFORGE

In Victoria, all stations having 60 years or more of annual maxima were used for both the model calibration and (initially) the FORGE steps. Later, in order to deliver a sufficiently dense geographic coverage of focal stations in some areas, growth curves focussed on stations with significantly fewer years of annual maxima were added.

In Queensland it was decided that the independence Model should be calibrated across the full state, but that the FORGE step of the CRCFORGE method should be conducted on the regions selected on the basis of strict statistical homogeneity.

In Queensland, all stations having 70 years or more of annual maxima were used for the model calibration step, and all stations having 30 years or more of annual maxima were used for the FORGE steps - applied within the regions, as previously selected. The number of years were chosen based on the dataset and fundamental classical statistics respectively.

2.9 Post Processing

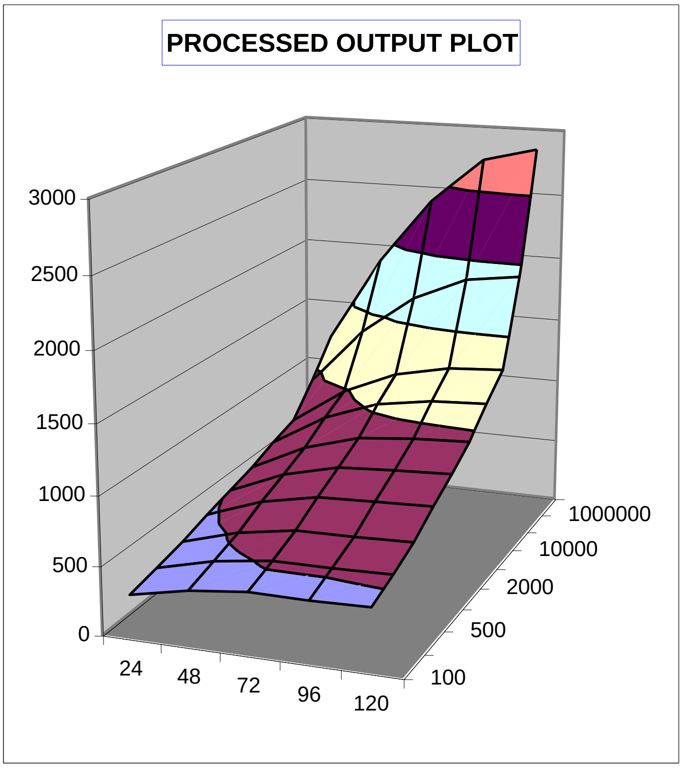
Firstly, it must be remembered that the primary data samples were derived from rainfall stations recording daily rainfall to 9am. Therefore a correction needs to be applied to the estimates to bring them to 'worst case' or 'open duration' events.

The correction factors applied were drawn from the work of Dwyer and Reed (1995), and appear in the table below:

CONVERSION	1 Day to 24 hours	2 Days to 48 hours	3 Days to 72 Hours	4 Days to 96 Hours	5 Days to 120 Hours
FACTOR	1.160	1.106	1.072	1.049	1.034

Figure 12 - Table of Correction Factors for Open Durations

Secondly, processing is conducted in CRCFORGE separately for each of 1 – 5 days duration for all stations. Resulting sample sets are not the same size across durations, and, for longer durations in particular, are limited by availability. This can occasionally result in an anomaly for estimates, where total event duration rainfall does not increase with increasing duration.



In the Victorian case, automatic smoothing routines were used to average a curve to the raw ordinates. In Queensland, once the limited extent of anomalies was confirmed, manual adjustment was made by inspection of 3D plots in Excel.

The few adjustments required were to the longer durations - 72 to 120 hours, and much less than 5% in magnitude. An example, of the 3D plots utilised for visual comparison is at left.

Note that this plot includes processed data beyond that considered suitable for design rainfall estimates.

Figure 13 - Post Processing 3D Plot of CRCFORGE Station Output

The resulting data sets for the CRCFORGE stations were surface-fitted using ANUDEM Version 4.6 (Hutchinson, 1997). The resulting surfaces were converted to grids for use (initially) with the Graphical Information System (GIS), Arcview 3.2.

3 (CRC)ARF ESTIMATION

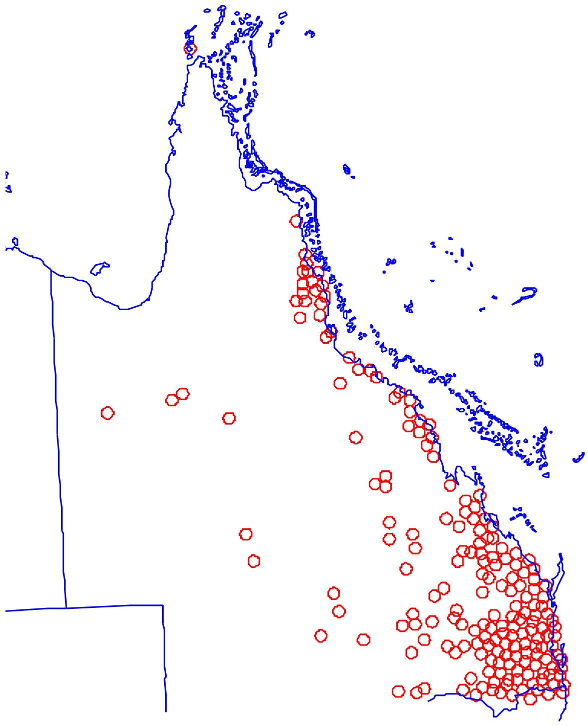
3.1 Introduction to (CRC)ARF

A preferred method of converting design point rainfalls to design catchment rainfalls is to apply an Areal Reduction Factor (ARF) to weighted average point estimates. ARF's had not usually been applied in the past by professionals. Factors available were inconsistent and/or typically based on very limited (if any) local data. Significant conservatism was preferred.

The other CRCCH partnership project successfully implemented in Queensland, produced a new set of Areal Reduction Factors (ARF's). The CRCCH analysis used a modified Bell's Method - ie. nominal circular 'catchments' for sampling over areas 125 km^2 to 8,000 km^2.

3.2 Data Selection Issues

In selecting samples of stations for processing, the number of stations considered acceptable for different areas of catchment had been set by the CRC at: three stations, plus an additional station for each 500km of catchment area. However, a decision needed to be made as to the amount of overlap of stations that would be considered reasonable for catchment samples.



In Victoria, catchments had been selected manually using judgement.

In Queensland, it was decided that up to 30% overlap of stations across sample catchments was a reasonable balance between excessive elimination of useful samples, and contamination of samples.

An Avenue script was commissioned for Arcview 3.2 to select idealised circular catchments across the state on that basis.

The image at left is an indicative representation of the idealised circular catchments used in the analysis. The ones shown are for a catchment size of 125 km2.

This typical pattern of idealised sample catchments are highly weighted to the coast and South East Queensland.

Figure 14 - Typical Coverage of Idealised Catchments (Bell's Method)

3.3 Processing Aspects

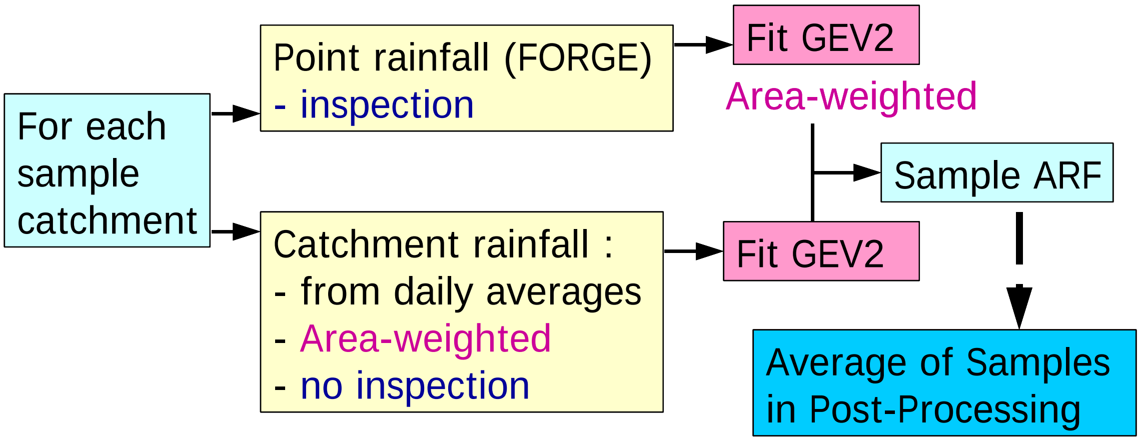
The CRCCH method of estimating ARF's involves area-weighting across sample catchments of rainfall event samples from recording stations. In the method, the distinction between point and catchment rainfall components for a trial catchment, was the data source and how the area-weighting was applied. These distinctions are as follows, and in the diagram below.

Point Rainfall Components for a Sample Catchment:
Point rainfall series for each station in the trial catchment were derived by fitting a GEV2 distribution to the raw station maxima for each duration - previously sampled for input to the CRCFORGE method. As each distribution is based on one individual station, any point estimates taken from those distributions are limited by the data source to (say) AEP 1 in 100.

Once the point rainfall maxima were fitted as series for stations, estimates were made of point design rainfall at a station for a range of useful AEP targets from 1 in 2 to 1 in 100. The point estimates for each target AEP were then area-weight averaged across the sample catchment.

Catchment Rainfall Components for a Sample Catchment:
Catchment rainfall events for the trial catchment were produced by sampling for events of relevant durations across the stations in the trial catchment. Each sample event was area-weight averaged to form a catchment rainfall sample, and maxima were then selected for the various durations. A GEV2 series was then fitted to the resulting catchment series, and estimates made for a range of useful AEP targets from 1 in 2 to 1 in 100.

ARF Estimates for the Sample Catchment and Overall:
The Areal Reduction Factor estimate for the sample catchment is then the ratio of the catchment estimates over the point estimates at the relevant AEP level. Once all sample catchments are processed then the samples of ARF for a particular catchment size, event duration, and AEP (risk) level; were averaged as part of post processing.



Comment:
The inclusion of AEP as a test variable in the CRC-ARF analysis, probably resulted in the need to fit a statistical distribution. Because of the nature of the method, point and catchment estimates are not 'event concurrent' - but neither are they in application of the final output. Inspection of all potential catchment events was not practically viable nor justified.

Figure 15 - Block Diagram for CRCCH(ARF) Technique

3.4 Post Processing

The CRC-ARF project software had within it checks to eliminate catchment samples as being inadequate. This severely reduced the number of valid catchment samples in some cases – particularly for the larger catchments – where the minimum station rule was more severe.

In addition, the output was manually inspected and incomplete samples eliminated. The following number of valid catchment samples were achieved after basic post-processing. While the set for 8,000 km2 might be considered statistically marginal, it needs to be remembered that considerable data across stations is contained in these larger catchments.

50 km^2	48 catchments
125 km^2	97 catchments
250km^2	74 catchments
500 km^2	219 catchments
1,000 km^2	147 catchments
2,000 km^2	78 catchments
4,000 km^2	33 catchments
8,000 km^2	12 catchments

In Victoria, to generalise and facilitate application of the results, these averaged results had been fitted to a log and exponential relationship (mathematical model) for Areal Reduction Factor (ARF) dependent on three parameters: Area of catchment, Duration of event, and AEP.

This presupposes a clear trend in the AEP domain. An example of the resulting averaged output for Victoria is below for the 48 hour duration. Unlike Victoria, in Queensland no clear trend of variation with AEP was found. In South Australia also, a clear trend did not appear for all durations. (Overleaf are comparative examples for South Australia and Queensland.)

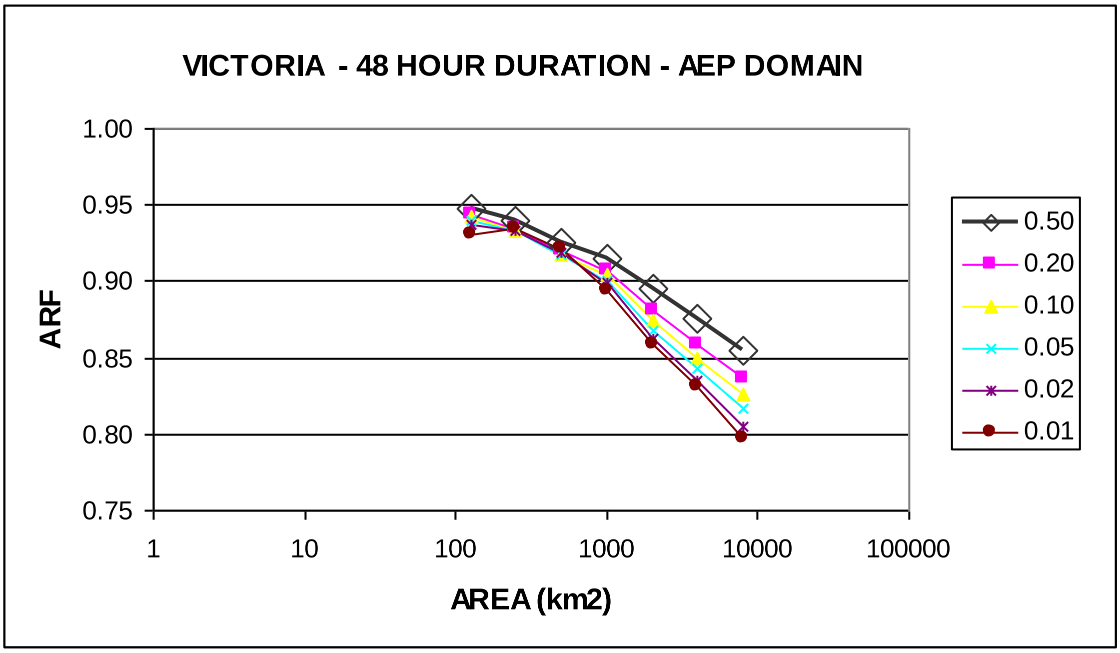


Figure 16 - Example of Victorian Raw ARF Output

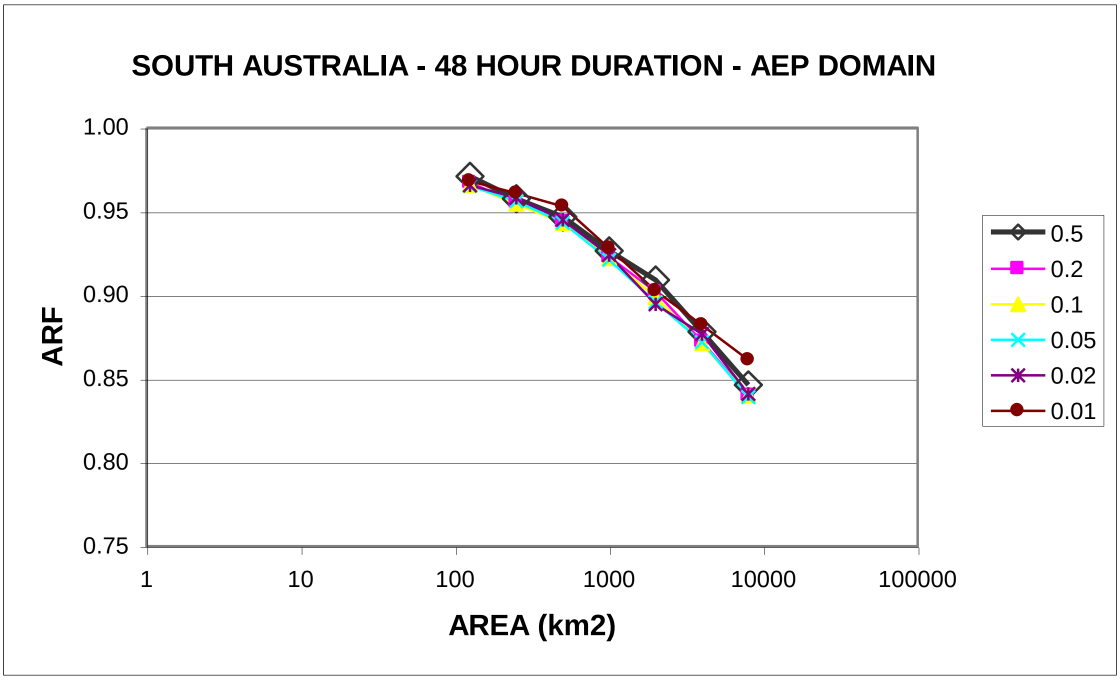
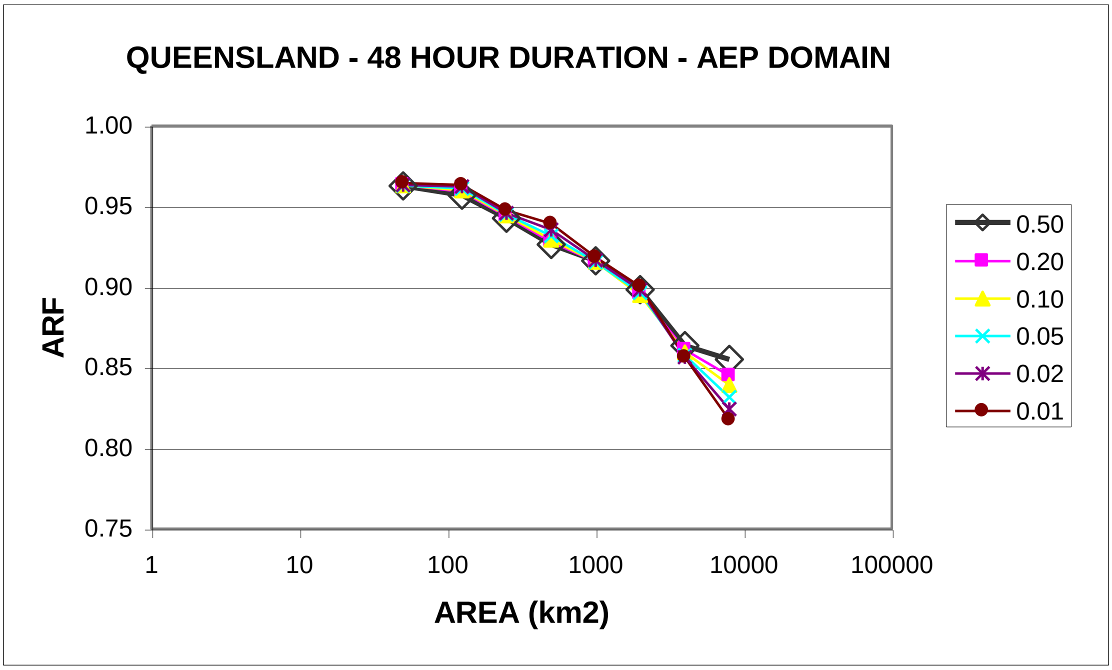


Figure 17 - Examples of South Australian and Queensland Raw ARF Output



Therefore, in Queensland, a conservative envelope model dependent only on area and duration was therefore fitted manually - using the mathematical software package Statistica.

Conservative Envelope Model – based on Queensland Data:

ARF = 1 - 0.2257 (Area $^{0.1685}$ - 0.8306 log (Duration)) Duration $^{-0.3994}$
But NOT > 1.0 (for smaller areas)

4 APPLICATION OF OUTPUT AND BENCHMARKING

4.1 General Comments on Application of Output

The CRCFORGE method produces design point rainfall estimates for durations from 24 hours to 120 hours (in 24 hour increments), and from AEP 1 in 50 to AEP 1 in 2,000. Estimates in AR&R 1987 had been extended to durations less than 24 hours and for more frequent events by virtue of the use of a limited number of pluviograph stations nationwide.

Because the CRCFORGE method initially plots focal station data from a larger source data set - using a conventional plotting position formula; the lower end of the fitted curve, represents a fresh estimate of the design rainfalls at the AEP 1 in 50 to AEP 1 in 100 levels.

In Victoria the decision was taken use the AR&R (AEP 1 in 50) design rainfall estimates as a base with growth factors (ratios) from CRCFORGE. In Queensland, it was decided that the CRCFORGE represented the best estimates at this risk level and AR&R was used as an extender to lower durations and more frequent design events.

Amongst other things, independent rainfall analyses support this decision – see next section. Benchmarking has consisted of extensive flood analyses conducted using these estimates and the new techniques described in AR&R 1999, on a variety of catchment sizes across the state.

For application of ARF factors to estimate catchment rainfalls, accurate and precise area-weighting using GIS tools is preferred. The Queensland ARF model allows use across AEP, and for most practical event durations, when used conservatively and in concert with AR&R.

Application to catchments larger than 8,000 km^2 is a matter for professional judgement. The appropriateness of the general 'design rainfall method' needs to be considered.

4.2 Comparison with AR&R 1987 Design Rainfall Estimates

Australian Water Engineering was commissioned in the 1990's by the Gold Coast City Council to review the rainfall analysis for that region – using similar methods to those used in AR&R. The following indicates substantial agreement between CRCFORGE and AWE.

	Duration 24 hours – AEP 1 in 50				
	AR&R	**AWE**	**% Diff**	**CRCFORGE**	**% Diff**
Mt Tambourine	316	395	25	410	30
Springbrook	554	617	11	717	29
Little Nerang Dam	494	467	-6	456	-8
	Duration 24 hours – AEP 1 in 100				
	AR&R	**AWE**	**% Diff**	**CRCFORGE**	**% Diff**
Mt Tambourine	352	449	28	461	31
Springbrook	632	704	11	807	28
Little Nerang Dam	560	534	-5	512	-9

Figure 18 - Comparative Design Estimates for Gold Coast

One small catchment in Queensland, for which design rainfall values had been supplied, showed a considerable difference between the AR&R and the CRCFORGE design estimates.

Interestingly, there were no long-term daily rainfall stations located within this catchment – certainly no CRCFORGE stations. It appeared from a study of the rainfall contours that hydrometeorological opinion had been applied by BoM during the analysis for AR&R 1987 - in the form of expected increased rainfall due to the orographic effect of the coastal scarp.

The consultant involved produced their own design rainfall estimates based on research and independent analysis of limited additional rainfall data – yielding the following comparison.

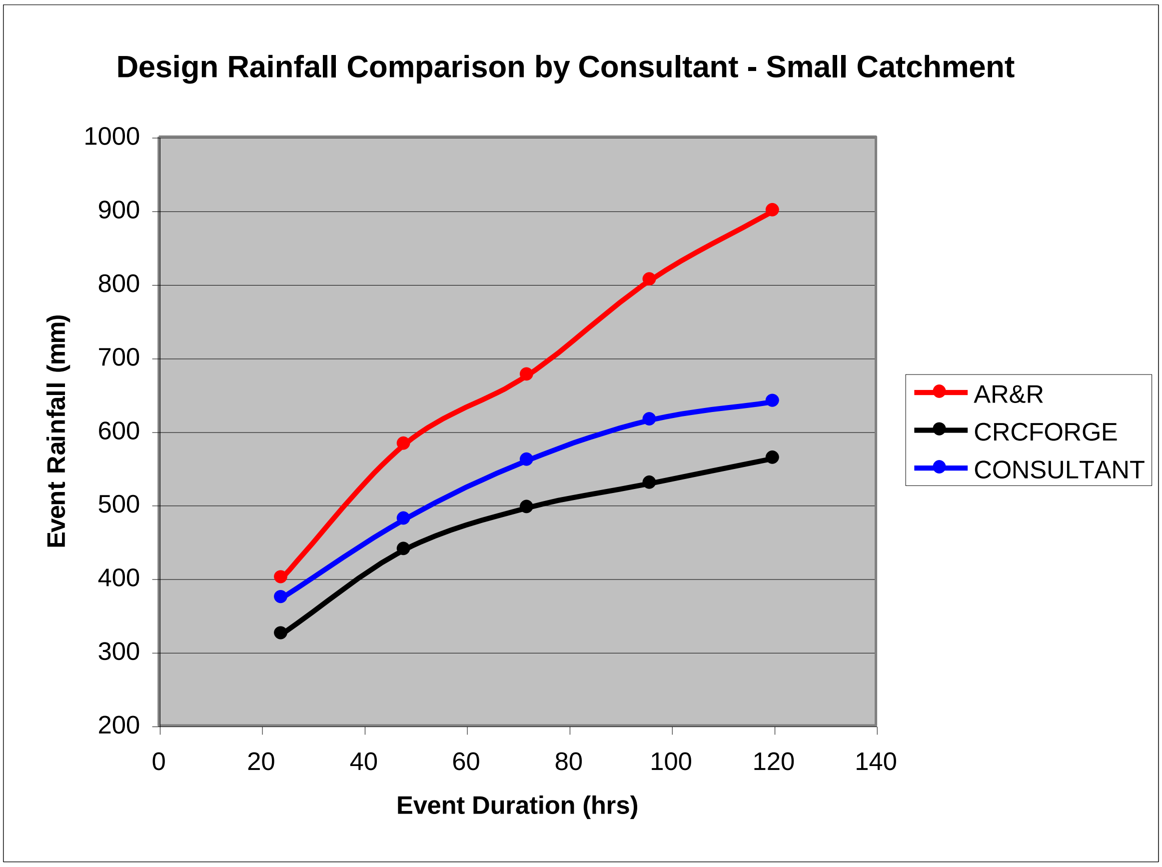


Figure 19 - Comparative Design Estimates for Small Catchment

These examples lend support to the decision to base current design rainfalls on the later CRCFORGE - which was based on a substantially larger source data set.

4.3 Tools for Professionals and other Stakeholders – The CD

The output from these two projects - CRCFORGE and (CRC)ARF, have now been consolidated onto a CD. A range of documentation is included, together with robust basic GIS tools to enable the production of estimates in the form of IFD tables.

The information on the CD is in the public domain, and the CD is available from NR&M at cost. (Note that only *ratios* of certain AR&R design values can be obtained from this CD.)

5 SUMMARY CONCLUSION

Other than the PMP (extreme catchment rainfall) design estimates provided by the Bureau of Meteorology (BoM), there are now two sources of *point* rainfall design estimates in Queensland. AR&R (1987) still offers values for event durations from *below* 24 hours to 72 hours, with an AEP range from 1 in 2 to 1 in 100. The basic CRCFORGE output offers values for durations from 24 hours to 120 hours, and AEP range from 1 in 50 to 1 in 2000.

CRCFORGE is a statistical (regional) analysis method that provides estimates of rare rainfall events at individual stations. However, for each station, the process includes a plot of that station's data *alone* - using a conventional (modified Cunnane) plotting position formula. Therefore, in the AEP range 1 in 50 to 1 in 100, CRCFORGE represents a fresh analysis of more up-to-date daily rainfall data for individual stations when compared with AR&R.

Queensland has decided to base design point rainfalls on CRCFORGE, and provide for short durations and frequent events by applying factors derived from AR&R in a similar manner to that envisaged in Book VI. Support for this decision comes from bench-marking and peer review - including independent rainfall analyses from raw data in two catchments.

A preferred method of converting design point rainfalls to design catchment rainfalls is to apply an Areal Reduction Factor (ARF). ARF's were not applied in previous studies as there were no factors both based on significant local data and showing reasonable consistency.

The other CRCCH partnership project successfully implemented in Queensland, was an analysis of the rainfall data set to produce new ARF's. This analysis used a modified Bell's Method (ie. nominal circular 'catchments') for sampling over areas ranging from 125 km^2 to 8,000 km^2. In Queensland, no clear trend of variation with AEP was found, and a conservative envelope model - dependent only on area and duration only - was fitted.

A CD has been prepared to streamline the output of these CRC projects - as a service to the Queensland sponsors of this project, to professionals in the field, and the people of Queensland. It is in the public domain and may be freely copied. The CD includes:

- A dataset suitable for introduction to any of the major GIS software, and tools that will provide a robust estimate leading to an IFD table for user-defined catchments.
- Documentation of the conduct of the project, and selected presentation material has been included. Hopefully you are reading this report as a result of receiving that CD.

In Summary:

- New tools for estimating catchment design rainfall have been developed by the CRCCH, have been successfully trialled in sub-tropical Queensland and extensively bench-marked.
- The combination of CRCFORGE/ARF allows for estimates across AEP and into the rare risk domain, covering most practical durations after extension using AR&R (1987) data.
- The application of design rainfall methods (of which these techniques form a part) to catchments larger than 8,000 km^2 is a matter for professional judgement.

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Ipswich Rivers Flood Study Rationalisation Project

Hydrology Component

It is a pre-requisite of the proposed methodology set out below, that all relevant model files, data files and results files from SKM's work in 2003 be provided for use in this study. These have been requested from BCC.

1. Methodology

In summary, the tasks in the hydrology component of the study are:

1. Review 2003 RAFTS modelling undertaken by SKM using CRC-FORGE rainfalls in terms of methodology, data and results for Bremer River and tributaries.
2. Review flood frequency analysis for Brisbane River at Savages Crossing
3. Extend the flood frequency analysis to include analysis of flood volumes.
4. Undertake a limited Monte Carlo analysis using the RAFTS model to develop more robust estimates of Q_{100} flows and to better define the remaining uncertainties in results.
5. Based on the above, produce revised design Q_{100} flow hydrographs for input to the hydraulic model.

Item 4 in the above list is the major part of the hydrology component of the study.

The following paragraphs outline the proposed methodology for each task.

1.1. Review of 2003 RAFTS Modelling

A brief review of the additional modelling will be undertaken in respect of the data and methodology adopted, and the impact of this modelling on design flows in the Bremer River and tributary catchments as these were not reported in SKM (2003).

A brief report on this review will be prepared.

1.2. Review of 2003 Flood Frequency Analysis

One of the components of the additional work undertaken in 2003 was an in-depth analysis of flood frequency for Brisbane River at Savages Crossing (composite series from current and former sites) both by direct site analysis and using a regional flood frequency approach with a number of different data sets and data adjustments to allow for the changes resulting from dam construction.

The resulting estimates of pre-dam Q_{100} ranged from 6,700m^3/s to 15,700m^3/s. The Independent Review Panel selected 12,000m^3/s as the "best estimate" of Q_{100} within a "likely" range of 10,000m^3/s to 14,000m^3/s. The Independent Review Panel regarded these figures to be the best available and the Q_{100} from the additional RAFTS modelling of 10,000m^3/s to be low.

SKM (2003) noted that high flows may be unreliable due to rating curve extrapolation (highest gauges flow being 30 – 45% of the peak flow in the record) but did not explore this aspect. However, the inclusion of regional data was expected to offset this to some degree.

The current and former gauging stations at Savages Crossing all have a gravel bed control which is liable to change over time, requiring the application of many rating curves over the period of record. In contrast, the station at Mt. Crosby (1901 -1975) had a weir control which is not subject to shifts in control.

Although Mount Crosby is about 40km downstream of Savages Crossing (AMTD of 91km and 131km respectively), the catchment area is only marginally greater (10,550km^2 and 10,180km^2 respectively), so the flood flows should be not only highly correlated but similar in magnitude. As the Mount Crosby records cover the period 1901 – 1975 they are unaffected by the operation of Wivenhoe Dam (although they are affected by Somerset Dam).

It is proposed to undertake a flood frequency analysis for the annual maximum series and partial duration series of floods at Mount Crosby, and also to analyse the correlation between flood peak flows at Savages Crossing and Mount Crosby. This will either support the recent SKM analysis or identify discrepancies.

A brief report will be prepared on this additional analysis.

1.3. Flood Frequency Analysis of Flood Volumes

The Independent Review Panel recommended that an analysis of flood volumes be undertaken in order to remove the impact of Wivenhoe and Somerset Dams on the analysis.

This analysis comprises the following:

- Obtaining flood volume data – due to the large number of flood events to be analysed, these will be obtained from the record of mean daily flows at Savages Crossing and/or Mount Crosby rather than from the continuous data;

- For the post-dam period, obtain the corresponding storage volume data for Somerset and Wivenhoe Dams to estimate the amount of volume of each flood retained;

- Adjust the flood volume data to estimate the gross flood volumes;

- Undertake a frequency analysis of the flood volume data;

- Estimate the volume of the 100 year ARI flood (and possibly other floods of interest) from the above;

- Critically compare the V_{100} from the above with the corresponding value from the RAFTS model; and

- Report on the above.

1.4. Monte Carlo Simulation

SKM (2003) looked at the sensitivity of peak flows in the Brisbane River to the following:

- Storm spatial variation using a number of historic storm patterns;
- Storm temporal patterns using a mix of ARR design and historic patterns; and
- Sensitivity to starting level in Wivenhoe Dam.

This modelling still assumed fixed values of:
- Rainfall frequency (100 year ARI only);
- Storm duration;
- Rainfall initial and continuing losses; and
- RAFTS model parameters.

The Independent Review Panel recommended that Monte Carlo methodology be used to simulate the possible combinations of storm temporal and spatial patterns which could also include variation of loss rates and reservoir drawdown.

A full Monte Carlo analysis would comprise running a large number of trials (typically in the order of tens of thousands) in order to adequately describe the distribution of the dependant variable, in this case flood peak magnitude.

In the case of the rainfall runoff process, the full range of variables which could be sampled using the Monte Carlo approach is:

- Rainfall intensity;
- Rainfall duration;
- Rainfall temporal pattern;
- Rainfall spatial pattern;
- Rainfall areal reduction factor;
- Initial loss;
- Possibly continuing loss although this a soil characteristic and not a random variable; and
- Possibly rainfall to runoff transfer function variables, in this case RAFTS model parameters. Although these should be well defined by the calibration process, in reality there is uncertainty about key parameters which could be tested in this way.

Also in this case, the drawdown in Wivenhoe Dam could be added to this list.

Previous applications of the Monte Carlo simulation process to rainfall – runoff modelling have used a simplified transfer function so that the sample trials could be automated and a large number of trials undertaken.

This is not possible in this case due to the complexity of the RAFTS model and its data input requirements and budget constraints. In this study, the process required comprises:

- Generation of sample parameter values selected from the above list;
- Estimation of catchment rainfall from design point rainfalls;
- Preparation of RAFTS input files to reflect the sampled parameters;
- Running the RAFTS model and extraction of key outputs (eg peak flows, flood volumes at key points) – pre dam conditions;
- Using Wivenhoe input hydrographs from the above together with the sampled dam starting level and running through the dam operations model to obtain the corresponding outflow hydrographs;
- Rerunning the RAFTS model with the Wivenhoe dam output hydrograph from the operations model instead of the dam inflow hydrograph; and
- Extraction of key outputs (eg peak flows, flood volumes at key points) – post dam conditions.

All of the above then needs to be repeated for each trial, then the results analysed to determine the flood frequency distributions at each of the key locations.

The process outlined above is time consuming, and in order to produce reasonably reliable results within the study budget, the number of trials must be reduced to a very limited number, of the order of hundreds not thousands of trials.

The following simplified sampling procedure is proposed in order to enable meaningful results to be obtained with so few trials:

- Base the analysis on the Q_{100} only – or more strictly on the 100 year ARI CRC-FORGE point rainfalls – this greatly reduces the sample size required as we are now concerned only with the distribution of estimates of Q_{100} and not the whole of the flood frequency distribution.

  (It is recognised that this is a severe limitation to the analysis, as it assumes that 100 year ARI runoff is obtained from 100 year rainfall and excludes the possibility of 100 year ARI runoff resulting from, say, a more extreme rainfall on only part of the catchment, or a less extreme rainfall widely spread over a pre-saturated catchment. However, this process does test the uncertainty within the RAFTS results.)

- Assume areal reduction factors are not random variables but are as estimated using the CRC-FORGE procedure.

- Assume the continuing loss is fixed and does not vary from one event to another, which is reasonable as this is a function of soil infiltration capacity.

- Assume the RAFTS parameters are fixed. Whilst this will not test the uncertainty in the RAFTS parameters, these should be relatively small given the extensive model calibration which has been undertaken. Omission of the uncertainty in these values will still enable the objective comparison of the Q_{100} distribution with the previous RAFTS estimates.

On this basis, the parameters tested will be:
- Storm duration – limited to a range of 18 to 72 hours (the range found to be critical for Bremer and Brisbane River catchments);
- Storm spatial distribution (limited range - to be determined);
- Storm temporal distribution (as per ARR plus a small number of variants);
- Initial loss; and
- Wivenhoe Dam starting level.

With 5 independent variables, even with a minimum of 3 possible values of each variable, there will be 3^5 or 243 possible combinations, and 1024 combinations if there are 4 possible values for each parameter. In order to fully define these distributions the sample size should be at least twice the number of combinations ie about 500 in the first instance and 2,000 in the second. Smaller sample numbers risk not defining the tails of the distribution. However, a smaller number of trials should give reasonable results around the mode of the distribution and within say 1 standard deviation of the mode.

Until this sampling is commenced, it is difficult to estimate the time it will take to do the catchment rainfall analysis, RAFTS modelling and dam operation modelling, but this is expected to be about 3 – 4 hours i.e. $360 - $480 per sample.

On this basis, a sample size of 100 will cost $36,000 - $48,000 and so on.

The results from these RAFTS runs will be used to define the distribution of Q_{100} estimates for key locations in Ipswich and Brisbane.

Both the Monte Carlo sampling procedure and the distribution analysis will be undertaken using the program @RISK which is an add-on to MS Excel. Each of the parameters to be sampled will be assigned an appropriate distribution based on their expected range of values and distribution types.

A report will be prepared describing the data synthesis, its subsequent analysis and its outcomes.

1.5. Preparation of Design Flood Hydrographs

Inflow hydrographs for the MIKE 11 model will be prepared using from appropriate runs of the RAFTS model. It is proposed to run the MIKE 11 model with a range of flow inputs such as those representing central estimates (mean, median) and other quantiles eg 10%, 90% in order to determine the effect of these flow variations in flood levels.

The current MIKE 11 model has 156 flow inputs (plus those for the upper catchment model), so this is a fairly time consuming task.

2. Estimated Cost

All of the estimated costs contained herein are based on all the necessary models (ie RAFTS model, DNR dam operation model, catchment rainfall surface fitting) and data files being made available at no cost to this project. If this is not the case, there will be additional costs in data acquisition and generating the required files.

The Monte Carlo simulation is the most costly part of the analysis. Estimated times and costs for the various components are outlined below.

As can be seen from the tabulated costs overleaf, the overall cost of the hydrology component is heavily dependent on the number of trials in the Monte Carlo simulation.

As outlined above 250 trials is about the same number as the possible parameter combinations, and should be undertaken if possible, or 200 trials as a minimum.

The other major cost component in the study will be the revised flood mapping which is expected to cost of the order of $20,000 - $30,000.

Hydrology Component
Cost Estimate

Item	Description	Hours	Cost
1	Review 2003 RAFTS modelling	8	$960
2	Extend Flood Frequency Analysis	16	$1,920
3	Flood Frequency Analysis of Volumes	24	$2,880
4	Monte Carlo Simulation (100 trials)	350	$42,000
5	MIKE 11 hydrographs	40	$4,800
6	Report	40	$4,800
	TOTAL		**$57,360**
Alternative 1	As above but Monte Carlo has 200 trials		$99,360
Alternative 2	As above but Monte Carlo has 250 trials		$120,360

David Sargent
20th April 2005

Ravi

WATER & ENVIRONMENT

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MIKE11 Model Review
Ipswich Rivers

Ipswich City Council

Final Report
May 2005

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MIKE11 Model Review Ipswich Rivers

Draft Report

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Authors Stefan Szylkarski	Date 23 May 2005 Approved by Stefan Szylkarski

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CONTENTS

1 INTRODUCTION

Ipswich City Council (ICC) commissioned DHI Water and Environment (DHI) to carry out a brief review of a MIKE11 model covering the Ipswich Rivers and associated tributaries (The Model).

Sinclair Knight Merz (SKM) originally developed the lower part of the Ipswich Rivers model in the year 2000 using MIKE11 version 1999. KBR subsequently developed a MIEK11 model of the upper Bremer system in 2002 using MIKE11 version 2000b.

The model has a number of stability issues that required a reduction of the model time step in order to maintain numerical stability. The model currently runs on a 2 second time step, which is excessively low for a model of this type.

The aim of the model review was to critically appraise the model from a holistic viewpoint. The appraisal focused on identifying necessary improvements and modifications required to improve stability and improve the model performance. A range of modifications has been proposed in order to update the model to a standard sufficient for future flood and forecasting studies.

The specific objectives of the model review included the following:

1. Identify the sources of model instabilities
2. Investigate the possibilities for reducing the model simulation times.
3. Provide a peer review of the model in relation to the suitability of the modelling techniques adopted in the model.

2 MIKE11 MODEL REVIEW

The review of the model was carried out as a series of tasks involving a detailed analysis of the four major components of the model:

- Model schematisation,
- Cross section review,
- Numerical parameters,
- Simulation time step.

2.1 Model Schematisation

The model schematisation was checked in detail to for the following elements:

- Branch layouts and grid spacing,
- Link channel usage,
- Duplication of storage,
- Structures,
- Boundary conditions.

2.1.1 Branch Layout and Grid Spacing

The model has generally been developed using single branches which combines river channel and floodplain flows together. This technique is suitable for the purposes of investigating large over bank floods but has many limitations when dealing with intermediate and in-bank flow events. The alternative schematisation technique is to divide the floodplain and channel into separate model branches which are connected by link channels to represent the exchange of flows between the channel and the floodplain. In some instances such as the Northrail and Southrail branches the floodplain has been divided but in many cases the floodplain is very wide and is represented by single cross sections. There is scope to improve the model schematisation where major flow path separation between channel and floodplain can be defined.

The model schematisation of the RailSouth and RailNorth branches are producing significant instabilities and are not well defined. The review of the model schematisation has been done without supporting information or mapping and it is difficult to determine the purpose of the branch layout that has been adopted. The branch layout does not appear to be very effective and should be completely redefined in this area. A large number of the connecting over bank flow paths have been modelled without link channels or overflow weirs to define the spilling from the channel. This is a significant flaw in the model design that has led to instabilities at low flow. To overcome the stability issues the cross sections have been modified with deep "slots" to allow flow to pass through at low levels. These slots have further decreased the model stability and are not a preferred modelling technique. The use of link channels is recommended to overcome the need for deep slots in cross sections in this area. Floodplains should be defined as separate flow paths and a single branch should be developed for the main flow path.

There are a number of branches within the model where there are extremely closely spaced grid points (less than 10meters). This close spacing is consistent with local storm drainage modelling but is not recommended for broad scale flood models. The close spacing of the grid points will significantly restrict the model time step.

The branch chainage has been defined with 2 decimal place accuracy. Some elements of the MIKE11 system will only recognise integer values in meters for chainage lengths and we recommend that all chainages be adjusted to integer values in metres. The measurement of chainage is subjective to the path and it is not realistic to assume an accuracy of less than 1 metre.

2.1.2 Link Channels

There are no "Link Channels" present in the model. The model has generally be developed with slots in model cross sections in order to avoid the need for link channels. However, these slots are often the cause of instabilities and we recommend that the model be adjusted to remove all the slots and link channels included where necessary.

2.1.3 Storage Duplication

There is significant duplication of storage in many areas of the model. The overlap of cross section extents in **Figure 1** (downstream end of Franklinvale Branch) shows overlapping cross sections which suggest that there is storage duplication. If the cross sections are only partially flooded at peak flow then the duplication of storage may be less important however this cannot be confirmed with the current set-up.

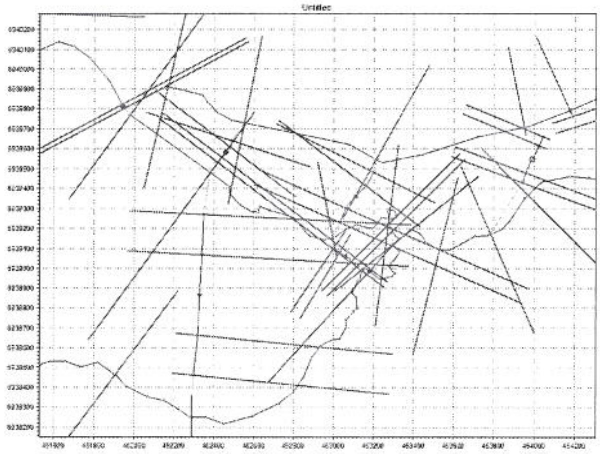

Figure 1 ***Typical example of storage duplication where cross section overlap.***

We would recommend the layout and chainage of the model be checked by importing an accurate aerial photographic background image. The cross section extents should then be checked against the topographic features in the image. Shortening cross section extents and redefining flow paths where necessary should be carried out to remove areas of storage duplication.

2.1.4 Structures

A number of changes to the model are required in relation to hydraulic structures in order to improve stability. The latest release of MIKE11 (version 2004) includes a "Bridge" structure type, which should be used in place of the culvert and weir approach that has been adopted for bridges in the past.

The Bridge structure uses a number of alternative methods and in general we would recommend that the FHWM WSPRO method be adopted. This method will improve the modelling and stability of bridges where there are little or no contraction and expansion losses under the bridge.

Where culvert and weir structures are adopted in the model then attention should be placed on the location of cross sections upstream and downstream of the model. The upstream and downstream cross sections should be placed at locations where contraction starts and expansion finishes in relation to the structure. In some cases the upstream and downstream cross sections have been placed unrealistically close to the structure opening and outlet.

2.1.5 Boundary Conditions

Model boundary conditions can have a significant artificial influence on simulation results within several model grid points of the boundary condition. It is therefore important to ensure that boundary conditions are placed away from the area of interest so that water level and flow results are not reported close to boundary conditions.

The upper reaches of the model are relatively steep and the boundary conditions at these locations may become unstable during low flows. It will be possible to stabilise these areas by adjusting the model time step or cross section however it is more appropriate to consider reducing the model to a downstream point where the boundary inflow enters the model with a relatively smaller slope.

There are a number of "trickle flows" that have been input to the model at various locations. These flows are generally used to stabilise the model by providing small stabilising flows. The "trickle" flows are not necessary and should be removed. Any model instability that occurs due to the removal of the trickle flows should be examined and the model schematisation changed in order to stabilise the model.

There is no cross section defined at the model outlet. A cross section should be placed at the outlet to define the outlet conditions where the Q-h boundary condition has been placed.

A structure has been placed very close to the upstream model boundary, as shown in **Figure 2,** for branch "Purga_2". This structure should be removed or the model branches extended upstream. The model will be unable to fully develop backwater conditions upstream and the boundaries flows will be forced through the structures.

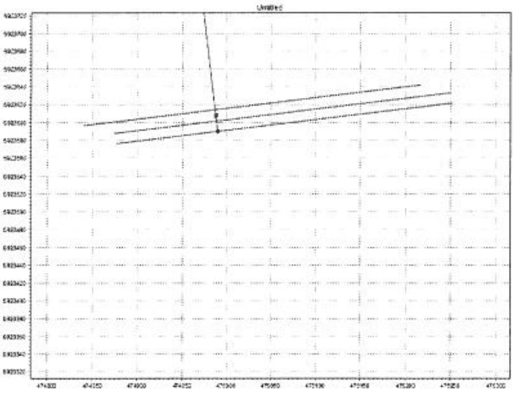

Figure 2 ***Upstream structre located close to Boundary in branch Purga_2***

2.2 Cross Sections

Cross sections throughout the model have been manipulated to include deep slots as shown **Figure 3**. This is a traditional technique that was used in the 1990's for stabilising models during low flow conditions. This technique often creates more stability issues than are solved and the need for these slots has been removed by advances in the model engine during the late 90's. These slots should be removed.

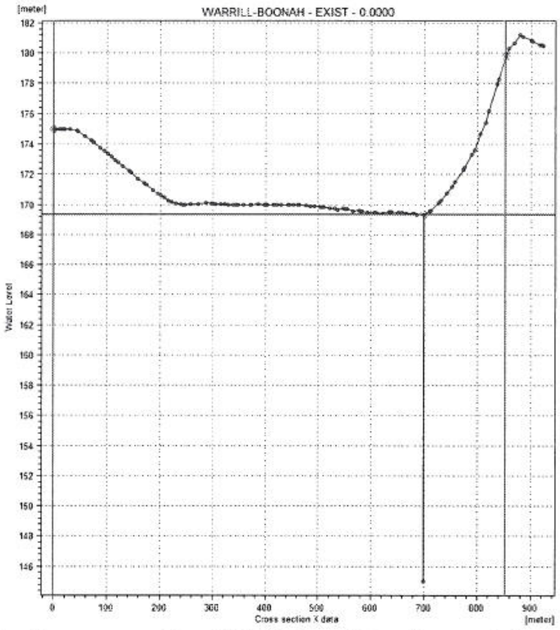

Figure 3 ***Example of a cross section "slot" placed into the model.***

There are many cross sections that are reported with chainages to two decimal places. The model processed data only reports to integer values in meters and we recommend that chainages are limited to integer values in meters. In general the measurements of chainages is subjective and is not accurate to more than 1 meter.

2.2.1 Hydraulic Radius

The hydraulic radius method selected within MIKE11 is critical for the computation of accurate conveyance in cross sections. MIKE11 offers three choices including

1. Resistance Radius
2. Hydraulic Radius, Effective Area
3. Hydraulic Radius, Total Area.

When flows are within bank or marginally over bank the resistance radius method will overestimate conveyance as it does not account for the side wall friction from the channel walls. In this case it is appropriate to use the Hydraulic Radius, Total Area method in combination with the setting of bank markers No 8 and No 9. The Total Area method in combination with the bank markers will calculate the conveyance of the cross section as separate sections (over bank and channel flows) whilst also accounting for sidewall friction in the Radius formulation. This will ensure that the model will accurately represent the cross section conveyance for the full range of water levels that are likely to occur.

The model has already been set with Hydraulic Radius using Total Area however we recommend that all cross sections be updated to include the setting of bank markers 8 and 9. This change will require that the model be re-calibrated.

2.2.2 Processed Data

Many of the cross sections have non-monotonically increase conveyance curves as demonstrated in **Figure 4**.

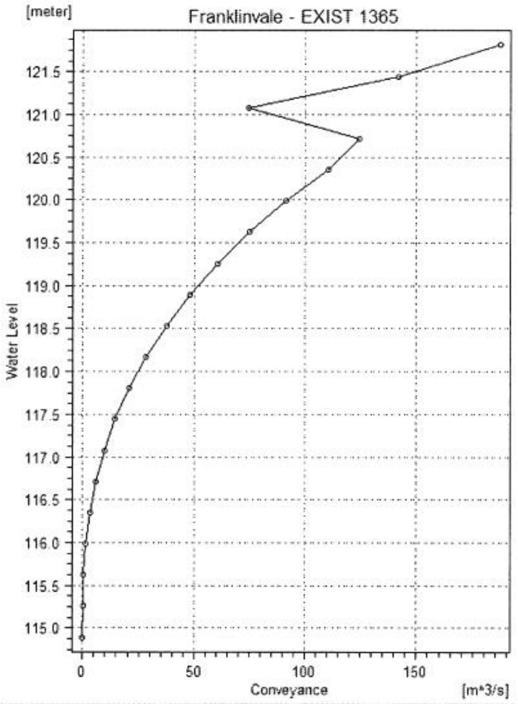

Figure 4 ***Example of Non-monotonically increasing conveyance curve in processed data.***

This in general is the result of the inclusion of floodplains and channels in a single cross section. The problem will be overcome by setting bank markers 8 and 9 as suggested in Section 2.2.1.

The default number of processed data values in MIKE11 is 20 points over a reasonable range in water level (5 to 10 meters). In some cases the water level range in the cross sections is over 20m and it is reasonable to double the number of processed data points to 40.

There are significant numbers of cross sections with less than 20 processed data points. This setting would have been changed to reduce the resolution of the processed data in an attempt to remove the non-monotonically increasing conveyance curves. We suggest that all the processed data points be re-calculated within the model and reasonable ranges selected.

2.3 Numerical Parameters

The numerical parameters that were reviewed include:

- Default Values
- Initial Conditions
- Roughness Values

The review notes are provided below.

2.3.1 Default Values

The default values were unchanged with the exception of the "Delta" parameter and the "NoIter" (Number of Iterations). The "Delta" value controls the centring of the numerical scheme and was changed from 0.5 to 0.7, which is slightly forward centring of the numerical scheme. We note that in contrast the "NoIter" parameter was increased from 1 to 2 that produces an additional iteration with the aim of centring the scheme.

The increase to the "Delta" value introduces a dissipative influence on the model results and can help to stabilise a model. The delta value has a varying level of influence on the model simulation that reduces as the model time step is decreased. In the current form the model is running on a 2 second time step and consequently the delta value will have a relatively minor influence on the model results.

The delta value is particularly important if tidal waves are to be correctly propagated within the model. A dissipative influence in the numerical scheme will dampen the tidal waves and adversely affect the model results. The model currently uses constant water level boundary conditions and as such the delta value will not influence tidal wave propagation.

The value of "Delta" will be dependant on the schematisation adopted for the model. If the steep upper branches are maintained in the model then it may be necessary to increase the "Delta" to 1. Alternatively the "Delta" should be set to 0.55 and the steep model branches removed.

The "NoIter" value should be changed to 1 as the second iteration will slow the model and is only counteracting the changes made to the "Delta" value.

2.3.2 Initial Conditions

The model currently operates from a hot start file that is used to generate an initial stable water surface profile. We suggest that the hot start file be removed and a very detailed set of initial conditions be developed that will allow the model to start from a "cold start". This will make the model more flexible in the future as it will allow the model to be modified without the need to update the hot start file in each case.

2.3.3 Roughness Conditions

The model roughness parameters were not set and all cross sections have a roughness of 0.045 Manning's "n". There have been little or no adjustments to the relative resistance parameters in cross sections. The roughness values should be reviewed to ensure that they are correctly specified.

2.4 Simulation Time Steps

The model simulation time step is currently set at 2 seconds. This is considered to be unreasonably low given the flow conditions that occur within the model. We believe that the model time step could be increased to between 30 seconds and 1 minute with appropriate changes to the model grid spacing and schematisation that has been recommended in this report.

Preliminary testing of the model was carried out as part of this review. The testing indicated that a model time step of 1 minute was achievable for low flow conditions. This time step may need to be reduced for large flood events when the depths and velocities increase significantly.

Based on this assessment we believe that the model simulation time can be reduced by a between 20 and 30 times.

A preliminary adjustment to the model was carried out by removing the RailNorth and RailSouth branches that were a major source of instability. The initial conditions were also modified to develop a relatively stable initial water surface profile. Using the adjusted model we were able to successfully carry out a simulation for and extended period at over 30 seconds time step. With further work on the model we feel confident that a 1-minute time step is achievable.

3 MERGING IPSWICH AND BRISBANE RIVER MODELS

An investigation of the requirements for merging the Ipswich Rivers (Ipswich City Council) and Brisbane River (Brisbane City Council) MIKE11 models was completed. A combined model was developed as shown in **Figure 5** and consists of approximately 300 branches and 1700 cross sections, 130 culverts and 120 weirs.

The combined model is not large in numerical terms and would be appropriate for use as a real time flood simulation tool with reasonable simulation times.

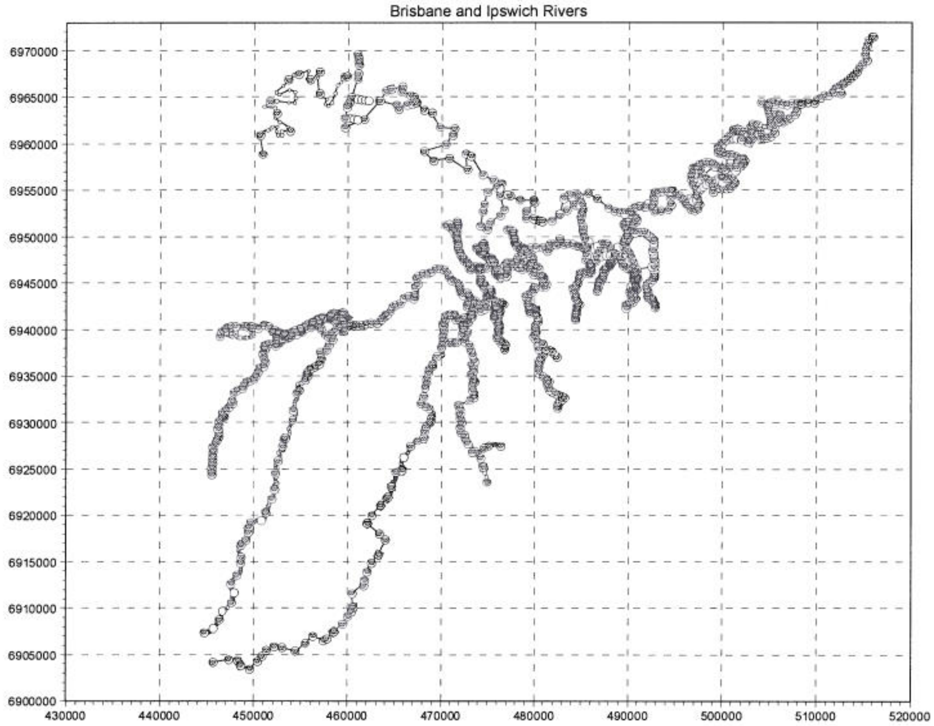

Figure 5 Merged Ipswich and Brisbane Rivers MIKE11 model network layout.

The models can be merged by utilising the "pfsmerge.exe" tool that is provided with MIKE11. The following steps are required to merge the model networks:

1. Recalculate the point numbering using the "Number Points Consecutively" tool under the NETWORK menu.
2. Utilise the PFSMERGE tool to combine the model network files
3. Export the cross sections to text format and import into a combined cross sectional data base.
4. Utilise the PFSMERGE tool to combine the model boundary and parameter files.

3.1 Modifications

A number of modifications to the combined models will be necessary to properly merge the two models. These modifications include:

- ➢Removing Model overlaps,
- ➢Updating model boundary conditions,
- ➢Combining roughness tables.

A brief description of these modifications is detailed in the following sections.

3.1.1 Model Overlap

There is a small area of overlap between the two models for branches Warrill and Purga from chainage's 25720 and 19940 to the downstream model outlet. The areas are evident in **Figure 6** where the overlap in the duplicated model branches is obvious in the network layout view in MIKE11. It will be necessary to remove the branches from the Brisbane River MIKE11 model in this area and utilise the branches from the Ipswich Rivers MIKE11 model which has a greater level of detail in this area

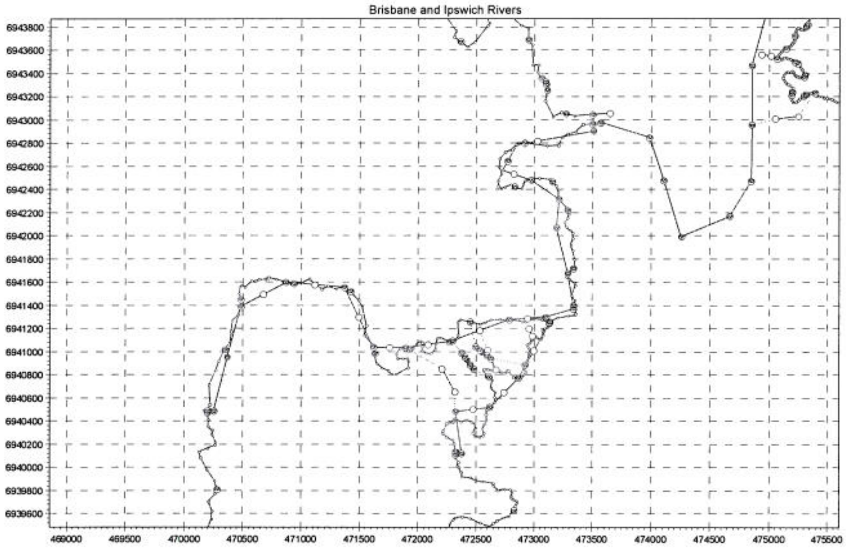

Figure 6 Overlap in network layout between Brisbane and Ipswich River models.

3.1.2 Boundary Conditions

The downstream boundary condition from the Ipswich River MIKE11 model on the Bremer River should be deleted and the branch connected directly to the Brisbane River MIKE11 model. The downstream boundary condition is no longer necessary, as flows will pass directly through to the Brisbane River model.

3.1.3 Reduce Upstream Branches

We believe that significant increase in the model time step will be achievable if the upstream reaches in the Ipswich Rivers area are reduced. The steep channel slopes in the upstream areas require significant reduction in the overall model time step in order to maintain model stability. It may not be necessary to include these areas in a combined flood model and therefore the model performance can be significantly improved by removal.

4 CONCLUSIONS AND RECOMMENDATIONS

The Ipswich Rivers MIKE11 model has been reviewed in order to identify necessary improvements and modifications required to update the model to a standard sufficient for flood and forecasting studies.

The primary issue is the removal of the large number of "slots" in the model cross sections, which are a major source of instability. The removal of these slots will require that a series of "link channels" be added to the model to ensure the stable simulation of flows from the river to the over-bank areas. In addition there are a range of changes required to the model schematisation and grid point spacing that are essential for the model to achieve stability at longer time steps. These changes to the model are fundamental to the performance of the model and as such the original model calibration will not be valid if the modifications are implemented.

We recommend that the following modifications be implemented to the model:

- Include accurate aerial photographic background image to ensure positional accuracy of the model branches and cross sections.
- Model Schematisation:
  - Re-schematise the RailNorth and RailSouth branches using link channels.
  - Remove closely spaced grid points
  - Include Link Channels in place of artificial slots in connecting cross sections
  - Check model chainages against registered photographic images.
  - Update branch layouts and cross section extents in areas of cross section overlap in order to eliminate storage duplication.
  - Divide channel and floodplain flows into separate branches for excessively wide floodplain sections.
- Cross Sections
  - Remove all artificial slots in cross sections..
  - Increase the number of processed data points in some cross sections to between 20 and 40.
- Numerical Parameters
  - Centre the numerical scheme using a delta value of 0.55
  - Define stable static initial condition to allow the model to cold start correctly.
- Simulation Time step
  - Update model time step to between 30 seconds and 1 minutes. (Dependant on model sensitivity testing)
- Model Calibration
  - Re-Calibrate over bank flood events using previous flood study information.

A preliminary investigation was carried out to determine the suitability of merging the Ipswich and Brisbane Rivers MIKE11 models into a single basin model. The investigation indicates that it is feasible merge the models with only minor adjustments required for some overlapping areas. The combined model is not excessively large in size and will have reasonable simulation times.

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MIKE11 Model Review
Ipswich Rivers

<u>Spelling</u>

metre (meter)

centring? (~~centering~~)

overbank? (over bank)

MIKE11 Model Review
Ipswich Rivers

Draft Report

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1 INTRODUCTION

Ipswich City Council (ICC) commissioned DHI Water and Environment (DHI) to carry out a brief review of a MIKE11 model covering the Ipswich Rivers and associated tributaries (The Model).

Sinclair Knight Merz (SKM) originally developed the lower part of the Ipswich Rivers model in the year 2000 using MIKE11 version 1999. KBR subsequently developed a MIEK11 model of the upper Bremer system in 2002 using MIKE11 version 2000b. MIKE

The model has a number of stability issues that required a reduction of the model time step in order to maintain numerical stability. The model currently runs on a 2 second time step, which is excessively low for a model of this type.

The aim of the model review was to critically appraise the model from a holistic viewpoint. The appraisal focused on identifying necessary improvements and modifications required to improve stability and improve the model performance. A range of modifications has been proposed in order to update the model to a standard sufficient for future flood and forecasting studies.

The specific objectives of the model review included the following:

1. Identify the sources of model instabilities
2. Investigate the possibilities for reducing the model simulation times.
3. Provide a peer review of the model in relation to the suitability of the modelling techniques adopted in the model.

2 MIKE11 MODEL REVIEW

The review of the model was carried out as a series of tasks involving a detailed analysis of the four major components of the model:

- Model schematisation,
- Cross section review,
- Numerical parameters,
- Simulation time step.

2.1 Model Schematisation

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The model schematisation was checked in detail ~~to~~ for the following elements:

- Branch layouts and grid spacing,
- Link channel usage,
- Duplication of storage,
- Structures,
- Boundary conditions.

2.1.1 Branch Layout and Grid Spacing

The model has generally been developed using single branches which combines river channel and floodplain flows together. This technique is suitable for the purposes of investigating large over bank floods but has many limitations when dealing with intermediate and in-bank flow events. The alternative schematisation technique is to divide the floodplain and channel into separate model branches which are connected by link channels to represent the exchange of flows between the channel and the floodplain. In some instances such as the Northrail and Southrail branches the floodplain has been divided but in many cases the floodplain is very wide and is represented by single cross sections. There is scope to improve the model schematisation where major flow path separation between channel and floodplain can be defined.

The model schematisation of the RailSouth and RailNorth branches are producing significant instabilities and are not well defined. The review of the model schematisation has been done without supporting information or mapping and it is difficult to determine the purpose of the branch layout that has been adopted. The branch layout does not appear to be very effective and should be completely redefined in this area. A large number of the connecting over bank flow paths have been modelled without link channels or overflow weirs to define the spilling from the channel. This is a significant flaw in the model design that has led to instabilities at low flow. To overcome the stability issues the cross sections have been modified with deep "slots" to allow flow to pass through at low levels. These slots have further decreased the model stability and are not a preferred modelling technique. The use of link channels is recommended to overcome the need for deep slots in cross sections in this area. Floodplains should be defined as separate flow paths and a single branch should be developed for the main flow path.

There are a number of branches within the model where there are extremely closely spaced grid points (less than 10 met~~er~~res). This close spacing is consistent with local storm drainage modelling but is not recommended for broad scale flood models. The close spacing of the grid points will significantly restrict the model time step.

The branch chainage has been defined with ~~2~~ two decimal place accuracy. Some elements of the MIKE11 system will only recognise integer values in meters for chainage lengths and we recommend that all chainages be adjusted to integer values in metres. The measurement of chainage is subjective to the path and it is not realistic to assume an accuracy of less than 1 metre.

2.1.2 Link Channels

There are no "Link Channels" present in the model. The model has generally be developed with slots in model cross sections in order to avoid the need for link channels. However, these slots are often the cause of instabilities and we recommend that the model be adjusted to remove all the slots and link channels included where necessary.

2.1.3 Storage Duplication

There is significant duplication of storage in many areas of the model. The overlap of cross section extents in **Figure 1** (downstream end of Franklinvale Branch) shows overlapping cross sections which suggest that there is storage duplication. If the cross sections are only partially flooded at peak flow then the duplication of storage may be less important however this cannot be confirmed with the current set-up.

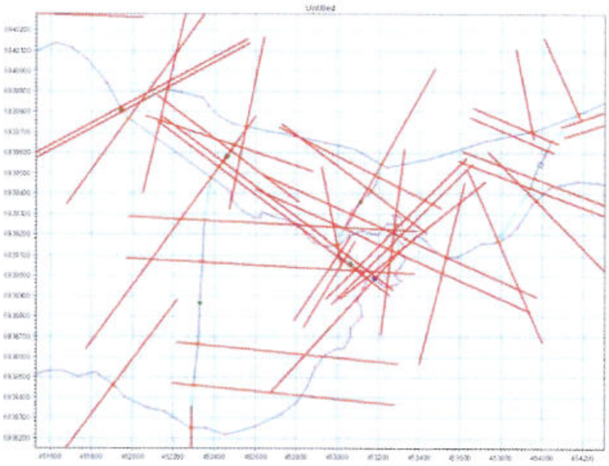


Figure 1 ***Typical example of storage duplication where cross section overlap.***

We would recommend the layout and chainage of the model be checked by importing an accurate aerial photographic background image. The cross section extents should then be checked against the topographic features in the image. Shortening cross section extents and redefining flow paths where necessary should be carried out to remove areas of storage duplication.

2.1.4 Structures

A number of changes to the model are required in relation to hydraulic structures in order to improve stability. The latest release of MIKE11 (version 2004) includes a "Bridge" structure type, which should be used in place of the culvert and weir approach that has been adopted for bridges in the past.

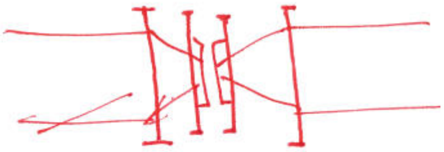
The Bridge structure uses a number of alternative methods and in general we would recommend that the FHWM WSPRO method be adopted. This method will improve the modelling and stability of bridges where there are little or no contraction and expansion losses under the bridge.

But how are losses ~~are~~ computed b/n starting ~~[illegible]~~ contraction + culvert? Similarly d/s end of structure to end of expansion?

Where culvert and weir structures are adopted in the model then attention should be placed on the location of cross sections upstream and downstream of the model. The upstream and downstream cross sections should be placed at locations where contraction starts and expansion finishes in relation to the structure. In some cases the upstream and downstream cross sections have been placed unrealistically close to the structure opening and outlet.

2.1.5 Boundary Conditions

Model boundary conditions can have a significant artificial influence on simulation results within several model grid points of the boundary condition. It is therefore



Traditional hydraulic schematic

important to ensure that boundary conditions are placed away from the area of interest so that water level and flow results are not reported close to boundary conditions.

The upper reaches of the model are relatively steep and the boundary conditions at these locations may become unstable during low flows. It will be possible to stabilise these areas by adjusting the model time step or cross section however it is more appropriate to consider reducing the model to a downstream point where the boundary inflow enters the model with a relatively smaller slope.

There are a number of "trickle flows" that have been input to the model at various locations. These flows are generally used to stabilise the model by providing small stabilising flows. The "trickle" flows are not necessary and should be removed. Any model instability that occurs due to the removal of the trickle flows should be examined and the model schematisation changed in order to stabilise the model.

There is no cross section defined at the model outlet. A cross section should be placed at the outlet to define the outlet conditions where the Q-h boundary condition has been placed.

A structure has been placed very close to the upstream model boundary, as shown in **Figure 2,** for branch "Purga_2". This structure should be removed or the model branches extended upstream. The model will be unable to fully develop backwater conditions upstream and the boundaries flows will be forced through the structures.

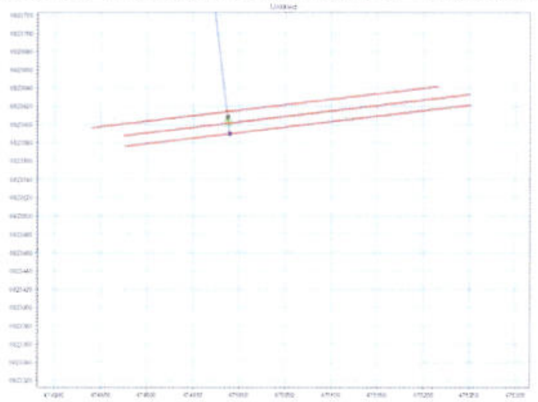


Figure 2 Upstream structre located close to Boundary in branch Purga_2

2.2 *Cross Sections*

Cross sections throughout the model have been manipulated to include deep slots as shown **Figure 3**. This is a traditional technique that was used in the 1990's for stabilising models during low flow conditions. This technique often creates more stability issues than are solved and the need for these slots has been removed by advances in the model engine during the late 90's. These slots should be removed.

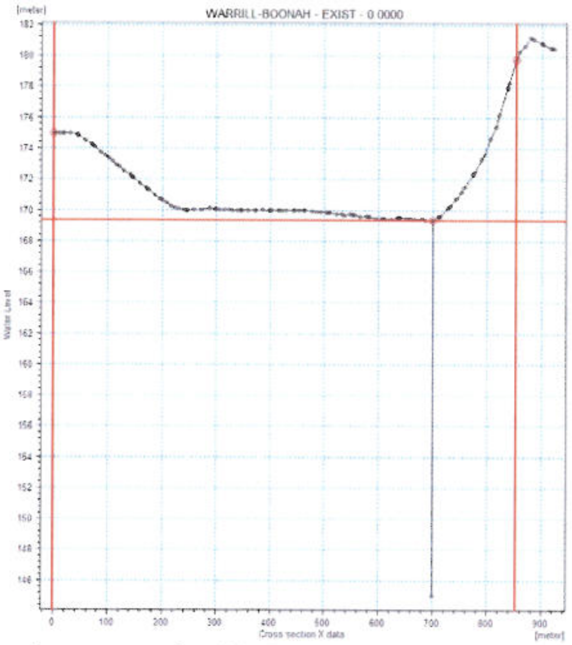


Figure 3 ***Example of a cross section "slot" placed into the model.***

There are many cross sections that are reported with chainages to two decimal places. The model processed data only reports to integer values in meters and we recommend that chainages are limited to integer values in meters. In general the measurements of chainages is subjective and is not accurate to more than 1 meter.

already written on page 7, is it worth repeating here?

2.2.1 *Hydraulic Radius*

The hydraulic radius method selected within MIKE11 is critical for the computation of accurate conveyance in cross sections. MIKE11 offers three choices including

1. Resistance Radius
2. Hydraulic Radius, Effective Area
3. Hydraulic Radius, Total Area.

When flows are within bank or marginally over bank the resistance radius method will overestimate conveyance as it does not account for the side wall friction from the channel walls. In this case it is appropriate to use the Hydraulic Radius, Total Area method in combination with the setting of bank markers No 8 and No 9. The Total Area method in combination with the bank markers will calculate the conveyance of the cross section as separate sections (over bank and channel flows) whilst also accounting for sidewall friction in the Radius formulation. This will ensure that the model will accurately represent the cross section conveyance for the full range of water levels that are likely to occur.

The model has already been set with Hydraulic Radius using Total Area however we recommend that all cross sections be updated to include the setting of bank markers 8 and 9. This change will require that the model be re-calibrated.

2.2.2 *Processed Data*

Many of the cross sections have non-monotonically increase conveyance curves as demonstrated in **Figure 4**.

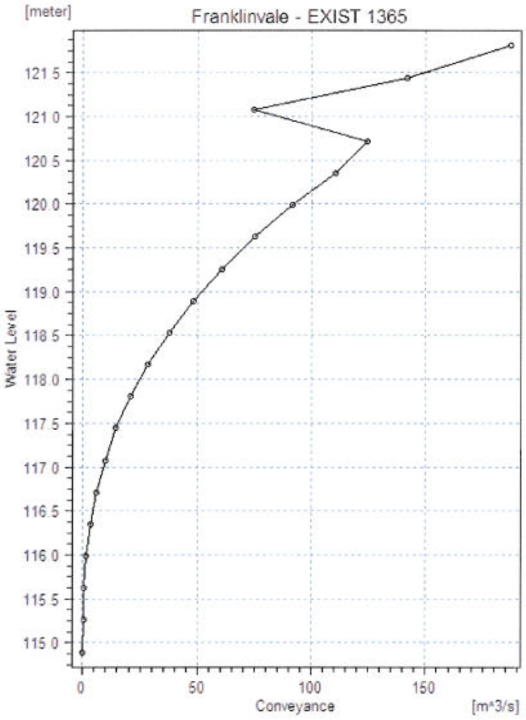


Figure 4 ***Example of Non-monotonically increasing conveyance curve in processed data.***

This in general is the result of the inclusion of floodplains and channels in a single cross section. The problem will be overcome by setting bank markers 8 and 9 as suggested in Section 2.2.1.

✗ The default number of processed data values in MIKE11 is 20 points over a reasonable range in water level (5 to 10 met~~er~~res). In some cases the water level range in the cross sections is over 20m and it is reasonable to double the number of processed data points to 40. metres?

There are significant numbers of cross sections with less than 20 processed data points. This setting would have been changed to reduce the resolution of the processed data in an attempt to remove the non-monotonically increasing conveyance curves. We suggest that all the processed data points be re-calculated within the model and reasonable ranges selected.

2.3 Numerical Parameters

The numerical parameters that were reviewed include:

- Default Values
- Initial Conditions
- Roughness Values

The review notes are provided below.

2.3.1 Default Values

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The default values were unchanged with the exception of the "Delta" parameter and the "NoIter" (Number of Iterations). The "Delta" value controls the centring of the numerical scheme and was changed from 0.5 to 0.7, which is slightly forward centring of the numerical scheme. We note that in contrast the "NoIter" parameter was increased from 1 to 2 that produces an additional iteration with the aim of centring the scheme.

The increase to the "Delta" value introduces a dissipative influence on the model results and can help to stabilise a model. The delta value has a varying level of influence on the model simulation that reduces as the model time step is decreased. In the current form the model is running on a 2 second time step and consequently the delta value will have a relatively minor influence on the model results.

The delta value is particularly important if tidal waves are to be correctly propagated within the model. A dissipative influence in the numerical scheme will dampen the tidal waves and adversely affect the model results. The model currently uses constant water level boundary conditions and as such the delta value will not influence tidal wave propagation.

The value of "Delta" will be dependant on the schematisation adopted for the model. If the steep upper branches are maintained in the model then it may be necessary to increase the "Delta" to 1. Alternatively the "Delta" should be set to 0.55 and the steep model branches removed.

The "NoIter" value should be changed to 1 as the second iteration will slow the model and is only counteracting the changes made to the "Delta" value.

2.3.2 *Initial Conditions*

The model currently operates from a hot start file that is used to generate an initial stable water surface profile. We suggest that the hot start file be removed and a very detailed set of initial conditions be developed that will allow the model to start from a "cold start". This will make the model more flexible in the future as it will allow the model to be modified without the need to update the hot start file in each case.

2.3.3 *Roughness Conditions*

The model roughness parameters were not set and all cross sections have a roughness of 0.045 Manning's "n". There have been little or no adjustments to the relative resistance parameters in cross sections. The roughness values should be reviewed to ensure that they are correctly specified.

2.4 *Simulation Time Steps*

The model simulation time step is currently set at 2 seconds. This is considered to be unreasonably low given the flow conditions that occur within the model. We believe that the model time step could be increased to between 30 seconds and 1 minute with appropriate changes to the model grid spacing and schematisation that has been recommended in this report.

Preliminary testing of the model was carried out as part of this review. The testing indicated that a model time step of 1 minute was achievable for low flow conditions. This time step may need to be reduced for large flood events when the depths and velocities increase significantly.

Based on this assessment we believe that the model simulation time can be reduced by a between 20 and 30 times.

A preliminary adjustment to the model was carried out by removing the RailNorth and RailSouth branches that were a major source of instability. The initial conditions were also modified to develop a relatively stable initial water surface profile. Using the adjusted model we were able to successfully carry out a simulation for and extended period at over 30 second~~s~~ time step. With further work on the model we feel confident that a 1-minute time step is achievable. X

3 MERGING IPSWICH AND BRISBANE RIVER MODELS

An investigation of the requirements for merging the Ipswich Rivers (Ipswich City Council) and Brisbane River (Brisbane City Council) MIKE11 models was completed. A combined model was developed as shown in **Figure 5** and consists of approximately 300 branches and 1700 cross sections, 130 culverts and 120 weirs.

The combined model is not large in numerical terms and would be appropriate for use as a real time flood simulation tool with reasonable simulation times.

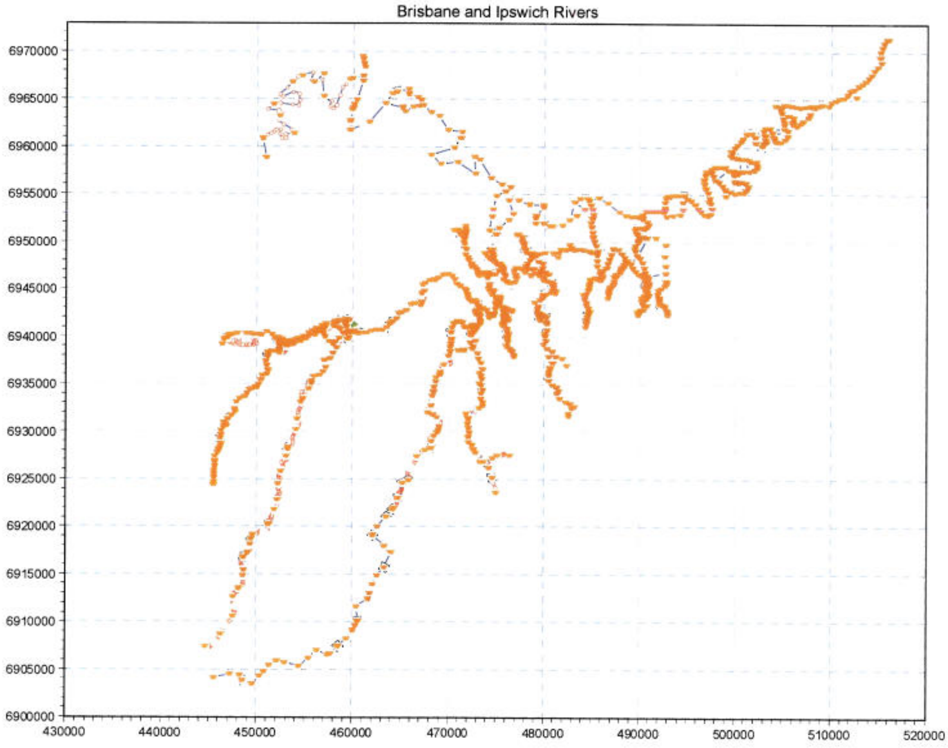

Figure 5 Merged Ipswich and Brisbane Rivers MIKE11 model network layout.

The models can be merged by utilising the "pfsmerge.exe" tool that is provided with MIKE11. The following steps are required to merge the model networks:

1. Recalculate the point numbering using the "Number Points Consecutively" tool under the NETWORK menu.
2. Utilise the PFSMERGE tool to combine the model network files

3. Export the cross sections to text format and import into a combined cross sectional data base.
4. Utilise the PFSMERGE tool to combine the model boundary and parameter files.

3.1 Modifications

A number of modifications to the combined models will be necessary to properly merge the two models. These modifications include:

- Removing Model overlaps,
- Updating model boundary conditions,
- Combining roughness tables.

A brief description of these modifications is detailed in the following sections.

3.1.1 Model Overlap

There is a small area of overlap between the two models for branches Warrill and Purga from chainage's 25720 and 19940 to the downstream model outlet. The areas are evident in **Figure 6** where the overlap in the duplicated model branches is obvious in the network layout view in MIKE11. It will be necessary to remove the branches from the Brisbane River MIKE11 model in this area and utilise the branches from the Ipswich Rivers MIKE11 model which has a greater level of detail in this area

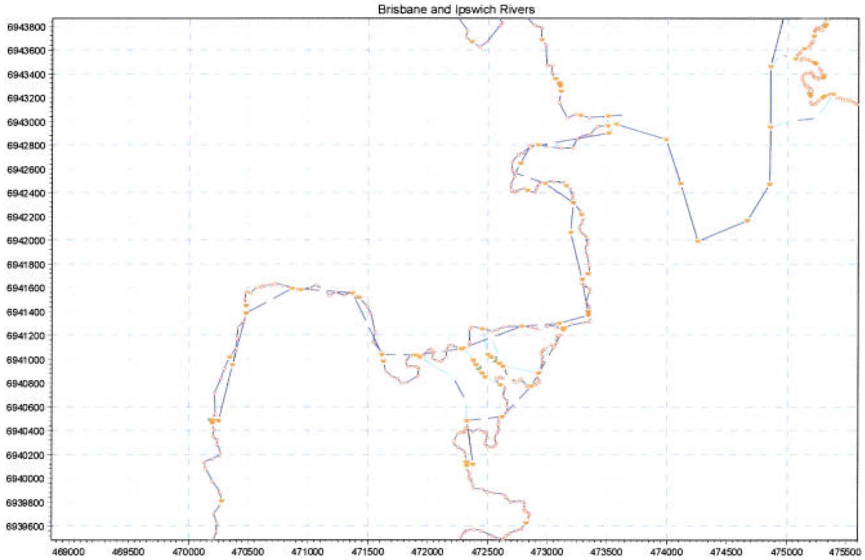

Figure 6 Overlap in network layout between Brisbane and Ipswich River models.

3.1.2 *Boundary Conditions*

The downstream boundary condition from the Ipswich River MIKE11 model on the Bremer River should be deleted and the branch connected directly to the Brisbane River MIKE11 model. The downstream boundary condition is no longer necessary, as flows will pass directly through to the Brisbane River model.

3.1.3 *Reduce Upstream Branches*

We believe that significant increase in the model time step will be achievable if the upstream reaches in the Ipswich Rivers area are reduced. The steep channel slopes in the upstream areas require significant reduction in the overall model time step in order to maintain model stability. It may not be necessary to include these areas in a combined flood model and therefore the model performance can be significantly improved by removal.

4 CONCLUSIONS AND RECOMMENDATIONS

The Ipswich Rivers MIKE11 model has been reviewed in order to identify necessary improvements and modifications required to update the model to a standard sufficient for flood and forecasting studies.

The primary issue is the removal of the large number of "slots" in the model cross sections, which are a major source of instability. The removal of these slots will require that a series of "link channels" be added to the model to ensure the stable simulation of flows from the river to the overbank areas. In addition there are a range of changes required to the model schematisation and grid point spacing that are essential for the model to achieve stability at longer time steps. These changes to the model are fundamental to the performance of the model and as such the original model calibration will not be valid if the modifications are implemented.

We recommend that the following modifications be implemented to the model:

- Include accurate aerial photographic background image to ensure positional accuracy of the model branches and cross sections.
- Model Schematisation:
    - Re-schematise the RailNorth and RailSouth branches using link channels.
    - Remove closely spaced grid points
    - Include Link Channels in place of artificial slots in connecting cross sections
    - Check model chainages against registered photographic images.
    - Update branch layouts and cross section extents in areas of cross section overlap in order to eliminate storage duplication.
    - Divide channel and floodplain flows into separate branches for excessively wide floodplain sections.
- Cross Sections
    - Remove all artificial slots in cross sections.
    - Increase the number of processed data points in some cross sections to between 20 and 40.
- Numerical Parameters
    - Centre the numerical scheme using a delta value of 0.55
    - Define stable static initial condition to allow the model to cold start correctly.
- Simulation Time step
    - Update model time step to between 30 seconds and 1 minutes. (Dependant on model sensitivity testing)

- Model Calibration
    - Re-Calibrate over bank flood events using previous flood study information.

A preliminary investigation was carried out to determine the suitability of merging the Ipswich and Brisbane Rivers MIKE11 models into a single basin model. The investigation indicates that it is feasible to merge the models with only minor adjustments required for some overlapping areas. The combined model is not excessively large in size and will have reasonable simulation times.