Main Report

Katherine River Flood Study

Report No. 02/2000D

February 2000
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>CATCHMENT DESCRIPTION</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>METHODOLOGY</td>
<td>5</td>
</tr>
<tr>
<td>4.</td>
<td>AVAILABLE DATA</td>
<td>6</td>
</tr>
<tr>
<td>4.1</td>
<td>Overview</td>
<td>6</td>
</tr>
<tr>
<td>4.2</td>
<td>Topographic Data</td>
<td>6</td>
</tr>
<tr>
<td>4.3</td>
<td>Streamflow Data</td>
<td>8</td>
</tr>
<tr>
<td>4.4</td>
<td>Stream Gauge Rating Curves</td>
<td>13</td>
</tr>
<tr>
<td>4.5</td>
<td>Katherine Floodplain Gauges</td>
<td>13</td>
</tr>
<tr>
<td>4.6</td>
<td>Peak Flood Levels</td>
<td>14</td>
</tr>
<tr>
<td>4.7</td>
<td>Pluviograph Data</td>
<td>14</td>
</tr>
<tr>
<td>4.8</td>
<td>Daily Rainfall Data</td>
<td>14</td>
</tr>
<tr>
<td>5.</td>
<td>SELECTION OF CALIBRATION EVENTS</td>
<td>17</td>
</tr>
<tr>
<td>6.</td>
<td>HYDROLOGIC MODELLING</td>
<td>21</td>
</tr>
<tr>
<td>6.1</td>
<td>Model Description</td>
<td>21</td>
</tr>
<tr>
<td>6.2</td>
<td>Model Configuration</td>
<td>22</td>
</tr>
<tr>
<td>6.3</td>
<td>Model Calibration</td>
<td>22</td>
</tr>
<tr>
<td>6.3a</td>
<td>Calibration Methodology</td>
<td>22</td>
</tr>
<tr>
<td>6.3b</td>
<td>Assignment of Total Rainfalls and Temporal Patterns</td>
<td>26</td>
</tr>
<tr>
<td>6.3c</td>
<td>Adopted Model Parameters</td>
<td>26</td>
</tr>
<tr>
<td>6.3d</td>
<td>Initial Losses</td>
<td>27</td>
</tr>
<tr>
<td>6.3e</td>
<td>Calibration Results</td>
<td>28</td>
</tr>
<tr>
<td>(i)</td>
<td>Overview</td>
<td>28</td>
</tr>
<tr>
<td>(ii)</td>
<td>Mt Ebsworth</td>
<td>28</td>
</tr>
<tr>
<td>(iii)</td>
<td>Katherine Gorge and Gorge Caravan Park</td>
<td>28</td>
</tr>
<tr>
<td>(iv)</td>
<td>Railway Bridge</td>
<td>29</td>
</tr>
<tr>
<td>(v)</td>
<td>Seventeen Mile Creek and McAdden Creek</td>
<td>29</td>
</tr>
<tr>
<td>7.</td>
<td>HYDRAULIC MODELLING</td>
<td>30</td>
</tr>
<tr>
<td>7.1</td>
<td>Model Description</td>
<td>30</td>
</tr>
<tr>
<td>7.2</td>
<td>CELLFLOW Model Configuration</td>
<td>30</td>
</tr>
<tr>
<td>7.3</td>
<td>Topographic Data</td>
<td>32</td>
</tr>
<tr>
<td>7.4</td>
<td>Hydraulic Structures</td>
<td>32</td>
</tr>
<tr>
<td>7.5</td>
<td>Calibration Methodology</td>
<td>33</td>
</tr>
<tr>
<td>7.6</td>
<td>Calibration Results - January 1998 Flood</td>
<td>35</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS - Cont'd

7.6a Overview 35
7.6b Peak Flood Levels 35
7.6c Stage Hydrographs 36
7.6d Comparison with Gauged Discharges 39
7.7 Calibration Results - March 1984 Flood 44
7.8 Calibration Results - February 1987 Flood 44
7.9 Calibration Results - January 1995 Flood 51
7.10 Summary of Calibration Results 51

8. FLOOD FREQUENCY ANALYSIS 54
8.1 Method of Analysis 54
8.2 Development of the Town of Katherine 54
8.3 Flood Data from Stream Gauging Station 55
8.3a Available Data 55
8.3b Rating Curves 55
8.3c Peak Annual Flood Data 57
8.4 Flood Data from Other Sources 57
8.4a Available Data 57
8.4b Major Floods 59
8.4c 1897 and 1914 Flood Levels 59
8.4d 1931 and 1940 Flood Levels 60
8.4e Peak Flood Discharges 60
8.5 Flood Frequency Analyses 60
8.6 ARI of the 1957 and 1998 Floods 63
8.7 Palaeohydrology 63

9. DESIGN FLOOD ESTIMATION 64
9.1 Methodology 64
9.2 Design Rainfalls 64
9.3 Rainfall Losses 65
9.4 Design Discharges 65
9.5 Estimation of PMF Discharges 65
9.6 Design Flood Levels 66
9.7 Flood Mapping 66
9.7a Estimation of Flood Extent 66
9.7b January 1998 and Design Flood Maps 67
9.7c Emergency Services Maps 67
9.8 Proposed Road and Railway Crossings 67

10. FLOOD FORECASTING MODEL 71
10.1 Adopted Model 71
10.2 Adopted Model Parameters 71
10.3 Flood Forecasting Model Results 72
10.4 Sensitivity Analyses 72

11. CONCLUSIONS 75

12. REFERENCES 76
LIST OF APPENDICES

APPENDIX A  Recorded And Predicted Discharges, URBS Model - March 1984 Event

APPENDIX B  Recorded And Predicted Discharges, URBS Model - February 1987 Event

APPENDIX C  Recorded And Predicted Discharges, URBS Model - February 1991 Event

APPENDIX D  Recorded And Predicted Discharges, URBS Model - January 1995 Event

APPENDIX E  Recorded And Predicted Discharges, URBS Model - January 1998 Event

APPENDIX F  Recorded Peak Flood Levels, January 1998 Flood

APPENDIX G  Adopted Rating Curves, Katherine River Stream Gauges

APPENDIX H  Listing Of URBS Model Catchment File

APPENDIX I  Adopted Pluviograph Station and Event Rainfall for URBS Model Sub-Catchments Calibration Events

APPENDIX J  Adopted PMP Rainfall for Various Storm Durations, URBS Model Sub-Catchments

APPENDIX K  Bureau Of Meteorology Report - Probable Maximum Precipitation For The Katherine River Catchment

APPENDIX L  Predicted Peak Flood Levels For 20, 50 & 100 Year ARI and PMF Design Floods and the January 1998 Flood

(iii)
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Locality Map, Katherine and Environs</td>
<td>1</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Extent of Digital Elevation Data, Katherine River Floodplain</td>
<td>7</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Location of Surveyed Cross-Sections, Katherine River</td>
<td>9</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Location of Surveyed Cross-Sections, Katherine River Floodplain</td>
<td>10</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Locations of Streamgage and Rainfall Stations, Katherine River Catchment</td>
<td>11</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Representative Stage Hydrographs and Rainfall, March 1984 Flood Event</td>
<td>18</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Representative Stage Hydrographs and Rainfall, February 1987 Event</td>
<td>18</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Representative Stage Hydrographs and Rainfall, February 1991 Event</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>Representative Stage Hydrographs and Rainfall, January 1995 Event</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5.5</td>
<td>Representative Stage Hydrographs and Rainfall, January 1998 Event</td>
<td>20</td>
</tr>
<tr>
<td>Figure 6.1</td>
<td>Katherine River URBS Model Configuration</td>
<td>23</td>
</tr>
<tr>
<td>Figure 6.2</td>
<td>Adopted Catchment Regions, Katherine River URBS Model</td>
<td>25</td>
</tr>
<tr>
<td>Figure 6.3</td>
<td>Comparison of URBS and CELLFLOW River Routing Downstream of Katherine Gorge</td>
<td>26</td>
</tr>
<tr>
<td>Figure 7.1</td>
<td>Katherine River CELLFLOW Model Configuration</td>
<td>31</td>
</tr>
<tr>
<td>Figure 7.2</td>
<td>Typical Variation of Manning's 'n' with Flow Depth, Katherine River Channel</td>
<td>34</td>
</tr>
<tr>
<td>Figure 7.3</td>
<td>Typical Variation of Manning's 'n' with Flow Depth, Katherine River Floodplain</td>
<td>34</td>
</tr>
<tr>
<td>Figure 7.4</td>
<td>URBS Hydrographs &amp; Modified Inflow Hydrographs, Leight &amp; Maud Creeks and Lake Hickey Inflow, January 1998 Flood</td>
<td>35</td>
</tr>
<tr>
<td>Figure 7.5</td>
<td>Difference Between Recorded and Predicted Peak Flood Levels, January 1998 Flood</td>
<td>36</td>
</tr>
<tr>
<td>Figure 7.6</td>
<td>Katherine River Longitudinal Flood Profile, January 1998 Flood</td>
<td>37</td>
</tr>
<tr>
<td>Figure 7.7</td>
<td>Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), January 1998 Event</td>
<td>38</td>
</tr>
<tr>
<td>Figure 7.8</td>
<td>Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), January 1998 Event</td>
<td>38</td>
</tr>
<tr>
<td>Figure 7.9</td>
<td>Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River Floodplain Near Pump Station No. 7 (G814 0411)</td>
<td>40</td>
</tr>
<tr>
<td>Figure 7.10</td>
<td>Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River Floodplain Behind BP Service Station (G814 0409)</td>
<td>40</td>
</tr>
</tbody>
</table>
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.11</td>
<td>Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River Floodplain Opposite Dalgety's Victoria Highway (G814 0407)</td>
</tr>
<tr>
<td>7.12</td>
<td>Predicted Discharge Hydrographs, Katherine River at Stuart Highway, CELLFLOW Model, January 1998 Flood</td>
</tr>
<tr>
<td>7.13</td>
<td>Comparison of River Gaugings and Derived Rating Curves, Katherine River at Railway Bridge (G814 0001)</td>
</tr>
<tr>
<td>7.14</td>
<td>Comparison of River Gaugings and Derived Rating Curves, Katherine River at Katherine Gorge (G814 0019)</td>
</tr>
<tr>
<td>7.15</td>
<td>Comparison of River Gaugings and Derived Rating Curves, Katherine River at Gorge Caravan Park (G814 0023)</td>
</tr>
<tr>
<td>7.16</td>
<td>Peak Stage Relationship, Katherine Gorge (G814 0019) and Gorge Caravan Park (G814 0023)</td>
</tr>
<tr>
<td>7.17</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), March 1984 Event</td>
</tr>
<tr>
<td>7.18</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G8140001), March 1984 Event</td>
</tr>
<tr>
<td>7.19</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), March 1984 Event</td>
</tr>
<tr>
<td>7.20</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), March 1984 Event</td>
</tr>
<tr>
<td>7.21</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), March 1984 Event</td>
</tr>
<tr>
<td>7.22</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), March 1984 Event</td>
</tr>
<tr>
<td>7.23</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), February 1987 Event</td>
</tr>
<tr>
<td>7.24</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), February 1987 Event</td>
</tr>
<tr>
<td>7.25</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), February 1987 Event</td>
</tr>
<tr>
<td>7.26</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), February 1987 Event</td>
</tr>
<tr>
<td>7.27</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), February 1987 Event</td>
</tr>
<tr>
<td>7.28</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), February 1987 Event</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>7.29</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), January 1995 Event</td>
</tr>
<tr>
<td>7.30</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), January 1995 Event</td>
</tr>
<tr>
<td>7.31</td>
<td>Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), January 1995 Event</td>
</tr>
<tr>
<td>7.32</td>
<td>Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), January 1995 Event</td>
</tr>
<tr>
<td>8.1</td>
<td>Distribution of Peak Annual Flows, Katherine River at Railway Bridge</td>
</tr>
<tr>
<td>9.1</td>
<td>Extent of Flooding, 100 Year ARI Event</td>
</tr>
<tr>
<td>9.2</td>
<td>Extent of Flooding, January 1998 Flood</td>
</tr>
<tr>
<td>9.3</td>
<td>Extent of Flooding, PMF</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 4.1</td>
<td>Summary of Gauging Station Details, Katherine River and Tributaries</td>
<td>8</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Summary of Streamgauge Event Data, Katherine River Catchment</td>
<td>12</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Maximum Gauged Discharge and Estimated January 1998 Discharge, Katherine River Stream Gauges</td>
<td>13</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Details of Katherine Floodplain Gauges</td>
<td>14</td>
</tr>
<tr>
<td>Table 4.5</td>
<td>Summary of Pluviograph Event Data, Katherine River Catchment</td>
<td>15</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Summary of Available Daily Rainfall Data, Katherine River Catchment</td>
<td>16</td>
</tr>
<tr>
<td>Table 5.1</td>
<td>Adopted Calibration Events, Katherine River Hydrologic and Hydraulic Models</td>
<td>17</td>
</tr>
<tr>
<td>Table 5.2</td>
<td>Modelling Period of Calibration Events, Katherine River Catchment</td>
<td>20</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>Katherine River URBS Model Sub-Catchment Areas</td>
<td>22</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Adopted URBS Model Parameters, Katherine River URBS Model</td>
<td>27</td>
</tr>
<tr>
<td>Table 6.3</td>
<td>Adopted Initial Loss Rates, Katherine River URBS Model</td>
<td>28</td>
</tr>
<tr>
<td>Table 8.1</td>
<td>Details of Available Streamflow Records, Katherine River</td>
<td>55</td>
</tr>
<tr>
<td>Table 8.2</td>
<td>Rating Curves, Katherine River at Katherine Railway Bridge</td>
<td>56</td>
</tr>
<tr>
<td>Table 8.3</td>
<td>Peak Annual Water Levels, Katherine River, 1952 to Present</td>
<td>58</td>
</tr>
<tr>
<td>Table 8.4</td>
<td>Details of Major Floods, Katherine, 1872 - 1952</td>
<td>59</td>
</tr>
<tr>
<td>Table 8.5</td>
<td>Statistics of Annual Flood Peaks, Katherine River at Railway Bridge, 1953 to 1998</td>
<td>61</td>
</tr>
<tr>
<td>Table 8.6</td>
<td>Statistics of Annual Flood Peaks, Katherine River at Katherine, 1897 - 1998</td>
<td>61</td>
</tr>
<tr>
<td>Table 8.7</td>
<td>Peak Flood Discharge Estimates, Katherine River at Railway Bridge</td>
<td>61</td>
</tr>
<tr>
<td>Table 9.1</td>
<td>Design Rainfall Intensities, Katherine River Catchment</td>
<td>64</td>
</tr>
<tr>
<td>Table 9.2</td>
<td>Adopted Initial Losses for Design Flood Estimation, Katherine River Catchment</td>
<td>65</td>
</tr>
<tr>
<td>Table 9.3</td>
<td>Comparison of Estimated Design Flood Discharges from URBS Model and Flood Frequency Analysis, Katherine River at Railway Bridge</td>
<td>65</td>
</tr>
<tr>
<td>Table 9.4</td>
<td>PMP Rainfalls for the Katherine River Catchment to Katherine</td>
<td>66</td>
</tr>
<tr>
<td>Table 9.5</td>
<td>Estimated Design Flood Levels and Gauge Heights, Katherine River at Railway Bridge</td>
<td>66</td>
</tr>
<tr>
<td>Table 10.1</td>
<td>Flood Forecasting Model Parameters</td>
<td>71</td>
</tr>
<tr>
<td>Table 10.2</td>
<td>Flood Forecasting Model Results for Calibration Events</td>
<td>72</td>
</tr>
<tr>
<td>Table 10.3</td>
<td>Sensitivity Analyses, Katherine River Flood Forecasting Model</td>
<td>73</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

1.01 The township of Katherine is located some 300 km south-east of Darwin in the Northern Territory. Katherine is drained by the Katherine River, a major tributary of the Daly River. The Daly River discharges to Anson Bay some 300 km north-west of Katherine. Figure 1.1 is a locality map showing the area of interest. The catchment area of the Katherine River at Katherine is about 8,200 km².

1.02 During the period 17th to 25th January 1998, heavy rains associated with the remnants of Tropical Cyclone 'Les', fell over the Katherine River catchment. As a consequence, major flooding occurred in Katherine and its environs over the period 26th to 30th January. With a recorded peak flood level of 20.38 m at the Katherine River Railway Bridge stream gauge, the January 1998 Flood became the largest on record in Katherine. Almost all residential, commercial and industrial properties in the town area, except in East Katherine, were flooded.

1.03 The flood of January 1998 was the first occasion in more than 40 years that floodwaters had escaped from the main river channel to flood the town of Katherine. The significant amount of flood data collected during the 1998 flood provided an ideal opportunity to re-assess flooding behaviour in and around Katherine. On this basis, in June 1998 Water Studies Pty Ltd was invited by the Department of Lands, Planning & Environment (DLPE) to undertake a flood study of the Katherine River. In response, this report presents the results of hydrologic and hydraulic analyses of the Katherine River.

Figure 1.1 Locality Map, Katherine and Environs
1.04 This report contains a further 12 sections and is structured as follows:

- Section 2 contains a general description of the Katherine River catchment.
- Section 3 provides an overview of the study methodology.
- Section 4 details the available topographic, rainfall and flood data available for the Katherine River catchment.
- Section 5 outlines the selected calibration flood events for the hydrologic and hydraulic models used in this study.
- Section 6 describes the adopted configuration and calibration of the hydrologic model used in this study.
- Section 7 describes the adopted configuration and calibration of the hydraulic model used in this study.
- Section 8 outlines the methodology and results of a flood frequency analysis of available flood data at the Katherine River Railway Bridge.
- Section 9 describes the estimation of design flood discharges and flood levels for the area of interest.
- Section 10 describes the flood forecasting model developed using the hydrologic and hydraulic models of this study.
- Section 11 presents the conclusions of the study.
- Section 12 is a list of references.

1.05 This report also contains 8 appendices:

- Appendix A contains plots of recorded and predicted flood discharges at the various stream gauging stations for the March 1984 calibration event.
- Appendix B contains plots of recorded and predicted flood discharges at the various stream gauging stations for the February 1987 calibration event.
- Appendix C contains plots of recorded and predicted flood discharges at the various stream gauging stations for the February 1991 calibration event.
- Appendix D contains plots of recorded and predicted flood discharges at the various stream gauging stations for the January 1995 calibration event.
- Appendix E contains plots of recorded and predicted flood discharges at the various stream gauging stations for the January 1998 calibration event.
- Appendix F contains recorded peak flood levels in and around Katherine for the January 1998 Flood.
- Appendix G contains tables of adopted rating curves for stream gauges in the Katherine River catchment.
- Appendix H contains a listing of the hydrologic model catchment file.
• Appendix I details the adopted pluviograph station and total event rainfall for each of the URBS model sub-catchments for the five calibration events.

• Appendix J details the adopted PMP rainfall for each of the URBS model sub-catchments for various storm durations.

• Appendix K contains a copy of the Bureau of Meteorology Report on Probable Maximum Precipitation for the Katherine River Catchment.

• Appendix L contains predicted peak flood levels at each of the hydraulic model nodes for the 20, 50 and 100 year ARI and PMF design floods, as well as the January 1998 flood.
2 CATCHMENT DESCRIPTION

2.01 The location of the Katherine River catchment is shown in Figure 1.1. The total catchment of the river to the Stuart Highway crossing is some 8,240 km$^2$. The Katherine River catchment is essentially undeveloped and includes portions of the Kakadu and Nitmiluk (Katherine Gorge) National Parks.

2.02 The Katherine River consists of an incised main channel (of the order of 200 m to 300 m wide and some 20 m deep) with a wide, flat floodplain on either side. Whilst the main channel is heavily vegetated, vegetation across the floodplain is generally sparse.

2.03 In the vicinity of Katherine, three bridges cross the river:

• The 'low-level' crossing located some 3.4 km downstream of the Railway Bridge.
• The Stuart Highway crossing.
• The disused Railway Bridge located about 100 m downstream of the Stuart Highway Crossing.

2.04 With respect to hydrologic and hydraulic behaviour, key features of the Katherine River catchment include:

• The presence of 'Karst' limestone geology within the catchment, and
• The Katherine Gorge.

2.05 The Karst limestone geology of portions of the catchment provides opportunity for significant infiltration of rainfall to fill large sub-terranean voids. In addition, surface runoff is able to discharge directly to groundwater via numerous 'sink holes' across the catchment.

2.06 The Katherine Gorge begins approximately 30 km upstream of Katherine and extends upstream along a 25 km reach of the river. The gorge represents a distinct change in floodplain topography from that observed across the remainder of the catchment. Within the gorge, the river is confined within vertical rock escarpments.
3 METHODOLOGY

3.01 Two numerical models were used to simulate flooding behaviour in the Katherine River catchment:

- A runoff-routing model ('URBS') was used to estimate flood discharges throughout the Katherine River Catchment, and

- An unsteady flow hydraulic model ('CELLFLOW') was used to estimate flood discharges and flood levels along a 60 km reach of the river downstream of Katherine Gorge.

3.02 The URBS model was calibrated against recorded flood data for five historical flood events. In addition, the channel routing parameters of the URBS model for the river reach downstream of Katherine Gorge were calibrated to produce flood routing characteristics consistent with the hydraulic model.

3.03 The calibrated runoff-routing model was used to estimate discharge hydrographs at the boundaries of the hydraulic model. The hydraulic model was then calibrated against recorded flood data for the five historical events used in the URBS model calibration.

3.04 The calibrated runoff-routing model was used to estimate design flood discharges throughout the Katherine River catchment. Rainfall initial losses were adjusted to ensure that estimated design flood discharges were consistent with the results of flood frequency analysis. The hydraulic model was then used to estimate design flood discharges and flood levels along the river and its floodplain over the 60 km reach downstream of Katherine Gorge.

3.05 A modified version of the URBS model for use in flood forecasting was developed in consultation with the Bureau of Meteorology. The flood forecasting model was based on the calibrated URBS model with modified parameters to simplify application of the model during a flood event. As part of the flood forecasting model development, the sensitivity of model results to various key parameters was investigated.
4 AVAILABLE DATA

4.1 OVERVIEW

4.01 Available data for the Katherine River catchment consists of:

- Rainfall,
- Flood level, and
- Topographic information.

Rainfall data includes both continuous (pluviograph) rainfall records and daily rainfall totals. Flood level information includes continuous flood level records at both stream gauges (located in rivers and creeks) and floodplain gauges, along with peak flood levels across the floodplain recorded after a flood. A rating curve is used to convert recorded flood levels at stream gauges to flood discharges. Topographic data is used to define catchment boundaries and the extent and depth of flooding across the river and floodplain.

4.02 The following sections describe the available data for the Katherine River catchment.

4.2 TOPOGRAPHIC DATA

4.03 Available topographic data for the Katherine River catchment consists of:

- 1:50,000, 20 m contour maps of the Katherine area.
- 1:250,000, 50 m contour maps of the catchment.
- Digital elevation data comprising ground levels at 30 m spacing over the river and floodplain along a 60 km reach downstream of Katherine Gorge.
- Surveyed cross-sections of the Katherine River main channel and various waterways across the river floodplain in the vicinity of Katherine.

4.04 The 1:250,000 km contour maps of the Katherine River catchment were published by the Royal Australian Survey Corps in 1991. These maps were used to define the boundaries of the Katherine River catchment and the various tributary creeks within the river catchment.

4.05 The digital elevation data of the Katherine River floodplain was compiled by Kevron Aerial Surveys Pty Ltd from aerial photography undertaken in April 1998. The extent of this data is shown in Figure 4.1. This information was presented as a series of 71 one metre orthophoto contour maps at a scale of 1:5,000, published in 1998. Subsequent to the publication of these maps, systematic errors were discovered in the contour information for a 140 km² region surrounding the town. Ground levels across this region were biased up to 0.4 m too low. The extent of this region is shown in Figure 4.1. In 1999, Kevron published revised maps of this region with the above errors corrected. The creation of a digital elevation model (DEM) based on the supplied digital elevation data is discussed in Section 7.3.
Figure 4.1 Extent of Digital Elevation Data, Katherine River Floodplain
4.06 Additional cross-section data for the Katherine River and various waterways across the river floodplain was obtained from:

- A survey of 33 river cross-sections over a 33 km reach downstream from the low-level crossing. This survey was undertaken by Water Resources/PAWA in 1994. Unfortunately, this survey was not well documented and a number of the surveyed cross-sections could not be located with certainty.

- A survey of 42 river cross-sections and 35 floodplain cross-sections undertaken by DLPE in 1998.

4.07 Further data was obtained from 39 longitudinal sections of various roads in and around Katherine undertaken by J. Matthews & Associates Surveyors in March 1998.

4.08 The locations of surveyed cross-sections along the Katherine River are shown in Figure 4.2. The locations of surveyed cross-sections across the river floodplain are shown in Figure 4.3.

4.3 STREAMFLOW DATA

4.09 The DLPE operates a number of stream gauging stations within the Katherine River catchment. Summary details of existing and former stream gauges along the Katherine River and its tributaries are given in Table 4.1. Figure 4.4 shows the gauge locations.

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Station Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Period of Record</th>
<th>Rated</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 8140 001</td>
<td>Katherine River at Railway Bridge</td>
<td>14º27'54&quot;</td>
<td>132º16'28&quot;</td>
<td>03-03-1960</td>
<td>Yes</td>
</tr>
<tr>
<td>G 8140 019</td>
<td>Katherine River at Gorge</td>
<td>14º18'50&quot;</td>
<td>132º17'01&quot;</td>
<td>25-11-1954</td>
<td>Yes</td>
</tr>
<tr>
<td>G 8140 002</td>
<td>Katherine River at Knotts Crossing</td>
<td>14º26'16&quot;</td>
<td>132º16'32&quot;</td>
<td>01-04-1953 13-08-1987</td>
<td>No</td>
</tr>
<tr>
<td>G 8140 020</td>
<td>Katherine River at Landsdowne</td>
<td>14º26'00&quot;</td>
<td>132º17'60&quot;</td>
<td>01-03-1970 29-08-1988</td>
<td>No</td>
</tr>
<tr>
<td>G 8140 023</td>
<td>Katherine River at Gorge Caravan Park</td>
<td>14º18'50&quot;</td>
<td>132º25'19&quot;</td>
<td>07-03-1973</td>
<td>No</td>
</tr>
<tr>
<td>G 8140 158</td>
<td>McAdden Creek at Dam Site</td>
<td>14º21'05&quot;</td>
<td>132º20'09&quot;</td>
<td>14-11-1962</td>
<td>Yes</td>
</tr>
<tr>
<td>G 8140 159</td>
<td>Seventeen Mile Creek at Waterfall View</td>
<td>14º16'54&quot;</td>
<td>132º23'56&quot;</td>
<td>15-11-1962</td>
<td>Yes</td>
</tr>
<tr>
<td>G 8140 218</td>
<td>Katherine River at Mt Ebsworth</td>
<td>13º56'14&quot;</td>
<td>132º47'14&quot;</td>
<td>23-04-1964</td>
<td>Yes</td>
</tr>
<tr>
<td>G 8140 219</td>
<td>Katherine River at D/S Birdie Ck Confluence</td>
<td>13º58'30&quot;</td>
<td>132º46'30&quot;</td>
<td>28-08-1997</td>
<td>No</td>
</tr>
</tbody>
</table>

a The station G 8140 001 prior to 1960 was located approx. 900 m upstream of the railway bridge at the works yard where the river heights were read by a gauge reader.

b No data available.

c Manually read daily stages.

4.10 Note that no data is available for Katherine River at Knotts Crossing (G 8140 002). Note also that data for Landsdowne (G 8140 020) was not available for this study.

4.11 Table 4.2 summarises peak flood levels recorded at the eight streamgauging stations for various floods since 1957. Note that Table 4.2 does not include all flood events during this period, but lists the largest recent floods at the Railway Bridge (G 8140 001) and Katherine Gorge (G 8140 019 and G 8140 023) along with a number of recent smaller floods used by the Bureau of Meteorology in their preliminary flood forecasting model calibration.
Figure 4.2  Location of Surveyed Cross-Sections, Katherine River
Figure 4.3    Location of Surveyed Cross-Sections, Katherine River Floodplain
Figure 4.4    Locations of Streamgauge and Rainfall Stations, Katherine River Catchment
### Table 4.2  Summary of Streamgauge Event Data, Katherine River Catchment

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>G8140019</td>
<td>Katherine River @ Gorge ND</td>
<td></td>
<td>8.75</td>
<td>10.42</td>
<td>10.74</td>
<td>10.02</td>
<td>ND</td>
<td>8.54</td>
<td>10.92</td>
<td>11.13</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>G8140023</td>
<td>Katherine River @ Gorge Caravan Pk ND</td>
<td></td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>6.94</td>
<td>6.70</td>
<td>5.20</td>
<td>5.21</td>
<td>7.36</td>
<td>7.32</td>
<td>4.67b</td>
<td>5.16b</td>
<td>ND</td>
<td>ND</td>
<td>6.24</td>
</tr>
<tr>
<td>G8140158</td>
<td>McAdden Ck ND</td>
<td></td>
<td>ND</td>
<td>3.76</td>
<td>4.37</td>
<td>ND</td>
<td>3.63</td>
<td>4.67</td>
<td>3.46</td>
<td>4.57</td>
<td>3.35</td>
<td>ND</td>
<td>3.94</td>
<td>ND</td>
<td>3.19</td>
<td>6.68</td>
</tr>
<tr>
<td>G8140159</td>
<td>Seventeen Mile Ck ND</td>
<td></td>
<td>ND</td>
<td>3.55</td>
<td>3.25</td>
<td>4.30</td>
<td>3.97</td>
<td>4.63</td>
<td>3.52</td>
<td>4.77</td>
<td>3.42</td>
<td>ND</td>
<td>3.91</td>
<td>3.39</td>
<td>3.33</td>
<td>7.24</td>
</tr>
<tr>
<td>G8140218</td>
<td>Katherine River @ M t Ebsworth</td>
<td></td>
<td>ND</td>
<td>9.62</td>
<td>10.03</td>
<td>10.73</td>
<td>10.43</td>
<td>9.04</td>
<td>9.92</td>
<td>10.55</td>
<td>9.92</td>
<td>6.71</td>
<td>5.90</td>
<td>5.65</td>
<td>9.60</td>
<td>10.34</td>
</tr>
<tr>
<td>G8140219</td>
<td>Katherine River @ DS Birdie Ck</td>
<td></td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

**NOTES:**
- Calibration event
- One of three largest events in table at each gauge
- ND  No Data
  - a  Peak level uncertain
  - b  Some event data missing
  - p  Peak level only available
  - ?  Data availability uncertain
The January 1998 flood was the largest on record at all stream gauges, except McAdden Creek (G 8140 158). The second largest event since the commencement of continuous recording was March 1957. Note however, that limited streamflow data exists for this event. The third largest event at the Railway Bridge gauge (G 8140 001) occurred in March 1984.

### 4.4 STREAM GAUGE RATING CURVES

As indicated in Table 4.1, DLPE have developed rating curves for five of the eight stream gauges in the Katherine River catchment. These rating curves were revised to incorporate all available gauging data, including that recorded during the January 1998 flood. In particular, it was necessary to extend the rating curve at each gauging station up to the estimated peak discharge for the January 1998 flood. The highest gauged flow and the estimated peak flow during the January 1998 flood at each Station are given in Table 4.3. No gauging data was available for the Knotts Crossing Station (GS 8140 020). Hence, a rating curve was not derived for this station.

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Station Name</th>
<th>Maximum Gauged Discharge (m$^3$/s)</th>
<th>Estimated Jan. 1998 Discharge (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 8140 001a</td>
<td>Katherine River - Railway Bridge</td>
<td>7,100</td>
<td>9,400</td>
</tr>
<tr>
<td>G 8140 019</td>
<td>Katherine River - Gorge</td>
<td>2,920</td>
<td>6,640</td>
</tr>
<tr>
<td>G 8140 023</td>
<td>Katherine River at Gorge Caravan Park</td>
<td>2,520</td>
<td>7,530</td>
</tr>
<tr>
<td>G 8140 158</td>
<td>McAdden Creek at Dam Site</td>
<td>28</td>
<td>640</td>
</tr>
<tr>
<td>G 8140 159</td>
<td>Seventeen Mile Creek at Waterfall View</td>
<td>187</td>
<td>1,540</td>
</tr>
<tr>
<td>G 8140 218</td>
<td>Katherine River at Mt Ebsworth</td>
<td>9</td>
<td>2,680</td>
</tr>
<tr>
<td>G 8140 219</td>
<td>Katherine River at D/S Birdie Ck Confluence</td>
<td>&lt;1</td>
<td>3,170</td>
</tr>
</tbody>
</table>

* The station G 8140 001 prior to 1960 was located approx. 2.5 km upstream of the railway bridge at the works yard where the river heights were read by a gauge reader.

At Mt Ebsworth, Birdie Creek, Seventeen Mile Creek and McAdden Creek, only a single cross-section was available at each station. Hence, Manning's equation was used to extend the rating curve beyond the range of gauged discharges.

At the Railway Bridge, Katherine Gorge and Katherine Gorge Caravan Park gauging stations, the CELLFLOW hydraulic model was used to extend the rating curve beyond the range of gauged discharges. Further details of the derivation of rating curves for these three stations are given in Section 7. The adopted rating curves for each of the seven rated stations are given in Appendix G.

### 4.5 KATHERINE FLOODPLAIN GAUGES

In addition to stream gauging stations described in Section 4.2, the DLPE operates a number of continuous flood level recorders on the Katherine River floodplain within Katherine. Details of the floodplain gauges are given in Table 4.4. The locations of the floodplain gauges are shown in Figure 4.4. Note that none of these floodplain gauges have been rated.

The floodplain gauges were installed after the 1957 flood event. The January 1998 flood is the only event which has caused significant river flooding of Katherine since the 1957 flood. Two of the floodplain gauges were closed prior to January 1998 and hence have no recorded data. The
remaining three gauges have data for the January 1998 event only. Note however, that the gauge upstream of Chambers Drive (G 8140 411) was overtopped during the January 1998 flood and hence has no recorded data for a 30 hour period near the event peak.

Table 4.4  Details of Katherine Floodplain Gauges

<table>
<thead>
<tr>
<th>Gauge Number</th>
<th>Location</th>
<th>Available Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 8140 407</td>
<td>Opposite Dalgety’s Victoria Highway</td>
<td>January 1998 only</td>
</tr>
<tr>
<td>G 8140 408</td>
<td>Drain at Bicentennial Road</td>
<td>None</td>
</tr>
<tr>
<td>G 8140 409</td>
<td>Behind BP, Stuart Highway</td>
<td>January 1998 only</td>
</tr>
<tr>
<td>G 8140 411</td>
<td>Near Pump Station No. 7 U/S Chambers Drive</td>
<td>January 1998^</td>
</tr>
<tr>
<td>G 8140 412</td>
<td>Near Disused Airfield</td>
<td>None</td>
</tr>
</tbody>
</table>

^ Some event data missing.

4.6  PEAK FLOOD LEVELS

4.18 A large data collection program was undertaken by the DLPE and others following the January 1998 flood. In addition to stage hydrographs recorded at the various stream and floodplain gauges, more than 300 peak flood levels were surveyed in and around Katherine at various maximum height indicators (MHI’s) and from debris and high water marks. A summary of recorded peak flood levels along the Katherine River is given in Appendix F. Note that the flood levels given in Appendix F are raw data and have not been checked for accuracy or consistency and could contain significant errors.

4.19 Peak flood level data for other floods is limited. However, a previous report on Katherine River flooding (NTA, 1970) shows an extent of flooding map of Katherine for the March 1957 Flood. The basis and accuracy of the flood map are not known.

4.7  PLUVIOGRAPH DATA

4.20 Table 4.5 shows the available data from pluviograph stations and daily rainfall stations within the Katherine River catchment for the flood events listed in Table 4.2. The locations of the pluviograph stations are shown in Figure 4.4.

4.21 Table 4.5 shows that prior to 1976, pluviograph data in the Katherine River catchment was limited to two or three sites. Since 1976, pluviograph records for the floods of interest are generally available at five to eight sites. The most comprehensive pluviograph data is available for the January 1998 flood.

4.8  DAILY RAINFALL DATA

4.22 Table 4.6 shows the available daily rainfall data within the area of interest. The location of the daily rainfall stations are shown in Figure 4.4. All the stations shown in Table 4.5 are operated by the Commonwealth Bureau of Meteorology.

4.23 Table 4.6 shows that some daily rainfall records for the Katherine area are available since the 1870’s. However, most of the daily rainfall stations within the area of interest have been established since about 1940.
### Table 4.5  Summary of Pluviograph Event Data, Katherine River Catchment

<table>
<thead>
<tr>
<th>Gauge Number</th>
<th>Station Operator</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Month &amp; Year of Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>R8140001</td>
<td>DLPE</td>
<td>Railway Bridge</td>
<td>14°27'54&quot;</td>
<td>132°16'28&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
</tr>
<tr>
<td>R8140002</td>
<td>DLPE</td>
<td>Sculpture Cave South</td>
<td>14°34'29&quot;</td>
<td>132°26'12&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
</tr>
<tr>
<td>R8140003</td>
<td>DLPE</td>
<td>Sculpture Cave East</td>
<td>14°37'33&quot;</td>
<td>132°26'57&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
</tr>
<tr>
<td>R8140004</td>
<td>DLPE</td>
<td>Katherine Depot</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R8140017</td>
<td>DLPE Near Eva Valley H'stead</td>
<td>14°14'33&quot;</td>
<td>132°55'40&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>R8140018</td>
<td>DLPE Sleisbeck</td>
<td>13°46'00&quot;</td>
<td>132°50'33&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>R8140019</td>
<td>DLPE Gorge</td>
<td>14°18'50&quot;</td>
<td>132°27'00&quot;</td>
<td>ND a a a ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>R8140021</td>
<td>DLPE Upper Reaches</td>
<td>13°28'52&quot;</td>
<td>133°11'53&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>R8140159</td>
<td>DLPE 17 Mile Upper Catchment</td>
<td>14°05'45&quot;</td>
<td>132°27'30&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>R8140160</td>
<td>DLPE 17 Mile Below Falls</td>
<td>14°11'23&quot;</td>
<td>132°23'40&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>R8140219</td>
<td>DLPE DS Birdie Ck</td>
<td>13°58'30&quot;</td>
<td>132°46'30&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>014 904</td>
<td>CBM Katherine Exp Farm</td>
<td>14°29'00&quot;</td>
<td>132°15'00&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>014 910</td>
<td>CBM Katherine Research Farm</td>
<td>14°28'00&quot;</td>
<td>132°18'00&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
<tr>
<td>014 932</td>
<td>CBM Tindal AWS</td>
<td>14°31'27&quot;</td>
<td>132°22'53&quot;</td>
<td>ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND ND</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**
- ♦ Data Available
- ND No data
- a Data unprocessed but may be available
- b Some event data missing
### Table 4.6  Summary of Available Daily Rainfall Data, Katherine River Catchment

<table>
<thead>
<tr>
<th>Gauge Number</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>From</th>
<th>To</th>
<th>Period of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>014 029</td>
<td>KATHERINE EXP. FARM</td>
<td>14°29’00&quot;</td>
<td>132°15’00&quot;</td>
<td>1944</td>
<td>1968</td>
<td></td>
</tr>
<tr>
<td>014 030</td>
<td>KATHERINE POST OFFICE</td>
<td>14°28’00&quot;</td>
<td>132°16’00&quot;</td>
<td>1873</td>
<td>1974</td>
<td></td>
</tr>
<tr>
<td>014 034</td>
<td>MANBULLOO</td>
<td>14°31’00&quot;</td>
<td>132°12’00&quot;</td>
<td>1917</td>
<td>1974</td>
<td></td>
</tr>
<tr>
<td>014 036</td>
<td>MARANBOY</td>
<td>14°36’00&quot;</td>
<td>132°38’00&quot;</td>
<td>1923</td>
<td>1974</td>
<td></td>
</tr>
<tr>
<td>014 094</td>
<td>KATHERINE CDW</td>
<td>14°27’00&quot;</td>
<td>132°15’00&quot;</td>
<td>1957</td>
<td>1966</td>
<td></td>
</tr>
<tr>
<td>014 098</td>
<td>KATHERINE AIRPORT</td>
<td>14°27’00&quot;</td>
<td>132°16’00&quot;</td>
<td>1943</td>
<td>1974</td>
<td></td>
</tr>
<tr>
<td>014 155</td>
<td>BAM YILI</td>
<td>14°30’00&quot;</td>
<td>132°50’00&quot;</td>
<td>1965</td>
<td>1974</td>
<td></td>
</tr>
<tr>
<td>014 228</td>
<td>CORONATION HILL</td>
<td>13°35’24&quot;</td>
<td>132°36’12&quot;</td>
<td>1987</td>
<td>1989</td>
<td></td>
</tr>
<tr>
<td>014 615</td>
<td>BAM YILI</td>
<td>14°31’00&quot;</td>
<td>132°51’48&quot;</td>
<td>1965</td>
<td>1982</td>
<td></td>
</tr>
<tr>
<td>014 838</td>
<td>KATHERINE</td>
<td>14°17’00&quot;</td>
<td>132°51’00&quot;</td>
<td>1969</td>
<td>1982</td>
<td></td>
</tr>
<tr>
<td>014 902</td>
<td>KATHERINE COUNCIL</td>
<td>14°27’39&quot;</td>
<td>132°15’24&quot;</td>
<td>1873</td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>014 915</td>
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<tr>
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<tr>
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<td>MANBULLOO</td>
<td>14°31’10&quot;</td>
<td>132°11’52&quot;</td>
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<td></td>
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<td>132°09’17&quot;</td>
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<td>1912</td>
<td>1917</td>
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<tr>
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<td>TINDAL RAAF</td>
<td>14°31’27&quot;</td>
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<td>EVA VALLEY</td>
<td>14°17’50&quot;</td>
<td>132°50’15&quot;</td>
<td>1966</td>
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<td>014 947</td>
<td>UPPER FERGUSSON RIVER</td>
<td>14°00’43&quot;</td>
<td>132°12’27&quot;</td>
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<td>014 950</td>
<td>MOUNT TODD GOLD MINE</td>
<td>14°10’00&quot;</td>
<td>132°06’00&quot;</td>
<td>1997</td>
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<tr>
<td>014 952</td>
<td>CUTTA CUTTA</td>
<td>14°14’37&quot;</td>
<td>132°28’14&quot;</td>
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<tr>
<td>014 955</td>
<td>NITMILUK</td>
<td>14°19’18&quot;</td>
<td>132°25’17&quot;</td>
<td>1997</td>
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</tr>
</tbody>
</table>
5 SELECTION OF CALIBRATION EVENTS

5.01 The adopted five calibration events for the Katherine River hydrologic and hydraulic models are shown in Table 5.1 ranked in order of event magnitude. Initially it was proposed to use three of the selected events for model calibration and the remaining two events to verify the calibrated model. However, preliminary model runs indicated that only one or two ‘good’ calibration events (where recorded rainfalls were representative of actual rainfalls over a portion of the catchment) were available at each stream gauging station. Hence, not calibrating to a flood which represented the ‘good’ calibration event for a given gauging station could lead to major deficiencies in the model calibration. (Of course these deficiencies would have been identified during the model verification and the model parameters adjusted to eliminate gross errors, which is essentially the same as calibrating against all flood events). On this basis, the URBS model was calibrated against all of the five selected flood events.

Table 5.1 Adopted Calibration Events, Katherine River Hydrologic and Hydraulic Models

<table>
<thead>
<tr>
<th>Flood Event</th>
<th>Peak Flood Level at Katherine Railway Gauge (m GH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1998</td>
<td>20.39</td>
</tr>
<tr>
<td>March 1984</td>
<td>17.39</td>
</tr>
<tr>
<td>February 1987</td>
<td>16.97</td>
</tr>
<tr>
<td>January 1995</td>
<td>15.50</td>
</tr>
<tr>
<td>February 1991</td>
<td>14.04</td>
</tr>
</tbody>
</table>

5.02 The January 1998 flood is unique with respect to its severity and the significant amount of recorded flood data available. The last major event to flood the town of Katherine occurred in 1957. However, little reliable flood data is available for the 1957 flood. Hence, the January 1998 flood was adopted as the primary calibration event to ensure that the models correctly reproduced observed overbank flooding behaviour in Katherine.

5.03 The quantity of available flood data for the remaining four events shown in Table 5.1 is similar. Hence, these floods were selected to provide a range of event magnitudes for calibration of the Katherine flood models, which covers the Bureau of Meteorology’s range of flood warning threshold levels (Low: 15.0 m GH, Moderate: 16.5 m GH and Extreme: 17.5 m GH at the railway bridge gauging station G8140 001) and the expected range of design flood events. Note that the remaining four events in Table 5.1 are essentially ‘in-bank’ events within Katherine township (floodwaters do not breakout at Knotts Crossing until the river reaches about 18.2 m GH).

5.04 The adopted time periods over which the selected events were modelled are given in Table 5.2. Note that all modelling periods begin and end at 0900 hours to allow daily rainfall totals to be incorporated in estimating catchment rainfall.

5.05 Figures 5.1 to 5.5 show plots of recorded flood levels at Katherine (G 8140 001) and Mt Ebsworth (G 8140 218) along with recorded rainfalls at Katherine for the adopted modelling period of each of the calibration events. Note that during the wet season the Katherine River may flow continuously for several months at a time. Hence, many of the event hydrographs begin and end at a flow depth of several metres. Note also that the February 1987 and February 1991 events display multi-peak hydrographs.
Figure 5.1  Representative Stage Hydrographs and Rainfall, March 1984 Flood Event

Figure 5.2  Representative Stage Hydrographs and Rainfall, February 1987 Event
Figure 5.3     Representative Stage Hydrographs and Rainfall, February 1991 Event

Figure 5.4     Representative Stage Hydrographs and Rainfall, January 1995 Event
Figure 5.5  Representative Stage Hydrographs and Rainfall, January 1998 Event

Table 5.2  Modelling Period of Calibration Events, Katherine River Catchment

<table>
<thead>
<tr>
<th>Event</th>
<th>Event Type</th>
<th>Modelling Period</th>
<th>Duration (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 1984</td>
<td>Calibration</td>
<td>09:00 - 01-03-1984, 09:00 - 11-03-1984</td>
<td>10</td>
</tr>
<tr>
<td>Feb 1987</td>
<td>Calibration</td>
<td>09:00 - 05-02-1987, 09:00 - 03-03-1987</td>
<td>26</td>
</tr>
<tr>
<td>Feb 1991</td>
<td>Calibration</td>
<td>09:00 - 14-02-1991, 09:00 - 27-02-1991</td>
<td>13</td>
</tr>
<tr>
<td>Jan 1995</td>
<td>Calibration</td>
<td>09:00 - 25-01-1995, 09:00 - 03-02-1995</td>
<td>9</td>
</tr>
<tr>
<td>Jan 1998</td>
<td>Calibration</td>
<td>09:00 - 24-01-1998, 09:00 - 04-02-1998</td>
<td>11</td>
</tr>
</tbody>
</table>
HYDROLOGIC MODELLING

6.1 MODEL DESCRIPTION

6.01 URBS is a sub-catchment based runoff - routing model used to estimate flood discharges throughout a catchment. The model provides a number of options for conceptualising the rainfall - runoff process. For the Katherine River catchment the 'Split' model, in which sub-catchment runoff and channel flows are routed separately, was adopted.

6.02 In the Split model the rainfall excess for each sub-catchment is first determined by subtracting losses from the rainfall hyetograph. The rainfall excess is then routed through a conceptual catchment storage to determine the local runoff hydrograph for the sub-catchment. The storage - discharge relationship for catchment routing is:

\[
S_{\text{catch}} = \left(\beta A (1 + F)^2 \right) \left(\frac{1}{1 + U} \right)^2 Q^n
\]  

(6.1)

where \(S_{\text{catch}}\) is the catchment storage (m\(^3\) h/s),
\(\beta\) is the catchment lag parameter,
\(A\) is the area of sub-catchment (km\(^2\)),
\(U\) is the fraction urbanisation of sub-catchment,
\(F\) is the fraction of sub-catchment forested, and
\(m\) is the catchment non-linearity parameter.

Note that in the above equation, \(\beta\) is determined during model calibration, and is a global parameter.

6.03 The local runoff hydrograph is then combined with runoff from the upstream catchment and routed through a channel storage to obtain the outflow hydrograph at the outlet of the sub-catchment. The channel routing storage - discharge relationship is given by:

\[
S_{\text{chnl}} = \alpha f \frac{n L}{\sqrt{S_c}} \left( x Q_u + (1 - x) Q_d \right)^n
\]  

(6.2)

Channel routing is based on the non-linear Muskingum Model:

where \(S_{\text{chnl}}\) is the channel storage (m\(^3\) h/s),
\(\alpha\) is the channel lag parameter,
\(f\) is the reach length factor,
\(L\) is the length of reach (km),
\(S_c\) is the channel slope (m/m),
\(Q_u\) is the inflow at upstream end of reach (includes catchment inflow),
\(Q_d\) is the outflow at downstream end of the channel reach (m\(^3\)/s),
\(x\) is the Muskingum translation parameter,
\(n\) is the Muskingum non-linearity parameter (exponent), and
\(n\) is the Manning's 'n' or channel roughness. Note that in the above equation, \(\alpha\) and \(f\) are the principal calibration parameters. Note also that \(\alpha\) is a global parameter, whereas \(f\) can be varied for each channel reach.

6.2 MODEL CONFIGURATION

6.05 The configuration of the Katherine River URBS model is shown in Figure 6.1. The model covers the entire catchment upstream of Vampire Creek and consists of 86 sub-catchments ranging from 7 km$^2$ to 529 km$^2$. Details of sub-catchment areas are given in Table 6.1. A listing of the URBS model catchment file is given in Appendix H.

<table>
<thead>
<tr>
<th>Sub-Catch</th>
<th>Area (km$^2$)</th>
<th>Sub-Catch</th>
<th>Area (km$^2$)</th>
<th>Sub-Catch</th>
<th>Area (km$^2$)</th>
<th>Sub-Catch</th>
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<td>18.0</td>
<td>80</td>
<td>51.7</td>
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<td></td>
</tr>
</tbody>
</table>

6.3 MODEL CALIBRATION

6.3a Calibration Methodology

6.06 The URBS model was calibrated to achieve the best possible fit between recorded and predicted discharge hydrographs at the various gauging stations within the catchment for the following historical flood events:

- March 1984
- February 1987
- February 1991
- January 1995
- January 1998
Figure 6.1  Katherine River URBS Model Configuration
6.07 It was originally proposed to calibrate the URBS model against three events (1987, 1991 and 1998) and verify the model using another two events (1984 and 1995). However, due to the sparseness of recorded rainfall and streamflow data within the catchment it was found that the three calibration events did not provide sufficient information to adequately define the various model parameters for all regions of the model. The fit between recorded and predicted discharges for the 1991 event was so poor that this event provided no useful information for calibration of river routing parameters. Hence, to maximise the value of the available data, the URBS model was calibrated using information from all five calibration events.

6.08 Initial attempts were made to derive single URBS model parameters for the entire catchment. However it was found that no set of model parameters could adequately represent the hydrologic behaviour of the various river reaches and the tributary creeks. For this reason the catchment was divided into 5 regions and a consistent set of parameters adopted for each region for all events (with the exception of initial loss which varied between events). The adopted catchment regions are shown in Figure 6.2:

- Region 1 is the entire Katherine River catchment upstream of the Birdie Creek gauging station.
- Region 2 is the Katherine River catchment between Birdie Creek and the Seventeen Mile Creek confluence immediately downstream of the Katherine Gorge.
- Region 3 is the Seventeen Mile Creek catchment.
- Region 4 is the Maud Creek catchment.
- Region 5 is the remainder of the Katherine River catchment.

6.09 Calibration of the URBS model was achieved by:

- Adjusting the various 'global' model parameters (such as $a$ and $b$),
- Adjusting initial and continuing rainfall losses and infiltration capacity for the five model regions,
- Adjusting the 'reach length factor' and other channel routing parameters for various channel reaches, and
- Changing the assignment of pluviograph stations for some sub-catchment.

to obtain the best fit between recorded and predicted discharge hydrographs. The non-linear parameter estimation model 'PEST' (developed by Watermark Numerical Computing) was used to estimate the best model parameters (within reasonable limits) as measured by the sum of squares of the differences between recorded and predicted discharges over all calibration events.

6.10 Downstream of Katherine Gorge the channel routing parameters for the URBS model were matched to reproduce hydraulic routing characteristics from the CELLFLOW hydraulic model. A triangular discharge hydrograph (roughly representative of the January 1998 flood hydrograph) was adopted as the upstream inflow to the hydraulic model and routed downstream to the Railway Bridge crossing. All other inflows were set to zero. PEST was then used to determine appropriate channel routing parameters for the URBS model to achieve similar routing characteristics along the river channel. These parameters were then fixed throughout the URBS calibration process. A comparison of the inflow and routed flood hydrographs from the URBS and CELLFLOW models is shown in Figure 6.3.

6.11 To avoid difficulties associated with estimating baseflow for design events and flood forecasting, the URBS model parameters were calibrated to match the full event hydrographs, including baseflow.
Figure 6.2  Adopted Catchment Regions, Katherine River URBS Model
6.3b Assignment Of Total Rainfalls And Temporal Patterns

6.12 Total event rainfalls and appropriate temporal patterns at each sub-catchment were provided by the Bureau of Meteorology. The closest pluviograph station was assumed to be representative of the temporal variation in rainfall at each model sub-catchment. The total event rainfall at each model sub-catchment was determined by weighting the recorded total rainfall at nearby daily and pluviograph stations.

6.13 In some cases, the model results clearly showed that a particular rainfall station better represented the rain that fell upstream of a gauging station. In such cases the adopted pluviograph for some sub-catchments was changed to improve the fit between recorded and predicted discharges. This approach reduced the possibility of inappropriate rainfalls distorting the calibrated model parameters to compensate for errors in the rainfall record. The adopted pluviograph and total event rainfall at each of the URBS model sub-catchments for the five calibration events are given in Appendix I.

6.3c Adopted Model Parameters

6.14 Based on the results of the model calibration, the following values were adopted as ‘global’ model parameters which were applied to all regions for all calibration events:

- A catchment value of 2.5 was adopted for the catchment routing parameter $\beta$.
- A value of 0.55 was adopted for the channel routing parameter $\alpha$.
- A value of 0.8 was adopted for the catchment routing exponent ‘m’.
- Values of 1.0 and 0.4 were adopted for Muskingum channel routing parameters ‘n’ and ‘x’ respectively.
- A value of 0.9 was adopted for the infiltration capacity recovery factor ‘k’.
6.15 Note that the model calibration is based on current catchment conditions. An afforestation factor was not included in the model. Note also that the urbanised area is less than 0.1% of the catchment and hence the effects of urbanisation were ignored.

6.16 Adopted ‘regional’ model parameters for the five model regions (see Figure 6.1) are given in Table 6.2.

<table>
<thead>
<tr>
<th>Table 6.2 Adopted URBS Model Parameters, Katherine River URBS Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Infiltration Capacity (mm)</td>
</tr>
<tr>
<td>Tributary Reach Length Factor</td>
</tr>
<tr>
<td>River Reach Length Factor</td>
</tr>
<tr>
<td>Overbank/Channel Storage Ratio</td>
</tr>
<tr>
<td>Channel Capacity (m$^3$/s)</td>
</tr>
<tr>
<td>Continuing Loss Rate (mm/hr)</td>
</tr>
</tbody>
</table>

6.17 Adopted infiltration capacities vary from 66mm to 300mm. Conceptually, the infiltration capacity is related to catchment geology. However, given the sparseness of recorded rainfall and streamflow data within the catchment it is likely that the adopted values also account for non-representative rainfall for the calibration events. Note however that the high value of continuing loss adopted for Seventeen Mile Creek (8mm/hr) is consistent with the expected high infiltration capacity of the karst limestone geology which dominates the Seventeen Mile Creek catchment. Note also that it would be possible to reduce the infiltration capacities for Regions 2 and 4 with little effect on the model results due to the low (or zero) continuing loss rates adopted for these regions. This would provide greater consistency between adopted infiltration capacities for Regions 1, 2, 4 and 5.

6.18 It is likely that the high adopted values of the tributary reach length factors for Regions 2 and 4 (1.33 and 1.5 respectively) account for backwater effects limiting inflows to the river from tributaries in these regions.

6.19 Adopted river reach length factors vary from 0.57 to 0.88. It is likely that the lower value adopted for Region 2 is related to the effects of Katherine Gorge in reducing floodplain storage within this region.

6.20 Note that the ‘Channel Capacity’ and ‘Overbank/Channel Storage Ratio’ parameters have conceptual physical meaning, however in terms of calibrating against real data these parameters merely provide a means of modifying hydrograph shape.

6.3d Initial Losses

6.21 Adopted initial losses for the various model regions (see Figure 6.1) for each event are given in Table 6.3. Adopted values vary from 0mm to 155mm and indicate no clear pattern of relative losses between regions. The variability in the adopted values is due to changes in antecedent conditions between events, differing regional geology and errors in recorded rainfalls.
Table 6.3 Adopted Initial Loss Rates, Katherine River URBS Model

<table>
<thead>
<tr>
<th>Event</th>
<th>Region 1</th>
<th>Region 2</th>
<th>Region 3</th>
<th>Region 4</th>
<th>Region 5</th>
</tr>
</thead>
<tbody>
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<td>100</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>1995</td>
<td>0</td>
<td>155</td>
<td>40</td>
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</tr>
<tr>
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<td>0</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

6.3e Calibration Results

(i) Overview

6.22 Plots of recorded and predicted discharge hydrographs at the various gauging stations for the five calibration events are contained within Appendices A to E. Note that some of these plots are for ‘matched’ model runs, whereby one or more upstream hydrographs are matched to the recorded hydrograph before being routed downstream. This prevents gross errors in upstream hydrographs being carried downstream and gives a better indication of the routing characteristics of the model.

6.23 In general terms, the fit between recorded and predicted discharge hydrographs is reasonable. The adopted model calibration represents a compromise. It was possible to obtain a better fit for almost all stations if the URBS model parameters were varied from event to event. However, the sparseness of rainfall stations within the catchment and uncertainties in rating curves for the streamgauging stations prevent a significantly better average calibration.

(ii) Mt Ebsworth

6.24 An excellent fit between recorded and predicted hydrographs at Mt Ebsworth was obtained for the March 1984, January 1995 and January 1998 flood events. A reasonable fit was obtained for the February 1987 flood. However, it appears that recorded rainfall upstream of Mt Ebsworth may not have been generally representative of actual rainfall during this event. The fit at Mt Ebsworth for the February 1991 event was poor, again probably due to problems with recorded rainfalls.

(iii) Katherine Gorge and Gorge Caravan Park

6.25 The fit between recorded and predicted hydrographs at the Katherine Gorge and Katherine Gorge Caravan Park gauges for the various calibration events is generally reasonable.

6.26 The results of the hydraulic model indicate that both the Gorge and Gorge Caravan Park gauges are affected by backwater from Seventeen Mile Creek. Note that the predicted hydrograph at the Caravan Park gauge includes flow from Seventeen Mile Creek. Hence the rating curve at these gauges is dependent upon flow in both the Katherine River and Seventeen Mile Creek.

6.27 For the 1984 event, the predicted hydrographs significantly underestimate the recorded flood volume. Examination of recorded flood volumes at Katherine Gorge, Seventeen Mile Creek and McAdden Creek for this event indicates a problem with one or more of the adopted rating curves or recorded water levels at the Gorge and/or the Railway Bridge. The total recorded runoff volume (based on the adopted rating curves) at these three stations is some 1027 GL compared to a recorded volume of 1022 GL at the Railway Bridge. This indicates a loss of some 5 GL along this reach, assuming zero inflow from the 880 km² catchment between the gauges. On this basis it was assumed that the recorded hydrograph and rating curve at the Railway Bridge gauge were correct.
6.28 The fit between recorded and predicted hydrographs at the Katherine Gorge Caravan Park for the 1991 event is very poor (note that parts of the recorded hydrograph are missing for this event). This appears to be due to significant discrepancies between recorded and actual rainfalls.

6.29 For the 1995 event the fit at the Gorge Caravan Park is reasonable. Whilst the predicted peak discharge is approximately correct, the predicted peak occurs some 5 hours too early. The impact of flows from Seventeen Mile Creek is apparent in both the recorded and predicted hydrographs.

6.30 For the 1998 event the predicted discharge hydrograph matches the rising limb of the recorded hydrograph quite well. However the model overestimates the recorded peak discharge and flow volume for about 48 hours after the flood peak. Given the uncertainties in the Seventeen Mile Creek hydrograph (ungauged for this event) and in the rating curve at the Caravan Park gauge, more emphasis was placed on obtaining a good fit at the Railway Bridge gauge than at the Caravan Park Gauge.

(iv) Railway Bridge

6.31 For the 1984 event the fit between recorded and predicted hydrographs at the Railway Bridge is reasonable. The predicted hydrograph peaks earlier and higher than the recorded hydrograph. Note that matching upstream hydrographs does not significantly improve the fit.

6.32 For the 1987 event the fit between recorded and predicted hydrographs at the Railway Bridge is fair. Over-prediction of the first two peaks is associated with rainfall discrepancies in the upper catchment. If the URBS model is run with the predicted hydrograph matched to the recorded hydrograph at the Gorge station (Figure B.8), the fit at the Railway Bridge is much better over most of the hydrograph, with the exception of the main peak, which is over-predicted by the URBS model. Possible explanations for this discrepancy include errors in the estimation of inflows from ungauged tributaries (such as Maud and Leight Creeks) and the potential loss of volume from the peak of the hydrograph associated with breakout flows to overbank storage areas.

6.33 For the 1991 event the fit at the Railway Bridge is very poor for reasons discussed previously.

6.34 For the 1995 event the fit at the Railway Bridge is fair. However, the fit for the matched hydrograph case (Figure D.7) is significantly better.

6.35 For the January 1998 event the fit at the Railway Bridge (Figure E.6) is very good.

(v) Seventeen Mile Creek and McAdden Creek

6.36 The fit between observed and predicted hydrographs along Seventeen Mile and McAdden Creeks is generally fair to good. Good fits were obtained for the 1984 and 1998 flood events (although a timing difference of several hours was apparent at the McAdden Creek gauge for the 1984 event).

6.37 The good fits obtained at both Seventeen Mile Creek and McAdden Creek for some events indicate that the adopted model parameters are generally appropriate. Poor fits for some events are attributed to problems with recorded rainfalls and compromises on adopted rainfall loss rates between events.
HYDRAULIC MODELLING

7.1 MODEL DESCRIPTION

7.01 CELLFLOW is a quasi two-dimensional unsteady flow hydraulic model that simulates water levels, discharges and velocities along a network of open channels and across floodplains. In CELLFLOW, the floodplain area to be modelled is represented by a series of 'hydraulic cells'. Each cell is designated by a 'node' at the centroid of the cell. 'Nodes' are inter-connected by 'links'. Water flows from cell to cell along these links, cell boundaries forming link cross-sections. Link flows can be simulated either as open channel discharges or as discharges controlled by hydraulic structures such as culverts, road embankments, bridges or a combination thereof. Geometric data required by CELLFLOW include details of link discharge controls (cross-sections or hydraulic structures) and stage - surface area data for cells.

7.02 The computational heart of CELLFLOW is based on the equations of momentum and continuity. With the exception of the convective acceleration term, all other acceleration terms of the open channel flow momentum equation are incorporated in the model. The magnitude of the convective acceleration terms is insignificant for flat areas such as the area of interest to this study.

7.03 The model simulates water level behaviour at the nodes of cells and discharges along links. Open channel discharges depend upon cross-sectional properties at the mid-sections of links (the conveyance) and water levels at the end of links. Open channel discharges are governed by the momentum equation. Discharges at hydraulic structures depend upon the nature of the structure and upstream and downstream water levels. These discharges along each link are one-dimensional in space, but the assigned directions of links simulate 'two-dimensional' flow. CELLFLOW can accommodate either stage or discharge hydrographs or rating curves as boundary conditions. The model can also accommodate the 'wetting' and 'drying' of cells. Full details of the CELLFLOW model are given elsewhere (Water Studies, 1990).

7.2 CELLFLOW MODEL CONFIGURATION

7.04 The Katherine River CELLFLOW hydraulic model extends from the Katherine Gorge Gauging Station (G 814 0023) downstream to Vampire Creek, some 30 km downstream of the Katherine Railway Bridge. The model consists of 312 nodes with 613 links and includes 19 boundary conditions:

- An upstream inflow hydrograph along the Katherine River.
- 17 inflow hydrographs representing various tributary inflows between Katherine Gorge and the downstream boundary of the model.
- A rating curve at the downstream boundary of the model.

Direct rainfall over the hydraulic model area is also included in the CELLFLOW model. The adopted model configuration is shown in Figure 7.1.
Figure 7.1    Katherine River CELLFLOW Model Configuration
7.3 TOPOGRAPHIC DATA

7.05 The topographic data required by the CELLFLOW hydraulic model consists of:

- Cross-sections to define model links, and
- Stage - area relationships for model nodes.

The ILWIS (Integrated Land & Water Information System) GIS package was used to extract the above data from the DEM. Where possible, surveyed cross-sections were used to replace or enhance cross-sections extracted from the DEM. Details of the available cross-section data are given in Section 4.2.

7.06 Topographic data used to build the DEM was supplied by Kevron Surveyors, Perth and consisted of:

- 1:5,000 orthophoto maps with 1m contours overlayed with cadastral boundaries. This data was provided in hardcopy format.
- Point data on a regular 30m grid (defining the general ground surface) and point data extracted along breaklines (defining a change in grade, ie. creeks, roads, ridges and gullies) extracted from the digital topographic maps. This data was provided in digital format.

7.07 The point data was used to generate a DEM of the Katherine region with a pixel resolution of 15 m. The DEM area is covered by a series of 71 hardcopy 1:5,000 topographic maps, covering an area of around 830 km². Data was supplied in 142 digital files totalling 260 Mb of data. Each file was edited so that the format was compatible with the GIS. Regular grid and breakline data were imported into ILWIS separately and used to generate point maps. These maps were then converted into raster format (ie. pixel image) and overlaid to produce the final DEM.

7.08 Hardcopy orthophoto maps were used to define the configuration of the hydraulic CELLFLOW model. Cell layout was defined and drawn on topographic maps by manually identifying potential flow paths and controlling sections across the Katherine River floodplain. This information was incorporated into the GIS by digitising the cell boundaries and nodes, and overlaid on the DEM.

7.09 The DEM was used to produce stage-area relationships within each cell of the hydraulic model. By overlaying the DEM with planar surfaces generated at various levels, the area of available flood storage at each level was defined. This image was then combined with the digital CELLFLOW model configuration to provide data showing the area within each cell inundated at a particular flood level. Collation of this data was used to define the stage-area relationship for each of the hydraulic model cells.

7.10 The cross-sections defining the boundary between cells in the hydraulic model were obtained from the DEM by extracting ground levels along the cross-section alignment at 10 m to 50 m intervals (depending on the link length). The DEM cross-sections were supplemented or replaced by ground survey where available.

7.4 HYDRAULIC STRUCTURES

7.11 The 'HYDLOSS' hydraulic analysis program, developed by Water Studies Pty Ltd, was used to estimate affluxes at various hydraulic structures crossing the Katherine River and floodplain. HYDLOSS is a companion of the CELLFLOW model and for each structure produces an hydraulic structure 'matrix' defining the relationship between discharge and upstream water level for different downstream water levels.
7.12 In the vicinity of Katherine, three bridges cross the river:

- The 'low level' crossing located some 3.4 km downstream of the Railway Bridge.
- The Stuart Highway crossing.
- The disused Railway Bridge located about 100 m downstream of the Stuart Highway Crossing.

In addition, numerous culvert crossings of local drains and creeks are located on the floodplain.

7.13 After investigating the afflux at the three river bridges and the major floodplain culvert crossings it was found that most of these hydraulic structures had a negligible impact on flood levels during major flood events. The low level crossing is overtopped by more than 11 m during the 20 year ARI flood event. Across the floodplain most of the significant culvert crossings are drowned by more than 1 m during the 50 year ARI event. The afflux for the 20 year ARI event is generally small. For this reason only the existing Railway Bridge and Stuart Highway Bridge crossings of the river were included in the hydraulic model. Note however, that due to the fact that these bridges span almost the entire main channel the afflux associated with these bridges is also small (of the order of 0.04 to 0.06 m for each bridge).

7.5 CALIBRATION METHODOLOGY

7.14 The calibrated URBS model was used to estimate inflow hydrographs at the hydraulic model boundaries for the various calibration events. The CELLFLOW model was then calibrated to achieve the best fit between recorded and predicted discharges and flood levels at various locations along the Katherine River and its floodplain for the following historical flood events:

- March 1984
- February 1987
- January 1995
- January 1998

7.15 Note that the February 1991 flood event was not included in the model calibration due to the very poor fit between recorded and predicted inflow hydrographs to the hydraulic model.

7.16 The Katherine River CELLFLOW Model was calibrated by adjusting Manning's 'n' values for the model links to match recorded and predicted stage and discharge hydrographs and peak flood levels for the various calibration events.

7.17 For the river cross-sections and many of the floodplain cross-sections, Manning's 'n' was specified directly as a function of flow depth, rather than calculating a composite Manning's 'n' using the 'Total Force' or 'Total Discharge' method based on horizontal variations in hydraulic roughness. It was found that direct specification of Manning's 'n' was necessary to adequately reproduce flow behaviour along the river main channel as described by flood gaugings undertaken at the Katherine Railway Bridge. Typical variations in Manning's 'n' with depth for the river and floodplain are shown in Figures 7.2 and 7.3 respectively. The adopted values of Manning's 'n' are within the range of expected values.

7.18 Note that the January 1998 flood event was the most recent and by far the largest of the four calibration events and was the only event for which overbank flow occurred. For this reason, the focus of the model calibration was to satisfactorily reproduce recorded flooding behaviour during the January 1998 flood.
Figure 7.2  Typical Variation of Manning's 'n' with Flow Depth, Katherine River Channel

Figure 7.3  Typical Variation of Manning's 'n' with Flow Depth, Katherine River Floodplain
7.6 CALIBRATION RESULTS - JANUARY 1998 FLOOD

7.6a Overview

7.19 Initial calibration runs for the January 1998 event indicated that, using the URBS inflows, it was not possible to achieve a good match between recorded and predicted hydrographs and maintain a realistic rating curve at the Railway Bridge. To match the initial rise of the river hydrograph at the railway bridge, it was necessary to introduce significant additional inflow to the model at the commencement of the flood event. No information is available on the likely source of this additional inflow, however it is possible that actual flows in Leight and Maud Creeks could have been significantly greater than predicted by the URBS model (little rainfall and no streamflow data were available with these catchments). On this basis, a manual arbitrary adjustment was made to the inflow hydrograph from Leight and Maud Creeks and the inflow to Lake Hickey.

7.20 A comparison of the original URBS hydrographs and the modified hydrographs is shown in Figure 7.4 below. It is uncertain whether the adopted hydrographs, particularly for Leight Creek, are realistic. However, it is possible that more intense rain fell over the lower portion of Leight and McAdden Creeks than was recorded at surrounding rainfall stations. Hence, a proportion of the significant additional inflow assigned to Leight Creek may have come from the lower portion of McAdden Creek.

7.6b Peak Flood Levels

7.21 Approximately 300 peak flood levels were surveyed across the Katherine River floodplain following the January 1998 flood event. Figure 7.5 plots the difference between recorded flood levels and those predicted by the CELLFLOW model across the Katherine River Floodplain. Note the large group of points between about 105 and 110 m AHD which generally represent the large number of recorded flood levels in the Katherine town area.

Figure 7.4 URBS Hydrographs & Modified Inflow Hydrographs, Leight & Maud Creeks and Lake Hickey Inflow, January 1998 Flood
7.22 The results of Figure 7.5 indicate that predicted peak flood levels are generally within about 0.4 m of recorded values:

- 66% of predicted levels are within 0.2 m of recorded values.
- 84% of predicted levels are within 0.5 m of recorded values.
- Within the town area, 68% of predicted values are within 0.1 m of recorded values and 92% of predicted values are within 0.2 m of recorded values.

Note that many of the recorded values are subject to significant uncertainty and are not consistent with nearby recorded values.

7.23 Figure 7.6 is a longitudinal section showing the comparison between recorded and predicted flood levels along the modelled reach of the Katherine River. Recorded and predicted levels are generally in good agreement. Inconsistencies amongst a number of the recorded levels are apparent.

7.6c Stage Hydrographs

7.24 Figure 7.7 shows a comparison between recorded and predicted stage hydrographs at the Railway Bridge (G 814 0001) for the January 1998 flood. The hydrographs are in close agreement. The predicted peak flood level is 0.05 m lower than the recorded value.
Figure 7.6  Katherine River Longitudinal Flood Profile, January 1998 Flood
Figure 7.7  Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River at Railway Bridge (G 814 0001), January 1998 Event

Figure 7.8  Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River at Gorge Caravan Park (G 814 0023), January 1998 Event
7.25 Figure 7.8 shows a comparison between recorded and predicted stage hydrographs at the Gorge Caravan Park (G 814 0023). Predicted peak flood levels at this location are generally over-estimated by about 1 m or more, particularly on the falling limb. As outlined in the URBS calibration report, there is some uncertainty surrounding the rating curve at the Caravan Park Gauge due to the influence of Seventeen Mile Creek.

7.26 Figures 7.9, 7.10 and 7.11 show recorded and predicted stage hydrographs at the three floodplain gauges in Katherine. The shapes of the recorded and predicted hydrographs are in reasonably good agreement. Predicted peak flood levels are within 0.1 m of recorded values. The predicted time of the peak flood level is generally about 2 to 4 hours earlier than recorded.

7.27 The principal factor governing the timing of predicted floodplain hydrographs was found to be the river stage hydrograph. Whilst the recorded and predicted stage hydrographs at the Railway Bridge appear similar, the predicted hydrograph is generally higher by about 0.05 m to 0.15 m during the initial period of overbank flow. This relatively small difference in flood level translates to a noticeable difference in the total breakout flow from the river, as evidenced in the earlier rise of the predicted floodplain stage hydrographs. Since the completion of the study, DLPE have also advised that the timing of the flood peak at the Railway Bridge may be in error by about ± 1 hour as the gauge has submerged near the peak. This possible error in timing of the recorded river hydrograph could also have contributed to the observed difference in timing of the recorded and predicted floodplain hydrographs.

7.6d Comparison With Gauged Discharges

7.28 Figure 7.12 shows predicted discharge hydrographs for the Katherine River left bank (town side), main channel, right bank (Kalano) and the total river. Gauged and estimated discharges from a gauging undertaken by DLPE on the falling limb of the hydrograph are also shown in Figure 7.12. The predicted total and component flows are in good agreement with the gauged values.

7.29 Figure 7.13 shows the comparison between flood gaugings and the stage - discharge relationships at the Railway Bridge gauge derived from the CELLFLOW model. For a given gauge height, the discharge on the lower portion of the rising limb of the January 1998 hydrograph is some 15% to 20% higher than for the March 1984 event. This difference is related to an increased hydraulic gradient associated with the initial steep rate of rise of the January 1998 flood.

7.30 Figure 7.13 also shows the adopted rating curve for calibration of the URBS model. The URBS rating curve was obtained from preliminary hydraulic model runs. The adopted URBS rating curve is generally appropriate. However, there is a small discrepancy between the URBS and CELLFLOW rating curves above 20 m gauge height. Hence, the estimated peak flood discharges for the January 1998 event differ by about 3% (9,430 m$^3$/s from CELLFLOW compared to 9,175 m$^3$/s from URBS).

7.31 Figures 7.14 and 7.15 show the comparison between flood gaugings and the CELLFLOW stage-discharge relationships at the Gorge and Gorge Caravan Park gauges respectively for the 1998 and 1987 flood events. Note the hysteresis in the CELLFLOW rating curves, particularly for the January 1998 event. Note also that the CELLFLOW rating curves for the Caravan Park gauge differ significantly from the adopted rating curve used in the URBS model.

7.32 The URBS rating curves were derived to match the peak stage relationship between the Gorge and Caravan Park gauges, assuming that the discharge at both gauges was similar. The recorded peak stage relationship for various historical events and the relationship derived from the URBS rating curve (assuming identical discharges at both gauges) are shown in Figure 7.16. However, the difference between the URBS and CELLFLOW rating curves shown in Figure 7.15 indicates that the rating curve at the Caravan Park gauge is dependent on discharges along the river and Seventeen Mile Creek.
Figure 7.9  Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River Floodplain Near Pump Station No. 7 (G 814 0411)

Figure 7.10  Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River Floodplain Behind BP Service Station (G 814 0409)
Figure 7.11 Recorded and Predicted Stage Hydrographs, CELLFLOW Model, Katherine River Floodplain Opposite Dalgety's Victoria Highway (G 814 0407)

Figure 7.12 Predicted Discharge Hydrographs, Katherine River at Stuart Highway, CELLFLOW Model, January 1998 Flood
Figure 7.13  Comparison of River Gaugings and Derived Rating Curves, Katherine River at Railway Bridge (G 814 0001)
Figure 7.14  Comparison of River Gaugings and Derived Rating Curves, Katherine River at Katherine Gorge (G 814 0019)

Figure 7.15  Comparison of River Gaugings and Derived Rating Curves, Katherine River at Gorge Caravan Park (G 814 0023)
7.7 CALIBRATION RESULTS - MARCH 1984 FLOOD

7.33 Figures 7.17 to 7.22 show comparisons of recorded and predicted stage and discharge hydrographs at the Railway Bridge (G814 0001), Gorge Caravan Park (G814 0023) and Katherine Gorge (G814 0019) for the 1984 calibration flood event.

7.34 For the 1984 event the comparison between recorded and predicted stage and discharge hydrographs at the Railway Bridge (Figures 7.17 and 7.18) is reasonably good; at the Gorge and Gorge Caravan Park Stations (Figures 7.19, 7.20, 7.21 and 7.22) there is a significant difference between recorded and predicted flood levels and discharges due to differences in recorded and predicted inflows along the Katherine River (see Section 6.3e).

7.8 CALIBRATION RESULTS - FEBRUARY 1987 FLOOD

7.35 Figures 7.23 to 7.28 show comparisons of recorded and predicted stage and discharge hydrographs at the Railway Bridge (G 814 0001), Gorge Caravan Park (G814 0023), and Katherine Gorge (G814 0019) for the 1987 calibration flood event. Note that inflows to the CELLFLOW model at the Gorge have been matched to recorded values.

7.36 For the 1987 event the comparison between recorded and predicted stage and discharge hydrographs at the Railway Bridge (Figures 7.23 and 7.24) is reasonably good. However, flood levels and discharges are slightly over-estimated throughout the event.
Figure 7.17 Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), March 1984 Event

Figure 7.18 Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), March 1984 Event
Figure 7.19  Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), March 1984 Event

Figure 7.20  Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), March 1984 Event
Figure 7.21  Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), March 1984 Event

Figure 7.22  Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), March 1984 Event
Figure 7.23  Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), February 1987 Event

Figure 7.24  Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), February 1987 Event
Figure 7.25   Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), February 1987 Event

Figure 7.26   Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), February 1987 Event
Figure 7.27  Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), February 1987 Event

Figure 7.28  Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine Gorge (G814 0019), February 1987 Event
7.37 At the Gorge and Gorge Caravan Park stations (Figures 7.25, 7.26, 7.27 and 7.28) observed differences between recorded and predicted flood levels and discharges are related to problems with the rating curves, as discussed in Section 7.6d.

7.9 CALIBRATION RESULTS - JANUARY 1995 FLOOD

7.38 Figures 7.29 to 7.32 show comparisons of recorded and predicted stage and discharge hydrographs at the Railway Bridge (G 814 0001), Gorge Caravan Park (G814 0023), and Katherine Gorge (G814 0019) for the 1995 calibration flood event.

7.39 For the 1995 event the comparison between recorded and predicted stage and discharge hydrographs at the Railway Bridge (Figure 7.29 and 7.30) is reasonable. Note however, that the predicted hydrograph misses the initial peak of the recorded hydrograph.

7.40 At the Gorge and Gorge Caravan Park stations (Figures 7.31 and 7.32) observed differences between recorded and predicted flood levels and discharges are related to problems with the rating curves as discussed in Section 7.6d.

7.10 SUMMARY OF CALIBRATION RESULTS

7.41 In general terms the calibrated CELLFLOW model satisfactorily reproduces recorded flood level and discharge behaviour along the modelled reach of the Katherine River. The comparison between recorded and predicted flood levels and flood discharges in the Katherine town area for the January 1998 flood is quite good.

7.42 The main difficulty with respect to calibration of both the URBS and CELLFLOW models is uncertainty in the rating curve at the Gorge Caravan Park related to the interaction of floodwaters from the Katherine River and Seventeen Mile Creek.
Figure 7.29  Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), January 1995 Event

Figure 7.30  Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Railway Bridge (G814 0001), January 1995 Event
Figure 7.31 Recorded and Predicted Stage Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), January 1995 Event

Figure 7.32 Recorded and Predicted Discharge Hydrograph, CELLFLOW Model, Katherine River at Gorge Caravan Park (G814 0023), January 1995 Event
8 FLOOD FREQUENCY ANALYSIS

8.1 METHOD OF ANALYSIS

8.01 Design flood discharges at the Katherine Railway Bridge were estimated by flood frequency analysis. The methodology of Australian Rainfall and Runoff (1987) was used to fit a Log-Normal and Log-Pearson Type III distribution to an annual series of recorded peak flood discharges at the Railway Bridge. Major historical floods dating back to 1897 were included in the flood frequency analysis.

8.2 DEVELOPMENT OF THE TOWN OF KATHERINE

8.02 The history of development of the town of Katherine and indeed the Northern Territory itself are briefly reviewed below because they have influenced the nature and availability of historical flood data for Katherine.

8.03 The Colony of South Australia annexed the Northern Territory by Letters of Patent dated 6th July 1863. The town of Palmerston, now inner Darwin, was surveyed in 1869 to foster settlement of the northern region of the Colony. In August 1872, Adelaide and Darwin were connected by the Overland Telegraph Line, so enabling communication between the southern and northern outposts of South Australia (Ogden, 1994).

8.04 The Overland Telegraph line crossed the Katherine River about 1 km upstream from a river crossing used by travellers. This river crossing was to become known as Knotts Crossing. A telegraph station was constructed on the eastern bank of the Katherine River at this location. The crossing and telegraph station formed the focus of a small community. A police station was established in 1879 and a 'permanent' post office in 1883 (Ogden, 1994).

8.05 In 1883, the South Australian Government decided to construct a railway from Palmerston to Pine Creek, where gold had been discovered. The Pine Creek line was completed in 1889 (Ogden, 1994).

8.06 By the first decade of the 20th Century, the cost of administering the Northern Territory had become unacceptably high for South Australia. In January 1911, South Australia passed control of the Northern Territory to the Commonwealth Government for a sum of £6,160,548.

8.07 After a Royal Commission in 1913, a decision was made to extend the Pine Creek Railway south of Pine Creek. By 1917, the railway had reached Emungalan, which is located about 4 km south of 'The Crossing' on the western side of the Katherine River. Emungalan then became the focus of future growth (a telegraph office was established there in 1919). After two years' construction, the railway bridge over the Katherine River at Emungalan was completed in January 1926. In that same year, the site of the present town of Katherine was surveyed on the eastern bank of the Katherine River.
8.08 The new town was adjacent to the railway line and was ‘.......protected from river floods by a fairly high secondary bank’ (Ogden, 1994, p.37). The new site of Katherine then became the focus of development, with the post office transferring from Emungalan to Katherine in 1927.

8.09 On 1st July 1978, the Territory received powers of self-government. Thus, the Territory has seen three distinct administrative periods:

- Up to 1911, the Territory was part of the Colony of South Australia,
- From 1911 to 1978, The Commonwealth Government was responsible for administration, and
- From 1978 onwards, the Territory was self-governed, but still remained a Commonwealth responsibility.

8.10 Prior to 1952, there was no systematic recording of streamflows in the Territory. At this stage, a number of stream gauging stations were established in the Territory, including one in the Katherine River some 900 m upstream of the railway bridge (GS 1). Stream gauging and the operation of the hydrographic network were then the responsibility of the Commonwealth Department of Works. In 1955, the Water Use Branch, a forerunner of the current Water Resources Division, was formed within the Northern Territory Administration for the purpose of surveying and investigating water resources in the Territory. In 1958, the Stream Gauging Section transferred from the Department of Works to the Water Use Branch. The Water Resources Division has been absorbed in a number of different Departments over the intervening years, including the Power and Water Authority (1987) and the present Department of Lands, Planning and Environment.

8.11 Since 1911, rainfall data have been collected throughout the Territory by the Commonwealth Bureau of Meteorology. Sporadic rainfall records collected by private individuals are available for the period before 1911.

8.3 FLOOD DATA FROM STREAM GAUGING STATION

8.3a Available Data

8.12 The systematic recording of water levels at Katherine commenced in April 1952, when a daily read staff gauge was installed on the eastern bank of the Katherine River some 900 m upstream of the railway bridge (GS 1). In March 1960, the gauging site was shifted to its present location some 30 m downstream of the railway bridge, where a continuous water level recorder was installed (GS 814 0001). However, no data is available for this location until January 1962.

8.3b Rating Curves

8.13 Table 8.1 shows details of the highest gauged discharges at the two sites. With respect to rating curves based on these discharges, the following comments are made:

<table>
<thead>
<tr>
<th>Table 8.1 Details of Available Streamflow Records, Katherine River</th>
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<tbody>
<tr>
<td>Station Details</td>
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<tr>
<td>No.</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>GS1</td>
</tr>
<tr>
<td>G814 0001</td>
</tr>
</tbody>
</table>

\(^a\) Partially gauged only
A total of 49 gaugings for flows greater than 100 \( m^3/s \) have been made, and 22 gaugings for flows greater than 1000 \( m^3/s \). The highest gauged discharge at the Railway Bridge (7,100 \( m^3/s \)) was recorded in January 1998. Note however, that this gauging was undertaken on the falling limb of the hydrograph and that only the eastern floodplain and main channel were gauged. The gauged discharge includes an estimate of flow across the western floodplain.

Watson et al (1970) undertook the first major review of flooding in the Katherine River and derived a rating curve for the Katherine River at the Railway Bridge. Key discharges and water levels according to this report were:

- 2,700 \( m^3/s \) (17.14 m GH), at which the Katherine River overtops the natural levee on the western side of the river around Leight Creek and flows down the western floodplain.
- 3,500 \( m^3/s \) (18.54 m GH), at which the Katherine River overtops the natural levees of the eastern bank at Landsdown's Farm and flows down the eastern floodplain.
- 5,700 \( m^3/s \) (19.18 m GH), at which the impeding effects of the railway embankment are drowned out.

Two previous estimates of the rating curve at the Railway Bridge are available. These estimates are shown in Table 8.2, along with the rating curve derived from the CELLFLOW model developed for this study. The sources of the two previous rating curves are as follows:

- Watson et al (1970) produced a rating curve with an 'extended' section based on the application of Manning's equation to overbank flows. Gaugings up to 17.14 m GH (2,750 \( m^3/s \)) were available for this study.
- Barlow (1985) produced a rating curve with an extended section based on predicted water levels from the quasi two-dimensional model of the floodplain developed by SMEC (1984). On the basis of the 1984 Flood, Barlow found it necessary to recalibrate the model to both the 1984 and 1957 Floods.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12 98.36</td>
<td>-</td>
<td>1,600</td>
<td>980</td>
</tr>
<tr>
<td>13 99.36</td>
<td>-</td>
<td>1,850</td>
<td>1,150</td>
</tr>
<tr>
<td>14 100.36</td>
<td>-</td>
<td>2,100</td>
<td>1,400</td>
</tr>
<tr>
<td>15 101.36</td>
<td>2,350</td>
<td>2,400</td>
<td>3,250</td>
</tr>
<tr>
<td>16 102.36</td>
<td>2,450</td>
<td>2,800</td>
<td>3,400</td>
</tr>
<tr>
<td>17 103.36</td>
<td>2,700</td>
<td>3,250</td>
<td>4,650</td>
</tr>
<tr>
<td>18 104.36</td>
<td>3,150</td>
<td>3,900</td>
<td>5,150</td>
</tr>
<tr>
<td>19 105.36</td>
<td>3,750</td>
<td>4,650</td>
<td>6,550</td>
</tr>
<tr>
<td>20 106.36</td>
<td>9,050</td>
<td>8,550</td>
<td>7,720</td>
</tr>
</tbody>
</table>

A comparison of these three rating curves indicates that:

- Barlow's curve generally predicts higher discharges than the curve of Watson et al.
- At higher levels (19 and 20 m GH) the rating curve derived from the CELLFLOW model of this study (Water Studies) estimates discharges about 10% lower than Barlow's rating curve. The discharges from the CELLFLOW model are significantly lower than Barlow's estimates for gauge heights of 18 m and less.
8.16 Given the significant additional information (including a gauged overbank flow) provided by the January 1998 flood, the rating curve derived from the calibrated CELLFLOW model has been used to assess peak annual discharges at the Railway Bridge for the flood frequency analysis.

8.3c Peak Annual Flood Data

8.17 Table 8.3 shows peak annual flood data at the Railway Bridge. These data have been obtained from three sources:

- From the HYDSYS Database operated by the Water Resources Section of DLPE.
- From the report by Barlow (1985), which lists annual peak water levels for water years in the period 1952 - 1953 to 1984 - 1985.

8.18 The following aspects of the data of Table 8.3 should be noted:

- Barlow (1985) has apparently manually extracted peak annual water levels at the railway bridge in the early years. His estimates have been adopted. In using these data, it is assumed that peak water levels recorded in the years prior to 1962 have been reduced appropriately to transpose the levels from the upstream gauge (GSI) to the railway bridge. It is understood that the adopted correction factor is 1.253 ft (0.382 m) - the equivalent level at the upstream gauge being higher than the level at the railway bridge.

- The only major flood to occur between 1953 and 1962 was the January 1957 event, which according to the DLPE records, reached 19.69 m GH at GSI. For this event, the flood slope of the Katherine River upstream of the railway bridge was $4.3 \times 10^{-4}$ m/m (Watson et al, 1970). This indicates that the recorded level was some 0.39 m higher than the water level at the railway bridge, which is estimated to be 19.30 m GH. This figure is in agreement with the value adopted by Barlow (1985) of 19.28 m GH, which has been adopted for the peak height at the railway bridge for the 1957 event.

8.4 FLOOD DATA FROM OTHER SOURCES

8.4a Available Data

8.19 Details of major floods between 1872, when an Overland Telegraph Station was constructed at 'The Crossing' and permanent European occupation of the site commenced, and 1952, when the systematic monitoring of water levels in the town of Katherine began, are available from a number of sources (Ogden, 1994, 1998; Watson et al, 1970). In her history of the town of Katherine, Ogden (1994) presents brief descriptions of major floods that occurred prior to 1952. The source of much of this information was newspapers from Darwin and Katherine.

8.20 It was thought that CBM may have had details of major floods in Katherine from 1911 onwards, when the Commonwealth Government became responsible for administering the Territory. Early records were apparently sent to Adelaide for archiving. An attempt was made to unearth these records, but was unsuccessful.

8.21 In the absence of official reports on flooding in Katherine in the period up to 1952, we are forced to rely on 'unofficial' descriptions of flooding in Ogden (1994) and Watson et al (1970).
Table 8.3  Peak Annual Water Levels, Katherine River, 1952 to Present

<table>
<thead>
<tr>
<th>Water Year Ending</th>
<th>Railway Bridge (GS 8140 001)</th>
<th>Month</th>
<th>GH (m)</th>
<th>Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1953</td>
<td></td>
<td></td>
<td>4.57</td>
<td>230</td>
</tr>
<tr>
<td>1954</td>
<td></td>
<td></td>
<td>11.05</td>
<td>825</td>
</tr>
<tr>
<td>1955</td>
<td></td>
<td></td>
<td>9.57</td>
<td>620</td>
</tr>
<tr>
<td>1956</td>
<td></td>
<td></td>
<td>11.73</td>
<td>935</td>
</tr>
<tr>
<td>1957</td>
<td>Mar</td>
<td></td>
<td>19.28</td>
<td>4,650</td>
</tr>
<tr>
<td>1958</td>
<td></td>
<td></td>
<td>6.25</td>
<td>340</td>
</tr>
<tr>
<td>1959</td>
<td></td>
<td></td>
<td>4.12</td>
<td>200</td>
</tr>
<tr>
<td>1960</td>
<td></td>
<td></td>
<td>9.45</td>
<td>605</td>
</tr>
<tr>
<td>1961</td>
<td></td>
<td></td>
<td>3.69</td>
<td>170</td>
</tr>
<tr>
<td>1962</td>
<td>Jan</td>
<td></td>
<td>7.38</td>
<td>440</td>
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<td>1963</td>
<td>Apr</td>
<td></td>
<td>12.16</td>
<td>1,000</td>
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<tr>
<td>1964</td>
<td>Mar</td>
<td></td>
<td>6.55</td>
<td>360</td>
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<td>1965</td>
<td>Dec</td>
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<td>11.52</td>
<td>900</td>
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<td>1966</td>
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</tr>
<tr>
<td>1967</td>
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<td></td>
<td>12.06</td>
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<td></td>
<td>17.15</td>
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</tr>
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<td>1969</td>
<td>Mar</td>
<td></td>
<td>13.28</td>
<td>1,210</td>
</tr>
<tr>
<td>1970</td>
<td>Feb</td>
<td></td>
<td>8.11</td>
<td>510</td>
</tr>
<tr>
<td>1971</td>
<td></td>
<td></td>
<td>8.83</td>
<td>560</td>
</tr>
<tr>
<td>1972</td>
<td>Mar</td>
<td></td>
<td>12.39</td>
<td>1,040</td>
</tr>
<tr>
<td>1973</td>
<td>Mar</td>
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<td>14.39</td>
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<td>Mar</td>
<td></td>
<td>16.64</td>
<td>2,300</td>
</tr>
<tr>
<td>1975</td>
<td>Jan</td>
<td></td>
<td>14.43</td>
<td>1,520</td>
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<tr>
<td>1976</td>
<td>Mar</td>
<td></td>
<td>16.69</td>
<td>2,330</td>
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<td>1977</td>
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<tr>
<td>1982</td>
<td>Mar</td>
<td></td>
<td>9.00</td>
<td>570</td>
</tr>
<tr>
<td>1983</td>
<td>Mar</td>
<td></td>
<td>9.59</td>
<td>625</td>
</tr>
<tr>
<td>1984</td>
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<td>17.39</td>
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<tr>
<td>1985</td>
<td>Feb</td>
<td></td>
<td>8.64</td>
<td>540</td>
</tr>
<tr>
<td>1986</td>
<td>Jan</td>
<td></td>
<td>5.75</td>
<td>300</td>
</tr>
<tr>
<td>1987</td>
<td>Feb</td>
<td></td>
<td>16.97</td>
<td>2,450</td>
</tr>
<tr>
<td>1988</td>
<td>Feb</td>
<td></td>
<td>10.82</td>
<td>790</td>
</tr>
<tr>
<td>1989</td>
<td>Mar</td>
<td></td>
<td>13.83</td>
<td>1,340</td>
</tr>
<tr>
<td>1990</td>
<td>Mar</td>
<td></td>
<td>3.67</td>
<td>175</td>
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<tr>
<td>1991</td>
<td>Feb</td>
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<td>14.04</td>
<td>1,400</td>
</tr>
<tr>
<td>1992</td>
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<td>735</td>
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<td>1993</td>
<td>Jan</td>
<td></td>
<td>16.55</td>
<td>2,260</td>
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<tr>
<td>1994</td>
<td>Mar</td>
<td></td>
<td>12.63</td>
<td>1,090</td>
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<tr>
<td>1995</td>
<td>Jan</td>
<td></td>
<td>15.50</td>
<td>1,860</td>
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<tr>
<td>1996</td>
<td>Jan</td>
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<tr>
<td>1997</td>
<td>Feb</td>
<td></td>
<td>14.41</td>
<td>1,510</td>
</tr>
<tr>
<td>1998</td>
<td>Jan</td>
<td></td>
<td>20.39</td>
<td>9,400</td>
</tr>
</tbody>
</table>

* Based on adopted rating curve from CELLFLOW Model results (see Table G.1 in Appendix G).
8.4b Major Floods

8.22 The area around the present town of Katherine was subject to more or less regular flooding over the period 1872 to 1952. Early residents learned to cope with this phenomenon (Ogden, 1994). Table 8.4 shows details of four major floods in this period (Ogden, 1994):

December 1897
Some 2691 points (750 mm) of rain fell in December, making it the wettest December until 1970.

January 1914
Over 9 inches (230 mm) of rain fell in 4 days at Pine Creek. There was over 1 m of water through the police station. Believed by locals to be the highest flood on record.

March 1931
Two floods occurred in 1931: the first peaked on 28th January, the second on 29th March, when the river rose to within 8 inches (200 mm) of the bottom of the girders of the railway bridge. The force of floodwaters on 29th March tore trees and logs from the Gorge and carried them downstream, where they were trapped by paperbark trees in the main channel, creating a natural ‘dam’. When this dam breached, floodwaters in Katherine rose 20 feet (6.1 m) in 15 minutes. There was 1 m of water through Rundles Store and 0.5 m through O’Shea’s Hotel.

January 1940
Similar to 1931 Flood. On 12th January, the water was 4 inches (100 mm) below the record level of 1931. On 16th January, it was 5 inches (125 mm) above the 1931 level, i.e. within 3 inches (75 mm) of the bottom of the railway bridge girders.

Table 8.4 Details of Major Floods, Katherine, 1872 - 1952

<table>
<thead>
<tr>
<th>Date</th>
<th>Peak Flood Level at Railway Bridge</th>
<th>Peak Flood Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ogden (1994) (m AHD) (m GH)</td>
<td>Adopted (m GH)</td>
</tr>
<tr>
<td>Dec 1897</td>
<td>356.0 105.73</td>
<td>105.73 19.36</td>
</tr>
<tr>
<td>Jan 1914</td>
<td>353.4 104.94</td>
<td>104.94 18.57</td>
</tr>
<tr>
<td>Apr 1931</td>
<td>354.9 105.40</td>
<td>105.63 19.27</td>
</tr>
<tr>
<td>Jan 1940</td>
<td>355.6 105.61</td>
<td>105.76 19.40</td>
</tr>
</tbody>
</table>

- *a* m AHD = m DTD - 2.775
- *b* According to Newspaper Reports (Ogden, 1994), the flood peaked on 29th March
- *c* Based on Watson et al peak levels
- *d* Based on adopted peak levels

8.4c 1897 and 1914 Flood Levels

8.23 The accuracy of peak levels for the 1897 and 1914 Floods, as shown in Table 8.4, is unknown. Neither the railway embankment nor bridge were in place for these floods.

- The 1897 flood level (356 ft DTD) quoted by Watson et al is the value that occurred in the absence of the railway embankment and bridge.

- It is not clear whether the 1914 flood level (353.4 ft DTD) reflects the presence or absence of the embankment and bridge.

The peak flood levels attributed to these events (and the associated peak discharges) are regarded as approximate only. For this reason no adjustment was made to these values to correct for the presence or absence of the railway bridge.
8.4d 1931 And 1940 Flood Levels

8.24 For the 1931 and 1940 Floods, Ogden (1994) cites specific (newspaper) references to peak flood levels in relation to the railway bridge girders (see paragraph 4.04). The lower edge of the bridge girders has an RL of 105.83 m AHD (SMEC, 1984). Thus, on the basis of the newspaper reports cited by Ogden (1994):

- The 1931 Flood had a peak level some 8 inches below the girder (i.e. 105.63 m AHD), and
- The 1940 Flood had a peak level some 3 inches below the girder (i.e. 105.76 m AHD).

The levels for the 1931 and 1940 Floods reported by Watson et al are respectively 0.23 m and 0.15 m below these estimates (see Table 4.1). Details of the source of Watson's data are not known. In view of the definite estimates of the newspaper reports, and the fact that they are slightly higher than Watson's estimates, the newspaper estimates have been adopted.

8.25 The levels given above for the 1931 and 1940 floods are likely to have been observed from upstream of the railway bridge. However, the automatic stream gauge at which levels have been recorded since 1962 is located about 30 m downstream of the railway bridge. Hence, the peak levels for the 1931 and 1940 floods were reduced to account for the different recording locations. Based on the results of a steady flow hydraulic model (HEC-RAS) of a short reach of the river, the estimated difference in flood level between the automatic stream gauge location and immediately upstream of the railway bridge during a major flood is about 0.05 m. Hence, the estimated discharges for flood frequency analysis were based on flood levels of 105.58 m AHD (19.22 m GH) for the 1931 flood and 105.71 m AHD (19.35 m GH) for the 1940 flood.

8.4e Peak Flood Discharges

8.26 Table 8.4 also shows the estimated peak discharges for the four flood events, as presented by Watson et al (1970), Barlow (1985) and on the basis of the current rating curve. The values from the current rating curve were adopted for the flood frequency analysis.

8.5 FLOOD FREQUENCY ANALYSES

8.27 The standard method of frequency analysis, as described in Chapter 8 of ARR (1987), was used to estimate flood discharges for various recurrence intervals in the Katherine River at the Railway Bridge.

8.28 Annual flood data are available for both a 'Recorded Period' of 1953 - 1998 (46 values) and an 'Historical Period' of 1897 - 1998 (102 years), which contains an additional four flood peaks (1897, 1914, 1931 and 1940).

8.29 On the basis of the statistics of the Log10 values of flood peaks in the Record Period (see Table 8.5), low and high outlier discharges were calculated. These values were respectively 10,780 m$^3$/s and 93 m$^3$/s. All 50 peak annual values in the Historical Period fell within these two limits, and so it was not necessary to omit outliers from the sample of flood peaks.

8.30 Next, the 4 historical flood peaks were incorporated in the frequency analysis and revised plotting positions calculated. The cumulative distribution of the resulting flood peaks is shown in Figure 8.1.

8.31 Finally, the revised statistics of the flood peaks were calculated. These results are shown in Table 8.6 and were used to estimate peak flood discharges for standard recurrence interval events (see Table 8.7) based on the fitted Log-Pearson Type III (LPIII) distribution.
### Table 8.5  Statistics of Annual Flood Peaks, Katherine River at Railway Bridge, 1953 to 1998

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arithmetic</strong></td>
<td></td>
</tr>
<tr>
<td>Mean (m$^3$/s)</td>
<td>1,337</td>
</tr>
<tr>
<td>Standard Deviation (m$^3$/s)</td>
<td>1,490</td>
</tr>
<tr>
<td>Coefficient of Skew</td>
<td>3.896</td>
</tr>
<tr>
<td>No. of Values</td>
<td>46</td>
</tr>
<tr>
<td><strong>Log 10</strong></td>
<td></td>
</tr>
<tr>
<td>Mean (m$^3$/s)</td>
<td>2.970</td>
</tr>
<tr>
<td>Standard Deviation (m$^3$/s)</td>
<td>0.365</td>
</tr>
<tr>
<td>Coefficient of Skew</td>
<td>0.085</td>
</tr>
<tr>
<td>No. of Values</td>
<td>46</td>
</tr>
</tbody>
</table>

### Table 8.6  Statistics of Annual Flood Peaks, Katherine River at Katherine, 1897 - 1998

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Log 10</strong></td>
<td></td>
</tr>
<tr>
<td>Mean (m$^3$/s)</td>
<td>2.996</td>
</tr>
<tr>
<td>Standard Deviation (m$^3$/s)</td>
<td>0.379</td>
</tr>
<tr>
<td>Coefficient of Skew</td>
<td>0.086</td>
</tr>
<tr>
<td>No. of Values</td>
<td>50</td>
</tr>
</tbody>
</table>

### Table 8.7  Peak Flood Discharge Estimates, Katherine River at Railway Bridge

<table>
<thead>
<tr>
<th>ARI</th>
<th>Peak Discharge (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>980</td>
</tr>
<tr>
<td>5</td>
<td>2,060</td>
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<tr>
<td>10</td>
<td>3,060</td>
</tr>
<tr>
<td>20</td>
<td>4,260</td>
</tr>
<tr>
<td>50</td>
<td>6,210</td>
</tr>
<tr>
<td>100</td>
<td>8,000</td>
</tr>
<tr>
<td>200</td>
<td>10,100</td>
</tr>
<tr>
<td>500</td>
<td>13,430</td>
</tr>
</tbody>
</table>
Figure 8.1   Distribution of Peak Annual Flows, Katherine River at Railway Bridge
8.6 **ARI OF THE 1957 AND 1998 FLOODS**

8.32 On the basis of the results of Table 8.7, the estimated ARI of the January 1998 flood is about **155 years**. The estimated ARI of the 1957 flood is about **25 years**.

8.7 **PALAEOHYDROLOGY**

8.33 A number of palaeohydrologic investigations of sediment deposits in the Katherine Gorge have been undertaken by Baker and others (undated, 1985, 1987). The most recent study of Katherine River geomorphology undertaken by the Geography Department of the University of Western Australia (Sandercock, 1998) indicates that:

- There is evidence of at least two flood events of comparable magnitude to the January 1998 flood occurring within the past 600 years, and
- There are other sediments which indicate that a flood of approximately twice the magnitude of the January 1998 event has occurred.

8.34 Based on the results of flood frequency analysis, it would be expected that on average, about three or four floods of similar magnitude to January 1998 would occur in a 600 year period. This is supported by the results of the palaeohydrology study.

8.35 A flood of twice the magnitude of the January 1998 event would have a peak discharge of some 19,000 m$^3$/s. The expected ARI of such a flood, based on flood frequency analysis, is of the order of 1000 to 2000 years.

8.36 On this basis, the findings of the palaeohydrology study are generally consistent with the results of the flood frequency analysis.
9 DESIGN FLOOD ESTIMATION

9.1 METHODOLOGY

9.01 The calibrated URBS model was used to estimate design flood discharges throughout the Katherine River catchment based on design rainfall intensity - frequency - duration data from ARR (1987). Design flood discharge hydrographs were estimated for a range of storm durations up to 72 hours for the 2, 5, 10, 20, 50 and 100 year Average Recurrence Interval (ARI) events and for the Probable Maximum Precipitation (PMP) event. The calibrated CELLFLOW hydraulic model was then used to rout these hydrographs along the river and floodplain downstream of Katherine Gorge to estimate design flood discharges and flood levels along the modelled reach of the river.

9.2 DESIGN RAINFALLS

9.02 Design rainfall intensities and temporal patterns for storms of various durations up to 100 years ARI were obtained from ARR (1987). Estimation of the Probable Maximum Flood (PMF) using PMP rainfalls is discussed in Section 9.5.

9.03 Given the large size of the Katherine River catchment an estimate of design rainfalls was made at two locations within the catchment to assess the spatial variability of design rainfall across the catchment. Design rainfalls were estimated at Katherine Gorge (representative of the lower catchment) and Mt Evelyn (representative of the upper catchment). The estimated rainfalls at both these locations were found to be in close agreement (differences of generally less than 2%). On this basis, estimated design rainfalls at Katherine Gorge were adopted for the entire river catchment. Adopted design rainfall intensities for storms of various duration and severity are given in Table 9.1. Note that an areal reduction factor of 1.0 was adopted for all design events up to 100 years ARI.

<table>
<thead>
<tr>
<th>Storm Duration (Hrs)</th>
<th>2 Year ARI</th>
<th>5 Year ARI</th>
<th>10 Year ARI</th>
<th>20 Year ARI</th>
<th>50 Year ARI</th>
<th>100 Year ARI</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>12.60</td>
<td>15.80</td>
<td>17.59</td>
<td>20.17</td>
<td>23.64</td>
<td>26.35</td>
</tr>
<tr>
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<td>7.40</td>
<td>9.33</td>
<td>10.42</td>
<td>11.98</td>
<td>14.08</td>
<td>15.72</td>
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<td>5.70</td>
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<td>4.72</td>
<td>6.09</td>
<td>6.89</td>
<td>8.01</td>
<td>9.53</td>
<td>10.74</td>
</tr>
<tr>
<td>36</td>
<td>3.60</td>
<td>4.71</td>
<td>5.36</td>
<td>6.27</td>
<td>7.52</td>
<td>8.52</td>
</tr>
<tr>
<td>48</td>
<td>2.94</td>
<td>3.89</td>
<td>4.45</td>
<td>5.23</td>
<td>6.31</td>
<td>7.17</td>
</tr>
<tr>
<td>60</td>
<td>2.49</td>
<td>3.32</td>
<td>3.83</td>
<td>4.52</td>
<td>5.47</td>
<td>6.24</td>
</tr>
<tr>
<td>72</td>
<td>2.17</td>
<td>2.91</td>
<td>3.36</td>
<td>3.98</td>
<td>4.84</td>
<td>5.53</td>
</tr>
</tbody>
</table>
9.3 RAINFALL LOSSES

9.04 Design flood discharges were initially estimated using the calibrated URBS model parameters for continuing loss with an initial loss of zero for all events. However, it was found that this over-estimated peak flood discharges for smaller design floods compared to the results of the flood frequency analysis. On this basis, an initial loss which varied with event severity was adopted to produce peak design discharges consistent with flood frequency analysis. Adopted initial losses for the various design events are given in Table 9.2.

<table>
<thead>
<tr>
<th>Event ARI (Years)</th>
<th>Adopted Initial Loss (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9.2 Adopted Initial Losses for Design Flood Estimation, Katherine River Catchment

9.4 DESIGN DISCHARGES

9.05 Table 9.3 shows estimated design flood discharges at the Railway Bridge from the URBS model and from the results of the flood frequency analysis. The critical duration storm event producing the highest peak discharge at the railway bridge for all ARI’s was 72 hours.

<table>
<thead>
<tr>
<th>Event ARI (Years)</th>
<th>Peak Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>URBS</td>
</tr>
<tr>
<td>2</td>
<td>990</td>
</tr>
<tr>
<td>5</td>
<td>2,120</td>
</tr>
<tr>
<td>10</td>
<td>3,080</td>
</tr>
<tr>
<td>20</td>
<td>4,220</td>
</tr>
<tr>
<td>50</td>
<td>6,200</td>
</tr>
<tr>
<td>100</td>
<td>7,950</td>
</tr>
</tbody>
</table>

Table 9.3 Comparison of Estimated Design Flood Discharges from URBS Model and Flood Frequency Analysis, Katherine River at Railway Bridge

9.5 ESTIMATION OF PMF DISCHARGES

9.06 Estimates of Probable Maximum Precipitation (PMP) for the Katherine River catchment, based on the Generalised Tropical Storm Method (GTSM), were completed by the Bureau of Meteorology in May 1998 (BoM, 1998). A copy of the Bureau of Meteorology Report is given in Appendix K. The calibrated URBS model was used to obtain an estimate of the Probable Maximum Flood (PMF) based on PMP rainfalls.

9.07 Table 9.4 shows PMP rainfall depths for the Katherine River catchment. The 72 hour PMP rainfall is 880 mm, which is more than double the 100 year ARI 72 hour rainfall of about 400 mm.
### Table 9.4  PMP Rainfalls for the Katherine River Catchment to Katherine

<table>
<thead>
<tr>
<th>Event Duration (Hours)</th>
<th>PMP Rainfall Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>260</td>
</tr>
<tr>
<td>12</td>
<td>490</td>
</tr>
<tr>
<td>18</td>
<td>630</td>
</tr>
<tr>
<td>24</td>
<td>700</td>
</tr>
<tr>
<td>36</td>
<td>770</td>
</tr>
<tr>
<td>48</td>
<td>810</td>
</tr>
<tr>
<td>60</td>
<td>850</td>
</tr>
<tr>
<td>72</td>
<td>880</td>
</tr>
</tbody>
</table>

#### 9.08
For the estimation of PMF discharges the spatial distribution of PMP rainfall across the catchment was determined in accordance with the methodology outlined in Section 3.3 of the Bureau of Meteorology Report (BoM, 1998). The adopted PMP rainfall for each of the 86 URBS model subcatchments for various storm durations is given in Appendix J. The adopted temporal distribution of rainfall was also taken from the Bureau of Meteorology Report (BoM, 1998). Rainfall losses identical to those used in the estimation of 100 year ARI discharges were adopted for estimates of the PMF.

#### 9.09
The results of the URBS model indicate a PMF discharge at the Railway Bridge of some 27,000 m$^3$/s, more than three times the estimated 100 year ARI discharge. The critical storm duration for PMF discharges was found to be 36 hours; half the critical duration for the 100 year ARI event.

### 9.6 DESIGN FLOOD LEVELS

#### 9.10
The calibrated CELLFLOW hydraulic model was used to estimate design flood levels downstream of Katherine Gorge for the 20 year, 50 year, 100 year ARI events and the PMF based on flood discharge hydrographs from the URBS model. Estimated design flood levels for these four events at each of the 312 CELLFLOW model nodes are given in Appendix L. Estimated design flood levels and corresponding gauge heights at the railway bridge gauge (located immediately downstream of the railway bridge) are given in Table 9.5.

#### Table 9.5  Estimated Design Flood Levels and Gauge Heights, Katherine River at Railway Bridge

<table>
<thead>
<tr>
<th>Event</th>
<th>Peak Flood Level (m AHD)</th>
<th>Peak Flood Level (m GH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Year ARI</td>
<td>105.23</td>
<td>18.87</td>
</tr>
<tr>
<td>50 Year ARI</td>
<td>105.96</td>
<td>19.60</td>
</tr>
<tr>
<td>100 Year ARI</td>
<td>106.34</td>
<td>19.98</td>
</tr>
<tr>
<td>PMF</td>
<td>109.48</td>
<td>23.12</td>
</tr>
</tbody>
</table>

### 9.7 FLOOD MAPPING

#### 9.7a  Estimation of Flood Extent

#### 9.11
To obtain an extent of flooding map based on a DEM, it is first necessary to derive a mathematical flood surface which is essentially a DEM of the flood surface, assuming peak flood levels are achieved simultaneously at all locations. The extent of flooding is then the line along which the flood surface and ground surface intersect.
9.12 The 'ILWIS' GIS package and the 'SURFER' surface interpolation program were used to derive a continuous flood surface for the CELLFLOW model area based on the predicted peak level at model nodes. After trialing a number of methods, the 'minimum curvature' interpolation technique was used to derive the flood surface. This method was found to produce the most realistic flood surface, however it was necessary to manually insert a significant number of flood level points in addition to the CELLFLOW model nodes to avoid inappropriate interpolation of the flood surface between areas which were not hydraulically connected.

9.13 The maximum discrepancy between the flood levels at model nodes and the flood levels from the mathematical surface is 0.01 m. Between model nodes (especially where node spacing is large) and at the limit of the flood extent, the discrepancy between the mathematical flood surface and a manual interpolation of flood levels is significantly greater than this (probably up to 0.5 m or more) at some locations. However, within the urban area of Katherine the expected maximum value of this discrepancy is of the order of 0.05 m increasing to 0.1 m to 0.2 m near the limits of the flood extent.

9.7b January 1998 and Design Flood Maps

9.14 Flood maps showing the depth and extent of flooding across the modelled area of the Katherine River floodplain were prepared for the 20, 50 and 100 year ARI design flood events, the PMF and the January 1998 flood. These maps show the depth of flooding in four ranges: 0 m to 0.5 m depth; 0.5 m to 1.2 m depth; 1.2 m to 2.0 m depth; and greater than 2.0 m depth. These maps also show flood level contours at an interval of 0.25 m.

9.15 Digital and hard copies of the maps were provided to DLPE. Abbreviated versions of the maps showing the extent of flooding for the 100 year ARI event, the January 1998 flood and the PMF are shown in Figures 9.1, 9.2 and 9.3 respectively.

9.7c Emergency Services Maps

9.16 To assist with flood emergency planning in Katherine, a series of 8 flood emergency maps was prepared. These maps show the depth and extent of flooding in and around Katherine when the river has reached the following levels at the Railway Bridge: 17.5 m GH; 18.0 m GH; 18.5 m GH; 19.0 m GH; 19.5 m GH; 20.0 m GH; 21.5 m GH; and 23.12 m GH.

9.17 Note that 23.12 m GH is the PMF height at the Railway Bridge. The maps for gauge heights up to 20.0 m GH were produced for the rising limb of the 100 year ARI design event. The remaining two maps were produced for the PMF event.

9.18 The emergency services maps are intended to provide a general indication only of flooding behaviour and should be used with caution. The extent and depth of flooding in and around Katherine will vary considerably during different flood events depending on the rate of rise of the flood hydrograph and the relative contribution from various tributaries, especially Tindal Creek.

9.8 PROPOSED ROAD AND RAILWAY CROSSINGS

9.19 The proposed Darwin and Alice Springs Railway and a revised alignment for the Stuart Highway will cross the Katherine River floodplain about 2.4 km downstream of the low-level crossing. The impacts of the proposed crossings on flooding behaviour across the Katherine River floodplain were considered as part of a separate investigation by Water Studies in December 1999 ('Impact of Proposed Katherine River Crossings on Upstream Flood Levels', DLPE Report No. 12/99D). The results of that investigation indicate that the proposed road and rail crossings will increase flood levels within the urban area of Katherine by about 0.02 m to 0.12 m, depending on the adopted configuration of the crossings. Note that the impact of these crossings has not been included in the design flood levels given in this report or the associated flood mapping.
Figure 9.3  Extent of Flooding, PMF
10 FLOOD FORECASTING MODEL

10.1 ADOPTED MODEL

10.01 The objective of the calibrated URBS and CELLFLOW models was to reproduce, as accurately as possible, observed flooding behaviour within the area of interest over the full range of flow conditions. However, for the purposes of flood forecasting in Katherine, the main objective is to accurately predict the height and timing of the flood peak at the Katherine Railway Bridge. It is desirable to keep the flood forecasting model as simple as possible with respect to the number of parameters that have to be assigned values. In addition, the model should be easy to set up and run in real-time during flood conditions. For these reasons a modified simpler version of the URBS model was developed for flood forecasting along the Katherine River, without compromising the accuracy of forecasts at the Railway Bridge.

10.02 The possibility of incorporating the CELLFLOW hydraulic model in the flood forecasting system was investigated. However, it was found that due to the size and complexity of the CELLFLOW model its useability in a real-time flood forecasting situation would be limited. The CELLFLOW model is capable of being run in a flood-forecasting mode, however the run time for an extended event could be up to several hours. Given that real-time flood forecasting generally relies on the results of numerous runs with various forecast rainfalls, the use of the CELLFLOW model is likely to be impractical.

10.2 ADOPTED MODEL PARAMETERS

10.03 The adopted model parameters for the flood forecasting model are similar to those adopted in the calibrated URBS model used in design flood estimation with the following exceptions:

- An infinite infiltration capacity (IF) has been adopted in the flood forecasting model for all regions.

- A single value of initial and continuing loss has been adopted for the entire flood forecasting model (i.e. entire catchment).

With the above modifications the flood forecasting model has only four parameters which need to be adjusted during a real-time flood event. These parameters, their recommended initial values and their likely range of values are given in Table 10.1.

Table 10.1 Flood Forecasting Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Recommended Initial Value</th>
<th>Units</th>
<th>Likely Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha ($\alpha$)</td>
<td>0.55</td>
<td>None</td>
<td>0.50 to 0.65</td>
</tr>
<tr>
<td>Beta ($\beta$)</td>
<td>2.5</td>
<td>None</td>
<td>2.0 to 2.5</td>
</tr>
<tr>
<td>Initial Loss (IL)</td>
<td>30 mm</td>
<td></td>
<td>0 to 100</td>
</tr>
<tr>
<td>Continuing Loss (CL)</td>
<td>1.5 mmy/hr</td>
<td></td>
<td>0.5 to 4.5</td>
</tr>
</tbody>
</table>
10.3 FLOOD FORECASTING MODEL RESULTS

10.04 The parameter values given in Table 10.1 were derived by applying the flood forecasting model to the five flood events used in the URBS model calibration. The model parameters were then varied to obtain the best estimate of the magnitude and timing of the flood peak at the Railway Bridge. The adopted model parameters for each of the five flood events are shown in Table 10.2. Note that no matching of upstream hydrographs was used to derive the flood forecasting model results shown in Table 10.2. (In real time, recorded hydrographs from upstream gauging stations would be used to improve the prediction of flood peaks).

Table 10.2 Flood Forecasting Model Results for Calibration Events

<table>
<thead>
<tr>
<th>Event</th>
<th>Recorded tp&lt;sup&gt;a&lt;/sup&gt; (hrs)</th>
<th>Recorded Peak WL (m GH)</th>
<th>Calibrated URBS Model tp&lt;sup&gt;a&lt;/sup&gt; (hrs)</th>
<th>Calibrated Peak WL (m GH)</th>
<th>Flood Forecasting Model tp&lt;sup&gt;a&lt;/sup&gt; (hrs)</th>
<th>Flood Forecasting Peak WL (m GH)</th>
<th>Adopted Flood Forecasting Model Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>165</td>
<td>17.39</td>
<td>160</td>
<td>17.72</td>
<td>166</td>
<td>17.45</td>
<td>0.65 2.5 30 2.0</td>
</tr>
<tr>
<td>1987</td>
<td>435</td>
<td>16.97</td>
<td>430</td>
<td>18.76</td>
<td>430</td>
<td>16.98</td>
<td>0.60 2.5 30 2.7</td>
</tr>
<tr>
<td>1991</td>
<td>194</td>
<td>14.03</td>
<td>232</td>
<td>14.11</td>
<td>230</td>
<td>14.14</td>
<td>0.50 2.5 30 1.2</td>
</tr>
<tr>
<td>1995</td>
<td>55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.48</td>
<td>110</td>
<td>16.20</td>
<td>66</td>
<td>15.43</td>
<td>0.63 2.0 30 4.5</td>
</tr>
<tr>
<td>1998</td>
<td>81</td>
<td>20.38</td>
<td>82</td>
<td>20.25</td>
<td>81</td>
<td>20.33</td>
<td>0.55 2.5 30 0.5</td>
</tr>
</tbody>
</table>

<sup>a</sup> Time to peak from adopted start of event
<sup>b</sup> Secondary peak of 15.37 m GH at 116 hours

10.05 Table 10.2 shows the recorded time to peak (from the adopted start of each event) and recorded peak gauge height for each event, together with predicted values from:

- the calibrated URBS model used for design flood estimation, and
- the flood forecasting model.

10.06 The adopted flood forecasting model parameters to obtain the tabulated results are also shown. For all events the flood forecasting model gives a better prediction of the time-to-peak and the peak gauge height than the calibrated model. Note however, that the calibrated model provides a better overall description of the hydrograph shape than the flood forecasting model, which is focussed on predicting peaks only. Note also that the predicted peaks from the flood forecasting model were relatively insensitive to the adopted initial loss. Hence, the adopted 'default' value of 30 mm was used for all five events.

10.4 SENSITIVITY ANALYSES

10.07 Table 10.3 shows the results of sensitivity analyses undertaken to demonstrate the impact of the four variable parameters on predicted time-to-peak and peak flood level. Note that the sensitivity analyses have been undertaken for the 1984 and 1998 events only as the recorded and predicted hydrographs for these events are in reasonably close agreement compared to the other three calibration events.

10.08 The results of Table 10.3 indicate that the sensitivity of model results to the various parameters depends on the individual event. Note that only one parameter was changed for each of the sensitivity runs. The remaining 3 parameters were fixed at their default values. Varying α over the range of expected values (0.5 to 0.65) changes the time to peak by 17 hours and the peak height by 0.8 m for the 1984 event. For the 1998 event the same variation in α changes the time to peak by only 7 hours and the peak height by only 0.4 m.
Table 10.3  Sensitivity Analyses, Katherine River Flood Forecasting Model

| Event   | Change in Predicted Time to Peak (Hours) and Peak Water Level (m) |  
|---------|-------------------------------------------------------------------|---|
|         | $a = 0.5$  | $a = 0.55$  | $a = 0.60$  | $a = 0.65$  | $b = 2.0$  | $b = 2.5$  | $IL = 0$  | $IL = 30$  | $IL = 60$  | $CL = 0.5$  | $CL = 1.5$  | $CL = 3.0$  |
| March 1984 tp = 165 hrs | -15  | -8  | -3  | +2  | -11  | -8  | -11  | -8  | -3  | -13  | -8  | -8  |
|         | Peak WL = 17.39 m GH | +1.18  | +0.95  | +0.66  | +0.38  | +1.04  | +0.95  | +1.08  | +0.95  | +0.11  | +1.42  | +0.95  | -0.01  |
| Jan 1998 tp = 81 hrs | -2  | 0  | +3  | +5  | -1  | 0  | -1  | 0  | +2  | 0  | 0  | +2  |
|         | Peak WL = 20.38 m GH | -0.17  | -0.31  | -0.45  | -0.58  | -0.23  | -0.31  | -0.18  | -0.31  | -0.54  | -0.05  | -0.31  | -0.67  |

Default Parameters: $a = 0.55$, $b = 2.5$, $IL = 30$, $CL = 1.5$
10.09 The results of Table 10.3 indicate that:

- The model results may be sensitive to the adopted $\alpha$ value depending on the individual flood event.
- The model results are relatively insensitive to the adopted $\beta$ value.
- The model results may be sensitive to initial loss (during a real-time event initial loss would normally be selected to match the rising limb of recorded hydrographs).
- The model results are sensitive to adopted continuing loss values.
CONCLUSIONS

11.01 The Katherine River flood of January 1998 was the largest on record. The estimated peak flood discharge at the railway bridge crossing for this event is 9,400 m$^3$/s. Based on a flood frequency analysis of historical data dating back to 1897, the estimated Average Recurrence Interval (ARI) of the January 1998 flood is 155 years. The estimated ARI of the 1957 flood is 25 years.

11.02 An 'URBS' runoff-routing model of the entire Katherine River catchment to Vampire Creek has been developed and calibrated to recorded flood data at 7 stream gauging stations. The model consists of 86 sub-catchments.

11.03 The URBS model was calibrated against five historical flood events:

- March 1984
- February 1987
- February 1991
- January 1995
- January 1998

In general terms the calibration of the URBS model is considered to be reasonable. However, calibration of the model was hampered by:

- Missing data,
- The sparseness of recorded rainfall and streamflow data, and
- Uncertainties in the rating curve at the Gorge Caravan Park associated with the interaction of floodwaters from the Main Channel and Seventeen Mile Creek.

11.04 A flood forecasting model, based on the calibrated URBS model, has been developed for use in real-time flood forecasting.

11.05 A'CELLFLOW' hydraulic model of the Katherine River floodplain from Katherine Gorge to Vampire Creek has been developed and calibrated to recorded flood data for the five historical flood events adopted in the URBS model calibration. Note that the January 1998 flood was the only one of the calibration events which flooded the town. For this reason, the available flood data for the January 1998 flood vastly exceeded that for the other calibration floods. Hence, the focus of the model calibration was to reproduce observed flooding behaviour for the January 1998 event. The calibrated hydraulic model generally predicted flood levels within the Katherine urban area to within about 0.2 m of levels recorded during the January 1998 flood.

11.06 The calibrated hydrologic and hydraulic models were used to estimate design flood discharges and flood levels in the area of interest. Design flood discharges were matched to the results of the flood frequency analysis. Based on the model results, flood maps showing the extent of flooding across the hydraulic model area have been prepared for the 100 year ARI, January 1998 and Probable Maximum Flood (PMF) events. The estimated 100 year ARI flood discharge at the railway bridge is 7,950 m$^3$/s. The estimated flood level at the railway bridge stream gauge for this event is 106.34 m AHD (19.98 m GH) - approximately 0.4 m lower than the January 1998 flood level. PMF flood levels are more than 3 m higher than 100 year ARI flood levels.
REFERENCES


Baker, V.R., Pickup, G. & Webb, R.H. (Undated) 'Palaeoflood Hydrologic Analysis at Ungauged Sites, Central and Northern Australia'.


