Regional Floodplain Database:

Design Rainfall

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Regional Floodplain Database

Design Rainfall - Burpengary Pilot Project

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MORETON BAY REGIONAL COUNCIL
REGIONAL FLOODPLAIN DATABASE
DESIGN RAINFALL - BURPENGARY PILOT PROJECT

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PROJECT 301018/00042 - REGIONAL FLOODPLAIN DATABASE

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1. INTRODUCTION

WorleyParsons Services Pty Ltd (WorleyParsons) has been commissioned by Moreton Bay Regional Council (MBRC) to carry out an investigation into design rainfall as part of Council's Regional Floodplain Database Project (RFD Project).

The RFD Project involves a three year (three stage) program for the development of comprehensive flood mapping across the Moreton Bay Regional Council Local Government Area. A key focus for the project is the standardisation of methods and procedures so as to ensure consistency in the flood information produced. The Burpengary 'Minor Basin', incorporating Burpengary Creek, Little Burpengary Creek and Deception Bay has been selected as the Stage 1 pilot study catchment for development of these standardised methods and procedures.

This report documents the development of standard design rainfall procedures for the Burpengary Minor Basin. Following test application Council will consider extension of the procedures documented herein for Stage 2 of the project which will include detailed flood modelling and mapping for the region.

1.1 Scope

This investigation is focussed on the Burpengary Creek catchment which is referred to in the RFD project as catchment 'BUR'. Design rainfall techniques developed for this project will be applied to the BUR catchment detailed modelling pilot study. If successful in the pilot study, it is anticipated that these design rainfall techniques will eventually be applied over the remaining regional catchments in the LGA. Consequently it has been necessary to consider how the design rainfall techniques developed for the pilot study will transfer to these other catchments.

The investigation covers the key areas associated with design rainfall including:

- Calculation of average design point rainfall intensities
- Temporal patterns
- Rare and extreme rainfall events
- Spatial distribution of rainfall over a catchment
- Ground infiltration rainfall losses
- Aerial Reduction Factors (ARFs)
- Development of a single MBRC 'Design Storm' which is able to provide a reasonable representation of peak flood levels over the full regional catchment.

In addition to carrying out an investigation into the topics listed above, the scope of works for this sub-project also includes generating a complete set of WBNM 'STORM_BLOCKS' for the full range of BUR catchment design rainfall events.

These storm blocks will be incorporated into a WBNM model setup as part of other RFD sub-projects. A complete set of WBNM run files and result files will then be generated.

Result files will be converted into the TUFLOW TS1 format for incorporation into the BUR catchment hydraulic TUFLOW modelling.

Hydrologic modelling and generation of inflow hydrographs for the BUR catchment TUFLOW model has been carried out for the following events:

- 2, 5, 10, 20, 50 and 100 year Average Recurrence Interval (ARI) events for all standard ARR design event durations ranging from 5 minutes to 72 hours.
- 200, 500, 1000, 2000 year ARI and the PMP for all the standard extreme event durations ranging from 15 minutes to 5 days.

It is noted that not all the above events are likely to be modelled in the hydraulic TUFLOW model due to the length of time it would take to complete the simulations.

1.2 Objectives

The overall objective of this investigation is to develop the most suitable approach to design rainfall and infiltration losses for applying to the RFD Project.

This investigation reviews the options currently available for each element of design rainfall, with the objective of determining the most suitable methodology. The key criteria considered during the investigation are as follows:

- Adopted methodology needs to be defendable.
- Techniques applied to the BUR catchment pilot study need to readily translate to the other LGA regional catchments.
- Where uncertainty exists, a reasonable level of conservatism is acceptable. Non-conservative results are not.

A complete set of WBNM run files and results files will be generated for each rainfall event using a base WBNM model setup as part of other RFD sub projects. The complete set of WBNM results files will be converted to a format suitable for incorporating directly into the RFD pilot project's detailed BUR catchment hydraulic TUFLOW model.

1.3 General Approach

The general approach to this investigation is to assess the options available for each element of design rainfall. In some instances this may involve developing customised techniques to suit the specific requirements of the RFD Project. Based on this a design rainfall methodology most suited to the RFD project will be adopted based on the criteria listed in the above section. The adopted methodology will be chosen in consultation with the Study Advisory Group (SAG).

A preference will be given to adhering to the 1987 Australian Rainfall and Runoff (ARR87) methodology where appropriate, as this is widely adopted in the industry and is therefore considered a very defendable approach. Unfortunately this document is quite out of date in many areas and is currently undergoing a major update. Therefore this investigation will consider whether the ARR87 techniques are actually the most suited to this project.

It is accepted that the guidelines may change with the release of the updated ARR however in the interim an approach needs to be adopted which is defendable.

Preliminary hydrologic and hydraulic modelling will be carried out as necessary to test the sensitivity of the various options available for each element of design rainfall.

The design rainfall techniques adopted will be applied to the BUR catchment detailed modelling pilot study with the intent of eventually rolling these out to all regional catchments if the methodology proves successful.

1.4 Related Sub-Projects

The sub-project most related to this design rainfall investigation is the ‘Hydrography’ sub-project that is being carried out by MBRC. The hydrography sub-project involved defining the catchment and streams over which the design rainfall will be applied. This includes developing the base WBNM model into which the design rainfall will be incorporated.

Output from this design rainfall sub-project (inflow hydrograph TS1 files) will be used for the detailed BUR catchment modelling pilot study sub-project.

2. AVAILABLE INFORMATION

The following information and documented rainfall analysis techniques are available and have been considered in this investigation.

Table 2.0 - Point Rainfall Intensities, Available Information

Data Source	Comment
Australian Rainfall and Runoff (IEAust 1987) IFD Maps	• Wide industry adoption • Available from BoM website • Does not utilise rainfall data over the last quarter century.
QLD CRCForge Method	• Uses more recent rainfall data than the 1987 ARR. • Primarily developed for developing rare event rainfall intensities (ARI greater than 100 years and up to 2000 years)
BoM Rainfall Gauges	• Rainfall data is still being collected around Australia. This is able to be used to carry out an up to date statistical assessment of rainfall intensities using the maximum record available.

Table 2.1 - Temporal Patterns, Available Information

Data Source	Comment
Australian Rainfall and Runoff (IEAust 1987)	• Wide industry adoption • Some concern that these patterns do not incorporate enough lead up rainfall prior to the peak intensities.
Gold Coast City Council	• GCCC has developed design rainfall temporal patterns based on analysis of rainfall in the region. • Generally produce higher peak flow rates than ARR87.
BoM Rainfall Gauges	• A customised analysis of historic storm events could be undertaken based on BoM rainfall gauges.
BoM's two PMP publications (GSDM and GTSMR)	• Detail temporal patterns for the PMP event.

Table 2.2 - Rare and Extreme Events, Available Information

Data Source	Comment
BoM's June 2003 "The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"	• PMP rainfall intensities up to 6 hours in duration • Includes point and aerial intensities.
BoM's June 2003 "Guidebook To The Estimation Of Probable Maximum Precipitation: Generalised Tropical Storm Method"	• PMP rainfall intensities for events ranging from 24 to 120 hours. • Includes aerial intensities for catchments ranging from 1 km^2 up to 150,000km^2.
QLD CRCForge Method	• Primarily developed for developing rare event rainfall intensities (greater than 100 years ARI). • No temporal patterns described.

Table 2.3 - Ground Infiltration Losses, Available Information

Data Source	Comment
Australian Rainfall and Runoff (IEAust 1987)	• Provides some guidance on suitable loss parameters based on previous calibrated studies throughout Queensland
Previous Calibrated Flood Studies carried out in the LGA	• 11 separate studies have been provided by MBRC.

Table 2.4 - Aerial Reduction Factors, Available Information

Data Source	Comment
Australian Rainfall and Runoff (IEAust 1987) (Book 2 and Book 6)	• Two sets of Aerial Reduction Factor (ARF) Curves provided. • Developed using Victorian and American rainfall data
QLD CRCForge Method	• Derived using QLD data

Table 2.5 - MBRC Design Storm Options

Data Source	Comment
Embedded Design Storms	• Described in the WBNM user manual
Duration Independent Storm	• Adopted by neighbouring local governments
Historic events rainfall data within the LGA (May 2009)	• Wide variance of temporal patterns across the catchments.

3. METHODOLOGY

The general methodology for this investigation is as follows:

1. Review available options for each element of the design rainfall procedures
2. Where necessary consider developing customised methods to better suit the project.
3. Carry out preliminary modelling where necessary to test the sensitivity of the various options. This includes testing preliminary results against recorded levels throughout the catchment using flood level rating curves developed using a preliminary BUR catchment 2d hydraulic model.
4. Check the suitability of adopting the standard ARR87 procedures. Unless this approach is shown to produce significant errors in modelling results (particularly non-conservative errors) it will be adopted. This is due to its widespread adoption in the industry and it generally being considered the most defendable approach.
5. In consultation with the Study Advisory Group (SAG), decide upon the most appropriate option for each element of design rainfall for incorporation into the RFD Project
6. Apply the adopted design rainfall approach to the BUR catchment pilot study and develop a complete set of design rainfall event "Storm Blocks" suitable for incorporating into the catchment's WBNM model. This model has been developed as part of other sub-projects of the RFD.
7. Run the WBNM model for all design events and produce hydrographs suitable for input to the BUR catchment TUFLOW hydraulic model.

3.1 Historic Event Comparison

There has been concern that ARR87 design rainfall techniques have potential to under-predict design flood levels as a result of the burst not containing sufficient antecedent rainfall prior to peak burst intensities when compared to actual flood producing storms. This has reportedly been the experience of the Sunshine Coast Regional Council immediately to the north of MBRC.

To address this concern it was decided to compare historic flood levels recorded throughout the BUR catchment with flood levels predicted by the preliminary BUR catchment TUFLOW model. The methodology used for this is as follows:

1. Incorporate flow measurement lines (PO Lines) into the preliminary BUR catchment TUFLOW model adjacent to each historic event flood level measurement. PO lines will be set to record flow and flood levels throughout the simulation.
2. Run the BUR catchment TUFLOW model for the 10 year and 100 year ARI 3 in 9 hour Embedded Design Storm events (EDS events). The 3 in 9 Hour EDS event has been chosen

because it has previously been shown by MBRC to provide a good match to peak flow rates predicted by the envelope of standard ARR design bursts within the BUR catchment.

3. Utilise the PO line results to develop a rising limb rating curve at each historic flood measurement.
4. Plot the Peak 10 year and 100 year ARI 3 in 9 hour EDS event flows on Log-Normal graph paper and use a straight line fit to estimate design flow rates for the remaining ARI events.
5. Use these flood level rating curves and estimated design flow rates to estimate the ARI of each historic event flood mark.
6. Review results and check for any evidence suggesting that the ARR design rainfall approach will significantly under-predict flood levels.

The accuracy of this approach is limited by several factors including:

1. Use of a preliminary hydraulic model only (no calibration, global roughness values, no stream bathymetry etc).
2. Limited by how well the 3 in 9 hour event replicates peak flows compared to the envelope of standard ARR87 rainfall bursts.

As a consequence of this, it is recommended that further testing be undertaken as part of future development of design rainfall methodologies.

Results of this analysis are discussed in Section 4.4 and additional details are provided in Appendix 1.

3.2 WBNM vs TUFLOW Stream Routing

Throughout the course of this project it became apparent that peak flow rates predicted by the WBNM model where considerably different to those predicted by the TUFLOW model (run with local WBNM inflow hydrographs). The reason for this lies with differences in the stream flow routing of the two modelling systems.

In order to provide a level of confidence that TUFLOW is indeed carrying out appropriate stream routing, it was decided to investigate this issue further by doing a direct comparison of routing between the two modelling systems. The methodology for this is described below:

1. Select several WBNM sub-catchments throughout the catchment suitable for the comparison. This primarily involved selecting catchments with appropriate shape, channel length and not impacted by other tributaries.
2. Incorporate Plot Output (PO) lines into the preliminary BUR catchment TUFLOW model at the top and the bottom of each of the above selected catchments

3. Run the preliminary BUR catchment TUFLOW model for a standard testing event (select the 100 year ARI 60 minute event) with the 2d_SA inflows removed over the selected catchments. This way with no inflows to the selected sub-catchments the difference between the flow hydrograph at the top and the bottom of the catchment is solely the result of stream routing.
4. Route the 'top of catchment' hydrographs through the appropriate WBNM sub-catchments by using an imported hydrograph and no other inflows.
5. Plot upstream and downstream hydrographs for the two modelling systems and compare the stream routing (note that the upstream hydrographs are identical)

Results of this investigation are discussed in Section 4.3 and results plots are provided in Appendix 2.

4. RESULTS

4.1 Comparison and Selection of Options

4.1.1 Design Event Point Rainfall Intensities (up to 100 year ARI)

Three options have been considered for developing design point rainfall intensities for the events with ARIs up to 100 years. A summary of these options is provided below.

ARR87: Currently this is the most commonly adopted method of developing design rainfall intensities in QLD however the following issues have been identified:

- Developed using relatively old historic rainfall data (approximately 25 years old)
- Produces a 'mounding' of increased rainfall intensities over the coast, where as other more recent studies suggest that the increased rainfall intensities are actually situated over the elevated coastal hinterland.

The benefit of adopting this method is that it is the most widely accepted and adopted method currently available.

CRCForge: This method was primarily developed for calculating extreme event rainfall intensities (up to 2000 year ARI). However, the CRCForge rainfall application developed by the QLD Department of Natural Resources and Water (Now a part of the Department of Environment and Resource Management - DERM) also generates rainfall intensities for the more frequent ARI events (down to 5 year ARI).

Benefits of adopting this method include:

- Allows a single method for developing rainfall intensities for all design storm events (excluding the PMP).
- Utilises more recent historic rainfall data than the ARR87 method.
- Does not produce the coastal mounding of rainfall intensities like ARR87 does. This is more consistent with other more recent studies including the Caboolture River Flood Study and the Gold Coast City Council IFD maps.
- In the BUR catchment, the CRCForge intensities are generally equivalent or slightly higher than the ARR87 intensities therefore this is a conservative approach. Similar results have been found in the other regional catchments.

A comparison of CRCForge design point rainfall intensities with ARR87 intensities is provided in Appendix 3. The comparisons are made at the BUR design rainfall gauges as shown on Figure 1.

A downside of using the CRCForge method is that it is not as widely accepted as ARR87.

Custom Method: Due to the upcoming revision of ARR and the budget/timing constraints of the current project it has not been considered worthwhile to undertake a customised analysis of rainfall intensities for the RFD Project.

Adopted Option: Based on review of the above options and the overall results of this investigation it has been decided to adopt ARR87 design point rainfall intensities.

Primary Justification: Industry accepted procedure

Also:

- Departure from adopted approaches is not warranted given the imminent release of adjusted design rainfall procedures and IFD estimates as part of the ARR Revision.
- A comparison between observed flood levels in the catchment and preliminary design flood surfaces indicates that the ARR87 design burst approach does not significantly under or over-predict flooding within the pilot catchment.

4.1.2 Design Rainfall Temporal patterns

Three options have been considered for developing design rainfall temporal patterns for events with ARIs up to 100 years. A summary of these options is provided below.

ARR87: Currently these are the most widely used temporal patterns in QLD however there are concerns that they are perhaps not conservative enough. This is largely due to the temporal patterns potentially not having enough ‘build up’ rain prior to the peak intensities.

GCCC: Gold Coast City Council (GCCC) have developed design temporal patterns based on analysis of rainfall in the region. These were found to generally produce higher peak flow rates than the ARR87 patterns and it is understood that this is in part due to them generally having peak intensities later in the event compared with ARR87.

Custom Method: Due to the upcoming revision or ARR and the budget/timing constraints of the current project it has not been considered worthwhile to undertake a customised analysis of rainfall temporal patterns for the RFD project.

Adopted Option: Based on review of the above options and the overall results of this investigation it has been decided to adopt the standard ARR87 design rainfall burst temporal patterns.

Primary Justification: Industry accepted procedure

4.1.3 Probable Maximum Precipitation

Procedures for defining the Probable Maximum Precipitation (PMP) rainfall event are clearly documented in two Bureau of Meteorology (BoM) publications.

- BoM (June 2003), “The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method” – GSDM
- BoM (June 2003), “Guidebook To The Estimation Of Probable Maximum Precipitation: Generalised Tropical Storm Method” (Revision Project) - GTSMR

These documents provide aerial rainfall intensities and temporal patterns. The GSDM also recommends varying rainfall intensities over the catchment using a series of ellipses. This methodology is only suited to the traditional flood study scenario whereby the study area is situated at the base of the catchment. When the study area consists of the entire catchment, as is the case with the RFD Project this technique is not suitable because it artificially lowers rainfalls at the catchment extremities.

Based on the above it is proposed to adopt the PMP methodologies outlined in these documents however spatial variation of rainfall intensities will not be adopted. PMP rainfall intensities across the catchment will be applied uniformly.

It has been decided to adopt PMP areal rainfall intensities based on a catchment area of $1km^2$. This assumption will lead to realistic PMP results in the upper head catchments however moving further downstream in the catchment, this assumption will lead to increasingly conservative results. This is because as the total catchment area increases it is un-realistic to apply the same rainfall intensities. This approach was considered acceptable given:

- PMF estimates are inherently uncertain
- PMF estimates are only used by Council for establishing an approximate floodplain limit
- The sensitivity of the flood prediction to change in flow is generally lowest in the downstream end of a catchment.
- If any major infrastructure is to be constructed in or across the PMF floodplain then an independent evaluation of PMF should be undertaken at that time using spatially variable intensities.

The alternative of applying larger catchment aerial rainfall intensities (reduced intensity) would lead to un-conservative results in the upper head catchments which corresponds to Council’s main area of interest so this option will not be adopted.

Adopted Option: Apply standard BoM PMP techniques without applying spatial variations to rainfall intensities (i.e. ellipses). Rainfall intensities are to be based on a 1km ^{2} aerial rainfall intensity applied uniformly over the regional catchment.

Primary Justification: Industry accepted procedure

4.1.4 Rare Rainfall Event Intensities

The Queensland CRCForge method has been developed specifically for the purpose of calculating design rainfall intensities for design events with ARIs beyond the current credible limit of extrapolation for individual rainfall stations in Queensland (rare rainfall events). It was developed by the QLD department of Natural Resources and Water (now a part of DERM) in 2005.

As part of the CRCForge project, a computer application was created which automatically generates rainfall intensities for a user specified point or catchment in QLD. Where a catchment is specified an aerial reduction factor (ARF) is automatically applied to the intensity. In keeping with the adopted ARF approach (refer Section 4.1.8) point rainfall intensities were instead used.

CRCForge point intensities have been calculated at the BUR01, BUR02, and BUR03 design rainfall gauge locations described in Section 4.1.6

Adopted Option: CRCForge Application – Point Intensities

Primary Justification: Industry accepted procedure

4.1.5 Rare Rainfall Event Temporal Patterns

Options that have been considered for rare event temporal patterns are as follows:

- ARR87 (> 30 year ARI) temporal patterns
- GDSM / GTSMR PMP Temporal Patterns
- A smoothed transition between the 100 year and the PMP temporal patterns.

An advantage of using the large event ARR87 temporal patterns is that it provides consistency with the design events with ARIs up to 100 years. Changing temporal patterns has a significant effect on peak flows and consequently it is possible to get discontinuities on the 'ARI vs Peak flow rate' curve when changing temporal patterns for different ARI events. Adopting ARR87 temporal patterns for the rare events would negate this issue between the large design events and the rare events.

The advantage of using the BoM's PMP temporal patterns for rare rainfall events is that they have been developed based on observations of very large rainfall events in Australia and it is therefore reasonable to apply them to rare rainfall events. The issue with this, as discussed above is that changing from the large event temporal patterns is likely to lead to discontinuities on the 'ARI vs Peak flow rate' curve between the 100 year event and the rare events. It is for this reason that sometimes a smoothed transition is applied for the rare events.

Applying a smoothed transition for the 100 year ARI temporal pattern up to the PMP temporal pattern is known to have been done in other recent investigations as a means of generating a smoother peak flow rate curve over the various ARI events. This method is considered un-desirable for the RFD project because of its subjective nature.

Adopted Option: Apply GSDM / GTSMR PMP Temporal Patterns for the rare events.

Primary Justification: Industry accepted procedure

4.1.6 Spatial distribution of rainfall over a catchment

<u>*PMP*</u>: It is not proposed to vary PMP rainfall intensities over a catchment using the standard ellipses provided in the GSDM handbook. This would artificially lower rainfall intensities over some areas of the catchment and lead to non-conservative results in Council's primary area of interest being the urban catchment.

<u>*CRCForge and ARR intensities:*</u> For each regional catchment, it is proposed to choose a set of design rainfall 'gauges' at locations able to represent the general pattern of rainfall intensities over the catchment. Three design rainfall gauges have been adopted to reflect the change in intensities over the BUR catchment. These locations line up with the BOM's grid of points provided on their website's IFD application. The location of these gauges within the catchment is shown below and their coordinates are provided in Table 4.1. ARR IFD Input variables are provided on Table 4.2.

Figure 1 – Proposed Design Rainfall Gauge Locations:

Table 4.1 – Design Rainfall Gauge Coordinates

Gauge Reference ID	Easting (MGA94 z56)	Northing (MGA94 z56)
BUR01	487617	6994175
BUR02	495047	6994181
BUR03	502477	6994181

Table 4.2 – BUR Design Gauge ARR IFD Input Variables

Gauge ID	$^{2}I_{1}$	$^{2}I_{12}$	$^{2}I_{72}$	$^{50}I_{1}$	$^{50}I_{12}$	$^{50}I_{72}$	F2	F50	G
BUR01	47.83	9.7	2.94	89.52	19.15	6.52	4.39	17.3	0.17
BUR02	48.36	9.56	2.95	91.06	19.48	6.76	4.39	17.32	0.15
BUR03	48.67	9.43	2.94	91.83	19.49	7.06	4.4	17.34	0.13

Charts and tables showing the adopted rainfall intensities at each gauge are provided in Appendix 4.

An alternative to this is to apply uniform rainfall intensity over each regional catchment. This approach was rejected because of the large size of the regional catchments and the significant variation in design rainfall intensities over them.

Adopted Approach: Small, large and rare design rainfall events will have spatial variation in rainfall intensities by the adoption of a set of representative design rainfall gauges over the catchment. No spatial variation in rainfall intensities will be applied over the BUR catchment for the PMP event.

Primary Justification: Industry accepted procedure

4.1.7 Ground infiltration rainfall losses

It is proposed to apply rainfall losses using the initial / continuing loss approach as this is the most widely applied method in QLD. Infiltration loss values applied in eleven calibrated flood studies carried out in the MBRC region have been reviewed.

There is a fairly wide range of values which have been adopted for the flood studies. Initial loss values vary from 0mm up to 25mm with a median value of 15mm. Continuing loss values vary from 1mm/hr up to 4mm/hr, with a median value of 2.5mm/hr.

Adopted Values: The values to be adopted for the BUR pilot studies are as follows:

- Pervious Area Initial Loss Values: 0mm for all design events
- Pervious Area Continuing Loss Values: 2.5mm/hr for all design events. This is consistent with clay soil types which are dominant in the region
- Impervious Area Initial Loss Values: 0mm for all design events
- Impervious Area Continuing Loss Values: 0mm/hr for all design events.

These values are considered reasonably conservative. The justification for the 0mm initial loss value for all design events is that there is evidence to suggest that large rainfall events typically occur during periods of generally wet weather so catchments are generally saturated.

It is recommended that these values be reviewed following the TUFLOW calibration being carried out as part of the BUR pilot study.

Primary Justification: Industry accepted procedure

Also:

- Evidence to suggest common condition where saturation of catchment achieved prior peak burst

4.1.8 Aerial Reduction Factors

Consideration has been given as to the most suitable Aerial Reduction Factor (ARF) curves to apply to design rainfall intensities across the extensive model domains being investigated for the Moreton Bay Regional Council Regional Floodplain Database Project (RFD Project).

The various ARF curves currently available have been reviewed and based on this a suitable ARF relationship for application to the RFD project is recommended.

ARF curves for each available option are presented for comparison purposes in Appendix 5 based on catchment areas of 100 km^2 and 1000 km^2.

The options which have been considered for this study are detailed below:

Book II of ARR97: For non-inland Australia, ARR97 Book II recommends the ARF curves developed by the United States National Weather Service for a study in the Chicago area published in 1980. It is stated that these curves were recommended due to a lack of Australian data and research that was available at the time.

When compared to the other options discussed in this document, the ARR97 Book II curves generally produce the smallest reduction in point rainfall intensities over most design storm durations. Therefore this is generally considered the most conservative ARF curve.

Book VI of ARR97: This provides an alternative method of calculating ARF values based on the work carried out by Siriwardena & Weinmann for design rainfall in Victoria (1996). This work represents a more up to date look at calculating ARFs in Australia; however its focus on Victorian rainfall presents uncertainty into how well these equations would apply to South East Queensland.

In comparison to the other options discussed in this paper, the ARR97 Book VI ARF equations generally produce the greatest reduction in point rainfall intensities over most design storm durations. Therefore this is generally considered the least conservative option.

QLD CRCForge ARF: The QLD CRCForge method of deriving design rainfall estimates presents the following relationship between ARF, Catchment area and event duration.

$$ARF = 1 - 0.2257\ (Area^{0.1685} - 0.8306 \log (Duration))\ Duration^{-0.3994}$$

But NOT > 1.0 *(for smaller areas)*

This relationship was derived using daily rainfall totals only and the CRCForge documentation warns that it is risky to extrapolate this relationship down to shorter rainfall durations.

Output from the CRCForge application states that for durations less than 24 hours, the 24 hour ARF value is conservatively applied. Review of the attached ARF curves suggests that this assumption is considered overly-conservative, particularly when considering event durations around 3 to 6 hours where ARF values reduce sharply in the other ARR curves.

The QLD CRCForge ARF method is the only method which utilises QLD rainfall data in developing the ARF relationship.

Adopt Point Rainfall Intensities (ARF = 1): The most conservative and the easiest to apply approach is to adopt point rainfall intensities only. This eliminates the difficulties in calculating ARF values that are representative over the entire study area (catchment).

Adopted Approach: Apply point rainfall intensities without applying any aerial reduction factor. The reason for this approach is associated with the difficulties in applying ARF to the very large study areas of the RFD project. This issue is described in the following section.

Primary Justification: Simple application and removes non-conservatism within urban areas (Council's area of interest. Also see Section 4.1.9).

4.1.9 Application of Aerial Reduction Factors

Calculation of aerial reduction factors (ARFs) is primarily a function of catchment area and rainfall event duration (and to a lesser extent, ARI). The issue with ARFs over the regional catchments of the RFD project is that the entire catchment is the study area. This means that there is not a single catchment area that can be applied for calculating an ARF that is representative over the study area.

The relatively small areas associated with the head catchments should have ARFs close to 1 (i.e. close to point rainfall intensity). However the bottom of the BUR catchment has a contributing catchment area of over 80km^2. Based on the ARR87 ARF curves (Book II) it is appropriate for a catchment of this size to have ARFs in the order or 20% for very short durations and around 97% for longer duration rainfall events.

The larger the regional catchment the more pronounced this effect will become. Consequently testing has also been carried out for the Stanley River (STA) catchment which is the largest regional catchment in the LGA with a total catchment area of approximately 480km^2.

There are several options for dealing with this issue as described below.

Apply point rainfall intensities only (i.e. ARF = 1) : This assumption will lead to realistic rainfall intensities in the upper head catchments however moving further downstream in the catchment, this assumption will lead to increasingly conservative results. Preliminary WBNM modelling for the STA catchment shows peak flow rates generated using this method will be in the order of 15% higher at the bottom of this catchment compared to an overall catchment size adjusted ARF value. This is based on comparison with model results simulated with an ARF value calculated using the full catchment area.

Apply ARFs based on total catchment areas: This assumption will lead to realistic results at the bottom of the regional catchments however results in the smaller urban catchments (Council's area of interest) will be significantly lower than they should be. Preliminary WBNM modelling for the STA catchment shows peak flow rates will be in the order of 30% too low in the head catchments using this approach. This is based on comparison with model results simulated with head catchment ARF values (ARF = 1). This level of under conservatism is clearly not appropriate.

Apply ARFs based on a proportion of the total catchment area: This method was also found to produce results which are significantly lower than they should be in the head catchments (compared with using ARF = 1).

Critical Duration Dependant ARF: This would initially involve defining which catchment areas are expected to be dominated by a given storm duration. Based on this, a representative catchment area would then be used to define an ARF value for a particular storm duration. This method is expected to reduce the likelihood of significant ARF induced errors impacting peak flood results however it is somewhat subjective in its application and there are issues with repeatability.

Customised Method: A customised method referred to as the Incremental ARF method has been developed for potential use in the RFD. This method involves calculating ARF values for each local sub-catchment based on the value required to reduce the average contributing catchment ARF to the desired value. While not adopted at this stage, this option has been documented in Appendix 6 should it be pursued in the future.

Adopted Approach: It has been decided to adopt point rainfall intensities and accept that there will be a level of conservatism for the results in the lower portions of the regional catchments. This may lead to over predicting flow rates in the lower catchment by up to approximately 15% (based on preliminary testing in the Stanley River catchment). It is noted however that flood levels in the lower floodplain of a large catchment are generally less sensitive to variation in flow estimate than the upper catchment making this approach more easily justified.

Primary Justification: Simple application and removes non-conservatism within urban areas

4.1.10 MBRC Design Storm

Council has expressed an interest in developing a single 1 in 100 year ARI equivalent storm which can be used for rapid initial assessment of the impact of new floodplain infrastructure (as opposed to a full suite of ARR87 design storms as used for flood planning level determination).

The options that have been considered for the MBRC design storm are as follows:

- Duration Independent Storm ('DIS' or 'magi' storm)
- A May 2009 storm scaled up to 1 in 100 year ARI intensities.
- 100 year ARI Embedded Design Storm (EDS)

Hydrologic modelling has been carried out for each of the above storms and peak flows across the catchment have been compared against those predicted by the envelope of the peak ARR87 design burst events.

DIS Event: Peak WBNM flow rates for the DIS storm were found to generally be around 20% to 30% greater than the envelope of design bursts however it is noted that no factors have been applied to the DIS rainfall intensities. The 1996 paper by Ken Morris (Brisbane City Council), where the DIS concept was originally developed, recommends that a factor should be applied in order to 'calibrate' results to a flood frequency analysis at several locations within the catchment. This has not been carried out as part of this investigation as inadequate flood frequency data was available.

May 2009 Historic Event: It was considered at the beginning of this investigation that the May 2009 event may be able to be utilised as a MBRC design storm. Benefits of using this storm are:

- The storm was a real event as opposed to an artificial design storm
- The storm occurred recently so it is well remembered by the community
- Relatively high number of flood level observations available for measurement and calibration.
- The storm contained a ‘back loaded’ temporal pattern meaning that catchment storages where largely full prior to the peak rainfall occurring.

Unfortunately, the nature of the storm was such that it did not include any intense, short duration rainfall bursts and as such factoring up this historic rainfall event to 100 year ARI intensities was not able to match the short duration rainfall bursts generated by the ARR method.

Embedded Design Storm:

The Embedded Design Storm (EDS) approach involves nesting an ARR87 rainfall burst inside an envelope storm. The edges of the resultant storm hyetograph (outside the burst) are scaled down to preserve the rainfall volume of the original envelope (prior to the burst being embedded within it).

This approach results in a storm which contains antecedent rainfall that has been developed in a repeatable manner. This approach has been found to better reflect flood producing storms within volume sensitive catchments compared to a normal design burst approach. The EDS approach was therefore considered suitable for consideration as an MBRC design storm option.

Preliminary testing for the BUR catchment identified that a 3 in 9 hour EDS event provided good results. However Council undertook further testing using a region-wide WBNM model. This testing included comparisons between the spectrum of design burst flows (from all duration bursts) and the spectrum of EDS flows (from all duration bursts embedded in all duration envelopes) at the outlet of all sub-areas within the region-wide model (approximately 4700 calculation points).

Using the maximum flow from all duration bursts as a benchmark, the level of under or over prediction made by each EDS combination was calculated for each location in the region. A statistical analysis was undertaken to derive the EDS event that best emulated the design burst approach. It was found that the storm having the lowest deviation from the burst approach across the region was an EDS storm involving the embedment of a 15 min burst inside a 270 min envelope storm.

Adopted Approach: ‘15 min in 270 min EDS’ event

Primary Justification: Simple and repeatable application to the region using adopted modelling software.

4.2 Identified Issues

A number of design rainfall issues have arisen through the course of the investigation have been considered. These include:

- The standard approach to design rainfall in Australia, which to date has been widely adopted, is based on the techniques detailed in the Institution of Engineers Australia's publication entitled Australia Rainfall and Runoff (ARR). This document was last released in the 1987 and is generally considered to be somewhat out of date in many areas. Consequently it is currently undergoing a major update and at this time it is unclear exactly what the new version will bring.
- Issues in the application of aerial reduction factors (ARFs) for single model domains covering entire regional catchments.
- Issues in applying spatial variation to rainfall intensities for single model domains covering entire regional catchments.

These and other issues have been considered in developing the most suitable design rainfall methodology.

A further issue which has been identified is that there are significant differences between TUFLOW stream routing and WBNM stream routing when global WBNM catchment lag parameters are adopted. This is discussed further in Section 4.3.

4.3 WBNM vs TUFLOW Stream Routing

The investigation has found that applying global WBNM catchment lag and stream lag parameters to the BUR catchment WBNM model leads to significant differences in peak flow rates when compared with the results of TUFLOW.

A direct comparison of TUFLOW vs WBNM stream routing has been carried out as described in Section 3.2.

Results suggest that adopting a global WBNM lag parameter of 1.47 leads to WBNM generally over attenuating flows in the upper head catchments and under attenuating flows in the lower catchments when compared to TUFLOW results.

These results have been reviewed and discussed within the RFD Project team and it has been decided to accept the TUFLOW stream routing based on the following:

1. Other recent studies have provided good evidence that it is sometimes necessary to vary WBNM catchment lag parameters within individual catchments to account for the differing amounts of floodplain storage within the catchment.
2. TUFLOW modelling is based on detailed hydraulic calculations and the simulations have been found to be stable with no significant mass errors.

3. Reducing the TUFLOW cell size down from 10m to 5m had very little impact on results suggesting that cell size issues are not a problem.
4. Given the small amount of floodplain storage which is available in the Burpengary Creek's steep upper catchments it is reasonable that a small WBNM lag parameter should be applied compared to the wide floodplains in the lower catchment.

As a further validation of TUFLOW's stream routing accuracy, the May 2009 historic event has also been modelled using TUFLOW (within WBNM inflows). The model results have been compared against recorded stream gauge data (levels) and the results show a good fit in regards to hydrograph timing.

Further details of this investigation are provided in Appendix 2.

4.4 Historic Event Comparison

Comparison of BUR catchment historic flood level measurements with results of the modelling described in Section 3.1 suggest that applying the standard 1987 ARR rainfall techniques without ARF values yields a good fit with observations from historic events. The results do not show any evidence that the standard ARR techniques systematically under-predict flood levels within the catchment as is reportedly the case by neighbouring local government authorities.

Further details of this investigation are provided in Appendix 1.

Modelling carried out for this investigation is preliminary in nature. It is recommended that further testing against historic events be undertaken as part of future development of design rainfall methodologies.

4.5 Pilot Study Outcomes

The outcome of this pilot study is a pragmatic and defendable approach to applying design rainfall in MBRC's RFD project. A range of options have been considered for all key elements associated with design rainfall and a range of issues have been identified and investigated.

A design rainfall methodology has been developed that is intended to be suitable not just for the BUR catchment pilot study but also for the remaining regional catchments.

A complete set of WBNM storm blocks have been developed and run through the BUR catchment WBNM model to produce inflow hydrographs for the BUR catchment TUFLOW model.

4.6 Recommended Areas of Further Study

The following items have been identified as possible areas of further study:

- Rainfall loss rates should be verified with detailed calibration – preferably to a flood frequency analysis where sufficient data is available.
- WBNM model(s) could be cross calibrated to the calibrated TUFLOW model(s).
- Comparison of the MBRC design storm(s) with the ARR design burst envelope using the calibrated TUFLOW model.
- Further consideration of ARF relationships and their application to the RFD Project
- The preliminary comparison of design flood levels with historic measurements should be re-visited using a more detailed and calibrated model.
- Update to the new version of ARR when released.

5. REFERENCES

Water Assessment and Planning, Water Assessment Group, Gary Hargraves (2005), *'Final Report, Extreme Rainfall Estimation Project, Crcforge and (Crc) Arf Techniques, Queensland and Border Locations, Development and Application'*

QLD DNRW (2005), Rainfall IFD v1.0 CRC-Forge-ARF (Computer Application)

The Institute of Engineers Australia (2000), *"Australian Rainfall and Runoff"*

Michael Boyd et al, January 2007, *"WBNM User Guide"*

http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml (BoM IFD Application)

Gold Coast City Council (2005), *"Land Development Guidelines"*

Commonwealth Bureau of Meteorology (June 2003), *"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"*

Commonwealth Bureau of Meteorology (November 2003), *"Guidebook To The Estimation Of Probable Maximum Precipitation: Generalised Tropical Storm Method"*

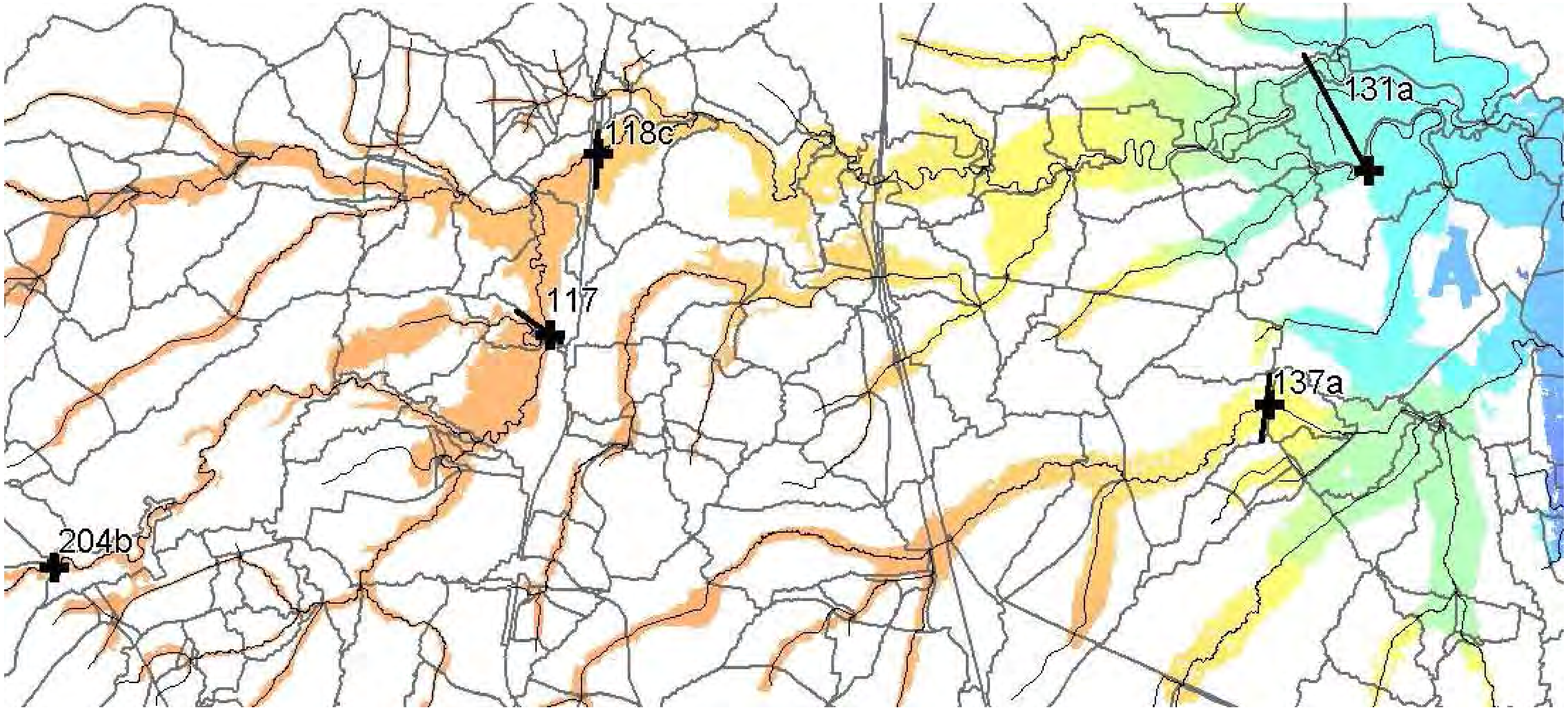
Australian Water Engineering (April 1994), *"Caboolture River Flood Study"*

Ataur Rahman et al (2006), *"Investigation of Design Rainfall Temporal Patterns in the Gold Coast Region of Queensland"*

SunWater (June 2007), *"North Pine Dam, Design Flood Hydrology"*

BMT WBM (2008), *"TUFLOW user manual"*

Appendix 1 - Historic Event Comparison

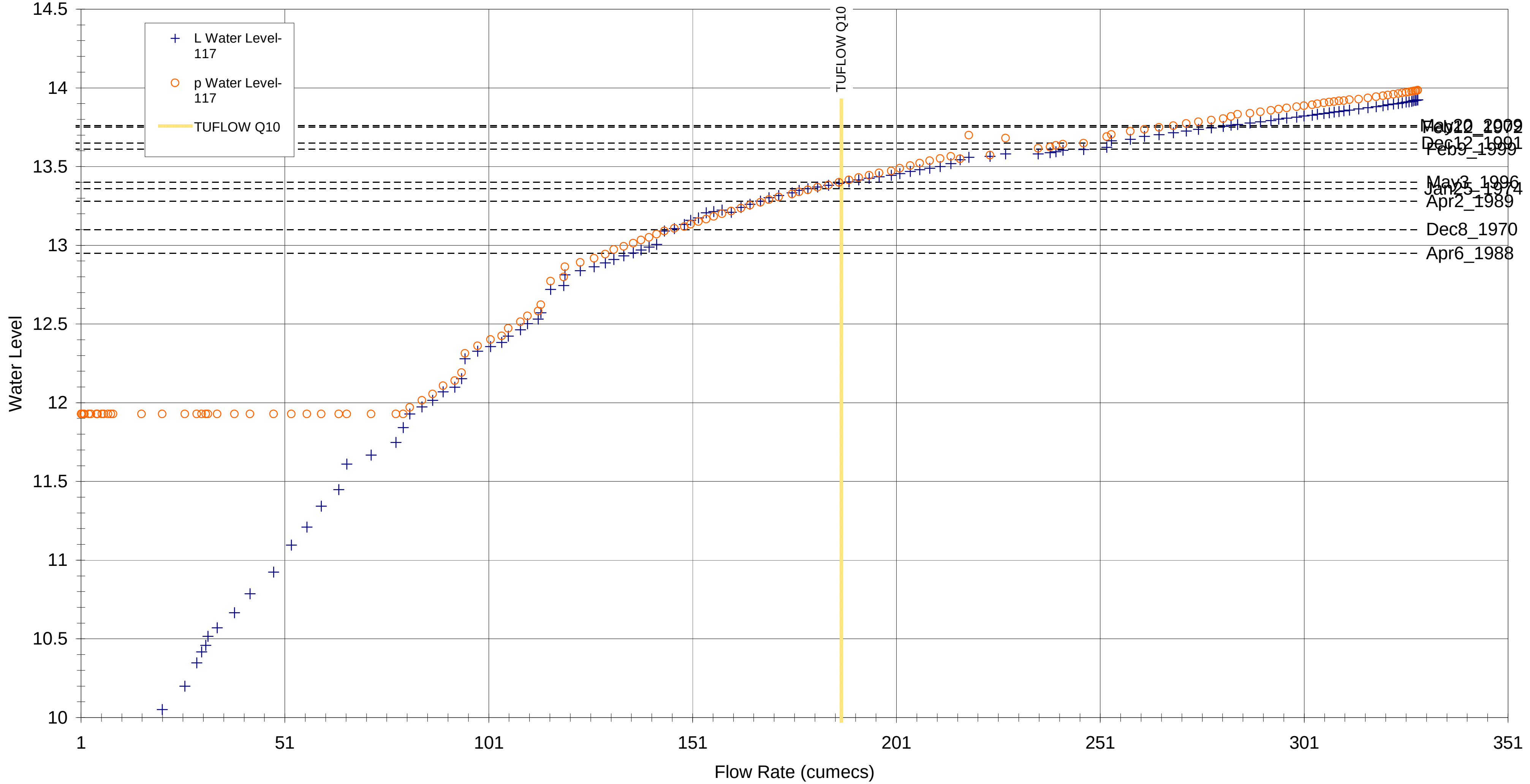


Historic Event Flood Marks and PO Line Locations

TUFLOW Rating and Flood Marks at Flood Record Number 117

Based on TUFLOW case "WP_Ex01d" run with a 100 year ARI 3 in 9 hour EDS

					Approx ARI:				Q5	Q45	Q10		Q3	Q7	Q30			Q10	Q25		Q45
Rec_no_	Mga_east	Mga_north	Rec_no	Location	Broad_loc		Yr_1893	Yr_1931	Dec8_1970	Feb12_1972	Jan25_1974	Yr_1975	Apr6_1988	Apr2_1989	Dec12_1991	Mar16_1992	Feb18_1995	May3_1996	Feb9_1999	Apr14_2009	May20_2009
117	495602.3	6995704	117	Rowley Rd(Mahrs)	BURPENGARY CREEK	-0.866	0	0	13.1	13.75	13.36	0	12.95	13.28	13.65	0	0	13.4	13.61	0	13.76



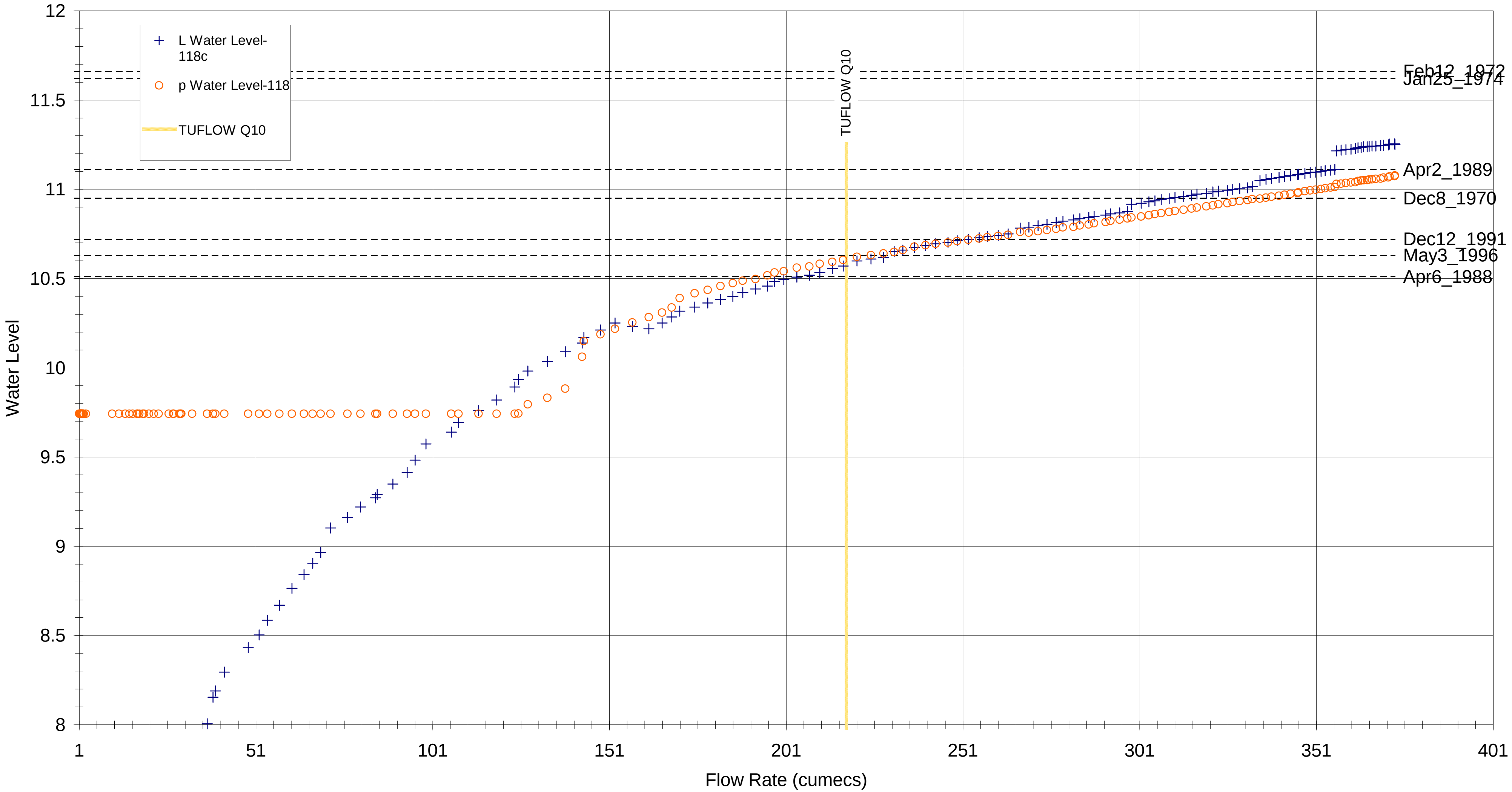
"p Water Level" series is based on the water level times series extracted from the flood mark point

"L Water Level" series is based on the water level times series extracted from the full PO Line

TUFLOW Rating and Flood Marks at Flood Record Number 118

Based on TUFLOW case "WP_Ex01d" run with a 100 year ARI 3 in 9 hour EDS

					Approx ARI:				Q60	Q1300	Q1300		Q7	Q110	Q17			Q11			
Rec_no_	Mga_east	Mga_north	Rec_no	Location	Broad_loc		Yr_1893	Yr_1931	Dec8_1970	Feb12_1972	Jan25_1974	Yr_1975	Apr6_1988	Apr2_1989	Dec12_1991	Mar16_1992	Feb18_1995	May3_1996	Feb9_1999	Apr14_2009	May20_2009
118	495920.3	6996918	118	O'Briens Rd	BURPENGARY CREEK	-0.529	0	0	10.95	11.66	11.62	0	10.51	11.11	10.72	0	0	10.63	0	0	0

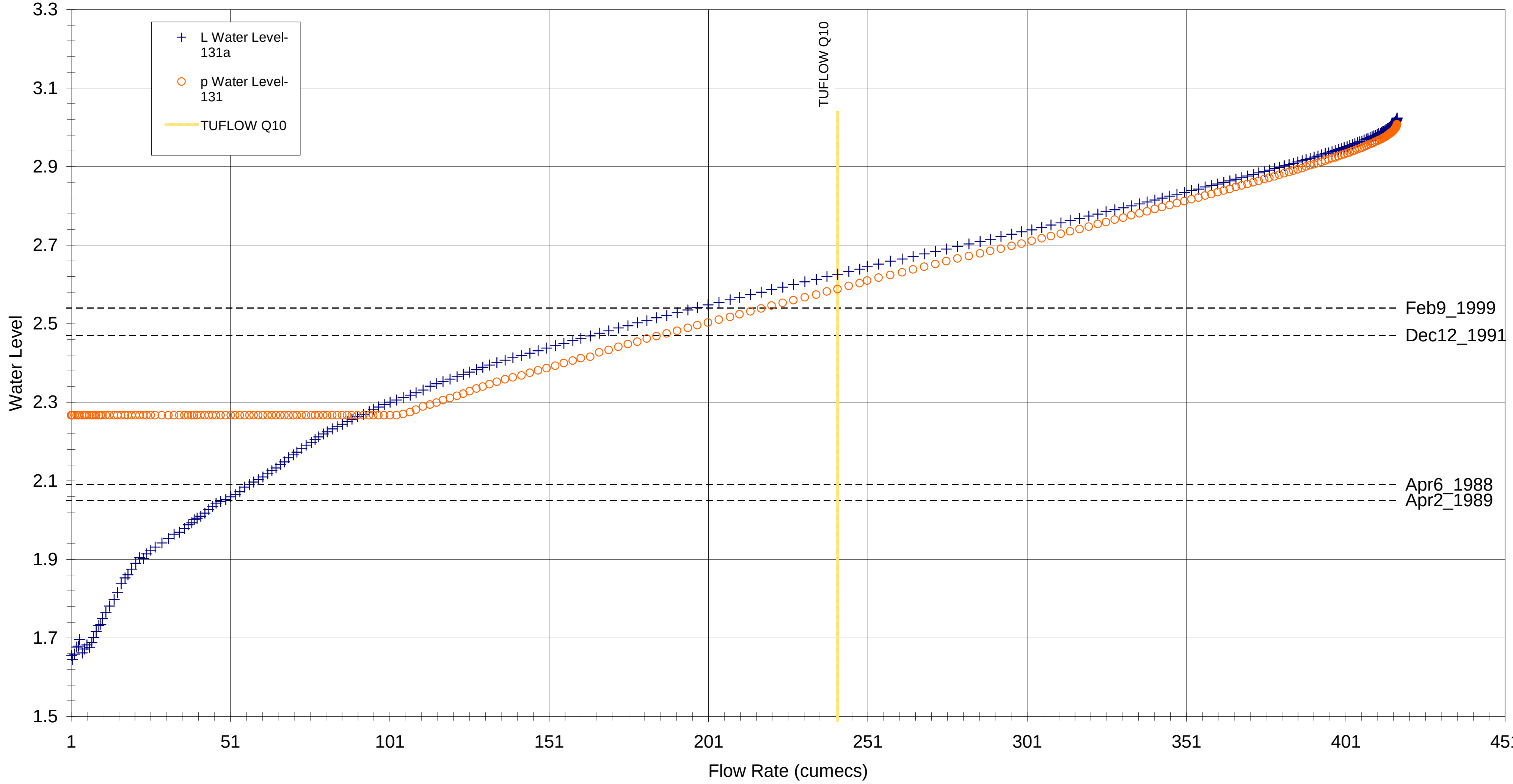


"p Water Level" series is based on the water level times series extracted from the flood mark point
"L Water Level" series is based on the water level times series extracted from the full PO Line

TUFLOW Rating and Flood Marks at Flood Record Number 131

Based on TUFLOW case "WP_Ex01d" run with a 100 year ARI 3 in 9 hour EDS

					Approx ARI:								< Q2	< Q2	Q5				Q8		
Rec_no_	Mga_east	Mga_north	Rec_no	Location	Broad_loc		Yr_1893	Yr_1931	Dec8_1970	Feb12_1972	Jan25_1974	Yr_1975	Apr6_1988	Apr2_1989	Dec12_1991	Mar16_1992	Feb18_1995	May3_1996	Feb9_1999	Apr14_2009	May20_2009
131	501086.6	6996799	131	O'leary Ave(ramp)	BURPENGARY CREEK	-0.64	0	0	0	0	0	0	2.09	2.05	2.47	0	0	0	2.54	0	0



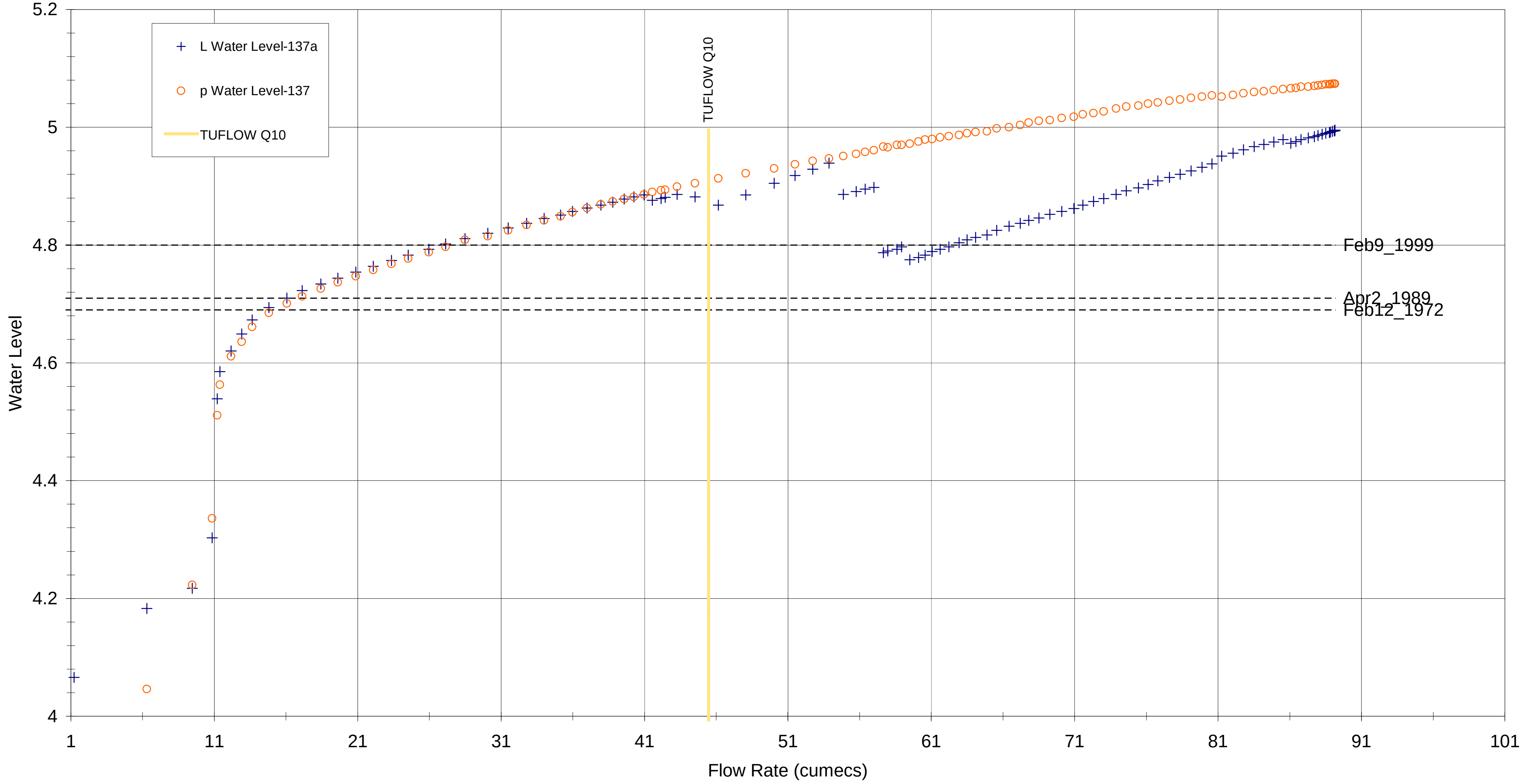
"p Water Level" series is based on the water level times series extracted from the flood mark point
"L Water Level" series is based on the water level times series extracted from the full PO Line

G:\301018\00042 - Burpengary Caboolture Hydraulic Modelling\10.0 Engineering\BUR_DES_Rain\FloodMark Calibration\Flood Mark Rating Curves (WP_Ex01d100Y_EDS_3in9hr) For Report rev0.xls 28/06/2010

TUFLOW Rating and Flood Marks at Flood Record Number 137

Based on TUFLOW case "WP_Ex01d" run with a 100 year ARI 3 in 9 hour EDS

					Approx ARI:					< Q2				< Q2					Q3		
Rec_no_	Mga_east	Mga_north	Rec_no	Location	Broad_loc		Yr_1893	Yr_1931	Dec8_1970	Feb12_1972	Jan25_1974	Yr_1975	Apr6_1988	Apr2_1989	Dec12_1991	Mar16_1992	Feb18_1995	May3_1996	Feb9_1999	Apr14_2009	May20_2009
137	500424.3	6995232	137	Old Bay Rd(culverts)	LITTLE BURPENGARY CREEK	-0.149	0	0	0	4.69	0	0	0	4.71	0	0	0	0	4.8	0	0

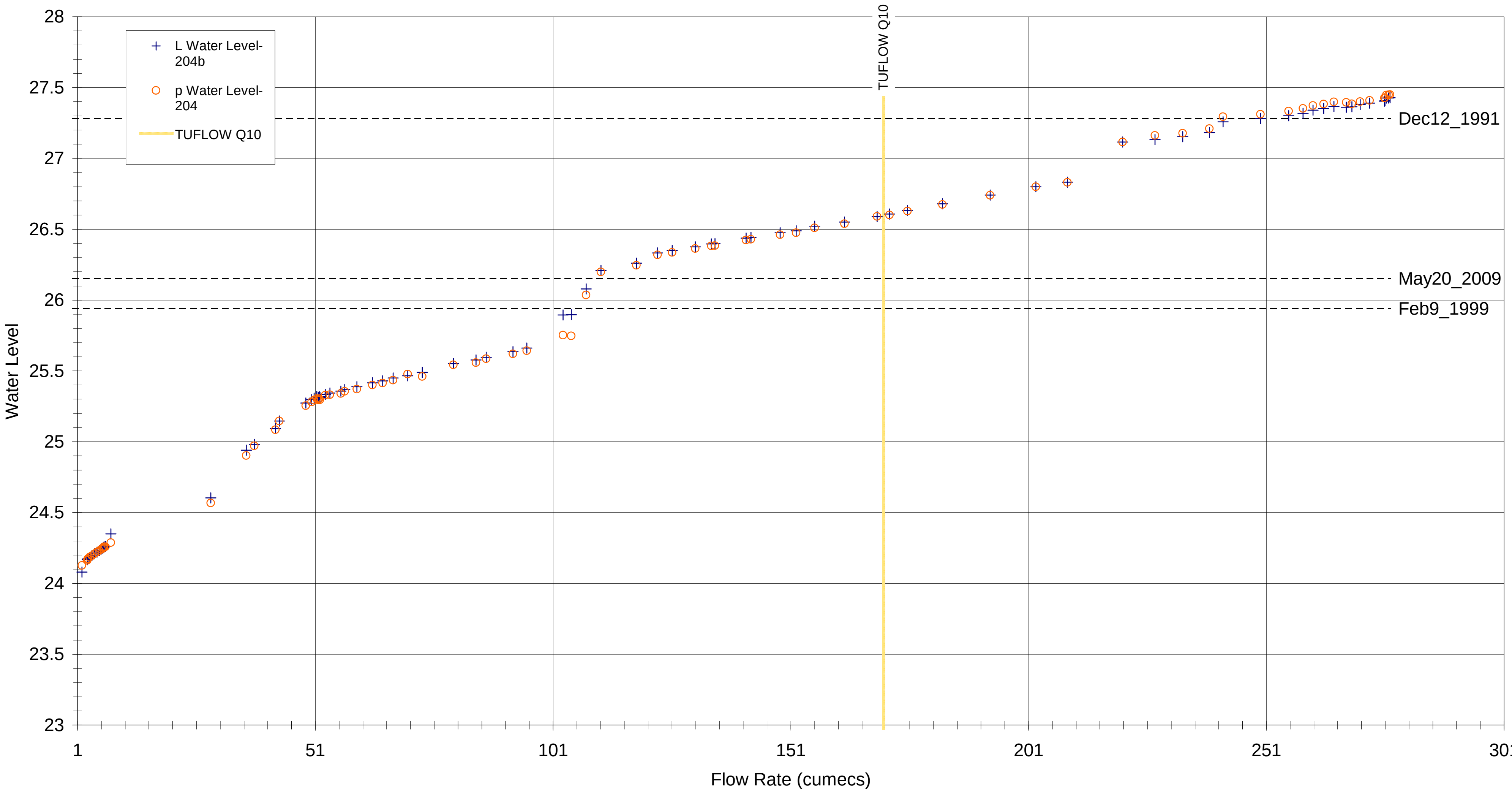


"p Water Level" series is based on the water level times series extracted from the flood mark point
"L Water Level" series is based on the water level times series extracted from the full PO Line

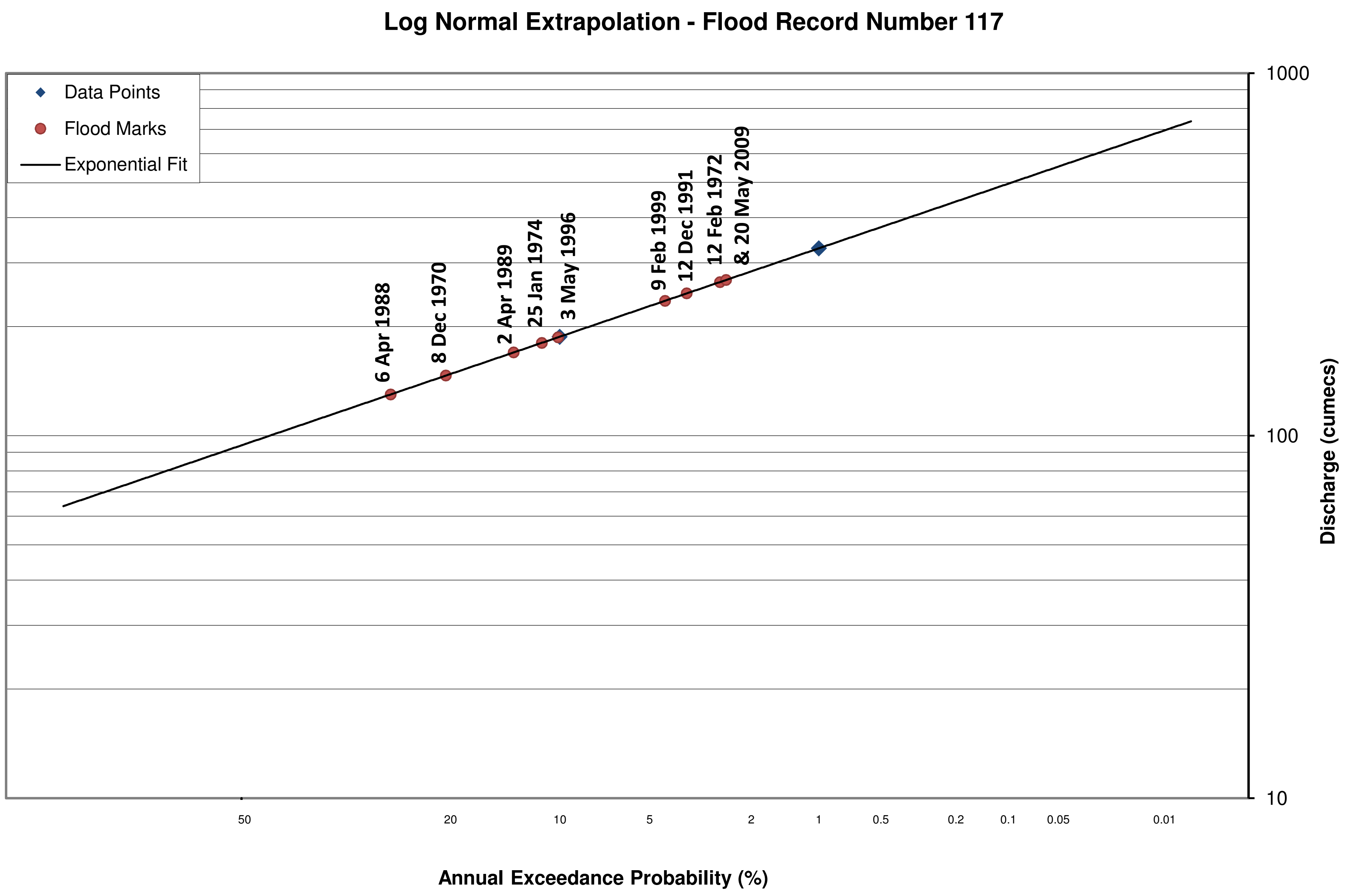
TUFLOW Rating and Flood Marks at Flood Record Number 204

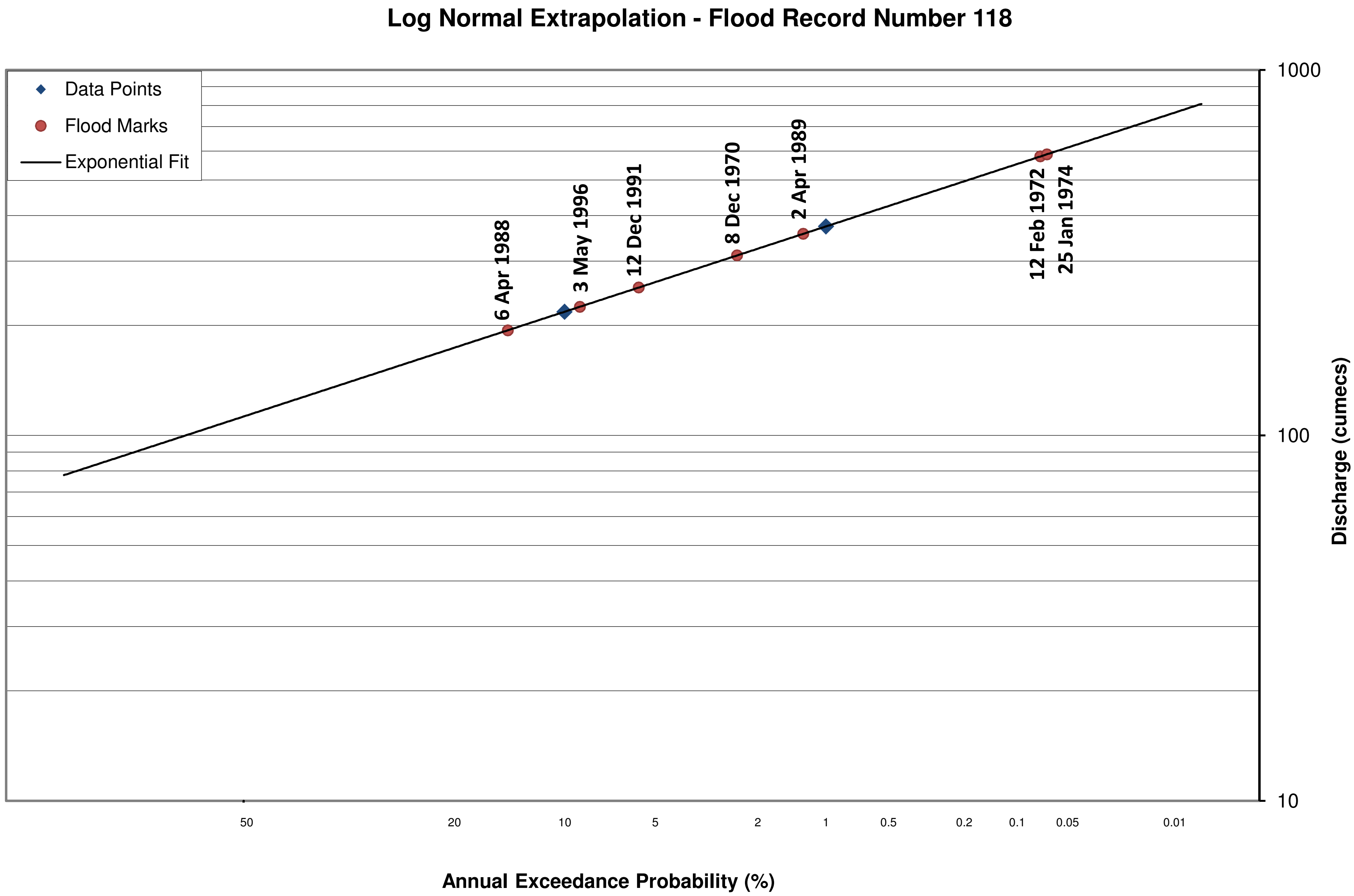
Based on TUFLOW case "WP_Ex01d" run with a 100 year ARI 3 in 9 hour EDS

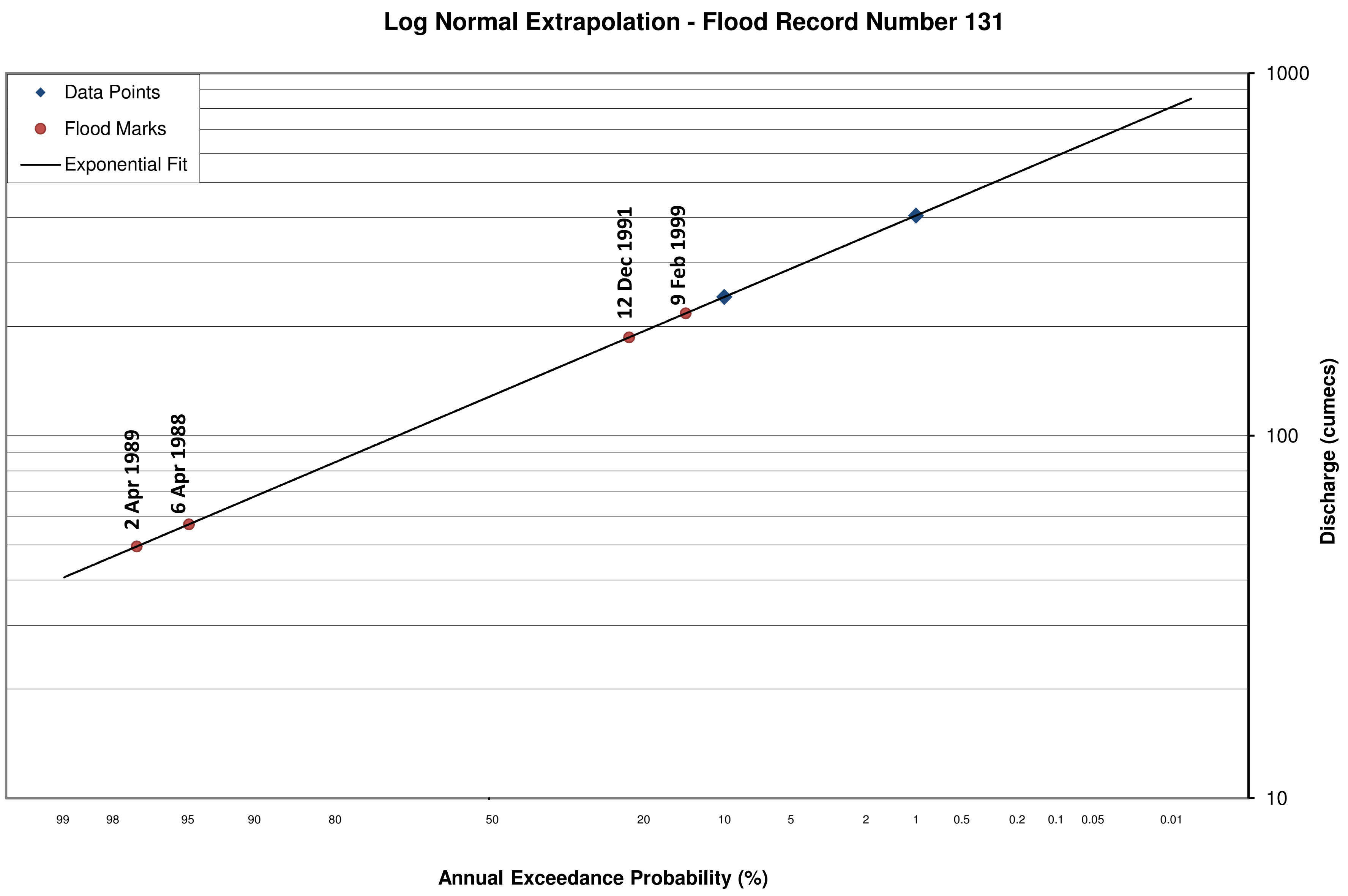
					Approx ARI:										Q50				Q3		Q3
Rec_no_	Mga_east	Mga_north	Rec_no	Location	Broad_loc		Yr_1893	Yr_1931	Dec8_1970	Feb12_1972	Jan25_1974	Yr_1975	Apr6_1988	Apr2_1989	Dec12_1991	Mar16_1992	Feb18_1995	May3_1996	Feb9_1999	Apr14_2009	May20_2009
204	492277.8	6994143	204	Oakey Flat RD (New Bridge)	BURPENGARY CREEK	0	0	0	0	0	0	0	0	0	27.28	0	0	0	25.94	0	26.15



"p Water Level" series is based on the water level times series extracted from the flood mark point
"L Water Level" series is based on the water level times series extracted from the full PO Line

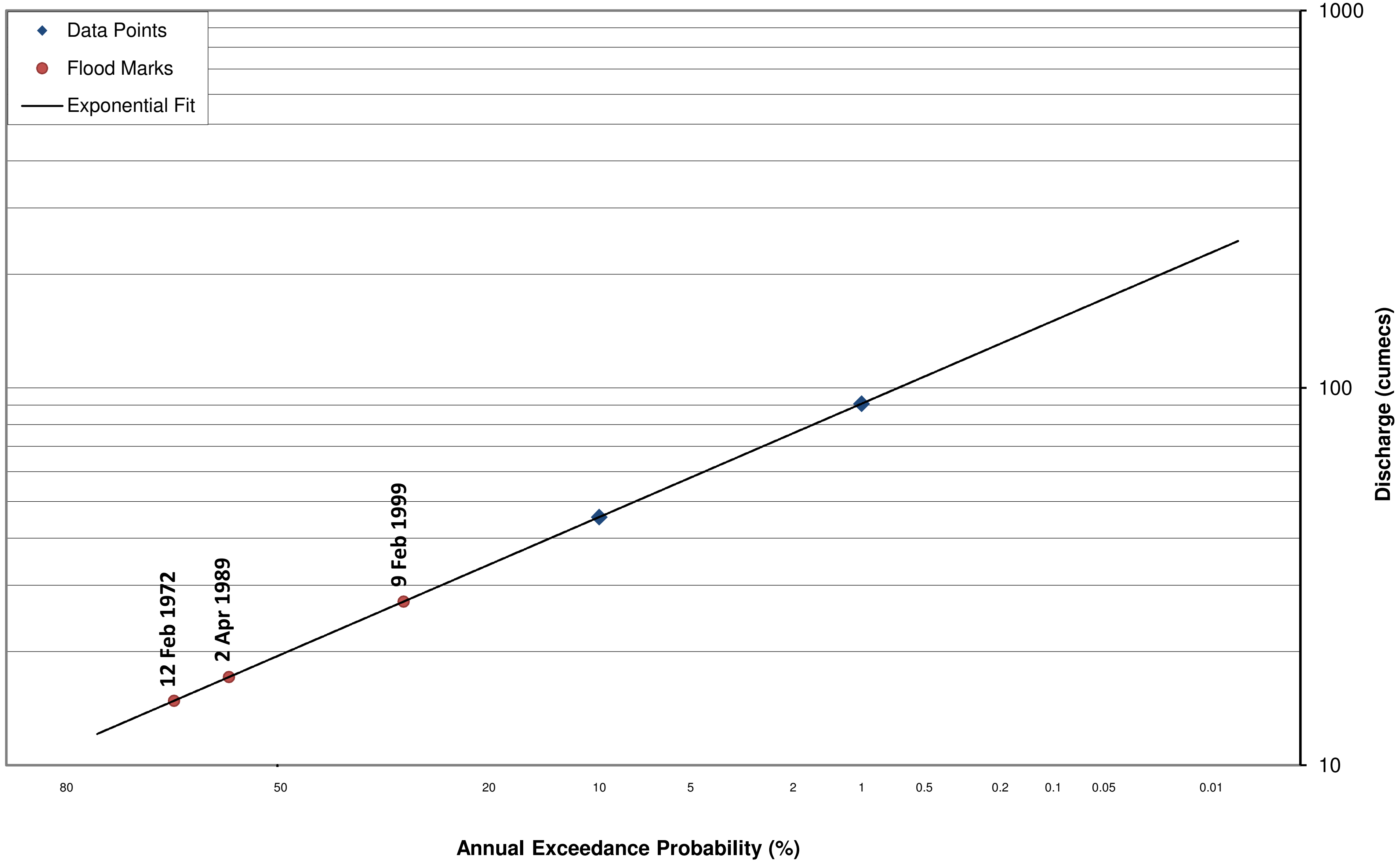

Log Normal Extrapolation - Flood Record Number 117
Data Points
Flood Marks
Exponential Fit
6 Apr 1988
8 Dec 1970
2 Apr 1989
25 Jan 1974
3 May 1996
9 Feb 1999
12 Dec 1991
12 Feb 1972
& 20 May 2009
1000
100
10
Discharge (cumecs)
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
Annual Exceedance Probability (%)


Log Normal Extrapolation - Flood Record Number 118
Data Points
Flood Marks
Exponential Fit
6 Apr 1988
3 May 1996
12 Dec 1991
8 Dec 1970
2 Apr 1989
12 Feb 1972
25 Jan 1974
1000
100
10
Discharge (cumecs)
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
Annual Exceedance Probability (%)

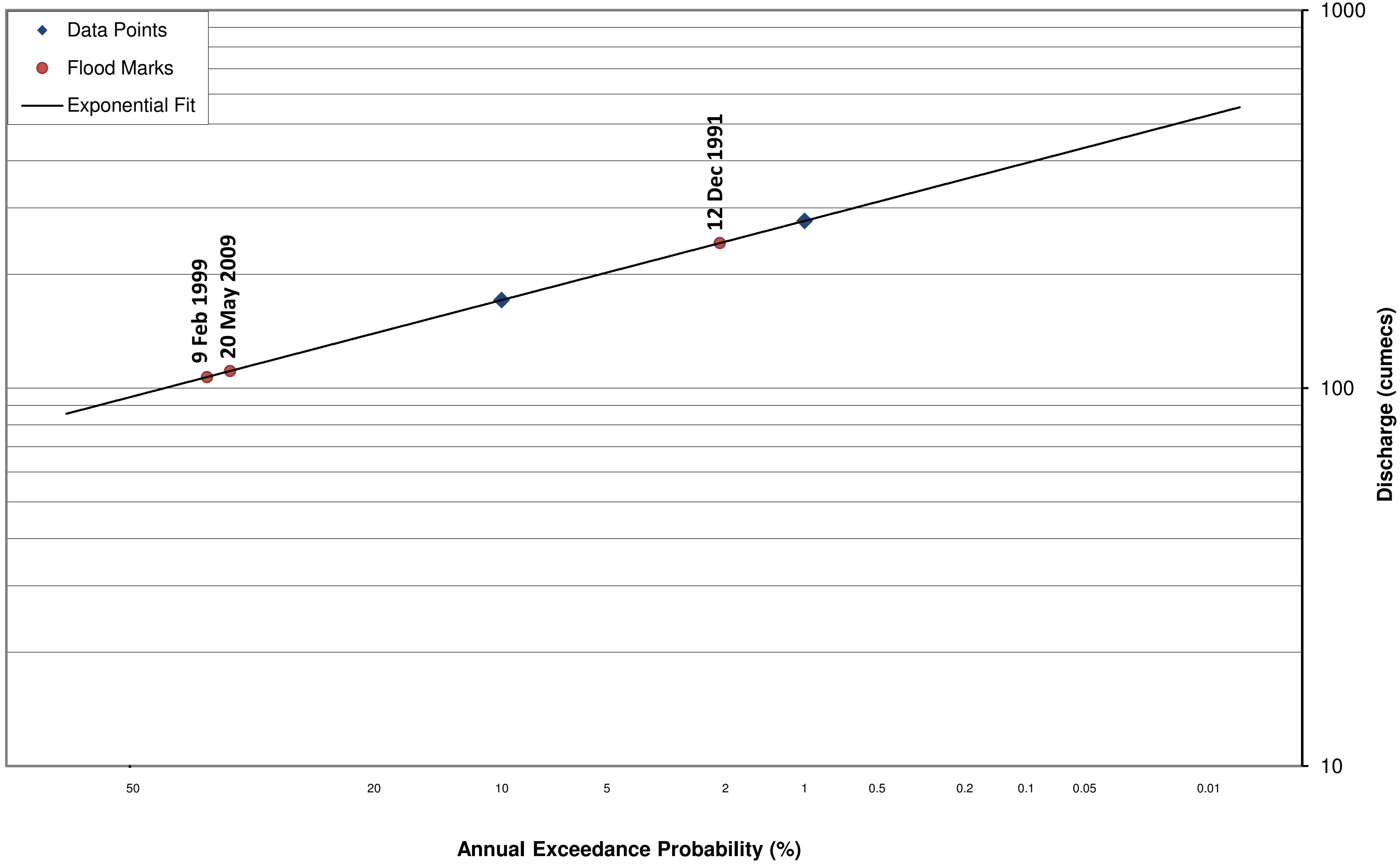


Log Normal Extrapolation - Flood Record Number 131
Data Points
Flood Marks
Exponential Fit
2 Apr 1989
6 Apr 1988
12 Dec 1991
9 Feb 1999
1000
100
10
Discharge (cumecs)
99
98
95
90
80
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
Annual Exceedance Probability (%)

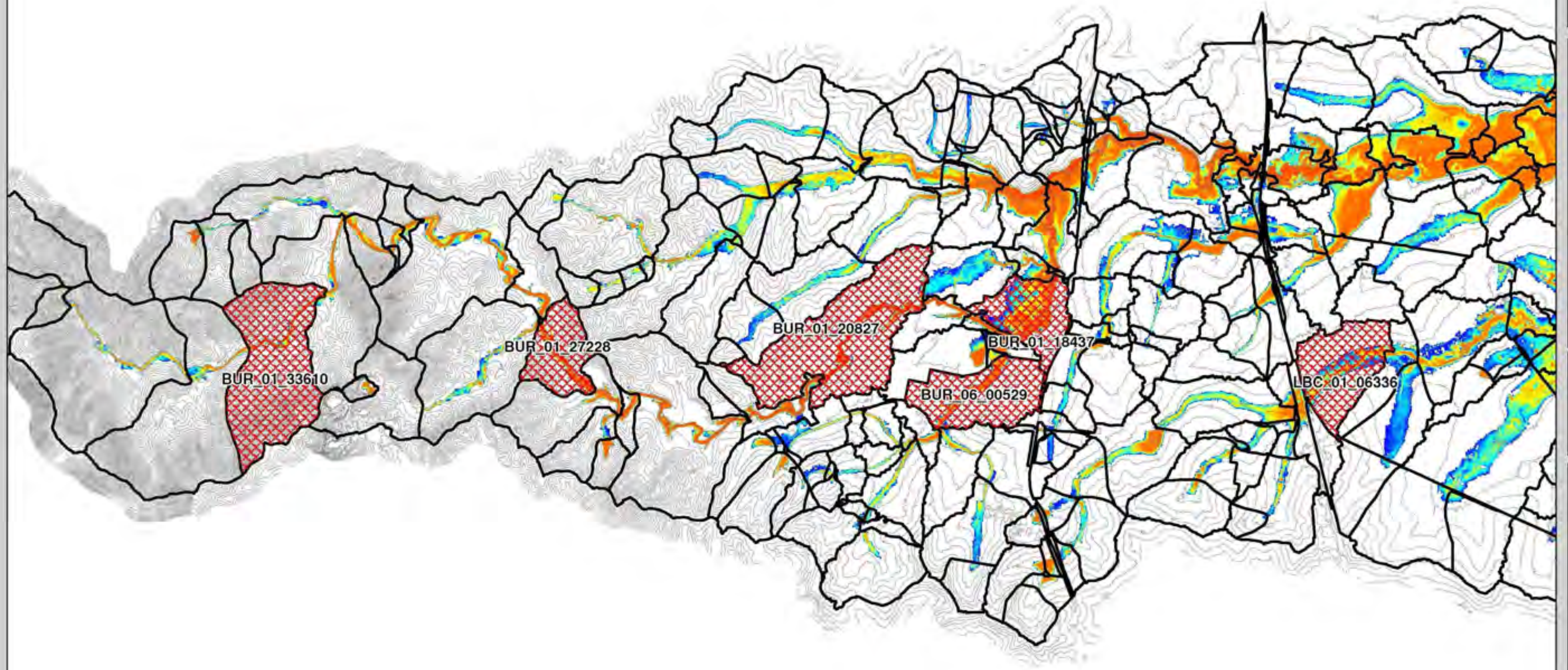
Log Normal Extrapolation - Flood Record Number 137



Log Normal Extrapolation - Flood Record Number 204



Appendix 2 - WBNM vs TUFLOW Stream Routing



500 0 500 1000 1500

Metres

Scale: 1:50,000

WBNM CATCHMENTS USED FOR ROUTING COMPARISON

WBNM VS TUFLOW

WorleyParsons

resources & energy

OneWay

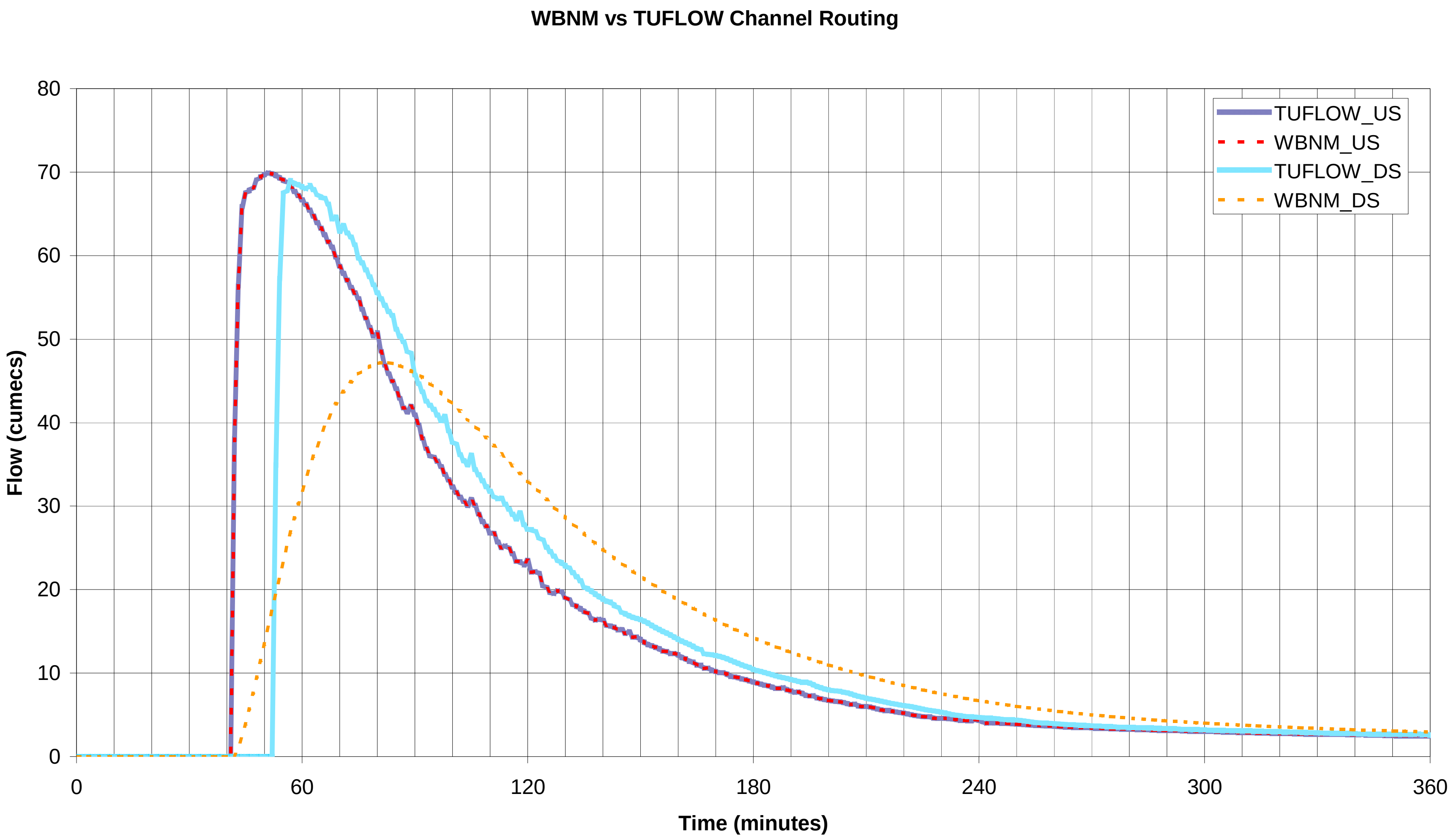
Worley Parsons Services Pty. Ltd.
ABN 61 001 279 812
PO Box 1757, Sunshine Plaza, QLD 4558
Ph. (07) 5475 6400 Fax. (07) 5475 6499

File Path : G:\301015\00042 Burpengary Caboolture Hydraulic Modelling\10.0 Engineering\BUR DES Item\MapInfo\Workspaces

Projection Trans. Merc. MGA56(GDA 94)

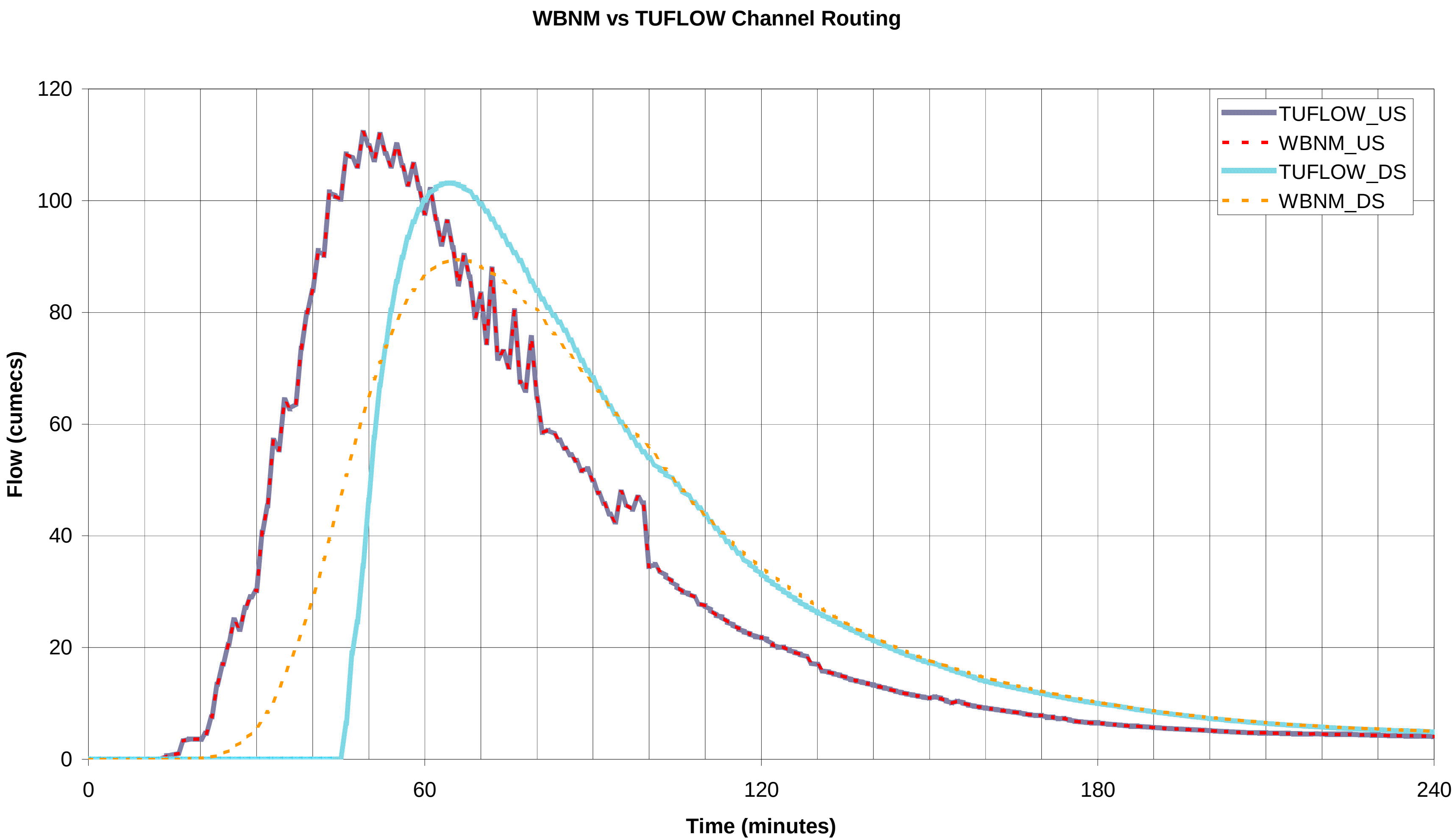
WBNM CATCHMENT: BUR_01_33610

(WBNM Lag Parameter = 1.47)



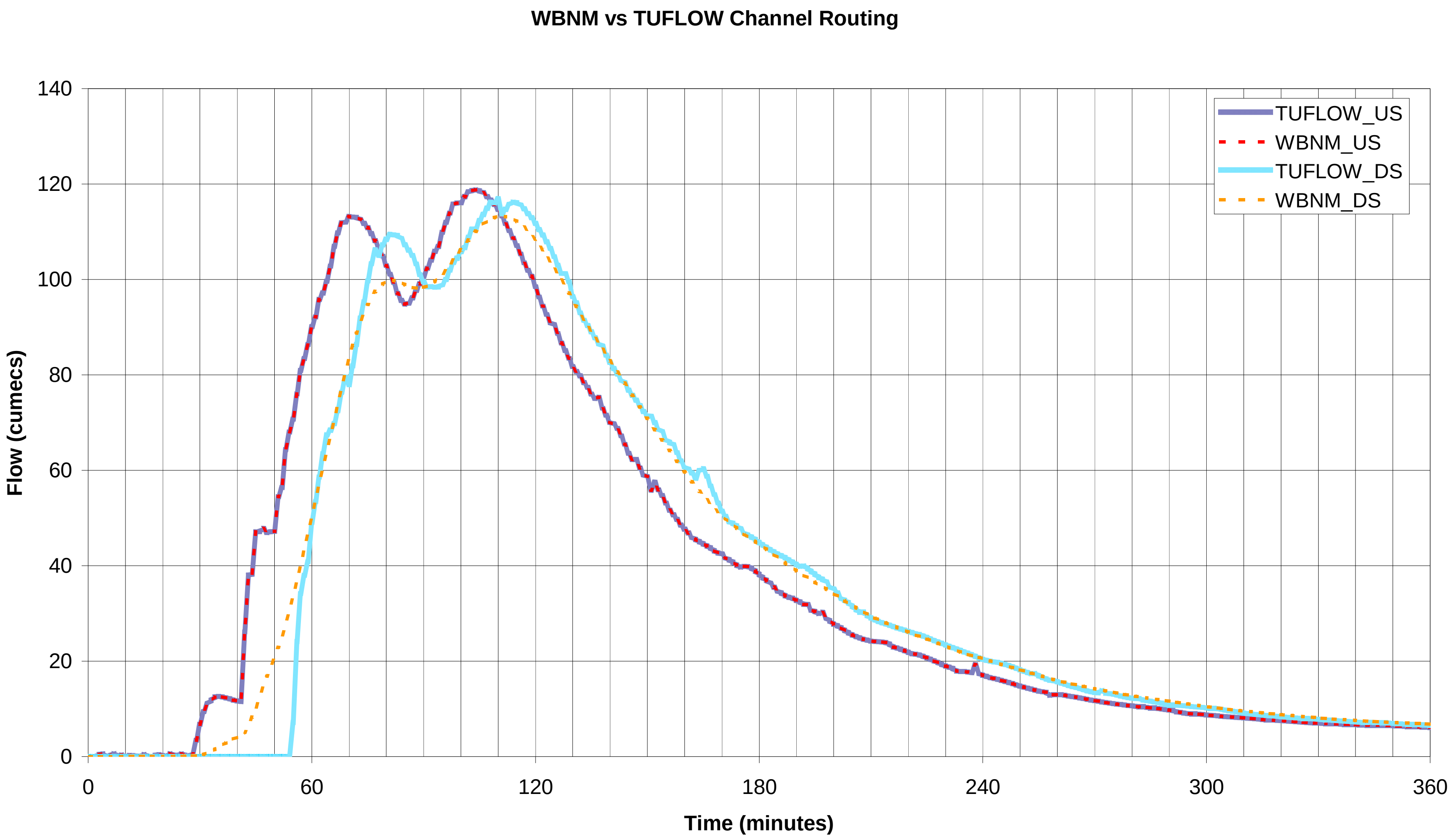
WBNM CATCHMENT: BUR_06_00529

(WBNM Lag Parameter = 1.47)



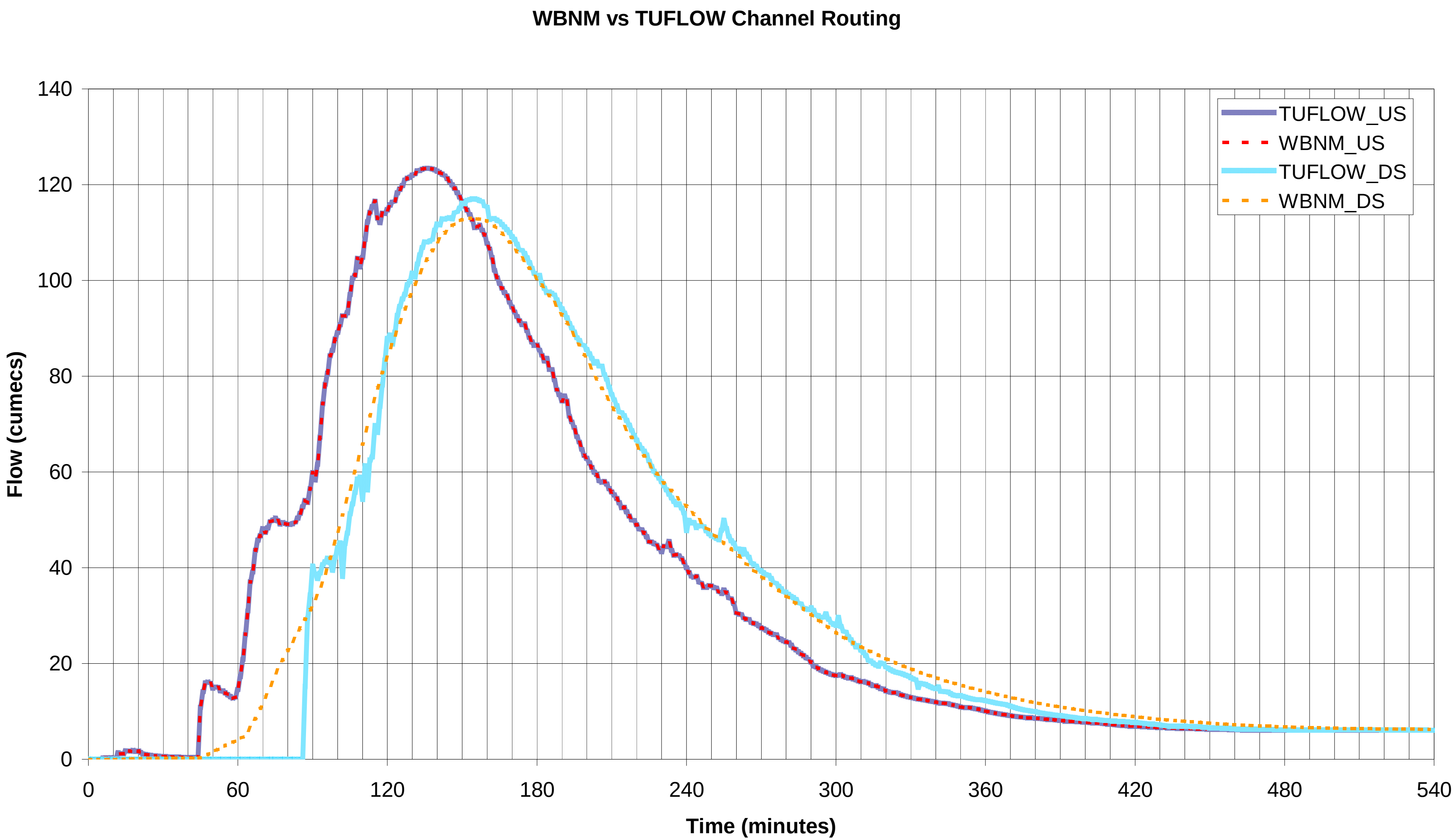
WBNM CATCHMENT: BUR_01_27228

(WBNM Lag Parameter = 1.47)



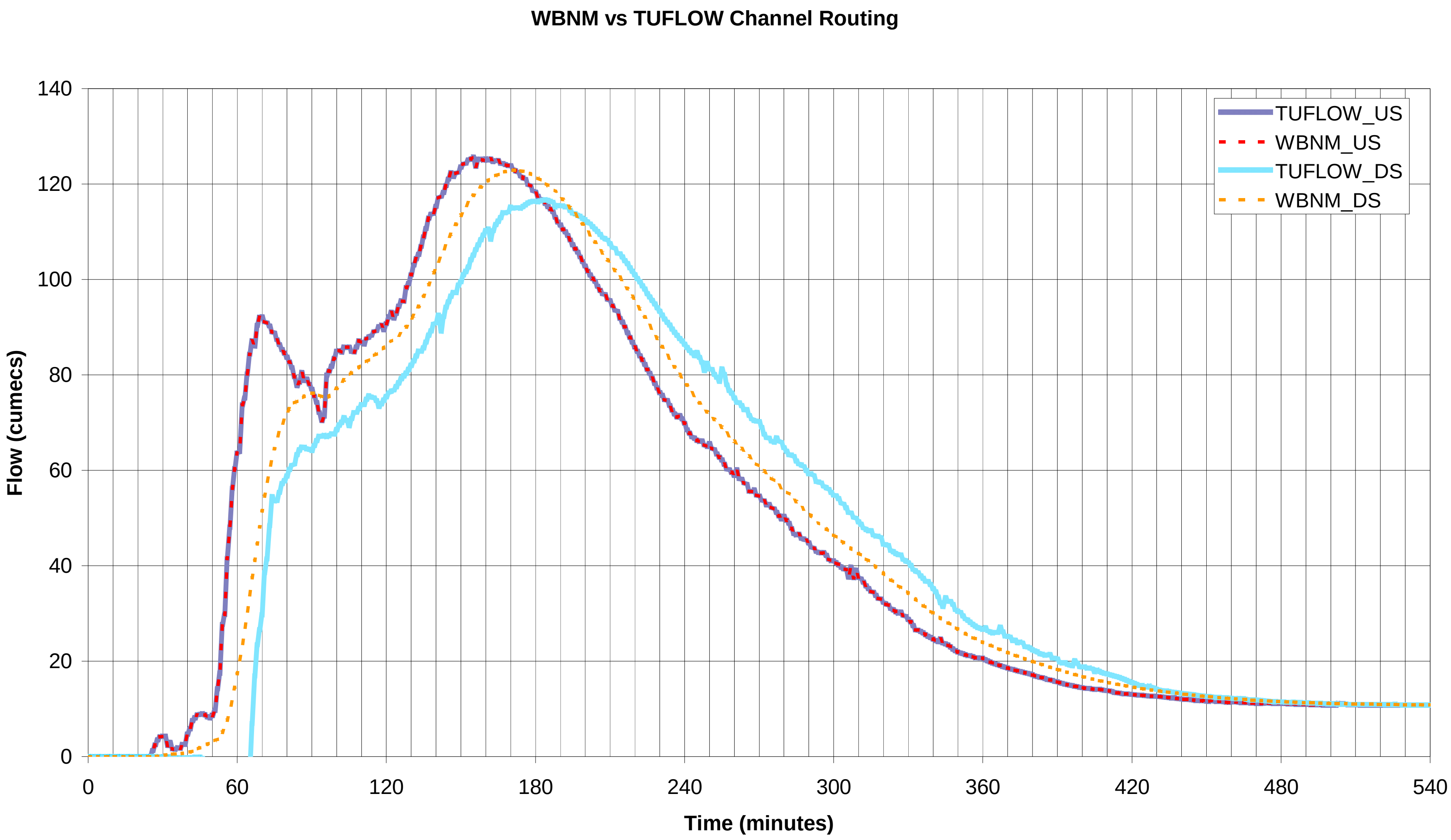
WBNM CATCHMENT: BUR_01_20827

(WBNM Lag Parameter = 1.47)



WBNM CATCHMENT: BUR_01_18437

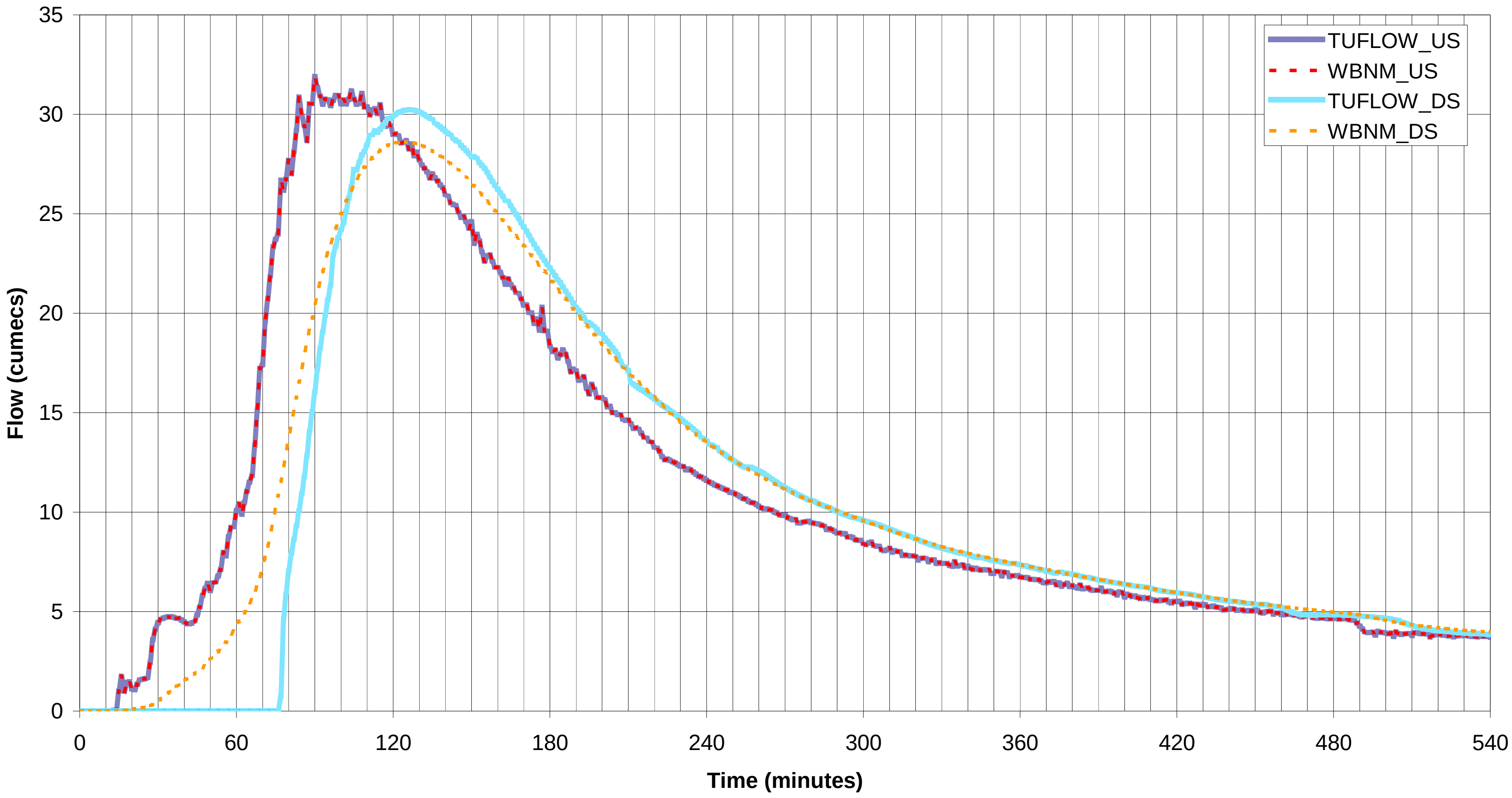
(WBNM Lag Parameter = 1.47)



WBNM CATCHMENT: LBC_01_06336

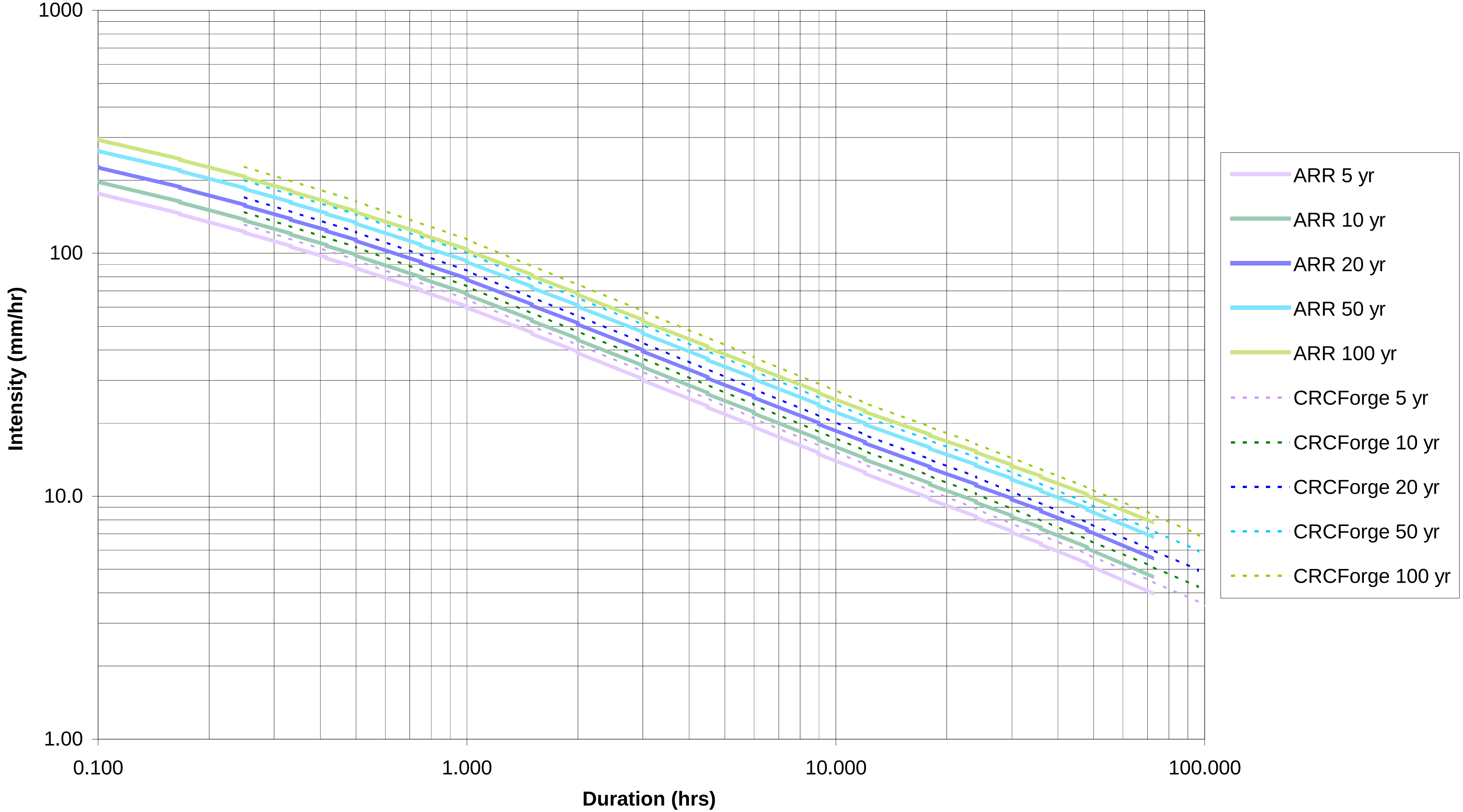
(WBNM Lag Parameter = 1.47)

WBNM vs TUFLOW Channel Routing

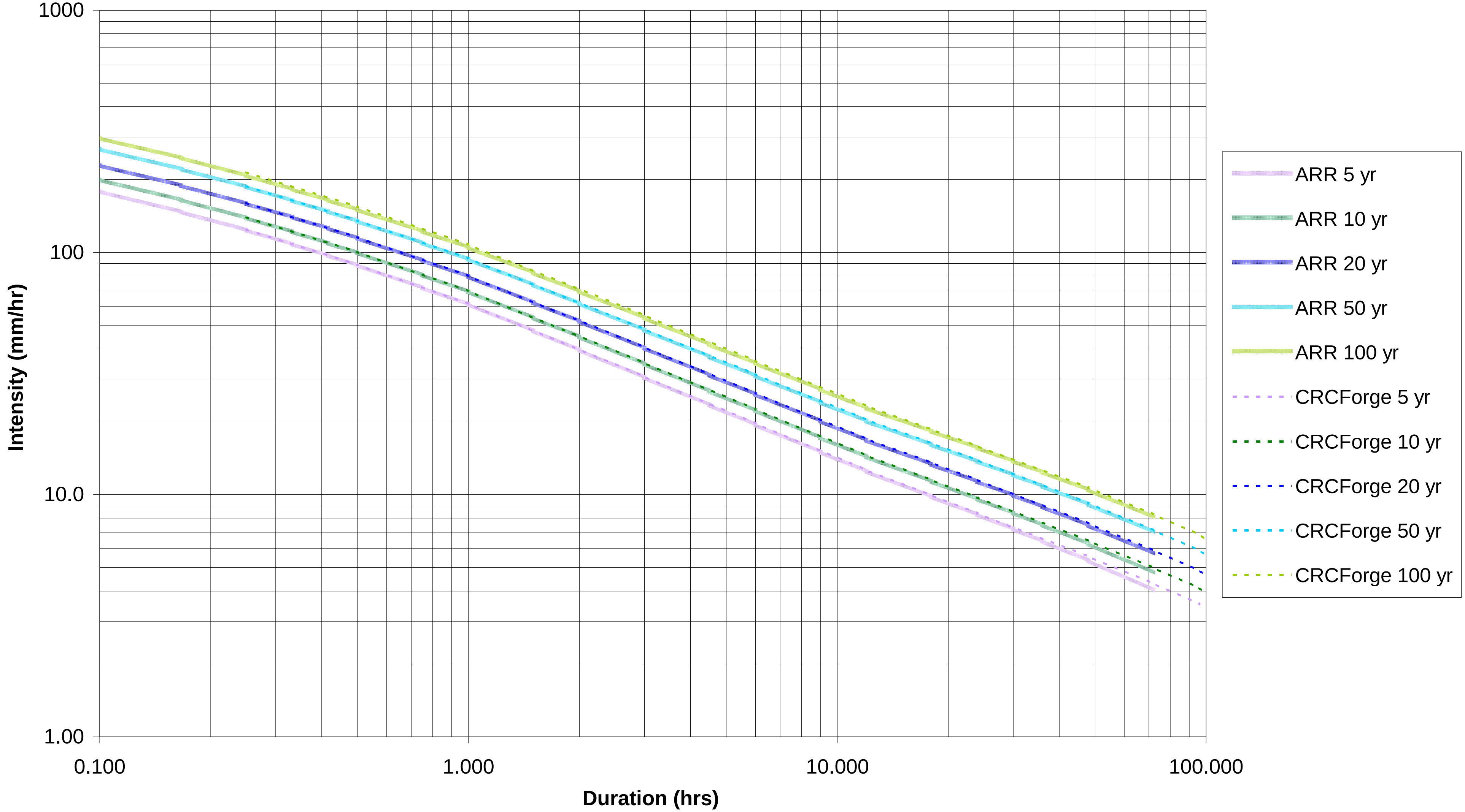


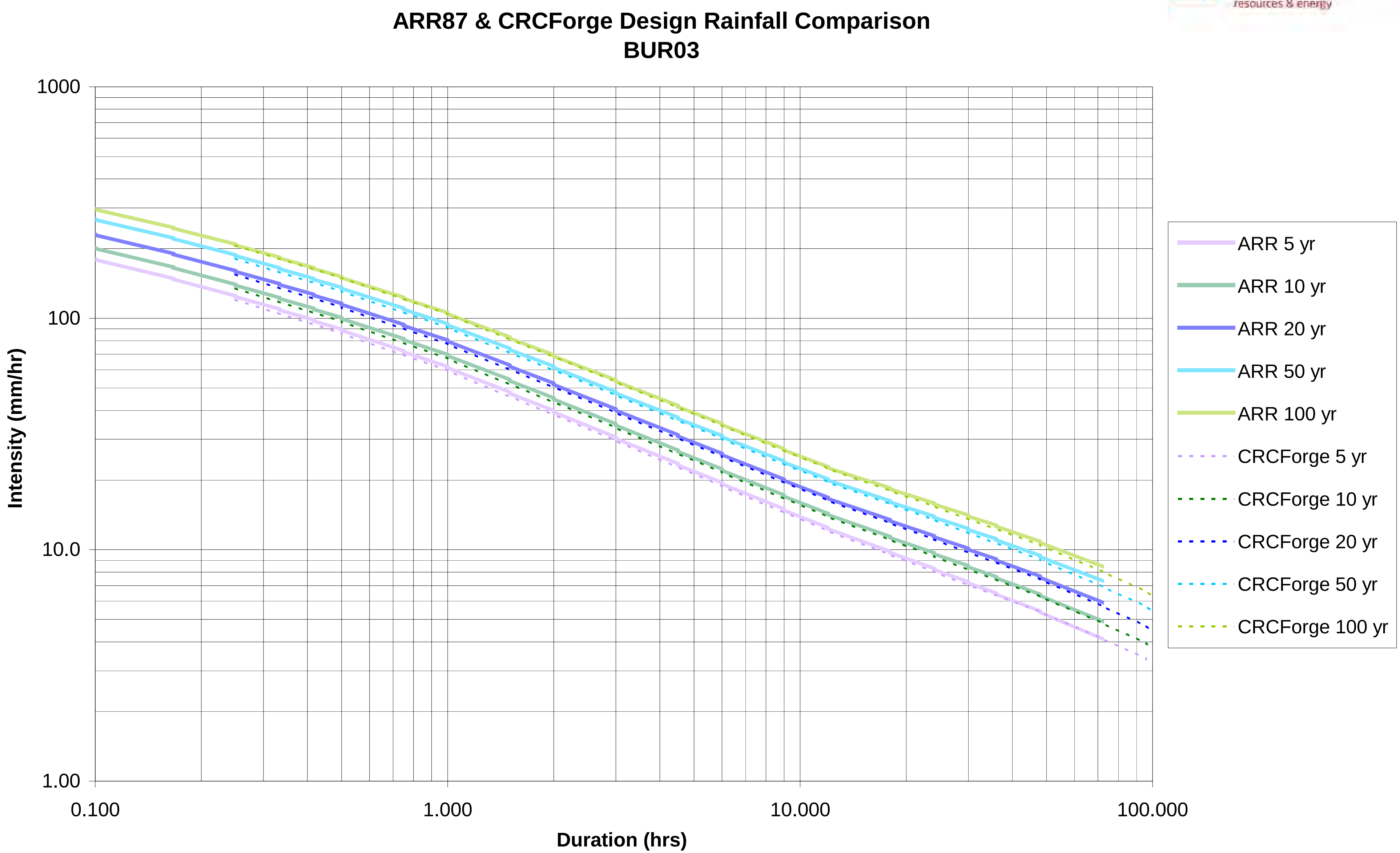
Appendix 3 - ARR87 vs CRCForge Rainfall Intensities

ARR87 & CRCForge Design Rainfall Comparison
BUR01



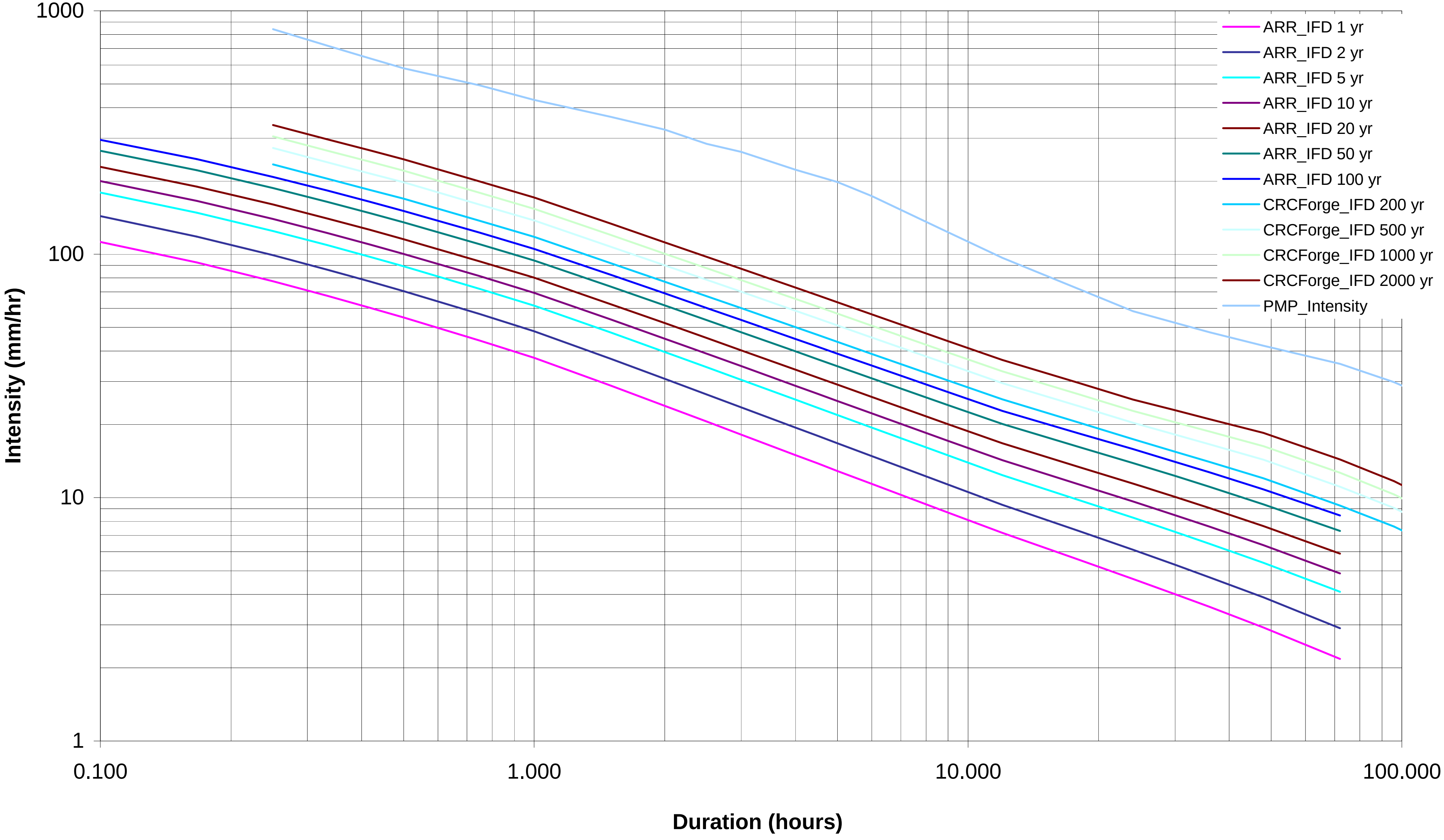
ARR87 & CRCForge Design Rainfall Comparison
BUR02

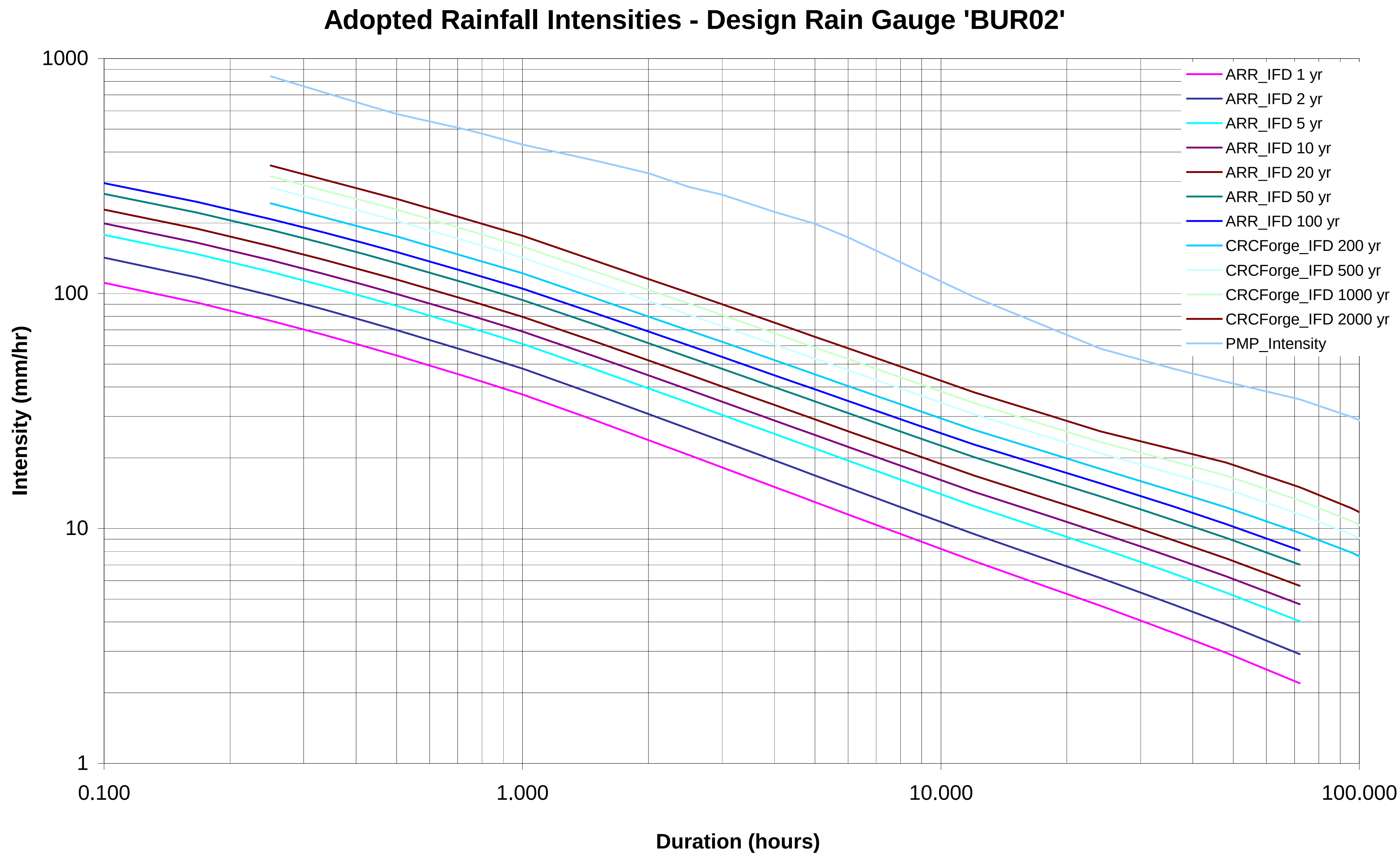



ARR87 & CRCForge Design Rainfall Comparison
BUR03
1000
100
10.0
1.00
Intensity (mm/hr)
0.100
1.000
10.000
100.000
Duration (hrs)
ARR 5 yr
ARR 10 yr
ARR 20 yr
ARR 50 yr
ARR 100 yr
CRCForge 5 yr
CRCForge 10 yr
CRCForge 20 yr
CRCForge 50 yr
CRCForge 100 yr

Appendix 4 - Adopted Rainfall Intensities

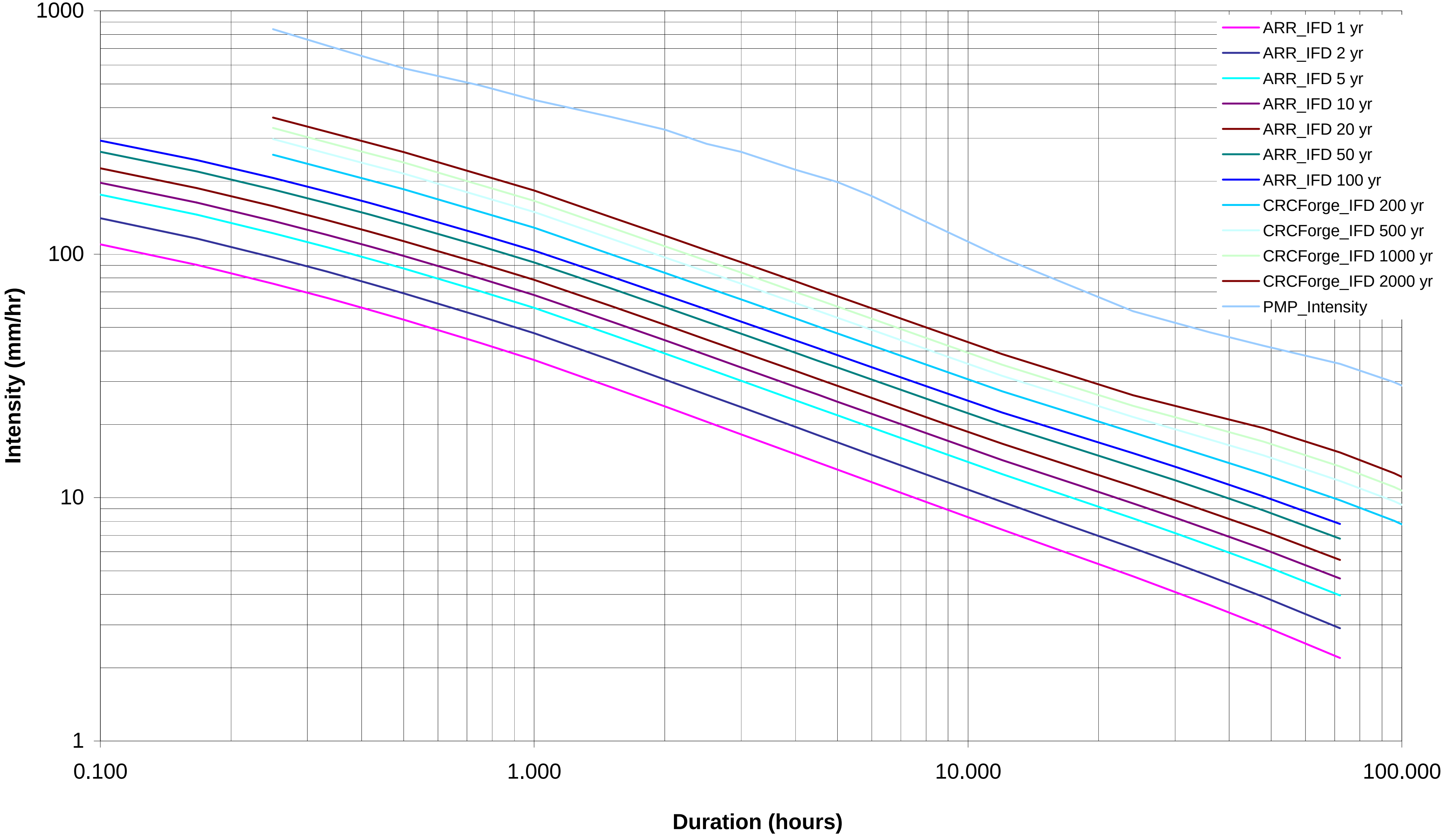
Adopted Rainfall Intensities - Design Rain Gauge 'BUR03'





Adopted Rainfall Intensities - Design Rain Gauge 'BUR02'
1000
100
10
1
0.100
1.000
10.000
100.000
Intensity (mm/hr)
Duration (hours)
ARR_IFD 1 yr
ARR_IFD 2 yr
ARR_IFD 5 yr
ARR_IFD 10 yr
ARR_IFD 20 yr
ARR_IFD 50 yr
ARR_IFD 100 yr
CRCForge_IFD 200 yr
CRCForge_IFD 500 yr
CRCForge_IFD 1000 yr
CRCForge_IFD 2000 yr
PMP_Intensity

Adopted Rainfall Intensities - Design Rain Gauge 'BUR01'



WorleyParsons

Design Rainfall Gauge 'BUR01'

Rainfall Intensity (mm/hr)

DURATION		AVERAGE RECURRENCE INTERVAL (years)									
		1	2	5	10	20	50	100	200	500	1000
(hours)	(minutes)	ARR_IFD 1 yr	ARR_IFD 2 yr	ARR_IFD 5 yr	ARR_IFD 10 yr	ARR_IFD 20 yr	ARR_IFD 50 yr	ARR_IFD 100 yr	CRCForge_IFD 200 yr	CRCForge_IFD 500 yr	CRCForge_IFD 10(
0.083	5	117.71	150.48	188.04	210.26	240.76	281.31	312.67			
0.167	10	90.50	115.88	145.38	162.91	186.88	218.81	243.55			
0.25	15	75.74	97.08	122.12	137.04	157.40	184.55	205.61	256.20	297.00	329.90
0.333	20	66.08	84.77	106.86	120.05	138.01	162.00	180.62	223.77	259.38	288.14
0.417	25	59.14	75.91	95.85	107.78	124.00	145.68	162.52	201.46	233.51	259.42
0.5	30	53.80	69.10	87.37	98.33	113.20	133.09	148.55	184.90	214.30	238.10
0.75	45	43.23	55.59	70.52	79.51	91.67	107.97	120.65	149.52	173.26	192.47
1	60	36.78	47.34	60.20	67.96	78.45	92.51	103.47	128.60	149.00	165.50
1.5	90	28.49	36.73	46.87	53.02	61.30	72.42	81.10	100.10	116.00	128.84
2	120	23.69	30.57	39.11	44.30	51.28	60.67	68.00	83.79	97.12	107.86
2.5	150	20.50	26.47	33.93	38.48	44.58	52.79	59.22	73.00	84.62	93.98
3	180	18.21	23.53	30.22	34.29	39.76	47.13	52.90	65.22	75.61	83.97
4	240	15.09	19.52	25.13	28.56	33.15	39.35	44.21	54.42	63.08	70.06
4.5	270	13.97	18.08	23.30	26.50	30.78	36.55	41.08	50.53	58.57	65.06
5	300	13.04	16.88	21.78	24.79	28.80	34.22	38.47	47.29	54.81	60.88
6	360	11.58	15.00	19.39	22.07	25.67	30.53	34.34	42.16	48.87	54.28
9	540	8.900	11.54	14.97	17.09	19.90	23.71	26.71	32.70	37.90	42.10
12	720	7.388	9.593	12.48	14.26	16.62	19.84	22.36	27.31	31.65	35.16
18	1080	5.705	7.437	9.773	11.23	13.16	15.79	17.86	21.78	25.25	28.04
24	1440	4.743	6.201	8.210	9.471	11.14	13.41	15.22	18.51	21.46	23.83
30	1800	4.095	5.366	7.146	8.271	9.750	11.78	13.39	16.31	19.09	21.37
36	2160	3.623	4.756	6.365	7.386	8.726	10.57	12.04	14.71	17.36	19.56
48	2880	2.969	3.909	5.274	6.146	7.289	8.865	10.13	12.50	14.93	17.00
72	4320	2.194	2.903	3.964	4.650	5.545	6.788	7.787	9.743	11.72	13.42
96	5760								8.040	9.662	11.05
120	7200								6.706	8.043	9.180

Rainfall Depths (mm)

DURATION		AVERAGE RECURRENCE INTERVAL (years)									
		1	2	5	10	20	50	100	200	500	1000
(hours)	(minutes)	ARR_IFD 1 yr	ARR_IFD 2 yr	ARR_IFD 5 yr	ARR_IFD 10 yr	ARR_IFD 20 yr	ARR_IFD 50 yr	ARR_IFD 100 yr	CRCForge_IFD 200 yr	CRCForge_IFD 500 yr	CRCForge_IFD 10(
0.083	0005	9.81	12.54	15.67	17.52	20.06	23.44	26.06			
0.167	0010	15.08	19.31	24.23	27.15	31.15	36.47	40.59			
0.25	0015	18.93	24.27	30.53	34.26	39.35	46.14	51.40	64.05	74.25	82.48
0.333	0020	22.03	28.26	35.62	40.02	46.00	54.00	60.21	74.59	86.46	96.05
0.417	0025	24.64	31.63	39.94	44.91	51.67	60.70	67.72	83.94	97.30	108.09
0.5	0030	26.90	34.55	43.69	49.16	56.60	66.54	74.27	92.45	107.15	119.05
0.75	0045	32.42	41.69	52.89	59.63	68.75	80.97	90.49	112.14	129.94	144.35
1	0060	36.78	47.34	60.20	67.96	78.45	92.51	103.47	128.60	149.00	165.50
1.5	0090	42.74	55.09	70.31	79.52	91.94	108.63	121.65	150.14	174.00	193.26
2	0120	47.38	61.14	78.23	88.60	102.56	121.33	136.00	167.58	194.24	215.73
2.5	0150	51.24	66.17	84.83	96.19	111.45	131.99	148.05	182.50	211.55	234.95
3	0180	54.62	70.58	90.65	102.87	119.28	141.38	158.69	195.66	226.83	251.91
4	0240	60.36	78.07	100.52	114.24	132.62	157.41	176.84	217.67	252.33	280.25
4.5	0270	62.87	81.36	104.87	119.25	138.50	164.49	184.87	227.38	263.58	292.75
5	0300	65.22	84.42	108.92	123.93	143.99	171.10	192.36	236.43	274.07	304.40
6	0360	69.48	90.00	116.31	132.45	154.01	183.16	206.04	252.96	293.22	325.68
9	0540	80.10	103.90	134.77	153.78	179.12	213.43	240.41	294.33	341.13	378.93
12	0720	88.66	115.12	149.71	171.06	199.49	238.02	268.36	327.72	379.80	421.92
18	1080	102.69	133.87	175.91	202.13	236.83	284.13	321.53	392.04	454.50	504.72
24	1440	113.84	148.83	197.03	227.31	267.24	321.86	365.19	444.24	515.04	571.92
30	1800	122.86	160.99	214.38	248.12	292.50	353.37	401.78	489.37	572.83	641.25
36	2160	130.42	171.22	229.13	265.89	314.15	380.52	433.41	529.63	624.83	704.09
48	2880	142.51	187.65	253.13	295.03	349.85	425.53	486.07	600.00	716.64	816.00
72	4320	158.00	209.02	285.40	334.82	399.25	488.73	560.67	701.50	843.84	966.24
96	5760								771.84	927.55	1060.80
120	7200								804.72	965.16	1101.60

Design Rainfall Gauge 'BUR02'

Rainfall Intensity (mm/hr)

DURATION		AVERAGE RECURRENCE INTERVAL (years)									
		1	2	5	10	20	50	100	200	500	1000
(hours)	(minutes)	ARR_IFD 1 yr	ARR_IFD 2 yr	ARR_IFD 5 yr	ARR_IFD 10 yr	ARR_IFD 20 yr	ARR_IFD 50 yr	ARR_IFD 100 yr	CRCForge_IFD 200 yr	CRCForge_IFD 500 yr	CRCForge_IFD 10(
0.083	5	119.07	152.14	190.08	212.37	242.94	283.42	314.63			
0.167	10	91.56	117.19	147.06	164.70	188.79	220.75	245.45			
0.25	15	76.63	98.19	123.59	138.64	159.12	186.36	207.42	242.30	282.50	315.20
0.333	20	66.86	85.76	108.18	121.51	139.61	163.70	182.35	211.69	246.85	275.41
0.417	25	59.84	76.80	97.07	109.13	125.50	147.29	164.18	190.64	222.32	248.03
0.5	30	54.44	69.92	88.51	99.59	114.61	134.63	150.15	175.00	204.10	227.70
0.75	45	43.74	56.26	71.48	80.60	92.90	109.34	122.10	141.64	165.14	184.28
1	60	37.22	47.92	61.05	68.93	79.55	93.76	104.81	121.90	142.10	158.60
1.5	90	28.70	37.02	47.42	53.69	62.12	73.41	82.21	95.13	110.90	123.77
2	120	23.78	30.72	39.50	44.82	51.94	61.50	68.97	79.78	93.01	103.80
2.5	150	20.52	26.54	34.22	38.89	45.13	53.52	60.08	69.60	81.15	90.56
3	180	18.19	23.55	30.44	34.64	40.24	47.78	53.68	62.26	72.59	81.00
4	240	15.02	19.48	25.27	28.82	33.54	39.90	44.89	52.04	60.68	67.71
4.5	270	13.89	18.02	23.42	26.73	31.13	37.07	41.72	48.36	56.38	62.92
5	300	12.95	16.81	21.88	24.99	29.12	34.70	39.08	45.28	52.80	58.92
6	360	11.47	14.90	19.44	22.24	25.94	30.96	34.90	40.42	47.13	52.59
9	540	8.773	11.42	14.98	17.19	20.10	24.05	27.16	31.44	36.65	40.89
12	720	7.257	9.463	12.46	14.32	16.78	20.12	22.75	26.30	30.66	34.21
18	1080	5.625	7.365	9.799	11.33	13.33	16.07	18.25	21.05	24.55	27.39
24	1440	4.690	6.158	8.255	9.581	11.32	13.70	15.59	17.94	20.92	23.35
30	1800	4.059	5.340	7.202	8.385	9.930	12.06	13.75	15.90	18.69	21.00
36	2160	3.597	4.742	6.426	7.502	8.905	10.84	12.38	14.40	17.05	19.26
48	2880	2.956	3.909	5.341	6.262	7.460	9.118	10.45	12.32	14.74	16.80
72	4320	2.195	2.916	4.033	4.760	5.702	7.014	8.070	9.577	11.50	13.15
96	5760								7.879	9.422	10.73
120	7200								6.501	7.759	8.812

Rainfall Depths (mm)

DURATION		AVERAGE RECURRENCE INTERVAL (years)									
		1	2	5	10	20	50	100	200	500	1000
(hours)	(minutes)	ARR_IFD 1 yr	ARR_IFD 2 yr	ARR_IFD 5 yr	ARR_IFD 10 yr	ARR_IFD 20 yr	ARR_IFD 50 yr	ARR_IFD 100 yr	CRCForge_IFD 200 yr	CRCForge_IFD 500 yr	CRCForge_IFD 10(
0.083	0005	9.92	12.68	15.84	17.70	20.24	23.62	26.22			
0.167	0010	15.26	19.53	24.51	27.45	31.46	36.79	40.91			
0.25	0015	19.16	24.55	30.90	34.66	39.78	46.59	51.86	60.58	70.63	78.80
0.333	0020	22.29	28.59	36.06	40.50	46.54	54.57	60.78	70.56	82.28	91.80
0.417	0025	24.93	32.00	40.44	45.47	52.29	61.37	68.41	79.43	92.63	103.35
0.5	0030	27.22	34.96	44.25	49.80	57.30	67.31	75.07	87.50	102.05	113.85
0.75	0045	32.81	42.20	53.61	60.45	69.68	82.00	91.58	106.23	123.86	138.21
1	0060	37.22	47.92	61.05	68.93	79.55	93.76	104.81	121.90	142.10	158.60
1.5	0090	43.05	55.54	71.12	80.54	93.17	110.11	123.31	142.69	166.35	185.65
2	0120	47.56	61.45	78.99	89.63	103.87	123.00	137.93	159.56	186.02	207.59
2.5	0150	51.30	66.35	85.55	97.23	112.83	133.81	150.21	174.01	202.88	226.39
3	0180	54.56	70.64	91.31	103.91	120.71	143.34	161.05	186.78	217.77	243.00
4	0240	60.08	77.90	101.08	115.27	134.14	159.61	179.57	208.16	242.71	270.83
4.5	0270	62.50	81.08	105.37	120.27	140.06	166.80	187.76	217.61	253.72	283.12
5	0300	64.74	84.04	109.38	124.93	145.59	173.50	195.40	226.42	264.00	294.59
6	0360	68.82	89.42	116.66	133.43	155.66	185.75	209.37	242.52	282.78	315.54
9	0540	78.96	102.80	134.85	154.68	180.90	216.47	244.47	282.92	329.85	368.05
12	0720	87.09	113.56	149.53	171.87	201.36	241.43	273.03	315.60	367.92	410.52
18	1080	101.26	132.56	176.38	203.89	240.00	289.34	328.42	378.90	441.90	493.02
24	1440	112.57	147.79	198.12	229.94	271.58	328.68	374.06	430.56	502.08	560.40
30	1800	121.76	160.21	216.05	251.55	297.91	361.67	412.46	476.87	560.70	630.06
36	2160	129.48	170.71	231.34	270.07	320.57	390.18	445.76	518.38	613.64	693.35
48	2880	141.90	187.65	256.35	300.58	358.09	437.67	501.44	591.36	707.52	806.40
72	4320	158.04	209.96	290.36	342.70	410.54	504.98	581.06	689.54	828.00	946.80
96	5760								756.38	904.51	1030.08
120	7200								780.12	931.08	1057.44

Design Rainfall Gauge 'BUR03'

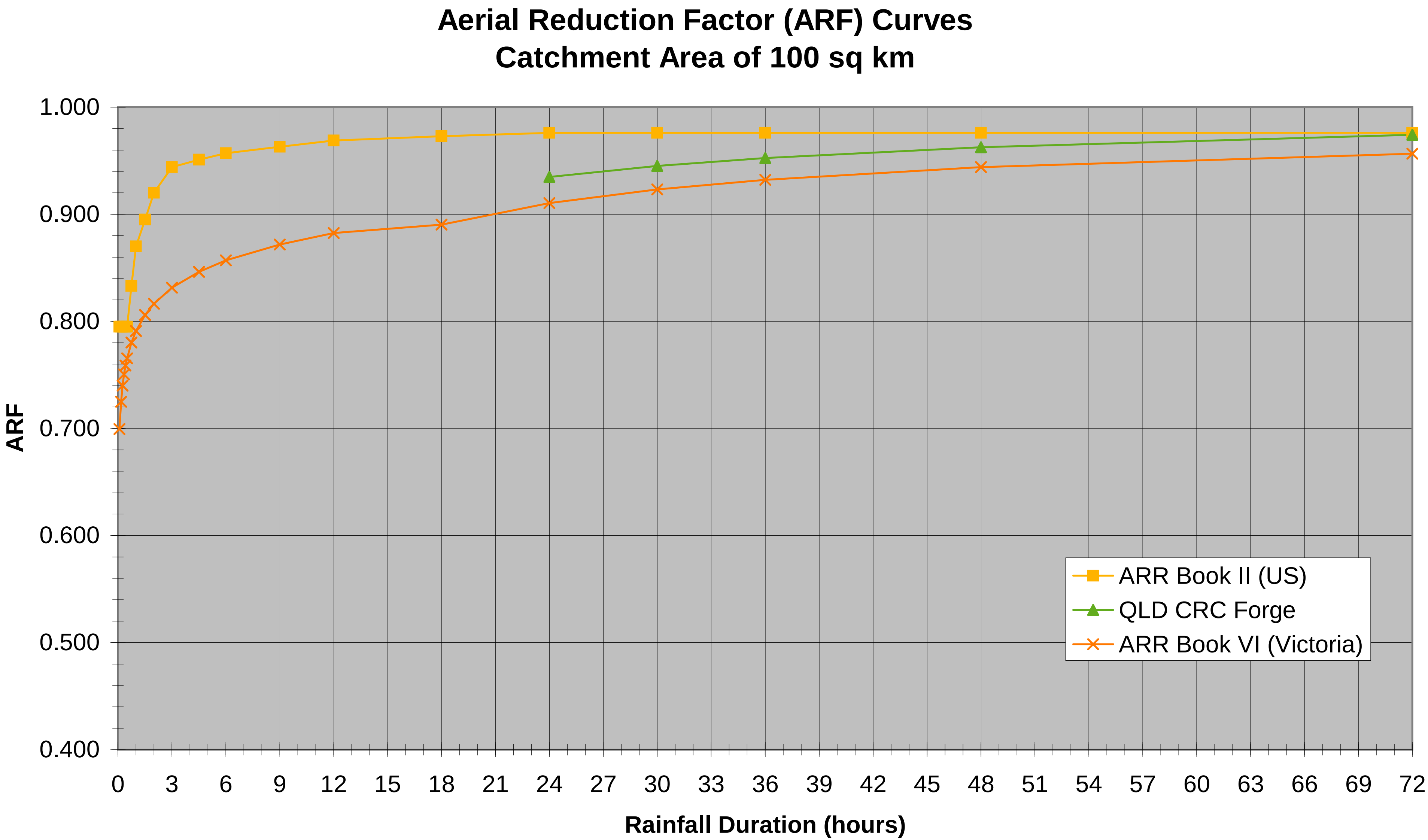
Rainfall Intensity (mm/hr)

DURATION		AVERAGE RECURRENCE INTERVAL (years)									
		1	2	5	10	20	50	100	200	500	1000
(hours)	(minutes)	ARR_IFD 1 yr	ARR_IFD 2 yr	ARR_IFD 5 yr	ARR_IFD 10 yr	ARR_IFD 20 yr	ARR_IFD 50 yr	ARR_IFD 100 yr	CRCForge_IFD 200 yr	CRCForge_IFD 500 yr	CRCForge_IFD 10(
0.083	5	120.31	153.56	191.55	213.69	244.05	284.10	314.84			
0.167	10	92.47	118.24	148.20	165.76	189.72	221.39	245.76			
0.25	15	77.36	99.05	124.54	139.54	159.95	186.96	207.78	233.80	273.10	305.10
0.333	20	67.48	86.49	109.02	122.31	140.35	164.27	182.72	204.38	238.73	266.68
0.417	25	60.38	77.44	97.81	109.86	126.18	147.84	164.56	184.14	215.08	240.24
0.5	30	54.92	70.49	89.19	100.27	115.25	135.15	150.53	169.10	197.50	220.60
0.75	45	44.11	56.70	72.03	81.15	93.45	109.81	122.47	136.94	159.87	178.64
1	60	37.52	48.28	61.52	69.41	80.04	94.20	105.16	117.90	137.60	153.80
1.5	90	28.83	37.19	47.67	53.96	62.39	73.66	82.41	91.93	107.31	119.94
2	120	23.83	30.79	39.64	44.98	52.11	61.65	69.08	77.05	89.96	100.54
2.5	150	20.52	26.55	34.29	38.99	45.24	53.62	60.15	67.19	78.46	87.68
3	180	18.16	23.52	30.47	34.69	40.30	47.84	53.72	60.08	70.16	78.40
4	240	14.96	19.41	25.25	28.82	33.55	39.91	44.89	50.19	58.62	65.50
4.5	270	13.82	17.94	23.38	26.71	31.12	37.06	41.71	46.63	54.46	60.85
5	300	12.87	16.72	21.83	24.96	29.10	34.68	39.06	43.66	50.99	56.98
6	360	11.38	14.80	19.38	22.19	25.91	30.92	34.86	38.96	45.50	50.84
9	540	8.674	11.31	14.90	17.12	20.04	24.00	27.11	30.28	35.35	39.50
12	720	7.157	9.346	12.37	14.24	16.71	20.05	22.69	25.32	29.56	33.03
18	1080	5.554	7.289	9.776	11.34	13.38	16.17	18.38	20.36	23.77	26.56
24	1440	4.634	6.104	8.265	9.636	11.42	13.87	15.82	17.40	20.32	22.71
30	1800	4.013	5.300	7.231	8.465	10.07	12.27	14.03	15.44	18.16	20.40
36	2160	3.558	4.711	6.468	7.597	9.060	11.08	12.70	14.01	16.57	18.69
48	2880	2.927	3.890	5.396	6.373	7.636	9.389	10.80	12.01	14.33	16.28
72	4320	2.176	2.909	4.099	4.881	5.890	7.301	8.442	9.265	11.09	12.64
96	5760								7.601	9.071	10.31
120	7200								6.268	7.470	8.475

Rainfall Depths (mm)

DURATION		AVERAGE RECURRENCE INTERVAL (years)									
		1	2	5	10	20	50	100	200	500	1000
(hours)	(minutes)	ARR_IFD 1 yr	ARR_IFD 2 yr	ARR_IFD 5 yr	ARR_IFD 10 yr	ARR_IFD 20 yr	ARR_IFD 50 yr	ARR_IFD 100 yr	CRCForge_IFD 200 yr	CRCForge_IFD 500 yr	CRCForge_IFD 10(
0.083	0005	10.03	12.80	15.96	17.81	20.34	23.67	26.24			
0.167	0010	15.41	19.71	24.70	27.63	31.62	36.90	40.96			
0.25	0015	19.34	24.76	31.13	34.88	39.99	46.74	51.94	58.45	68.28	76.28
0.333	0020	22.49	28.83	36.34	40.77	46.78	54.76	60.91	68.13	79.58	88.89
0.417	0025	25.16	32.27	40.76	45.78	52.58	61.60	68.57	76.73	89.61	100.10
0.5	0030	27.46	35.24	44.59	50.13	57.63	67.58	75.26	84.55	98.75	110.30
0.75	0045	33.08	42.53	54.02	60.86	70.09	82.36	91.85	102.70	119.90	133.98
1	0060	37.52	48.28	61.52	69.41	80.04	94.20	105.16	117.90	137.60	153.80
1.5	0090	43.24	55.78	71.50	80.94	93.59	110.48	123.61	137.89	160.97	179.90
2	0120	47.66	61.58	79.27	89.95	104.21	123.30	138.16	154.11	179.92	201.07
2.5	0150	51.30	66.37	85.74	97.47	113.09	134.04	150.38	167.98	196.14	219.19
3	0180	54.48	70.56	91.40	104.07	120.90	143.51	161.16	180.24	210.48	235.20
4	0240	59.83	77.62	101.01	115.27	134.19	159.65	179.56	200.78	234.47	262.00
4.5	0270	62.17	80.72	105.22	120.20	140.04	166.77	187.69	209.85	245.07	273.84
5	0300	64.35	83.59	109.15	124.80	145.50	173.42	195.28	218.31	254.95	284.88
6	0360	68.29	88.81	116.29	133.16	155.45	185.55	209.14	233.76	273.00	305.04
9	0540	78.06	101.76	134.08	154.05	180.35	215.96	243.95	272.51	318.19	355.54
12	0720	85.89	112.15	148.42	170.93	200.50	240.64	272.25	303.84	354.72	396.36
18	1080	99.97	131.20	175.96	204.10	240.86	291.07	330.83	366.48	427.86	478.08
24	1440	111.23	146.50	198.35	231.26	274.07	332.84	379.57	417.60	487.68	545.04
30	1800	120.38	159.01	216.93	253.94	301.99	368.17	420.97	463.27	544.77	612.07
36	2160	128.09	169.59	232.83	273.49	326.16	398.94	457.16	504.28	596.35	672.91
48	2880	140.49	186.73	259.01	305.92	366.53	450.69	518.31	576.48	687.84	781.44
72	4320	156.68	209.46	295.10	351.47	424.07	525.66	607.83	667.08	798.48	910.08
96	5760								729.70	870.82	989.76
120	7200								752.16	896.40	1017.00

Appendix 5 - ARF Curve Comparison



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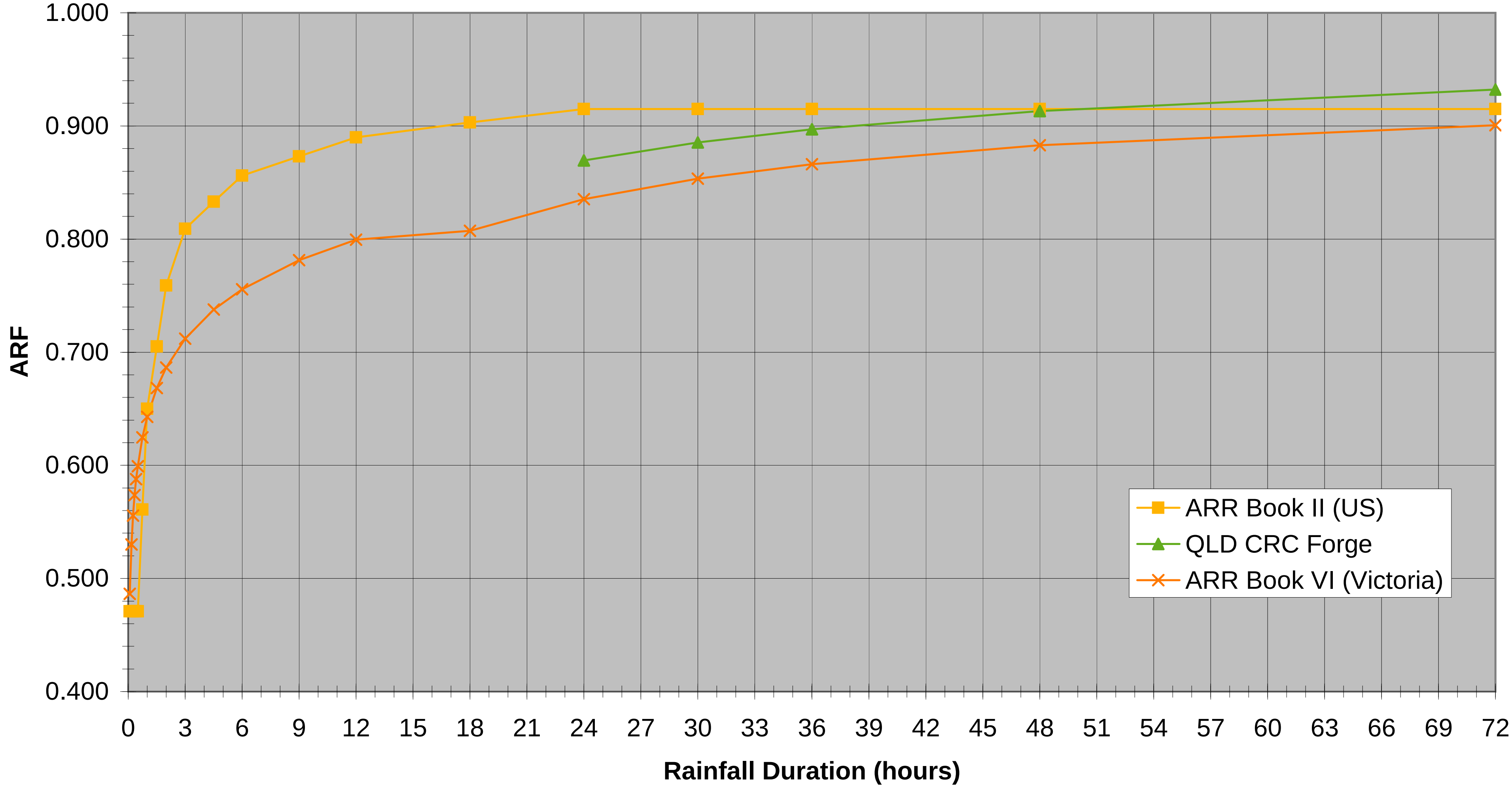
Aerial Reduction Factor (ARF) Curves
Catchment Area of 1000 sq km



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Appendix 6 - Customised ARF Application

WorleyParsons
resources & energy

Customised ARF Application: "Incremental ARF Method"

A customised method for applying Aerial Reduction Factors (ARFs) referred to as the Incremental ARF method has been developed for potential use in the RFD. This method involves calculating ARF values for each local sub-catchment based on the value required to reduce the average contributing catchment ARF to the desired value.

The concept is demonstrated in a simple 3 sub-catchment example below.

Table 1.0 – Customised ARF Application - Example Case

Sub-Catchment ID	Downstream Sub-Catchment	Local Sub-Catchment Area (LA)	Total Contributing Area (TA)	Desired ARF (for total contributing area) (darf)	Local sub-catchment ARF required (Larf)
SUB01	SUB03	100 km^2	100 km^2	0.96	0.96
SUB02	SUB03	200 km^2	200 km^2	0.93	0.93
SUB03	SINK	100 km^2	400 km^2	0.9	0.78

Where the SUB03 local catchment ARF ($Larf_{SUB03}$) value is calculated as follows:

$$Larf_{SUB03} = [Darf_{SUB03} \times TA_{SUB03} - LA_{SUB01} \times Larf_{SUB01} - LA_{SUB02} \times Larf_{SUB02}] / LA_{SUB03}$$

It is also necessary to define a minimum value for the local catchment ARF (Larf) for the following reasons:

- It is possible for the above formula to generate negative local catchment ARF values (For example at the confluence points of two or more large catchments).
- It may be considered un-desirable to have local catchment ARF values approaching zero.

Note that it is the Larf values which will be input the WBNM model.

This method has been successfully implemented in the BUR WBNM model and it has been demonstrated that the method generates appropriate catchment average rainfall intensities in both the upper and lower catchments.

Figures demonstrating the application of this technique to the BUR WBNM model are also provided. Figure 1 presents thematic mapping of the locally applied sub-catchment ARF values (Larf values). Figure 2 presents the average ARF values for the total catchments contributing to each sub-area.

An important limitation of this technique is that runoff generated from each sub-catchment should only be applied directly into a main reach and not into the top of local tributary. This lends itself to the SA Polygon approach which is currently being utilised for the RFD Project.

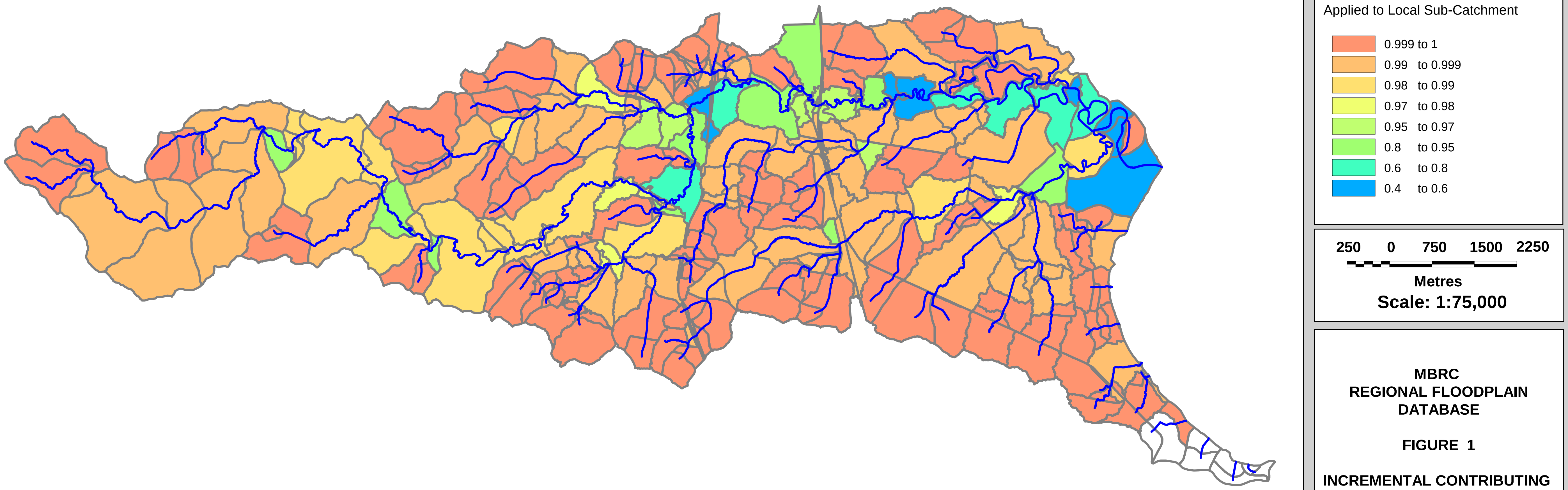

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FIGURE 1

INCREMENTAL CONTRIBUTING AREA ARF METHOD:

ARF VALUES APPLIED TO LOCAL SUB-CATCHMENTS

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PO Box 1757, Sunshine Plaza, QLD 4558
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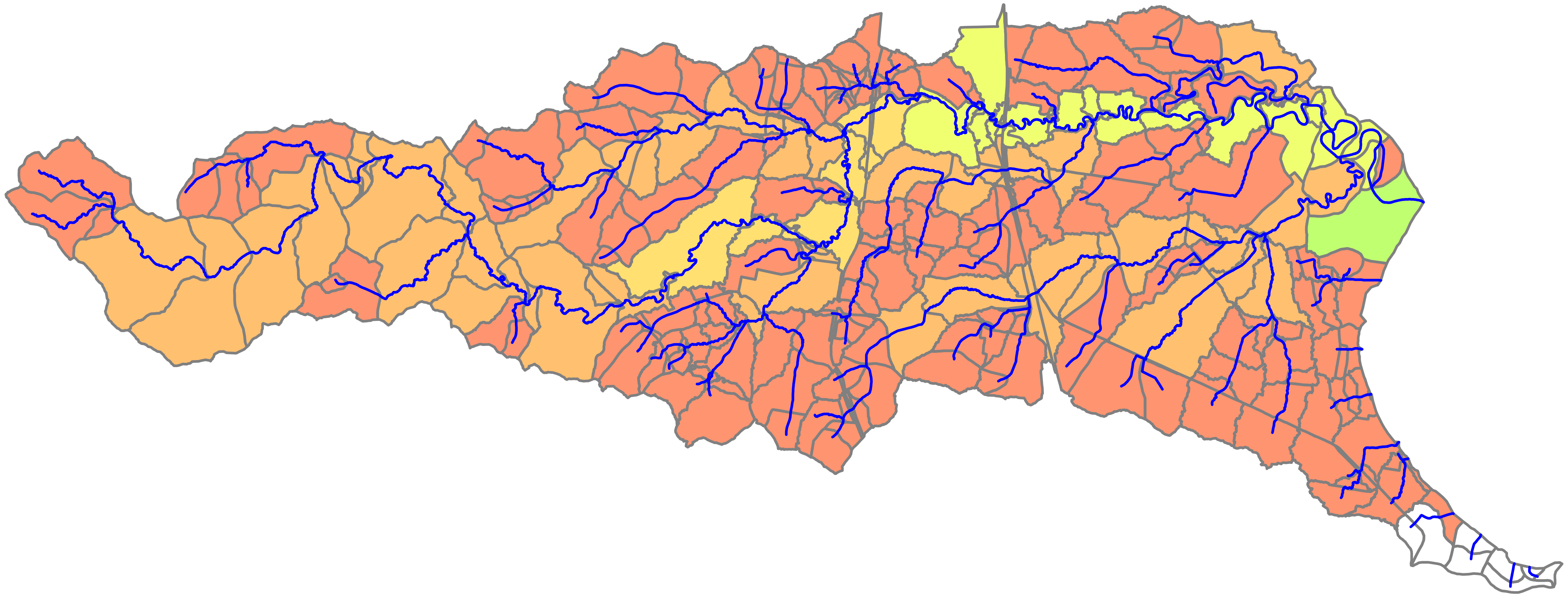
File Path : G:\301018\00042 - Burpengary Caboolture Hydraulic Modelling\10.0 Engineering\BUR_DES_Rain\MapInfo\Workspaces

Projection Trans. Merc. MGA56(GDA 94)



N
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ARF Value -
Contributing Catchment Area
(Area Weighted Average Value)

- 0.999 to 1
- 0.99 to 0.999
- 0.98 to 0.99
- 0.97 to 0.98
- 0.95 to 0.97
- 0.8 to 0.95
- 0.6 to 0.8
- 0.4 to 0.6

250 0 750 1500 2250

Metres

Scale: 1:75,000

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FIGURE 2

INCREMENTAL CONTRIBUTING AREA ARF METHOD:

AVERAGE CONTRIBUTING AREA ARF VALUES

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