FLINDERS AND GILBERT AGRICULTURAL RESOURCE ASSESSMENT

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Design flood hydrology for selected dam sites in the Flinders and Gilbert catchments

A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy

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The Strategy was guided by two committees:

(i) the **Program Governance Committee**, which included the individuals David Crombie (GRM International), Scott Spencer (SunWater, during the first part of the Strategy) and Paul Woodhouse (Regional Development Australia) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; and the Queensland Government.

(ii) the **Program Steering Committee**, which included the individual Jack Lake (Independent Expert) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; the Etheridge, Flinders and McKinlay shire councils; Gulf Savannah Development; Mount Isa to Townsville Economic Development Zone; and the Queensland Government.

This report was reviewed by Mr John Ruffini (Queensland Government), Dr Cuan Petheram (CSIRO) and Dr Peter Stone (CSIRO).

Director's foreword

Northern Australia comprises approximately 20% of Australia's land mass but remains relatively undeveloped. It contributes about 2% to the nation's gross domestic product (GDP) and accommodates around 1% of the total Australian population.

Recent focus on the shortage of water and on climate-based threats to food and fibre production in the nation's south have re-directed attention towards the possible use of northern water resources and the development of the agricultural potential in northern Australia. Broad analyses of northern Australia as a whole have indicated that it is capable of supporting significant additional agricultural and pastoral production, based on more intensive use of its land and water resources.

The same analyses also identified that land and water resources across northern Australia were already being used to support a wide range of highly valued cultural, environmental and economic activities. As a consequence, pursuit of new agricultural development opportunities would inevitably affect existing uses and users of land and water resources.

The Flinders and Gilbert catchments in north Queensland have been identified as potential areas for further agricultural development. The Flinders and Gilbert Agricultural Resource Assessment (the Assessment), of which this report is a part, provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in these two catchments as part of the North Queensland Irrigated Agricultural Strategy. The Assessment seeks to:

- identify and evaluate available soil and water resources
- quantify the productivity and scale of opportunities for irrigated agriculture
- quantify development costs and benefits and their distribution amongst different users.

By this means it seeks to support deliberation and decisions concerning sustainable regional development.

The Assessment differs from previous assessments of agricultural development or resources in two main ways:

- It has sought to 'join the dots'. Where previous assessments have focused on single development activities or assets – without analysing the interactions between them – this Assessment considers the opportunities presented by the simultaneous pursuit of multiple development activities and assets. By this means, the Assessment uses a whole-of-region (rather than an asset-by-asset) approach to consider development.
- The novel methods developed for the Assessment provide a blueprint for rapidly assessing future land and water developments in northern Australia.

Importantly, the Assessment has been designed to lower the barriers to investment in regional development by:

- explicitly addressing local needs and aspirations
- meeting the needs of governments as they regulate the sustainable and equitable management of public resources with due consideration of environmental and cultural issues
- meeting the due diligence requirements of private investors, by addressing questions of profitability and income reliability at a broad scale.

Most importantly, the Assessment does not recommend one development over another. It provides the reader with a range of possibilities and the information to interpret them, consistent with the reader's values and their aspirations for themselves and the region.

Peter Stone

Dr Peter Stone, Deputy Director, CSIRO Sustainable Agriculture Flagship

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Shortened forms

AEP	annual exceedance probability
AMTD	adopted middle thread distance
APSIM	Agricultural Production Systems Simulator
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
CMIP	Coupled Model Intercomparison Project
CRC-FORGE	Cooperative Research Centre – Focussed Rainfall Growth Estimation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	decay amplitude factor
DEM	digital elevation model
DSITIA	Department of Science, Information Technology, Innovation and the Arts (Queensland Government)
EL	elevation level
ENSO	El Niño Southern Oscillation
FSL	full supply level
GS	gauging station
GTSMR	Generalised Tropical Storm Method (revised)
IEAust	The Institute of Engineers Australia
MAF	moisture adjustment factor
MIRORB	MapInfo Runoff Routing program
NQIAS	North Queensland Irrigated Agriculture Strategy
ONA	the Australian Government Office of Northern Australia
PE	potential evaporation
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PPD	patch point data
RORB	Runoff Routing program
SILO	database of climate data provided by BOM and hosted by DSITIA
SRTM-H	Shuttle Radar Terrain Model
TAF	topographic adjustment factor

Units

MEASUREMENT UNITS	DESCRIPTION
GL	gigalitres, 1,000,000,000 litres
keV	kilo-electronvolts
kL	kilolitres, 1000 litres
km	kilometres, 1000 metres
L	Litres
m	Metres
mAHD	metres above Australian Height Datum
MeV	mega-electronvolts
mg	milligrams
MJ/m^2	megajoules per metre square
ML	megalitres, 1,000,000 litres
mm	millimetres

Preface

The Flinders and Gilbert Agricultural Resource Assessment (the Assessment) aims to provide information so that people can answer questions such as the following in the context of their particular circumstances in the Flinders and Gilbert catchments:

- What soil and water resources are available for irrigated agriculture?
- What are the existing ecological systems, industries, infrastructure and values?
- What are the opportunities for irrigation?
- Is irrigated agriculture economically viable?
- How can the sustainability of irrigated agriculture be maximised?

The questions – and the responses to the questions – are highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports must be read as a whole if they are to reliably inform discussion and decision making on regional development.

The Assessment is producing a series of reports:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the 12 research activities (outlined below) has a corresponding technical report.
- Each of the two catchment reports (one for each catchment) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- Two overview reports – one for each catchment – are provided for a general public audience.
- A factsheet provides key findings for both the Flinders and Gilbert catchments for a general public audience.

All of these reports are available online at <http://www.csiro.au/FGARA>. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

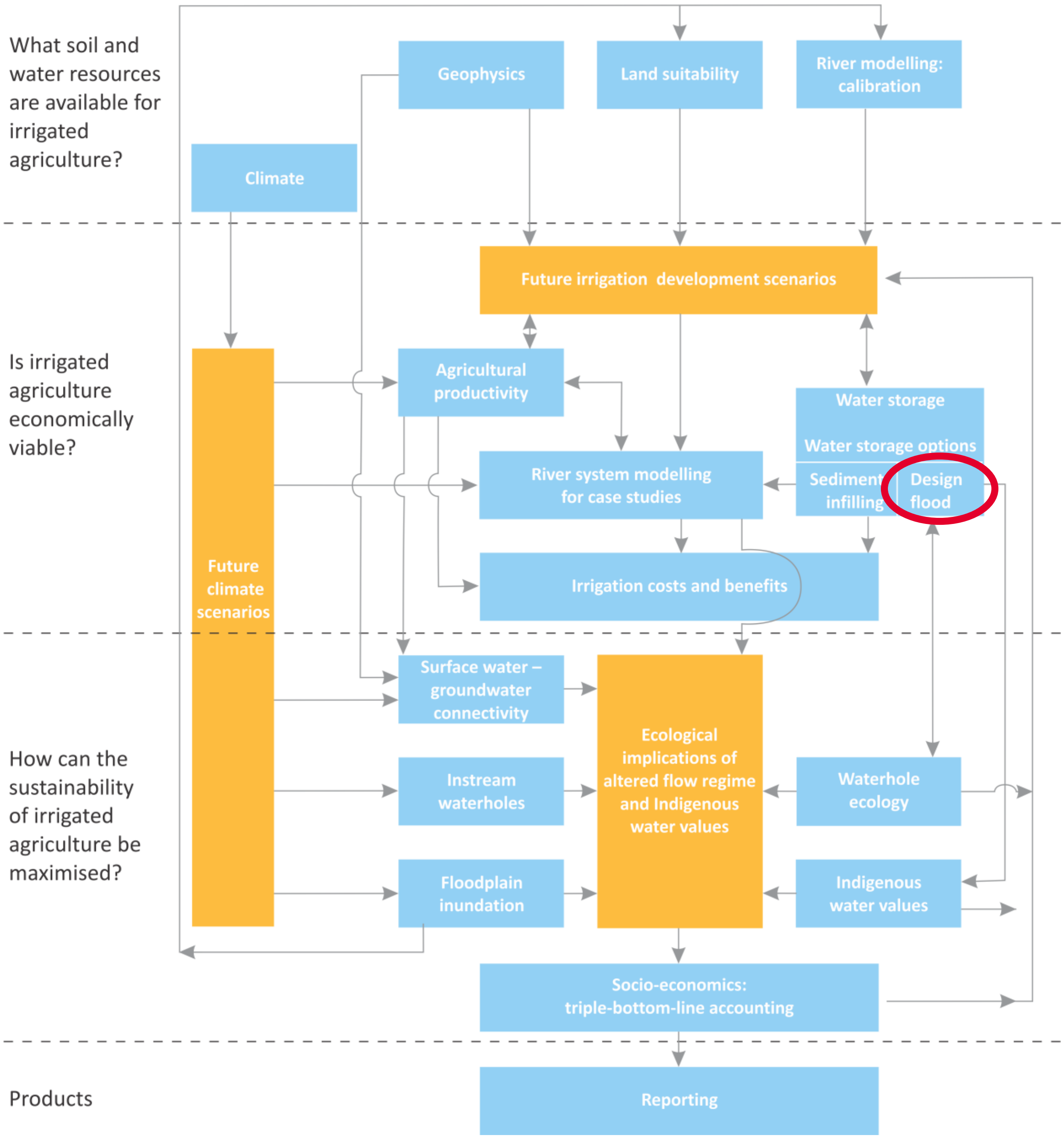
The Assessment is divided into 12 scientific activities, each contributing to a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 1 illustrates the high-level linkages between the 12 activities and the general flow of information in the Assessment. Clicking on an 'activity box' links to the relevant technical report.

The Assessment is designed to inform consideration of development, not to enable particular development activities. As such, the Assessment informs – but does not seek to replace – existing planning processes. Importantly, the Assessment does not assume a given regulatory environment. As regulations can change, this will enable the results to be applied to the widest range of uses for the longest possible time frame. Similarly, the Assessment does not assume a static future, but evaluates three distinct scenarios:

- Scenario A – historical climate and current development
- Scenario B – historical climate and future irrigation development
- Scenario C – future climate and current development.

As the primary interest was in evaluating the scale of the opportunity for irrigated agriculture development under the current climate, the future climate scenario (Scenario C) was secondary in importance to scenarios A and B. This balance is reflected in the allocation of resources throughout the Assessment.

The approaches and techniques used in the Assessment have been designed to enable application elsewhere in northern Australia.



Preface Figure 1 Schematic diagram illustrating high-level linkages between the 12 activities (blue boxes)

The orange boxes indicate information used or produced by several activities. The red oval indicates the activity (or activities) that contributed to this technical report. Click on a box associated with an activity for a link to its technical report (or click on 'Technical reports' on <http://www.csiro.au/FGARA> for a list of links to all technical reports). Note that some activities have multiple technical reports – in this case the separate reports are listed under the activity title. Note also that these reports will be published throughout 2013, and hyperlinks to currently unpublished reports will produce an 'invalid publication' error in the CSIRO Publication Repository.

Executive summary

Design floods are hypothetical floods (such as “one in a hundred year floods”) used for planning and floodplain management investigations. The primary objective of this study was to estimate design flood discharges at three potential dam sites in the Flinders and Gilbert catchments: the Dagworth dam site on the Einasleigh River, Greenhills dam site on the Gilbert River, and Cavehill dam site on the Cloncurry River. The design flood discharges will be used to develop conceptual arrangements for potential dams at these locations. The purpose of this technical report is to document the methods undertaken for this analysis, present the fitted model results and report on a flood frequency analysis undertaken at each site.

To undertake the design flood discharge analysis, suitable hydrological models for the potential dam sites were developed using the RORB (runoff-routing) program and calibrated against observed historical streamflow data. As part of this process simulated flood hydrographs were fitted to observed hydrographs by modifying the two model parameters that control flood routing (the non-linearity exponent, m, and the routing parameter, k_c) and the initial loss parameter. The continuing loss values were calculated using RORB once the other parameters were assigned.

Design rainfall estimates were computed for six different durations using the Probable Maximum Precipitation (PMP) method (BOM 2003a), CRC-FORGE method (Nandakumar et al. 1997) and the method of interpolation between regional estimates of rare rainfalls and PMP (IEAust 1998). To compute the design flood discharges, the RORB models were run with the calibrated routing parameters, recommended initial and continuing loss value for probable maximum flood (PMF) computations (IEAust 1998), storage and spillway configuration information and the aforementioned design rainfall estimates.

The design flood estimates obtained in this study were comparable to design flood estimates made in similar size catchments elsewhere using the same methods. They are, however, considerably larger than design flood estimates made by other studies in these catchments, which were undertaken in the 1970s and 1980s. This is a well-known consequence of changes to the recommended methods for estimating PMP (BOM 2003b). Checks were also undertaken on the peak and total flood volumes, taking into account quantity of rainfall and catchment area.

The design flood estimates provided in this report will be used by the water storage activity to assist in developing conceptual arrangements for the three potential dam sites, including the sizing of spillways and embankments. This will be reported in the companion technical report on water storage (see Preface Figure 1).

Contents

Figures

Tables

1 Introduction

The main objective of the study was to estimate design flood discharges based on design rainfall estimates of various durations to assist in the preliminary design of dams at three potential dam sites in the Flinders and Gilbert catchments: the Dagworth dam site on the Einasleigh River, Greenhills dam site on the Gilbert River, and Cavehill dam site on the Cloncurry River.

Suitable hydrological models for the study catchments were developed using the RORB (runoff-routing) program and calibrated against available historical streamflow data. A comprehensive review of both pluviograph data and Patch Point Data (PPD) (SILO 2013) within the study catchments was undertaken prior to model development. Design rainfall estimates were calculated for a number of different durations using the Probable Maximum Precipitation (PMP) method (BOM 2003a), CRC-FORGE (Nandakumar et al. 1997) and the method of interpolation between regional estimates of rare rainfalls and PMP (using the method described in Australian Rainfall and Runoff, Volume 1, Book VI (IEAust 1998)). In order to obtain the design flood discharges, the RORB models were run with the calibrated routing parameters, storage and spillway configuration information and the aforementioned design rainfall estimates.

This report describes the methods of using the RORB Runoff-Routing models and design rainfall estimates to simulate the design floods. Observed versus simulated flood peaks are presented and flood frequency analyses are reported.

2 Catchment descriptions

2.1 Dagworth and Greenhills in Gilbert River catchment

The greater Gilbert River catchment is located in north-west Queensland with the headwaters being on the western side of the Great Dividing Range and draining north into the Gulf of Carpentaria. One of the main tributaries is the Einasleigh River on which the potential Dagworth dam site is located. The RORB model for the Dagworth catchment was calibrated to recorded streamflow at the gauging station at the township of Einasleigh on the Einasleigh River (917106a). The catchment area to the gauging station is 8,244 km^2. The potential dam site is further downstream on the Einasleigh River and has a total catchment area of 15,318 km^2 (see Figure 2.1). The mean annual rainfall experienced in the Dagworth catchment varies across the catchment from 650 to 800 mm. The potential dam site of Greenhills is located on the Gilbert River to the west of the Dagworth catchment. The RORB model was calibrated to the flow recorded at Rockfields gauging station on the Gilbert River (917001d). The catchment area to the gauging station is 10,987 km^2. For Greenhills, the potential dam site is upstream of the gauging station with a catchment area of 8,400 km^2 (see Figure 2.1). The mean annual rainfall received in different parts of the Greenhills catchment varies from 650 to 750 mm.

2.2 Cavehill in Flinders River catchment

The greater Flinders River catchment is located in north-west Queensland and boasts the longest river in the state. The river runs from the Burra Range on the western side of the Great Dividing Range and Hughenden in the east to Cloncurry and the Selwyn Ranges in the west. One of the principal tributaries is the Cloncurry River on which the potential Cavehill dam site is located. The RORB model for the Cavehill catchment was calibrated to the streamflow recorded at Cloncurry gauging station on the Cloncurry River (915203b). The catchment area to the gauging station is 5,859 km^2. For the Cavehill catchment, the potential dam site is upstream of the gauging station on the Cloncurry River with a catchment area of 5,265 km^2 (see Figure 2.2). The mean annual rainfall received in different parts of the Cavehill catchment varies from 350 to 400 mm.

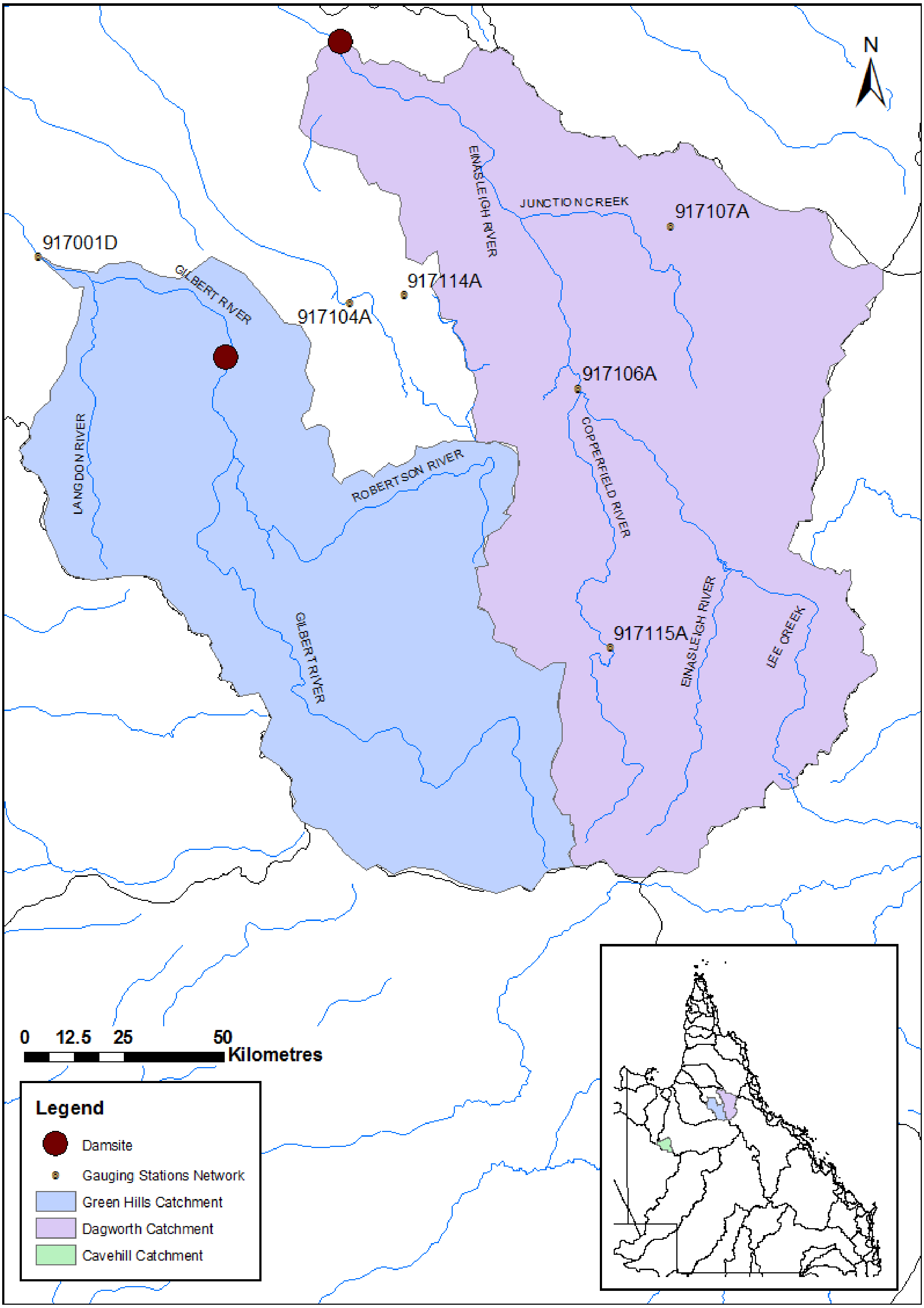


Figure 2.1 Dagworth and Greenhills catchments, streamflow gauging stations and location of potential dam sites

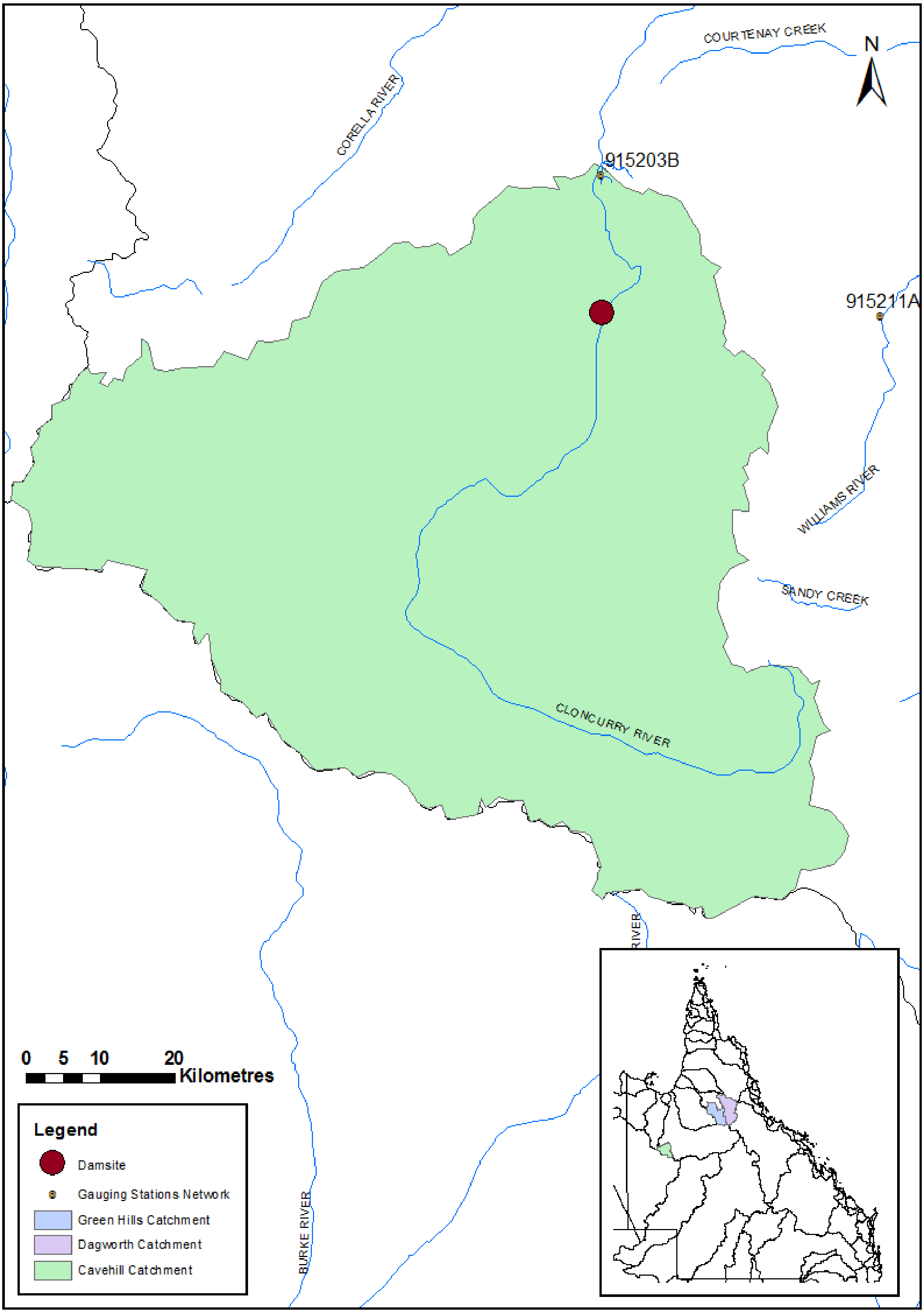


Figure 2.2 Cavehill catchment area, streamflow gauging station and location of potential dam site

3 Methods

The RORB modelling and design flood estimation for the Dagworth, Greenhills and Cavehill catchments was undertaken using a consistent set of methods. A systematic approach was adopted, which included the following steps:

Comprehensive review of the data

- Extraction of available streamflow data at the relevant gauging stations (917106a, 917001d and 915203b) and selection of the six highest peak flow events at each station against which to calibrate. Review of the quality of the recorded data for the selected periods.
- Extraction of pluviograph data and PPD and extensive review of the quality and validity of the rainfall data.
- Comparison of period of available data between selected peak flow events and rainfall data.
- Review of the storage-discharge characteristics of the three potential dams.

Model construction

- Design of RORB catchments including subareas, inflow nodes and reach links using MiRORB. MiRORB is a tool which uses the functionality of the GIS package MapInfo to generate RORB catchment files (SKM 2010).
- Exportation of RORB catchment files from MiRORB and allocation of appropriate output locations and calibration points (i.e. gauging stations and potential dam sites – see Section 2).

Model calibration

- Selection of peak streamflow events for calibration. As mentioned above, the six highest streamflow events were extracted for each of the gauging stations. Due, however, to lack of rainfall data for a number of the peak streamflow events, the models were calibrated to either two or three events. Dagworth and Greenhills both had two peak streamflow events against which to calibrate. Cavehill had three peak streamflow events. The peak streamflow events are discussed further in Section 5.
- Preparation of streamflow data for calibration.
- Generation of storm files for input into RORB for the selected peak events. The rainfall data used for calibration was predominantly pluviograph data, however in some cases the pluviograph data had to be scaled by rainfall observed at PPD stations (SILO 2013) due to low quality or incorrect data. That is, the pluviograph data were used to provide the sub-daily temporal pattern to the PPD (see Section 0 for the description of cases for which rainfall had to be scaled).
- Calibration of the RORB model against the peak historic flood events by adjusting routing model parameters (k_c and m).

Design flow discharge estimation:

- Design rainfalls of varying AEPs (annual exceedance probabilities) were estimated for each catchment. The annual exceedance probability is defined as “the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year” (BOM 2013). The following design rainfalls were estimated:
    - 1 in 1,000 year AEP (CRC-FORGE)
    - 1 in 2,000 year AEP (CRC-FORGE)
    - 1 in 10,000 year AEP (interpolation between CRC-FORGE and PMP)
    - PMP

- Inclusion of storages in RORB models using storage dimension and discharge information from a companion technical report.
- Running of calibrated RORB models (including storage) for each catchment with the estimated design rainfall mentioned above (except the 1 in 2,000 year AEP) for the following duration design storms:
    - 24 hour
    - 36 hour
    - 48 hour
    - 72 hour
    - 96 hour
    - 120 hour
- Selection of a critical duration flood based on maximum modelled storage outflow (m^3 per second).

4 Available data

Data required for this study included hydro-meteorological data for calibration of the runoff-routing models as well as storage dimension and spillway information for the three potential dams. Historical streamflow and rainfall data were collected for the selected peak streamflow events for the three catchments, and storage information was obtained from the companion technical report on water storages (see Preface Figure 1) and computed using the hydrologically corrected Shuttle Radar Terrain Model (SRTM-H).

4.1 Streamflow data

Historical streamflow records for three gauging stations were used for the calibration of the three runoff-routing models. The gauging stations to which each of the three RORB catchments were calibrated are mentioned in Section 2. Details for these gauging stations are provided in Table 4.1.

Table 4.1 Stream gauging stations used for RORB model calibration

CATCHMENT	STATION NUMBER	LOCATION	LATITUDE	LONGITUDE	AMTD (KM)	CATCHMENT AREA (KM^2)	PERIOD OF RECORD	HIGHEST GAUGED HEIGHT (M) & DATE OF GAUGING	HIGHEST GAUGED DISCHARGE (M^3/S) & DATE OF GAUGING
Dagworth	917106A	Einasleigh River at Einasleigh	-18.50	144.10	276	8,244	10/12/1966 – Current	11.3 15/02/1968	3,455 15/02/1968
Greenhills	917001D	Gilbert River at Rock Fields	-18.20	142.87	276	10,987	14/01/1967 – Current	6.1 22/03/2012	1,413 22/03/2012
Cavehill	915203B	Cloncurry River at Cloncurry	-20.70	140.49	327.6	5,859	01/10/1994 – Current	1.7 18/03/1997	28.4 02/12/1999

4.2 Rainfall data

Quality rainfall data is crucial for calibrating runoff-routing models as the temporal variation in rainfall is one of the most significant factors defining the shape and magnitude of the flood hydrographs. Due to the importance of spatial and temporal variation of rainfall depths over each of the catchments, both pluviograph and PPD were collected and checked thoroughly. In particular, comparisons were made between the pluviograph data and the rainfall observed at the PPD stations. This provided an additional quality check of the rainfall depths observed in the pluviograph data and in some cases highlighted periods during which the quality of pluviograph data were poor.

4.2.1 PLUVIOGRAPH DATA

Pluviograph data stations across Queensland record continuous rainfall during storm events. For this study, three stations were used for the model calibrations (see Table 4.2). Pluviograph data for these stations were extracted in six minute intervals and then summed to hourly intervals. The six minute interval rainfall data had to be converted to hourly interval data in order to match the hourly timestep of the streamflow data. A description of the exact rainfall used for the three RORB calibrations is provided in Section 0.

Table 4.2 Pluviograph data stations used for RORB model calibration

CATCHMENT	STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	START DATE	END DATE
Dagworth	30014	Einasleigh Township	-18.519	144.091	Dec-65	Sep-08
Greenhills	30112	North Head	-18.824	143.253	Aug-94	Sep-06
Cavehill	29141	Cloncurry Airport	-20.666	140.505	Feb-97	Aug-12

4.2.2 PATCH POINT DATA (PPD)

There are a number of rainfall PPD stations managed by the Bureau of Meteorology (BoM) located within the study catchment areas. Daily data from some of the PPD stations were extracted and compared to the (summed daily) pluviograph data. These comparisons were then used to infill or scale the pluviograph data in instances where pluviograph data were missing or values were of poor quality. Details of the rainfall stations used for the comparisons in this study are provided in Table 4.3. Highlighted stations were those that were ultimately used for scaling or infilling of rainfall data (see Section 0 for further information).

Table 4.3 Patch Point Data stations used for checking of pluviograph data

(highlighted stations were used for scaling or infilling of final model calibration rainfall)

CATCHMENT	STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	START DATE	END DATE
Dagworth	30030	Lyndhurst Station	-19.204	144.37	Apr-1886	Present
	30073	Van Lee	-17.85	143.703	Mar-68	Feb-09
	30103	Eveleigh Station	-18.223	143.97	Jan-40	Present
Greenhills	30019	Gilberton	-19.261	143.686	Apr-18	Present
	30090	Bagstowe Station	-19.196	144.001	Apr-64	Present
	30107	Robin Hood Station	-18.838	143.709	Oct-66	Present
Cavehill	29161	Brightlands Station	-21.073	140.281	Nov-87	Present
	29129	Devoncourt Station	-21.215	140.233	Feb-1887	Present
	29136	Farley Station	-21.366	140.499	Jan-77	Present

4.3 Storage and spillway rating curves

Information on the storage characteristics of three potential dams were obtained from the companion technical report on water storage (see Preface Figure 1). This information included the storage curve data and the spillway discharge rating curve for the three potential dams. The spillway rating curves had to be extended for the three potential storages as the maximum floods were higher than the maximum heights provided in the discharge curve. While the storage height and volume relationship was available for these high water levels, the storage discharge (in cubic metres per second) had to be extrapolated using the equation for flow over a weir. The spillway discharge curves for the potential storages are shown in the Table 4.4, Table 4.5 and Table 4.6 for Dagworth, Greenhills and Cavehill respectively. The highlighted cells indicate the discharge values that were extrapolated. These are the final storage spillway rating curves used in the RORB modelling.

Table 4.4 Potential Dagworth dam spillway rating curve

HEIGHT ABOVE FSL (M)	HEIGHT (M)	STORAGE VOLUME (M^3)	DISCHARGE (M^3/S)
0	227	498,187,110	0
1	228	558,931,902	500
2	229	623,766,894	1,430
3	230	692,650,030	2,700
4	231	765,549,646	4,260
5	232	842,584,306	6,100
6	233	923,772,894	8,230
7	234	1,009,121,050	10,640
8	235	1,098,557,438	13,310
9	236	1,192,115,574	16,250
10	237	1,289,969,370	19,480
11	238	1,392,205,826	22,980
12	239	1,499,110,966	26,770
13	240	1,610,785,678	30,180
14	241	1,727,272,114	33,730
15	242	1,848,491,870	37,400
16	243	1,974,609,698	41,216
17	244	2,105,546,942	45,140
18	245	2,241,380,182	49,181
19	246	2,382,063,830	53,335
20	247	2,527,680,158	57,601
21	248	2,678,336,334	61,975
22	249	2,834,281,826	66,454

Table 4.5 Potential Greenhills dam spillway rating curve

HEIGHT ABOVE FSL (M)	HEIGHT (M)	STORAGE VOLUME (M3)	DISCHARGE (M3/S)
0	253	227,197,062	0
1	254	271,348,014	330
2	255	321,325,878	950
3	256	377,597,294	1,780
4	257	440,551,010	2,820
5	258	510,793,434	4,030
6	259	588,657,794	5,440
7	260	674,330,326	7,030
8	261	767,759,534	8,800
9	262	869,409,506	10,740
10	263	979,874,096	12,880
11	264	1,099,909,887	15,190
12	265	1,230,099,321	17,700
13	266	1,365,128,121	19,950
14	267	1,500,156,921	22,300
15	268	1,635,185,721	24,700
16	269	1,770,214,521	27,232
17	270	1,905,243,321	29,824
18	271	2,040,272,121	32,494
19	272	2,175,300,921	35,240
20	273	2,310,329,721	38,058
21	274	2,445,358,521	40,948
22	275	2,580,387,321	43,907
23	276	2,715,416,121	46,934
24	277	2,850,444,921	50,028
25	278	2,985,473,721	53,188
26	279	3,120,502,521	56,410
27	280	3,255,531,321	59,696
28	281	3,390,560,121	63,043
29	282	3,525,588,921	66,450
30	283	3,660,617,721	69,917
31	284	3,795,646,521	73,442

Table 4.6 Potential Cavehill dam spillway rating curve

HEIGHT ABOVE FSL (M)	HEIGHT (M)	STORAGE VOLUME (M3)	DISCHARGE (M3/S)
0	224	248,067,069	0
1	225	301,554,081	425
2	226	361,343,569	1,240
3	227	426,562,329	2,340
4	228	496,630,105	3,700
5	229	571,880,769	5,301
6	230	652,855,893	7,170
7	231	740,395,821	9,250
8	232	834,847,989	11,310
9	233	935,075,123	13,500
10	234	1,041,268,979	15,810
11	235	1,153,625,049	18,240
12	236	1,272,235,975	20,780
13	237	1,397,389,041	23,430
14	238	1,522,542,107	26,190
15	239	1,647,695,173	29,040
16	240	1,772,848,239	32,000
17	241	1,898,001,305	35,046
18	242	2,023,154,371	38,184
19	243	2,148,307,437	41,410
20	244	2,273,460,503	44,721
21	245	2,398,613,569	48,117
22	246	2,523,766,635	51,595
23	247	2,648,919,701	55,152
24	248	2,774,072,767	58,788
25	249	2,899,225,833	62,500
26	250	3,024,378,899	66,287
27	251	3,149,531,965	70,148
28	252	3,274,685,031	74,081
29	253	3,399,838,097	78,085

5 Runoff-routing model

5.1 The RORB runoff-routing model

For this study, the RORB (runoff-routing) model was used to simulate design floods. The models were calibrated to recorded historical streamflow data using historical rainfall records, routing parameters and catchment loss parameters. MiRORB was used to generate the catchment files required for RORB. The layout of the RORB model for each catchment is provided in Section 5.2.

5.2 RORB model layout

The model layout of the pre-dam RORB calibration model for Dagworth is shown in Figure 5.1. The RORB model characteristics are tabulated in Table 5.1 (subcatchment areas), Table 5.2 (inflow node information) and Table 5.3 (reach information).

The model layout of the pre-dam RORB calibration model for Greenhills is shown in Figure 5.2. The RORB model characteristics are tabulated in Table 5.4 (subcatchment areas), Table 5.5 (inflow node information) and Table 5.6 (reach information).

The model layout of the pre-dam RORB calibration model for Cavehill is shown in Figure 5.3. The RORB model characteristics are tabulated in Table 5.7 (subcatchment areas), Table 5.8 (inflow node information) and Table 5.9 (reach information).

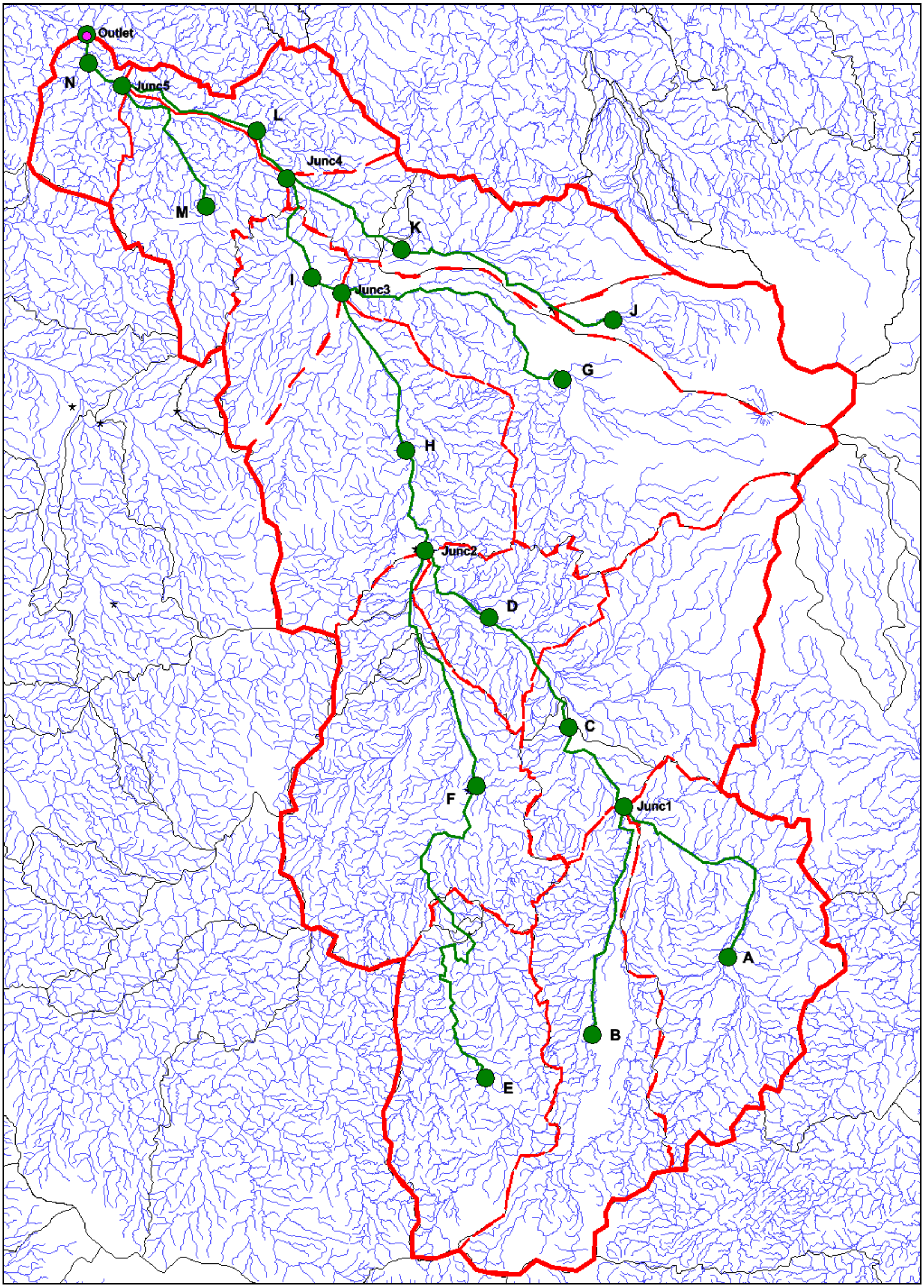


Figure 5.1 MapInfo representation of the Dagworth RORB model

Table 5.1 RORB subcatchment areas - Dagworth

SUBAREA ID	AREA (KM^2)
A	1,589
B	1,314
C	1,625
D	593
E	1,252
F	1,888
G	1,771
H	1,594
I	543
J	657
K	900
L	490
M	750
N	352

Table 5.2 RORB node information – Dagworth

NODE	LATITUDE	LONGITUDE	ELEVATION (M)
A	-19.119	144.582	565
B	-19.237	144.365	610
Junc1	-18.890	144.417	515
C	-18.769	144.329	490
D	-18.602	144.201	465
E	-19.303	144.195	725
F	-18.858	144.181	505
Junc2	-18.501	144.098	435
H	-18.349	144.069	380
G	-18.240	144.318	435
Junc3	-18.109	143.966	335
I	-18.085	143.917	330
J	-18.150	144.399	485
K	-18.043	144.061	350
Junc4	-17.934	143.877	280
L	-17.862	143.829	260
M	-17.978	143.748	285
Junc5	-17.793	143.614	210
Outlet	-17.715	143.557	200

Table 5.3 RORB reach information – Dagworth

REACH		REACH LENGTH (KM)	ELEVATION (M)		SLOPE (%)
From Node	To Node		Start of Reach	End of Reach	
A	Junc1	42.67	565	515	0.117
B	Junc1	43.34	610	515	0.219
Junc1	C	20.06	515	490	0.125
C	D	24.56	490	465	0.102
D	Junc2	18.55	465	435	0.162
E	F	72.24	725	505	0.305
F	Junc2	43.90	505	435	0.159
Junc2	H	19.71	435	380	0.279
H	Junc3	29.83	380	335	0.151
G	Junc3	50.29	435	335	0.199
Junc3	I	5.76	335	330	0.087
I	Junc4	19.61	330	280	0.255
J	K	41.87	485	350	0.322
K	Junc4	24.74	350	280	0.283
Junc4	L	10.10	280	260	0.198
L	Junc5	25.80	260	210	0.194
M	Junc5	29.32	285	210	0.256
Junc5	N	7.08	210	205	0.071
N	Outlet	5.01	205	200	0.100

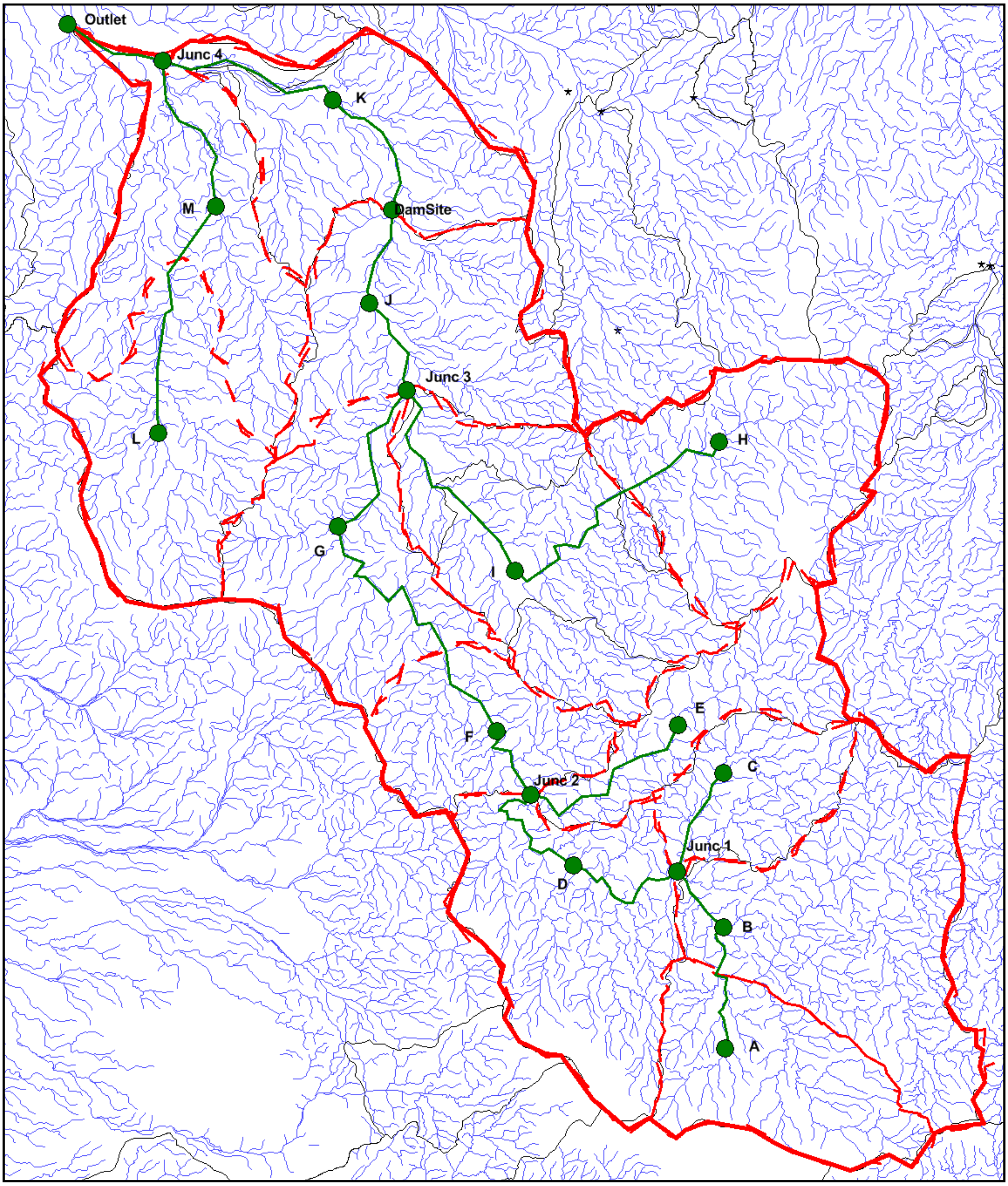


Figure 5.2 MapInfo representation of the Greenhills RORB model

Table 5.4 RORB subcatchment areas – Greenhills

SUBAREA ID	AREA (KM^2)
A	638
B	1,254
C	437
D	995
E	535
F	543
G	863
H	996
I	1,206
J	933
K	918
L	878
M	891

Table 5.5 RORB node information – Greenhills

NODE	LATITUDE	LONGITUDE	ELEVATION (M)
A	-19.485	143.744	670
B	-19.334	143.742	515
C	-19.139	143.741	545
D	-19.256	143.542	440
E	-19.079	143.681	520
F	-19.087	143.440	385
G	-18.829	143.229	305
H	-18.722	143.735	420
I	-18.885	143.464	325
J	-18.548	143.270	250
K	-18.292	143.222	215
L	-18.711	142.989	260
M	-18.426	143.066	220
Junc1	-19.263	143.681	490
Junc2	-19.167	143.485	440
Junc3	-18.657	143.321	270
Junc4	-18.243	142.996	190
Damsite	-18.43	143.301	235
Outlet	-18.197	142.870	170

Table 5.6 RORB reach information – Greenhills

REACH		REACH LENGTH (KM)	ELEVATION (M)		SLOPE (%)
From Node	To Node		Start of Reach	End of Reach	
A	B	20.25	670	515	0.765
B	Junc 1	10.29	515	490	0.243
C	Junc 1	15.47	545	490	0.356
Junc1	D	19.47	490	440	0.257
D	Junc 2	21.41	440	440	0.000
E	Junc 2	28.23	520	440	0.283
Junc 2	F	13.52	440	385	0.407
F	G	44.58	385	305	0.179
G	Junc 3	24.56	305	270	0.143
H	I	40.97	420	325	0.232
I	Junc 3	33.49	325	270	0.164
Junc 3	J	14.59	270	250	0.137
J	Damsite	14.01	250	235	0.107
Damsite	K	20.16	235	215	0.099
K	Junc 4	26.67	215	190	0.094
L	M	34.46	260	220	0.116
M	Junc 4	23.75	220	190	0.126
Junc 4	Outlet	14.64	190	170	0.137

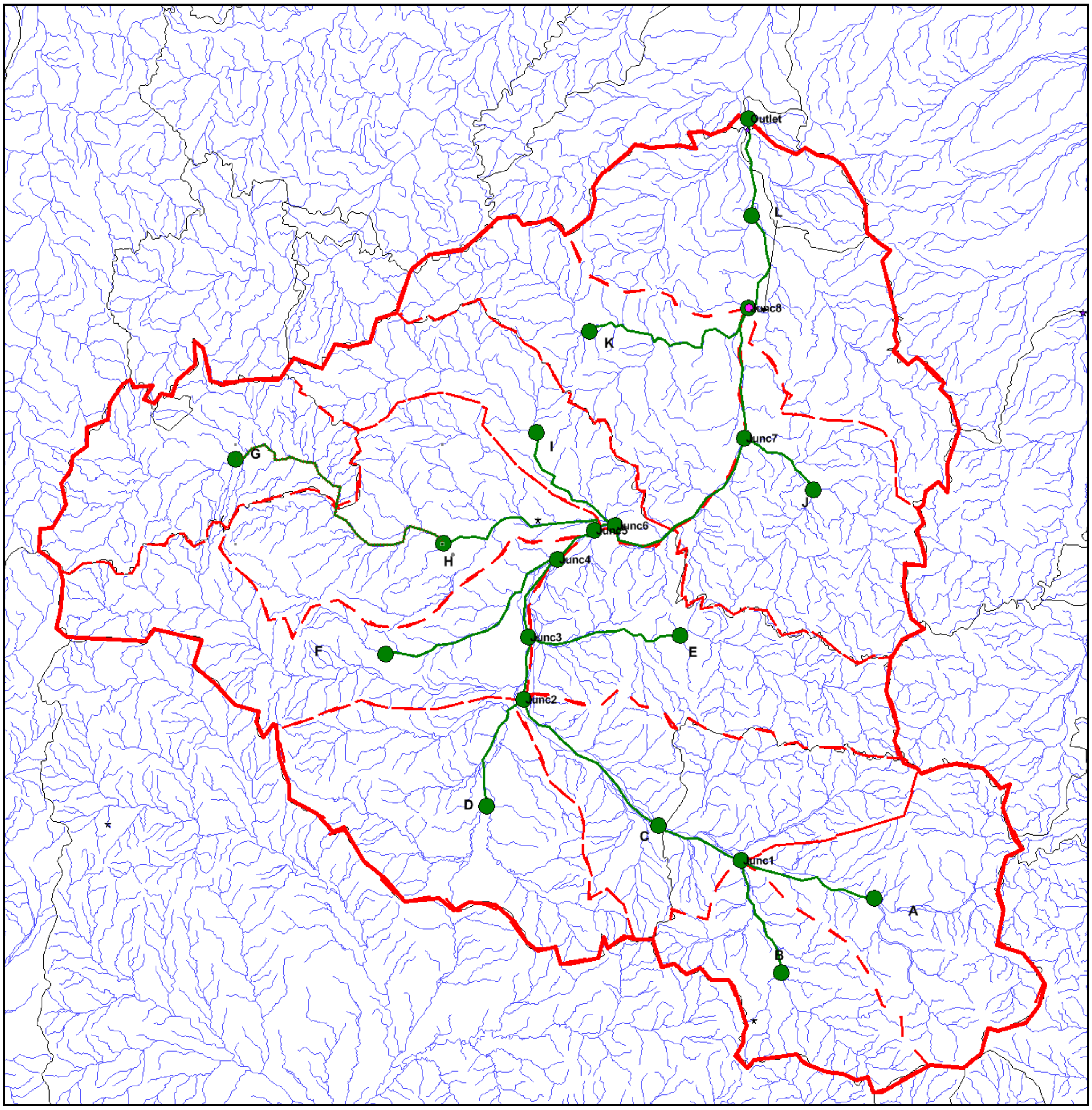


Figure 5.3 MapInfo representation of the Cavehill RORB model

Table 5.7 RORB subcatchment areas – Cavehill

SUBAREA ID	AREA (KM^2)
A	496
B	313
C	541
D	574
E	512
F	544
G	428
H	505
I	347
J	497
K	508
L	716

Table 5.8 RORB node information – Cavehill

NODE	LATITUDE	LONGITUDE	ELEVATION (M)
A	-21.418	140.622	365
B	-21.487	140.529	355
Junc 1	-21.382	140.488	330
C	-21.350	140.405	315
D	-21.331	140.232	290
Junc 2	-21.232	140.270	275
E	-21.173	140.427	300
Junc 3	-21.174	140.274	270
F	-21.190	140.131	305
Junc 4	-21.102	140.303	255
G	-21.009	139.980	335
H	-21.087	140.189	275
Junc 5	-21.075	140.341	250
I	-20.984	140.282	270
Junc 6	-21.070	140.362	245
J	-21.037	140.561	245
Junc 7	-20.989	140.492	225
K	-20.890	140.336	255
Junc 8	-20.868	140.496	215
L	-20.782	140.499	200
Outlet	-20.692	140.496	185

Table 5.9 RORB reach information – Cavehill

REACH		REACH LENGTH (KM)	ELEVATION (M)		SLOPE (%)
From Node	To Node		Start of Reach	End of Reach	
A	Junc1	14.98	365	330	0.234
B	Junc1	12.80	355	330	0.195
Junc1	C	9.63	330	315	0.156
C	Junc2	19.84	315	275	0.202
D	Junc2	12.77	290	275	0.117
Junc2	Junc3	6.56	275	270	0.076
E	Junc3	16.81	300	270	0.178
Junc3	Junc4	9.39	270	255	0.160
F	Junc4	22.46	305	255	0.223
Junc4	Junc5	5.40	255	250	0.093
G	H	31.16	335	275	0.193
H	Junc5	18.74	275	250	0.133
Junc5	Junc6	2.36	250	245	0.212
I	Junc6	14.72	270	245	0.170
Junc6	Junc7	20.55	245	225	0.097
J	Junc7	9.44	245	225	0.212
Junc7	Junc8	13.85	225	215	0.072
K	Junc8	21.90	255	215	0.183
Junc8	L	11.02	215	200	0.136
L	Outlet	10.34	200	185	0.145

5.3 Data used for model calibration

In order to calibrate the RORB models for each study area, historical hourly instantaneous streamflow was extracted for the three relevant gauging stations and the model calibrated to two peak events for Dagworth and Greenhills and three peak events for Cavehill. Periods of streamflow data used for the calibration are summarised in Table 5.10, and Table 5.11 provides the actual timing of the flood peak events used for calibration. The historical rainfall data used to create the storm file input to the RORB models are summarised in Table 5.12.

Table 5.10 Streamflow data used for RORB model calibration

DAM SITE	STREAMFLOW GAUGING STATION	CATCHMENT AREA (KM^2)	CALIBRATION PEAK ID	CALIBRATION PERIOD	
				Start	End
Dagworth	917106a	15,316	Peak 2	10/02/2002	23/02/2002
			Peak 5	01/01/1981	23/01/1981
Greenhills	917001d	11,086	Peak 2	22/01/2009	29/01/2009
			Peak 3	12/02/2002	19/02/2002
Cavehill	915203b	5,981	Peak 2	01/01/2009	13/01/2009
			Peak 3	10/01/2004	22/01/2004
			Peak 6	05/02/2009	17/02/2009

Table 5.11 Specific peak flow events used for RORB model calibration

DAM SITE	STREAMFLOW GAUGING STATION	CALIBRATION PEAK ID	MAXIMUM FLOW (M^3/S)	ACTUAL PEAK START	ACTUAL PEAK END	ACTUAL TIME OF PEAK
Dagworth	917106a	Peak 2	4,535	13/02/2002	04/03/2002	16/02/2002 13:00
		Peak 5	3,466	03/01/1980	25/03/1980	21/01/1981 08:00
Greenhills	917001d	Peak 2	6,373	20/01/2009	31/01/2009	27/01/2009 21:00
		Peak 3	5,702	16/02/2002	19/02/2002	17/02/2002 00:00
Cavehill	915203b	Peak 2	3,645	06/01/2008	13/01/2009	08/01/2009 16:00
		Peak 3	3,545	11/01/2004	30/01/2004	16/01/2004 05:00
		Peak 6	3,345	07/02/2009	27/02/2009	10/02/2009 10:00

Table 5.12 Rainfall data used in model calibration

DAMSITE	CALIBRATION PEAK ID	STREAMFLOW USED FOR CALIBRATION PERIOD Start	End	PLUVIOGRAPH STATION NUMBER	NUMBER OF RAINFALL BURSTS IN RORB STORM FILE	COMMENT ON RAINFALL USED FOR PEAK CALIBRATION
Dagworth	Peak 2	10/02/2002	23/02/2002	30014	3	Unaltered pluviograph rainfall data were used for calibration
	Peak 5	1/01/1981	23/01/1981	30014	2	Unaltered pluviograph rainfall data were used for calibration
Greenhills	Peak 2	22/01/2009	29/01/2009	30112	2	Unaltered pluviograph rainfall data were used for calibration
	Peak 3	12/02/2002	19/02/2002	30112	3	Unaltered pluviograph rainfall data were used for the first burst of rainfall The pluviograph data were scaled by rainfall station 30107 for the second burst of rainfall (rainfall in pluviograph was low compared to PPD rainfall stations in the catchment and recorded flow) The pluviograph data were scaled by rainfall station 30090 for the third burst of rainfall (rainfall in pluviograph was high compared to PPD rainfall stations in the catchment and recorded flow)
Cavehill	Peak 2	1/01/2009	13/01/2009	29141	2	Unaltered pluviograph rainfall data were used for the first burst of rainfall The pluviograph data were scaled by rainfall station 29161 for the second burst of rainfall (rainfall in pluviograph was low compared to PPD rainfall stations in the catchment and recorded flow)
	Peak 3	10/01/2004	22/01/2004	29141	1	Unaltered pluviograph rainfall data were used for calibration
	Peak 6	5/02/2009	17/02/2009	29141	1	Unaltered pluviograph rainfall data were used for calibration

5.4 RORB model calibration

The RORB model calibration was undertaken using the calibration periods and selected peak events provided in Table 5.10 and Table 5.11. In order to calibrate the RORB model, two parameters which control flood routing (the non-linearity exponent, *m,* and the routing parameter, k_c) and the initial loss parameter were systematically altered to attempt to match the historical flood data and mimic the flood routing characteristics of each catchment. A value of 0.8 was used for the exponent m. This value was judged to be a reasonably conservative value for estimating extreme floods in all three catchments (IEAust 1998). An initial loss of 5 mm was used in the model run and this was found to be satisfactory based on the matching starting times of the modelled and recorded hydrographs for each catchment. The parameter k_c was then adjusted in order to calibrate the modelled flow to the historical floods. Once the other parameters were assigned, the continuous loss was calculated by RORB based on a mass balance in the model. The continuous losses were calculated for each burst of rainfall and they were generally found to be reasonable for all peaks. Those bursts that have high continuous losses demonstrate rainfall which is inconsistent (i.e. too high) with the streamflow recorded during the flood event. Table 5.13 shows the adopted values of k_c, m and losses for each catchment as a result of the model calibration.

Table 5.13 Adopted model parameters for each catchment

DAMSITE	CALIBRATION PEAK ID	K_C	M	INITIAL LOSS (MM)	NUMBER OF BURSTS	CONTINUOUS LOSS (MM/H)
Dagworth	Peak 2	275	0.8	5	3	Burst 1 - 9.61 Burst 2 - 5.02 Burst 3 - 1.99
	Peak 5				2	Burst 1 - 2.03 Burst 2 - 3.52
Greenhills	Peak 2	100	0.8	5	2	Burst 1 - 4.79 Burst 2 - 1.98
	Peak 3				3	Burst 1 - 12.85 Burst 2 - 34.30 Burst 3 - 4.86
Cavehill	Peak 2	70	0.8	5	2	Burst 1 -10.19 Burst 2 - 4.30
	Peak 3				1	Burst 1 - 6.19
	Peak 6				1	Burst 1 - 7.97

The calibrated model performance for all three catchments is shown in the hydrograph plots of recorded versus calculated runoff in Appendix A. The comparisons of recorded and modelled peak discharges are given in the Table 5.14.

Table 5.14 Comparison of recorded and calculated peak discharges

DAMSITE	STREAMFLOW GAUGING STATION	CALIBRATION PEAK ID	PEAK DISCHARGE (M^3/S)	
			Recorded	Modelled
Dagworth	917106A	Peak 2	4,535	4,569
		Peak 5	3,466	4,202
Greenhills	917001D	Peak 2	6,373	6,632
		Peak 3	5,702	5,500
Cavehill	915203B	Peak 2	3,645	3,652
		Peak 3	3,581	3,623
		Peak 6	3,345	3,123

6 Design rainfall

6.1 Design rainfall estimation techniques

Three approaches to estimating design rainfall were used for this study. The approaches are as follows:

- PMP – a deterministic method to estimate extreme catchment rainfall based on meteorology and local catchment factors (BOM 2003a).
- CRC-FORGE point rainfall estimates for 1 in 1,000 year design rainfall (Nandakumar et al. 1997).
- Interpolation between the PMP and CRC-FORGE estimates to obtain a 1 in 10,000 year design rainfall estimate (IEAust 1998).

6.2 Design rainfall – probable maximum precipitation (PMP)

PMP has been defined by the World Meteorological Organisation (1986) as “the greatest depth of precipitation for a given duration, meteorologically possible for a given storm area at a particular location at a particular time of year, with no allowance made for climatic trends”. This method of design rainfall estimation was used to determine the probable maximum flood (PMF) for each of the catchments and also to allow for estimation of 1 in 10,000 year design rainfall (explained in Section 6.3). The specific PMP method was chosen according to the catchment location – in this case, all catchments lie in the Generalised Tropical Storm Coastal Zone. The Guidebook to Estimation of PMP (BOM 2003a) outlines the steps required to obtain PMP depths using the Revised Generalised Tropical Storm Method (GTSMR) (revised in 2002). First of all, catchment areas for each of the three study catchments were obtained and raw PMP depths calculated based on these catchment areas. Raw depths were calculated for storm durations of 24, 36, 48, 72, 96 and 120 hours. The next step comprised of obtaining average catchment adjustment factors such as the Moisture Adjustment Factor (MAF), the Decay Amplitude Factor (DAF), and the Topographic Adjustment Factor (TAF). This was achieved by overlaying study catchment layers on grids of each of the factor values and calculating an average. Following this, the raw PMP depths for each standard duration (24 to 120 hour) were multiplied by the three catchment factors. The preliminary PMP estimates were then plotted to ensure the enveloping curve had no discontinuities or other issues (see Table 6.1 for the final PMP depths). As the TAF was similar across the catchments, it was decided that having a uniform spatial rainfall pattern across the catchments was appropriate. Once the PMP depths were deemed appropriate, design temporal distributions (based on the standard area of the catchment) for each storm duration were applied to the PMP depths. This resulted in hourly rainfall (in millimetres) for each of the six durations for each of the three catchments. The standard areas used to determine the temporal patterns are shown in Table 6.2. The worksheets completed as part of the PMP estimation process (BOM 2003a) are shown in Appendix B, while Appendix C contains the temporal pattern files used based on the corresponding standard area of each catchment.

Table 6.1 Final PMP estimates for each catchment

DURATION (HOURS)	FINAL PMP ESTIMATES (MM)		
	Dagworth	Greenhills	Cavehill
24	670	720	840
36	800	850	980
48	920	980	1,110
72	1,130	1,190	1,340
96	1,280	1,360	1,530
120	1,330	1,420	1,610

Table 6.2 Standard areas corresponding to the catchments

CATCHMENT AREA (KM^2)	STANDARD AREA (km^2)	
1 - 300	100	
300 - 750	500	
750 - 1,750	1,000	
1,750 - 3,750	2,500	
3,750 - 7,500	5,000	Cavehill
7,500 - 15,000	10,000	Greenhills
15,000 - 30,000	20,000	Dagworth
30,000 - 50,000	40,000	
50,000 - 80,000	60,000	
80,000 - 125,000	100,000	
125,000 +	150,000	

6.3 Design rainfall – CRC-FORGE

CRC-FORGE is a database for Queensland and Border areas which provides estimates of rare rainfall events at individual stations using regional data. CRC-FORGE is a regional method that uses statistical methods to determine estimates of extreme rainfall events. For the purpose of this study, 1 in 1,000 AEP and 1 in 2,000 AEP rainfall events were extracted from FORGE for the six durations (24 to 120 hour). The temporal patterns described above (and shown in Appendix C) were applied to the 1 in 1,000 year AEP rainfall estimates for each of the three catchments to give design rainfall for each duration and catchment. The 1 in 2,000 year AEP design rainfall was only used for the interpolation between the CRC-FORGE and PMP estimates as described below.

6.4 Design rainfall – interpolation between CRC-FORGE and PMP

For the purpose of this study, an estimation of 1 in 10,000 year design rainfalls was required. ARR Book VI (1998) suggests a method for obtaining such an estimate by determining an approximation of the AEP of the PMP and then interpolating between this value and the CRC-FORGE design rainfall estimates. Due to the magnitude of uncertainty involved in PMP estimates, IEAust (1998) suggests that the AEP of PMP be computed based on catchment area (see Figure 6.1). The 1 in 10,000 year AEP design rainfall was then calculated by interpolating between the CRC-FORGE and PMP estimates; the method for this estimation is outlined in ARR Book VI and the interpolation equation is shown in Figure 6.2 (IEAust 1998). A description of the terms in the equation and how they apply to this study are provided in Table 6.3. Once design rainfall had been estimated for a 1 in 10,000 year event, the temporal pattern described above (and shown in Appendix C) was applied to the design rainfall for each of the six durations. The final design rainfall estimates for all four AEPs and all six durations are shown in Table 6.4 for Dagworth, Table 6.5 for Greenhills and Table 6.6 for Cavehill. Only the 1 in 1,000, 1 in 10,000 and PMP estimates were required in this study for RORB modelling to determine design flood estimates.

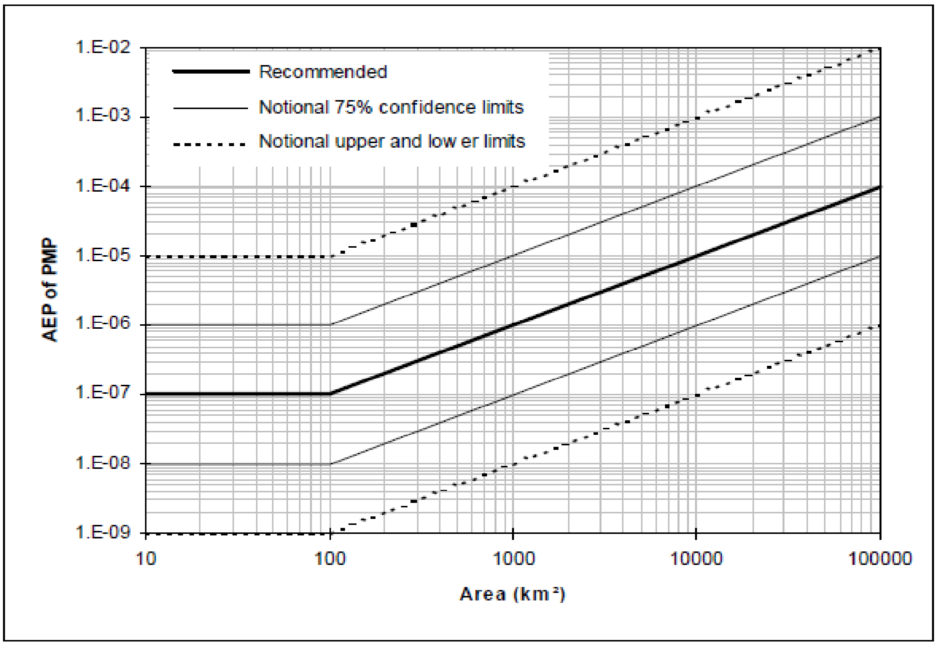


Figure 6.1 Plot to determine the AEP of the PMP based on catchment area (IEAust 1998)

A design rainfall estimate with an AEP of 1 in Y (denoted X_Y) can be estimated using:

$$X_Y = 10^{R_Y \log(X_{Y2})} \tag{1}$$

where R_Y is defined by the parabola fitted between X_{Y2} and X_{PMP}:

$$R_Y = 1 + S_{gc}\, z_d\, g_Y + (S_{gap} - S_{gc}) z_d\, g_Y^2 \tag{2}$$

$$z_d = \log(Y_{PMP} / Y_2) \tag{3}$$

$$g_Y = \frac{\log(Y / Y_2)}{z_d} \tag{4}$$

$$S_{gc} = \frac{\log(X_{Y1} / X_{Y2})}{\log(X_{Y2}).\log(Y_1 / Y_2)} \tag{5}$$

$$S_{gap} = \frac{\dfrac{\log(X_{PMP})}{\log(X_{Y2})} - 1}{z_d} \tag{6}$$

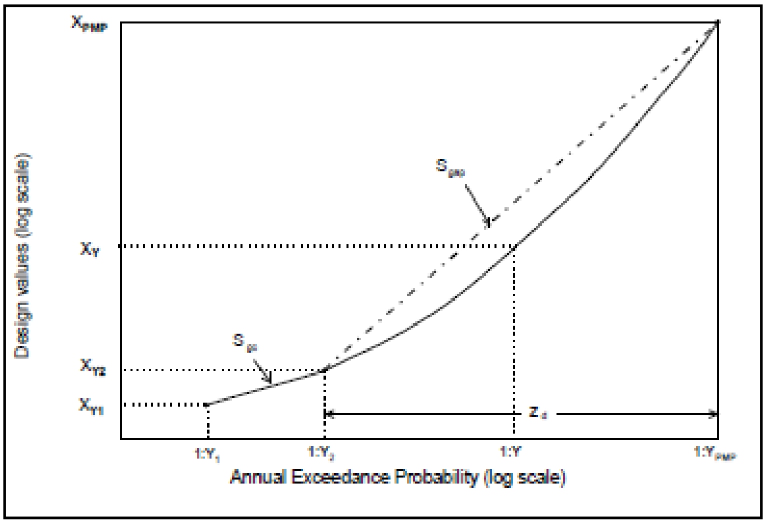


Figure 6.2 Equation and plot demonstrating the interpolation between CRC-FORGE and PMP design rainfall (IEAust 1998)

Table 6.3 Description of terms for equation shown above

VARIABLE	DESCRIPTION	VALUES USED FOR THIS STUDY
Y_1	AEP of lower value than starting point of interpolation	CRC-FORGE (1,000)
Y_2	AEP which is the starting point of interpolation	CRC-FORGE (2,000)
Y	AEP of interest	1 in 10,000 years
Y_{PMP}	AEP of the PMP	Determined from Figure 6.1
X_{Y1}	Design rainfall with AEP of 1 in Y_1	CRC-FORGE design rainfall (1 in 1,000 years)
X_{Y2}	Design rainfall with AEP of 1 in Y_2	CRC-FORGE design rainfall (1 in 2,000 years)
X_Y	Design rainfall with AEP of 1 in Y (design rainfall of interest)	Calculated using equation shown in Figure 6.2 and terms described in this table
X_{PMP}	Design rainfall with AEP of 1 in Y_{PMP}	PMP design rainfall (as described in Section 6.2 above)

Table 6.4 Design catchment rainfall for Dagworth

DURATION (HOURS)	CRC-FORGE (MM)		INTERPOLATION BETWEEN CRC-FORGE AND PMP RAINFALLS (MM)	PMP (MM)
	1 in 1,000 AEP	1 in 2,000 AEP	1 in 10,000 AEP	1 in 55,556 AEP
24	267	295	403	670
36	320	358	494	800
48	374	421	584	920
72	469	539	758	1,130
96	527	609	861	1,280
120	576	664	927	1,330

Table 6.5 Design catchment rainfall for Greenhills

DURATION (HOURS)	CRC-FORGE METHOD (MM)		INTERPOLATION BETWEEN CRC-FORGE AND PMP RAINFALLS	PMP (MM)
	1 in 1,000 AEP	1 in 2,000 AEP	1 in 10,000 AEP	1 in 90,909 AEP
24	277	295	402	720
36	327	358	486	850
48	376	421	570	980
72	468	539	740	1,190
96	526	609	847	1,360
120	579	664	927	1,420

Table 6.6 Design catchment rainfall for Cavehill

DURATION (HOURS)	CRC-FORGE METHOD (MM)		INTERPOLATION BETWEEN CRC-FORGE AND PMP RAINFALLS	PMP (MM)
	1 in 1,000 AEP	1 in 2,000 AEP	1 in 10,000 AEP	1 in 166,667 AEP
24	264	295	389	840
36	314	358	464	980
48	364	421	539	1,110
72	427	539	631	1,340
96	459	609	684	1,530
120	489	664	725	1,610

7 Design event modelling

7.1 Design flood estimation and results

The RORB models with calibrated routing parameters were used to estimate the design flood discharges for the study catchments at storm durations ranging from 24 to 120 hours using design rainfall estimates for the CRC-FORGE 1 in 1,000 AEP, interpolated 1 in 10,000 AEP, and PMP values. The potential storages were included in the RORB models and were assumed to be full at the start of the simulation. This assumption is based on the high likelihood of the storages being full during the wet season when rare and extreme flood events occur. Also, the aim is to be conservative in determining design flood estimates for preliminary planning purposes. For these reasons, it is appropriate to adopt a full reservoir level at the start of the simulation (IEAust 1998). Conservative values of initial loss (0 mm) and continuing loss (1 mm per hour) were used for the design flood simulations. These values were selected in the absence of any flood loss data for the area, and taking into account the recommendations in the relevant sections of the Australian Rainfall and Runoff guidelines (IEAust 1998). Rare and extreme floods are larger than the recorded floods, and this supports the use of low loss values. The output of RORB shows the peak and total flow of the storage inflow and storage outflow, as well as the storage level for the peak discharge event. The RORB design flood results for the three types of design rainfall estimates for each catchment are provided in Table 7.1, Table 7.2 and Table 7.3 for Dagworth, Greenhills and Cavehill respectively.

As can be seen in the result tables, the critical storm duration (that is, the design storm generating the highest design outflow peak) for the Greenhills and Cavehill catchments was 36 hours for all three design rainfall types. The critical duration for Dagworth was slightly more complicated. The critical storm duration resulting in the highest design flood peak for the 1 in 1,000 and 1 in 10,000 year AEP design storms was 120 hours. For the PMP design rainfall, the 120 hour storm resulted in the second highest peak discharge (57,038 m^3/s), with the critical storm (48 hour) having a peak discharge that was slightly higher (57,554 m^3/s) (see Table 7.1). Hydrograph plots of the design storage inflow and outflow at the three potential dam sites, for each critical design flood peak event are provided in Appendix D.

Table 7.1 RORB simulation results of design floods for Dagworth

DURATION	AEP 1 IN 1,000 YEARS					AEP 1 IN 10,000 YEARS					PMP (AEP 1 IN 55,556 YEARS)				
	INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH			INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH			INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH		
	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)
24	15,680	3,740,000,000	14,205	235.30	3,740,000,000	27,166	5,830,000,000	24,753	238.47	5,830,000,000	52,434	9,950,000,000	46,448	244.32	9,950,000,000
36	18,459	4,380,000,000	16,851	236.19	4,380,000,000	32,974	7,050,000,000	30,010	239.95	7,050,000,000	61,048	11,800,000,000	54,304	246.23	11,800,000,000
48	20,132	5,010,000,000	18,695	236.76	5,010,000,000	36,075	8,260,000,000	33,323	240.89	8,260,000,000	63,266	13,400,000,000	57,554	246.99	13,400,000,000
72	20,150	6,100,000,000	19,437	236.99	6,100,000,000	36,325	10,500,000,000	35,075	241.37	10,500,000,000	57,705	16,300,000,000	55,630	246.54	16,300,000,000
96	20,360	6,630,000,000	19,536	237.02	6,630,000,000	37,481	11,800,000,000	35,950	241.60	11,800,000,000	59,469	18,200,000,000	56,987	246.86	18,200,000,000
120	21,581	7,100,000,000	20,463	237.28	7,100,000,000	39,651	12,400,000,000	37,198	241.94	12,400,000,000	61,310	18,600,000,000	57,038	246.87	18,600,000,000

Table 7.2 RORB simulation results of design floods for Greenhills

DURATION	AEP 1 IN 1,000 YEARS					AEP 1 IN 10,000 YEARS					PMP (AEP 1 IN 90,909 YEARS)				
	INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH			INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH			INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH		
	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)
24	24,088	2,140,000,000	15,160	263.99	2,140,000,000	37,109	3,200,000,000	23,117	267.34	3,200,000,000	70,590	5,890,000,000	46,063	275.71	5,890,000,000
36	24,619	2,460,000,000	16,387	264.48	2,460,000,000	38,746	3,810,000,000	25,670	268.38	3,810,000,000	71,273	6,890,000,000	49,978	276.98	6,890,000,000
48	18,519	2,780,000,000	14,965	263.9	2,780,000,000	29,932	4,410,000,000	23,854	267.65	4,410,000,000	54,846	7,880,000,000	44,722	275.27	7,880,000,000
72	17,686	3,350,000,000	14,001	263.49	3,350,000,000	29,610	5,650,000,000	23,477	267.49	5,650,000,000	49,780	9,450,000,000	40,547	273.86	9,460,000,000
96	18,049	3,640,000,000	14,452	263.68	3,640,000,000	31,352	6,350,000,000	24,773	268.03	6,350,000,000	53,349	10,700,000,000	42,959	274.68	10,700,000,000
120	18,532	3,940,000,000	15,007	263.92	3,940,000,000	32,293	6,850,000,000	25,471	268.30	6,850,000,000	52,568	11,000,000,000	41,604	274.22	11,000,000,000

Table 7.3 RORB simulation results of design floods for Cavehill

DURATION	AEP 1 IN 1,000 YEARS					AEP 1 IN 10,000 YEARS					PMP (AEP 1 IN 166,667 YEARS)				
	INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH			INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH			INFLOW HYDROGRAPH		OUTFLOW HYDROGRAPH		
	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	TOTAL FLOOD VOLUME (M^3)	PEAK DISCHARGE (M^3/S)	EL (M) OF PEAK DISCHARGE	TOTAL FLOOD VOLUME (M^3)
24	15,332	1,270,000,000	10,122	231.42	1,270,000,000	24,712	1,920,000,000	15,822	234.00	1,920,000,000	61,146	4,300,000,000	37,490	241.78	4,300,000,000
36	14,775	1,470,000,000	10,891	231.80	1,470,000,000	23,478	2,260,000,000	17,031	234.50	2,260,000,000	54,708	4,980,000,000	39,157	242.30	4,980,000,000
48	12,387	1,670,000,000	9,746	231.24	1,670,000,000	19,739	2,590,000,000	15,222	233.75	2,590,000,000	44,626	5,600,000,000	34,061	240.68	5,600,000,000
72	11,053	1,870,000,000	8,913	230.84	1,870,000,000	17,151	2,950,000,000	14,022	233.23	2,950,000,000	38,248	6,680,000,000	32,169	240.06	6,680,000,000
96	10,753	1,920,000,000	8,319	230.55	1,920,000,000	17,248	3,100,000,000	13,257	232.89	3,100,000,000	42,677	7,560,000,000	32,649	240.21	7,560,000,000
120	11,279	2,000,000,000	8,290	230.54	2,000,000,000	18,344	3,220,000,000	13,221	232.87	3,220,000,000	46,265	7,870,000,000	31,963	239.99	7,860,000,000

7.2 Comparison to other studies

The design flood estimates obtained in this study were found to be comparable to design flood estimates made elsewhere using the same methods. Table 7.4 shows the storage peak inflow and peak outflow resulting from PMP design rainfall for seven other catchments in Queensland. The results in the table are ordered by catchment area and it can be observed that the peak flows determined for Cavehill, Greenhills and Dagworth are comparable to the other studies listed.

Table 7.4 Comparison of PMP design flood results to other PMP studies

DAM	RIVER	CATCHMENT AREA (KM^2)	PEAK INFLOW (M^3/S)	PEAK OUTFLOW (M^3/S)	REFERENCE
Rifle Creek	Rifle	90	3,332	2,685	SMEC - Rifle Creek Dam Failure Impact Assessment - Draft Report, October 2009
Corella	Corella	331	8,540	7,730	GHD - Corella Dam Failure Impact Assessment
Tinaroo	Barron	545	8,497	6,580	SunWater - Tinaroo Falls Dam Spillway Capacity Upgrade - Draft Report (Commercial in Confidence)
Leichardt River	Leichhardt	1,213	13,241	12,455	SMEC - Leichhardt River Dam Failure Impact Assessment - Final Report, December 2010
Julius	Leichhardt	3,806	44,625	42,550	SunWater - Julius Dam Failure Impact Assessment, July 2012 (Commercial in Confidence)
Cavehill	Cloncurry	5,265	54,708	39,157	DSITIA - Design flood hydrology for selected potential dam sites in the Flinders and Gilbert catchments (this study)
Greenhills	Gilbert	8,400	71,273	49,978	DSITIA - Design flood hydrology for selected potential dam sites in the Flinders and Gilbert catchments (this study)
Dagworth	Einasleigh	15,318	63,266	57,554	DSITIA - Design flood hydrology for selected potential dam sites in the Flinders and Gilbert catchments (this study)
Paradise	Burnett	30,591	106,863	104,451	Burnett Dam Alliance - Burnett River Dam Detail Design Report: Section 3 - Hydrology
Burdekin Falls	Burdekin	114,654	129,400	112,200	SunWater - Burdekin Falls Dam Comprehensive Risk Assessment, November 2009 (Commercial in Confidence)

The design flood estimates in this study would be considerably larger than those made by studies undertaken in the 1970s and 1980s as a result of changes to the PMP estimation methods. Revision of the PMP estimation method has increased estimates of PMP depths for individual catchments. This is due to the utilisation of greater amounts of data and better techniques for PMP estimation (BOM 2003b). The larger design PMF estimates are a direct result of the progressively higher estimates of PMP depths.

8 Flood frequency analysis

Flood frequency analysis for the study catchments was undertaken using streamflow data from streamflow gauging stations 917106A for Dagworth, 917001D for Greenhills and 915203A for Cavehill. The details of the three streamflow gauging stations are summarised in Table 4.1.

For each streamflow gauging station annual maximum discharges were extracted between the years 1967 and 2013. The resulting series of annual maximum discharges were used in the flood frequency analysis. Table 8.1 lists the annual maximum discharges for the three selected gauging stations. The analysis was undertaken based on the water year (July to June).

As the Log Pearson type III distribution is widely used for flood frequency analysis, this flood frequency analysis was undertaken by fitting Log Pearson III distributions to the series of recorded annual maximum discharges at the three gauging stations using a computer program called FLIKE (Kuczera 1999).

Flood frequency analysis results are provided in Table 8.2, Table 8.3 and Table 8.4 for Dagworth, Greenhills and Cavehill, respectively. The fitted distribution and confidence limit flood frequency plots are provided in Appendix E.

Table 8.1 Annual series of recorded maximum discharge used in flood frequency analysis

DAGWORTH EINASLEIGH RIVER AT EINASLEIGH GS 917106A		GREENHILLS GILBERT RIVER AT ROCK FIELDS GS 917001D		CAVEHILL CLONCURRY RIVER AT CLONCURRY GS 915203A	
Date	Peak Flow (m^3/s)	Date	Peak Flow (m^3/s)	Date	Peak Flow (m^3/s)
15/02/1968	3,261.4	16/02/1968	3,998.6	24/12/1969	788.6
18/01/1969	25.8	26/02/1969	412.7	05/03/1971	3,437.8
23/12/1969	154.3	25/12/1969	1,993.3	07/03/1972	2,848.9
09/02/1971	1,211.4	10/03/1971	2,530.1	28/03/1973	3,272.3
08/03/1972	3,419.8	12/01/1972	1,907.4	31/01/1974	2,862.7
23/02/1973	642.7	09/02/1973	2,002.9	25/02/1975	1,242.8
23/01/1974	7,225.0	23/01/1974	13,984.9	13/12/1975	544.2
15/01/1975	1,723.7	17/01/1975	2,726.4	25/01/1977	1,955.8
07/02/1976	2,261.7	26/03/1976	1,917.5	27/01/1978	439.7
06/02/1977	486.5	02/03/1977	566.0	23/02/1979	406.8
24/12/1977	138.0	22/12/1977	879.3	05/01/1980	406.8
10/03/1979	3,179.3	03/02/1979	3,804.1	22/01/1981	1,418.0
06/01/1980	3,038.7	11/02/1980	756.9	25/01/1982	356.6
21/01/1981	3,473.9	21/01/1981	3,893.0	20/03/1983	1,090.7
25/11/1981	489.0	22/01/1982	358.7	15/02/1984	2,317.2
30/04/1983	667.6	11/03/1983	718.4	19/12/1984	342.1
10/02/1984	1,423.0	16/02/1984	3,703.8	14/11/1985	237.9
24/01/1985	135.1	25/02/1985	632.0	28/01/1987	1,814.9

08/02/1986	670.6	22/01/1986	741.0	16/12/1987	577.7
07/03/1987	356.6	31/01/1987	1,499.9	27/12/1988	378.3
13/02/1988	1,091.0	13/02/1988	1,163.6	22/11/1989	2,032.0
15/03/1989	872.1	16/03/1989	1,516.2	14/01/1991	3,425.6
06/03/1990	1,491.2	06/03/1990	1,065.9	28/02/1992	1,803.9
13/01/1991	4,383.3	01/07/1990	1.5	16/02/1993	378.1
27/02/1992	471.9	07/02/1992	399.2	26/03/1994	0.1
19/02/1993	930.7	07/01/1993	746.3	19/01/1995	590.1
07/03/1994	191.2	21/04/1994	0.3	05/03/1996	544.6
10/03/1995	1,167.6	02/12/1994	35.1	02/03/1997	6,482.1
09/01/1996	324.8	25/01/1996	288.3	15/12/1997	341.9
04/03/1997	1,522.5	05/03/1997	1,601.7	02/01/1999	3,001.1
13/01/1998	602.2	05/03/1998	1,389.7	25/12/1999	779.4
15/01/1999	543.3	16/02/1999	1,137.8	17/12/2000	1,323.9
08/04/2000	1,753.2	27/12/1999	1,114.9	16/12/2001	194.8
01/01/2001	2,845.6	01/01/2001	1,978.5	28/02/2003	619.6
16/02/2002	4,539.5	16/02/2002	5,714.0	16/01/2004	3,584.1
02/03/2003	982.9	01/03/2003	1,007.4	06/01/2005	1,753.9
15/01/2004	504.4	15/01/2004	881.0	06/04/2006	1,000.0
24/01/2005	2,307.6	25/01/2005	2,034.2	18/06/2007	321.9
30/01/2006	1,246.5	30/01/2006	1,385.7	23/12/2007	179.6
05/02/2007	540.4	05/02/2007	784.9	08/01/2009	3,651.4
14/01/2008	2,240.4	11/02/2008	2,651.6	08/01/2010	1,095.0
27/01/2009	4,269.6	27/01/2009	6,389.4	12/03/2011	1,478.6
30/01/2010	1,044.4	30/01/2010	1,663.6	28/01/2012	904.4
05/02/2011	2,278.5	11/03/2011	2,912.9	-	-
20/03/2012	2,730.1	21/03/2012	3,649.0	-	-

Table 8.2 Flood frequency analysis results - Dagworth (GS 917106A)

ANNUAL EXCEEDENCE PROBABILITY (%)	AEP (1 IN X YEARS)	PEAK DISCHARGE (M^3/S)	MONTE CARLO 90% QUANTILE PROBABILITY LIMITS (M^3/S)	
10	10	881	617	1,312
5	20	1,297	890	2,163
2	50	1,908	1,222	3,871
1	100	2,400	1,427	5,758
0.5	200	2,906	1,581	8,294
0.2	500	3,585	1,723	12,972
0.1	1000	4,096	1,800	17,757

Table 8.3 Flood frequency analysis results - Greenhills (GS 917001D)

ANNUAL EXCEEDENCE PROBABILITY (%)	AEP (1 IN X YEARS)	PEAK DISCHARGE (M^3/S)	MONTE CARLO 90% QUANTILE PROBABILITY LIMITS (M^3/S)	
10	10	5,850	4,366	8,156
5	20	7,941	5,964	11,150
2	50	10,547	7,959	15,295
1	100	12,341	9,305	18,579
0.5	200	13,963	10,502	21,874
0.2	500	15,837	11,831	26,177
0.1	1000	17,060	12,649	29,395

Table 8.4 Flood frequency analysis results - Cavehill (GS 915203A)

ANNUAL EXCEEDENCE PROBABILITY (%)	AEP (1 IN X YEARS)	PEAK DISCHARGE (M^3/S)	MONTE CARLO 90% QUANTILE PROBABILITY LIMITS (M^3/S)	
10	10	3,746	2,960	4,866
5	20	4,730	3,796	6,134
2	50	5,796	4,715	7,783
1	100	6,441	5,263	8,942
0.5	200	6,965	5,696	10,037
0.2	500	7,505	6,113	11,368
0.1	1000	7,820	6,327	12,299

9 Conclusion

This report describes a design flood study for potential dam sites at Dagworth and Greenhills in the Gilbert River catchment and Cavehill in the Flinders River catchment. The study included the development and calibration of RORB runoff-routing models, estimation of design rainfall, model simulation of design floods and flood frequency analysis at each of the sites.

Three methods were used to estimate design rainfall. These were, CRC-FORGE (1 in 1,000 years and 1 in 2,000 years AEP) (Nandakumar et al. 1997), an interpolation between CRC-FORGE and PMP (1 in 10,000 years AEP) (IEAust 1998) and the PMP method (BOM 2003a). The calibrated models were used in conjunction with the design rainfall estimates to compute the design flood discharges at the potential dam sites.

The design flood estimates obtained in this study were found to be comparable to design flood estimates made elsewhere using the same methods. They would be, however, considerably larger than design flood estimates made by studies undertaken in the 1970s and 1980s as a result of changes to the PMP estimation method (BOM 2003b). Checks were also undertaken on the peak and total flood volumes, taking into account quantity of rainfall and catchment area.

These design flood estimates will be used in the companion technical report on water storages (see Preface Figure 1) to assist in developing conceptual arrangements for the three potential dam sites, including the sizing of spillways and embankments.

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Appendix A RORB model calibration hydrographs

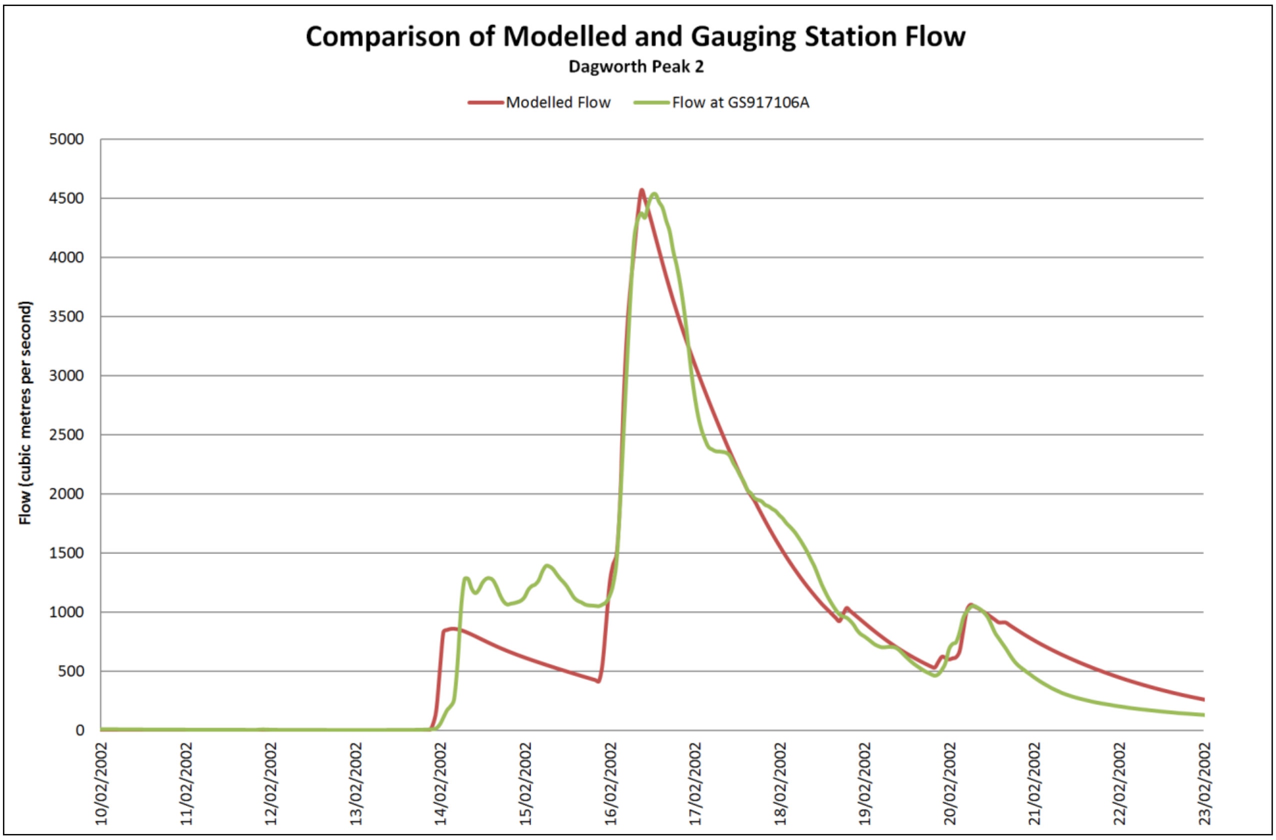


Figure A.1 Comparison of Modelled and Gauging Station Flow for Dagworth Peak 2

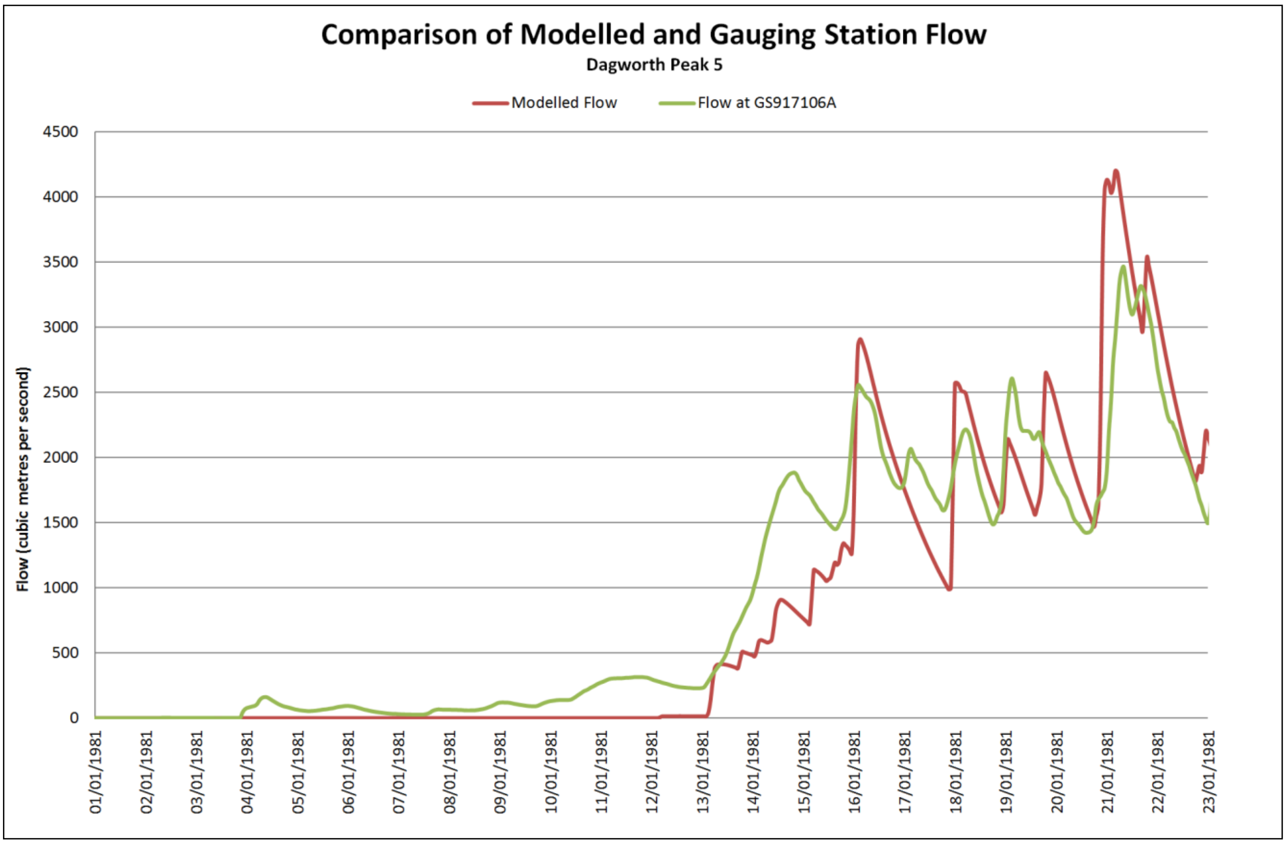


Figure A.2 Comparison of Modelled and Gauging Station Flow for Dagworth Peak 5

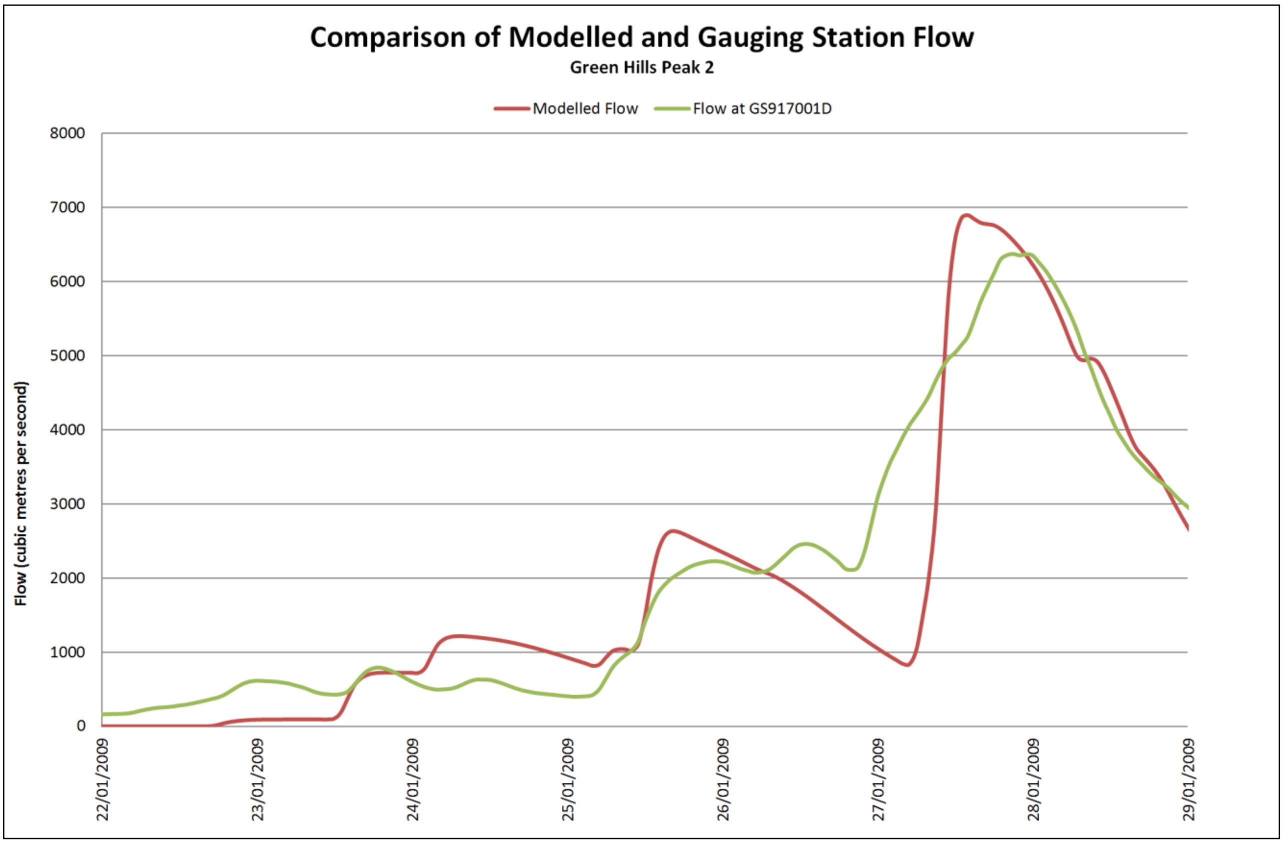


Figure A.3 Comparison of Modelled and Gauging Station Flow for Greenhills Peak 2

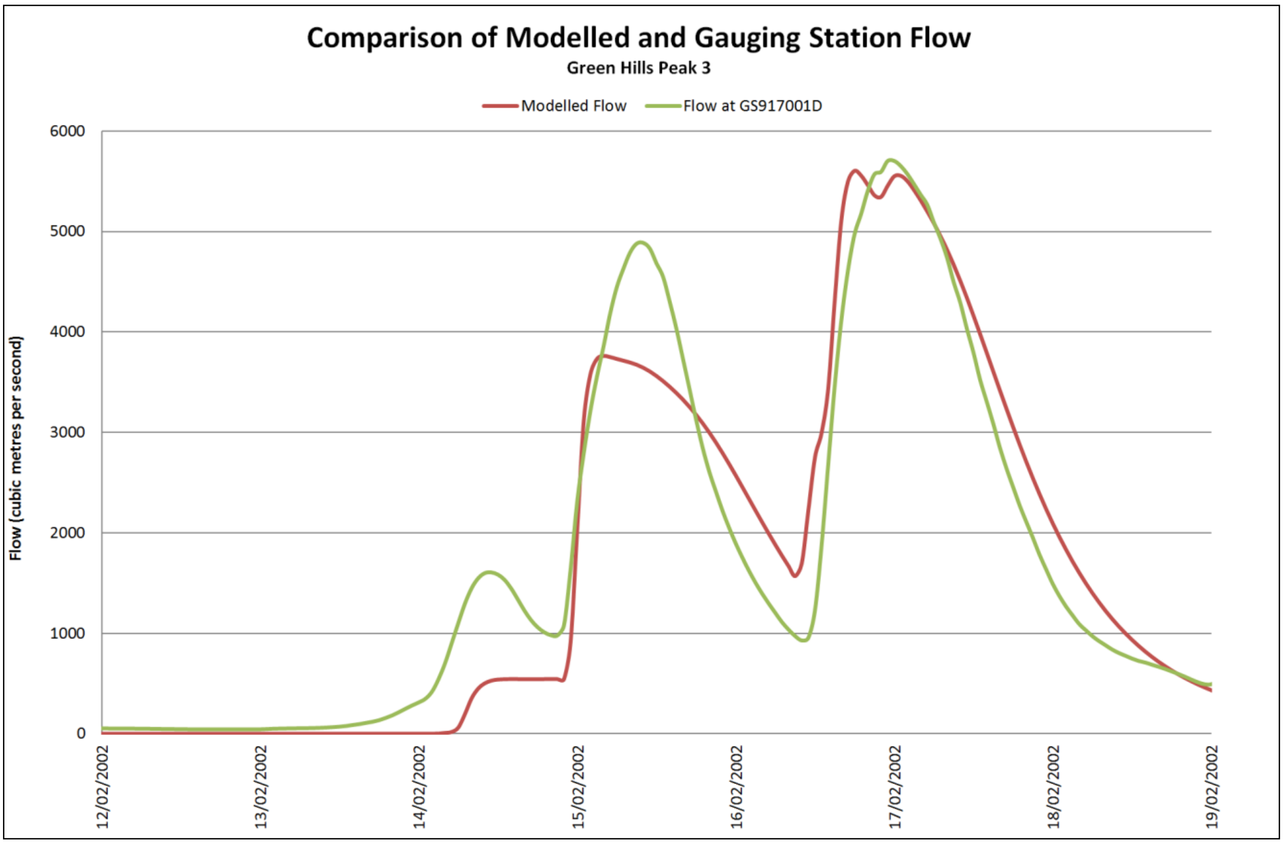


Figure A.4 Comparison of Modelled and Gauging Station Flow for Greenhills Peak 3

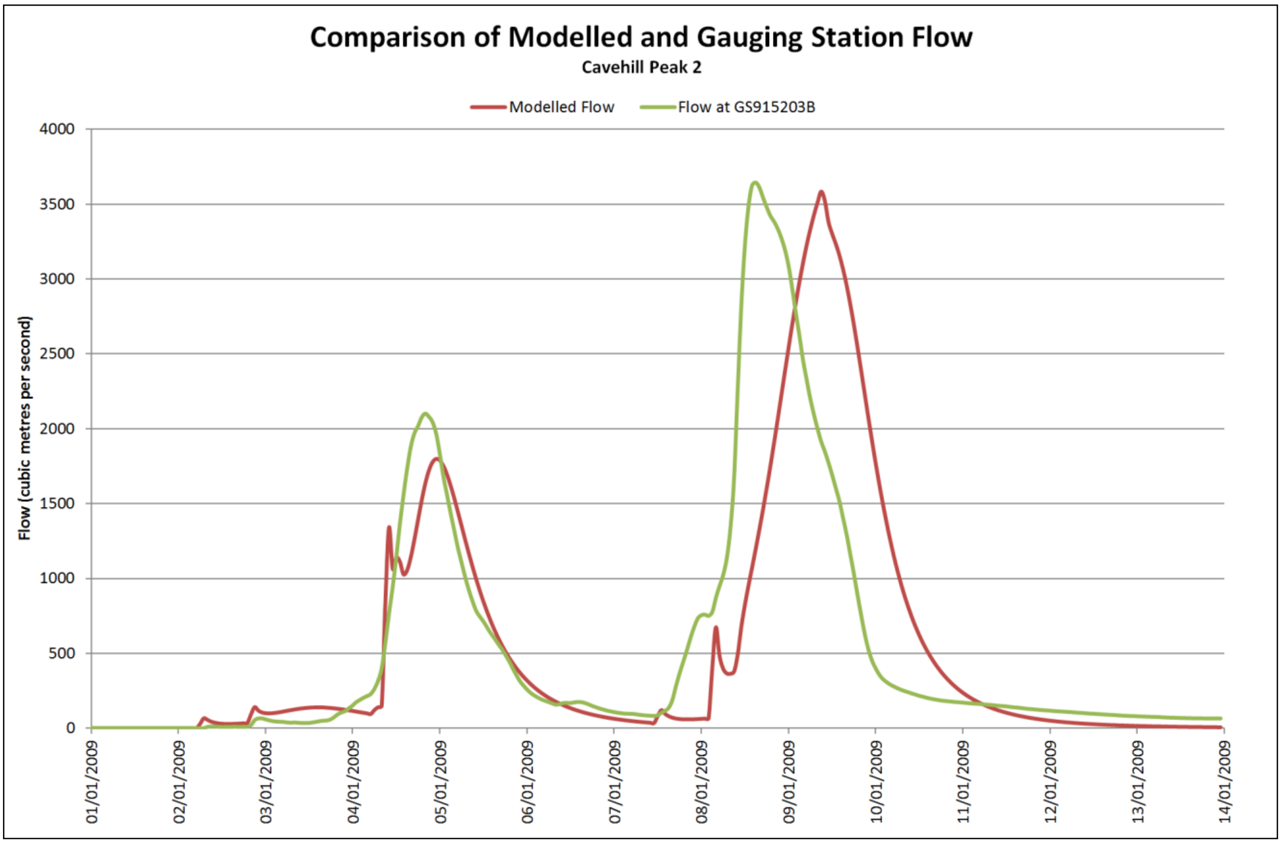


Figure A.5 Comparison of Modelled and Gauging Station Flow for Cavehill Peak 2

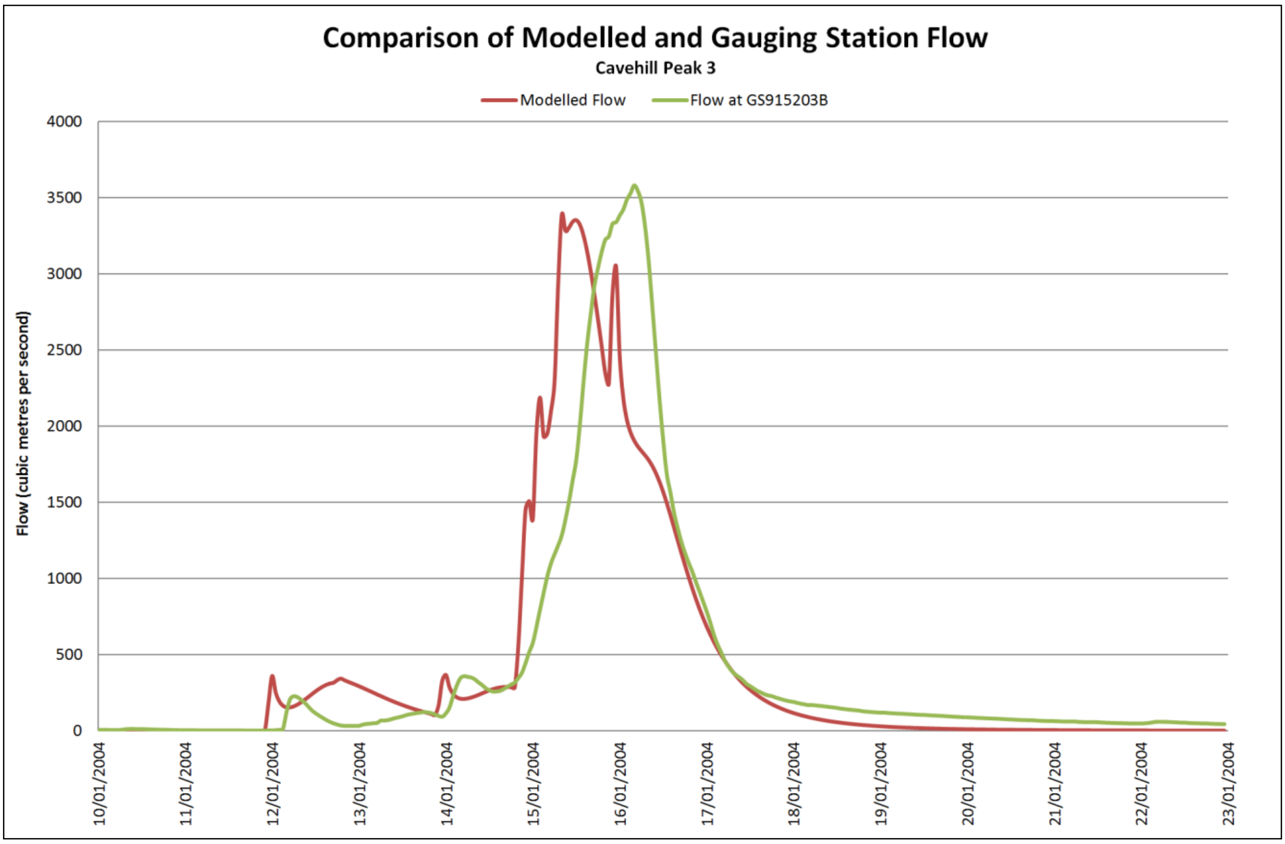


Figure A.6 Comparison of Modelled and Gauging Station Flow for Cavehill Peak 3

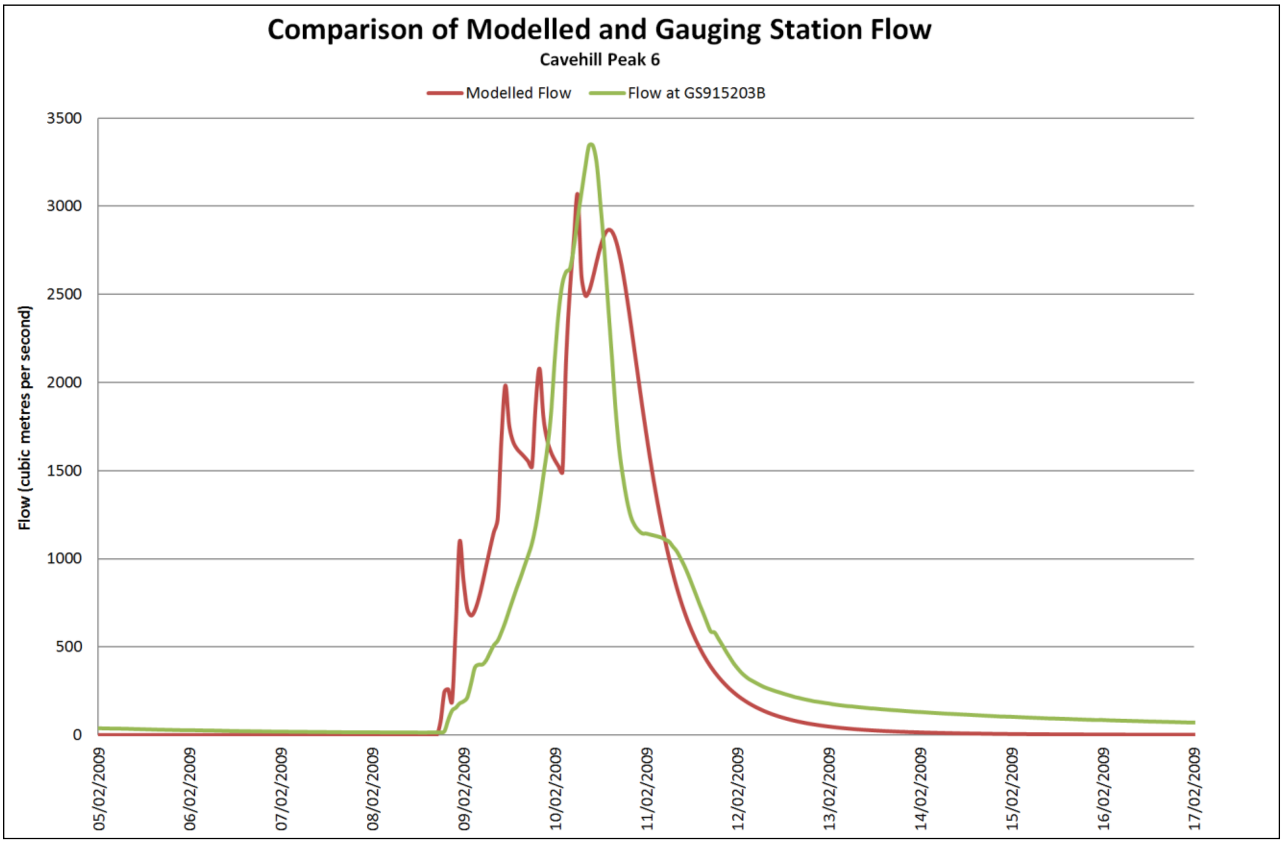


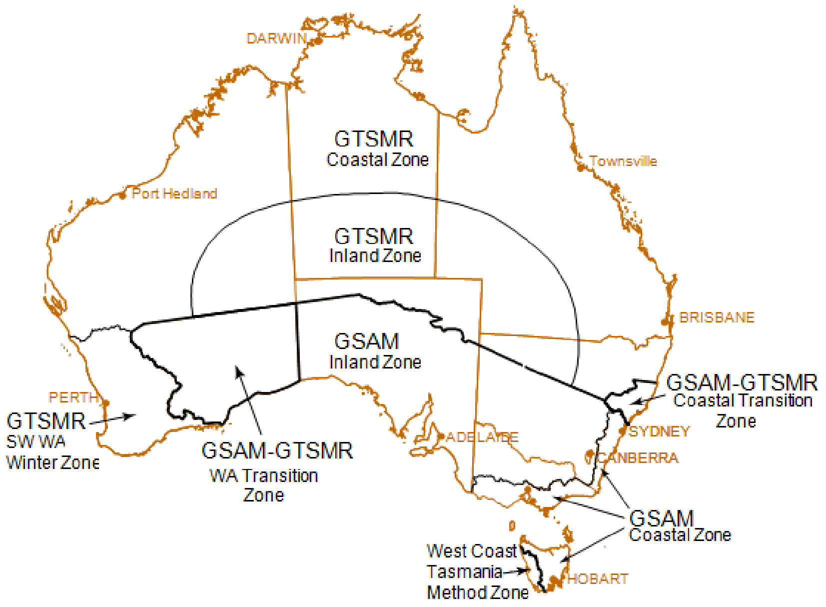
Figure A.7 Comparison of Modelled and Gauging Station Flow for Cavehill Peak 6

Appendix B PMP calculations

B1. WORKSHEET 1 PMP method selection

Catchment Name Dagworth Catchment Area 15,316km^2

LONG DURATION PMP



NB This diagram can is also available as a shapefile: [CD-ROM drive]:pmp_zones\zones_all.shp or it can be printed on A3 paper from [CD-ROM drive]:documents\method_zones.pdf

CIRCLE THE ZONE IN WHICH THE CATCHMENT IS LOCATED:

GTSMR (Coastal)	GTSMR (Inland)
GTSMR (Coastal & SWWA)	Coastal Transition - GTSMR Coastal - GSAM Coastal
GSAM (Coastal)	WA Transition - GTSMR Coastal - GSAM Inland
GSAM (Inland)	WCTas

SHORT DURATION PMP (GSDM)

Is the catchment less than 1000km^2?

- NO → Short duration PMP estimates can **not** be calculated for the catchment
- YES → Is the catchment less than 500km^2 and south of 30°S?
  - NO → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment
  - YES → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment and can include **winter** estimates

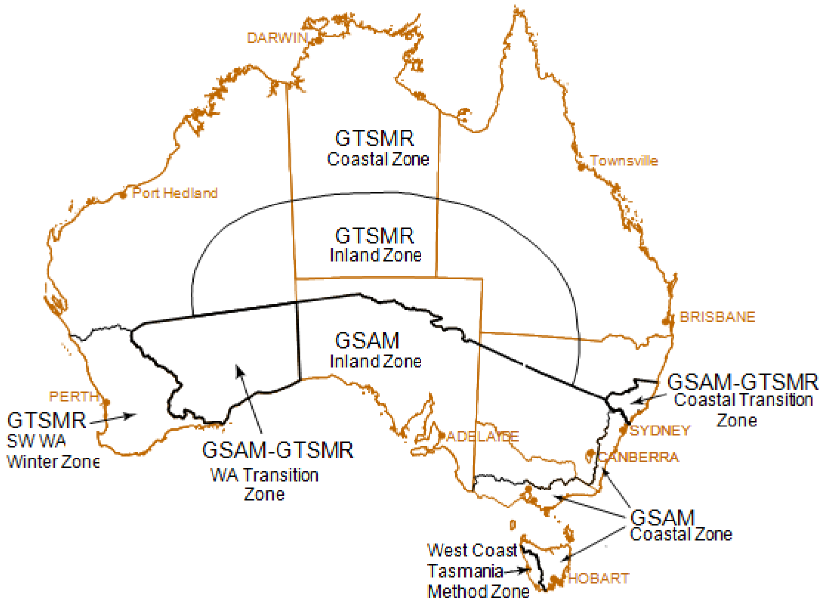
PMP METHOD SUMMARY

Fill in the table below with the PMP method/s applicable to the catchment, referring to Table 1.1 for any additional information needed. NB: for the Transition zones, write separate entries for GTSMR and GSAM.

METHOD	ZONE	SEASON	DURATIONS
GTSMR	Coastal	Summer	24-120 hours

Catchment Name Green Hills   Catchment Area 11,086km²

LONG DURATION PMP



NB This diagram can is also available as a shapefile: [CD-ROM drive]:pmp_zones\zones_all.shp or it can be printed on A3 paper from [CD-ROM drive]:documents\method_zones.pdf

CIRCLE THE ZONE IN WHICH THE CATCHMENT IS LOCATED:

GTSMR (Coastal)	GTSMR (Inland)
GTSMR (Coastal & SWWA)	Coastal Transition - GTSMR Coastal - GSAM Coastal
GSAM (Coastal)	WA Transition - GTSMR Coastal - GSAM Inland
GSAM (Inland)	WCTas

SHORT DURATION PMP (GSDM)

Is the catchment less than 1000km²?
- NO → Short duration PMP estimates can **not** be calculated for the catchment
- YES ↓

Is the catchment less than 500km² and south of 30°S?
- NO → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment
- YES → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment and can include **winter** estimates

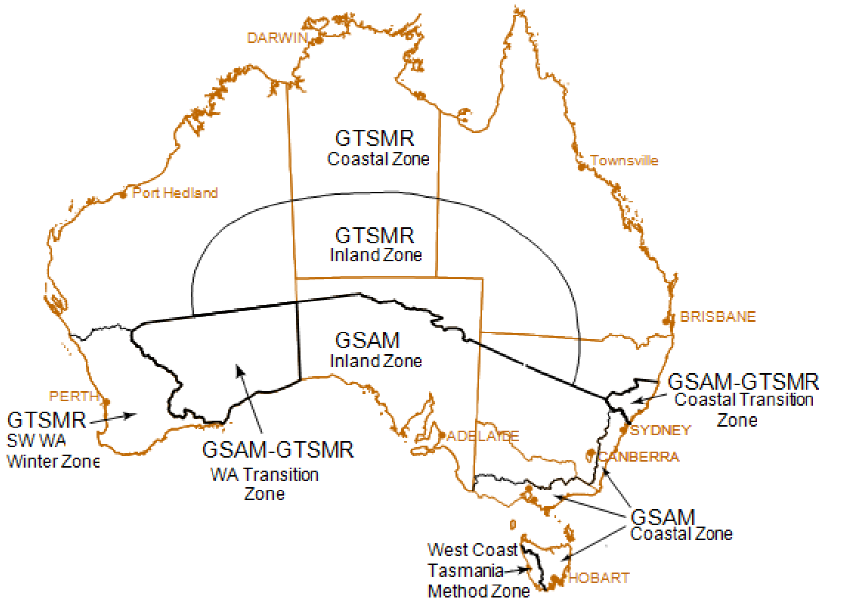
PMP METHOD SUMMARY

Fill in the table below with the PMP method/s applicable to the catchment, referring to Table 1.1 for any additional information needed. NB: for the Transition zones, write separate entries for GTSMR and GSAM.

METHOD	ZONE	SEASON	DURATIONS
GTSMR	Coastal	Summer	24-120 hours

Catchment Name Cavehill Catchment Area 5,981km²

LONG DURATION PMP



NB This diagram can is also available as a shapefile: [CD-ROM drive]:pmp_zones\zones_all.shp or it can be printed on A3 paper from [CD-ROM drive]:documents\method_zones.pdf

CIRCLE THE ZONE IN WHICH THE CATCHMENT IS LOCATED:

GTSMR (Coastal)	GTSMR (Inland)
GTSMR (Coastal & SWWA)	Coastal Transition - GTSMR Coastal - GSAM Coastal
GSAM (Coastal)	WA Transition - GTSMR Coastal - GSAM Inland
GSAM (Inland)	WCTas

SHORT DURATION PMP (GSDM)

Is the catchment less than 1000km²? — NO → Short duration PMP estimates can **not** be calculated for the catchment

YES ↓

Is the catchment less than 500km² and south of 30°S? — NO → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment

YES → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment and can include **winter** estimates

PMP METHOD SUMMARY

Fill in the table below with the PMP method/s applicable to the catchment, referring to Table 1.1 for any additional information needed. NB: for the Transition zones, write separate entries for GTSMR and GSAM.

METHOD	ZONE	SEASON	DURATIONS
GTSMR	Coastal	Summer	24-120 hours

B2. WORKSHEET 2 Generalised Tropical Storm method revised (GTSMR)

LOCATION INFORMATION				
Catchment Name Dagworth	State QLD			
GTSMR zone(s) Coastal				
CATCHMENT FACTORS				
Topographical Adjustment Factor			**TAF** = 1 (1.0 – 2.0)	
Decay Amplitude Factor			**DAF** = 0.986 (0.7 – 1.0)	
Annual Moisture Adjustment Factor			MAF_a = $EPW_{catchment}$/120.00	
Extreme Precipitable Water ($EPW_{catchment}$) = 98.915			$\mathbf{MAF_a}$ = 0.824 (0.4 – 1.1)	
Winter Moisture Adjustment Factor (where applicable)			MAF_w = $EPW_{catchment\_winter}$/82.30	
Winter EPW ($EPW_{catchment\_winter}$) = …………			$\mathbf{MAF_w}$ = ……………… (0.4 – 1.1)	
PMP VALUES (mm) - Annual				
Duration (hours)	Initial Depth (D_a)	PMP Estimate $=D_a x TAF x DAF x MAF_a$	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24	828.85	673.6625439	670	670
36	987.22	802.3805713	800	800
48	1131.18	919.3866156	920	920
72	1394.25	1133.201426	1130	1130
96	1580.76	1284.790738	1280	1280
120	1641.58	1334.223272	1330	1330
PMP VALUES (mm) – Winter (where applicable)				
Duration (hours)	Initial Depth (D_w)	PMP Estimate $=D_w x TAF x DAF x MAF_w$	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24				
36				
48				
72				
96				

LOCATION INFORMATION	
Catchment Name Greenhills	State QLD
GTSMR zone(s) Coastal	

CATCHMENT FACTORS	
Topographical Adjustment Factor	**TAF** = 1 (1.0 – 2.0)
Decay Amplitude Factor	**DAF** = 0.955 (0.7 – 1.0)
Annual Moisture Adjustment Factor	MAF_a = $EPW_{catchment}$/120.00
Extreme Precipitable Water ($EPW_{catchment}$) = 101.059	**MAF_a** = 0.842 (0.4 – 1.1)
Winter Moisture Adjustment Factor (where applicable)	MAF_w = $EPW_{catchment\_winter}$/82.30
Winter EPW ($EPW_{catchment\_winter}$) = ………..	**MAF_w** = ………………. (0.4 – 1.1)

PMP VALUES (mm) - Annual

Duration (hours)	Initial Depth (D_a)	PMP Estimate $=D_a x TAF x DAF x MAF_a$	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24	899.53	723.336802	720	720
36	1063.15	854.908142	850	850
48	1215.00	977.0149015	980	980
72	1484.43	1193.670971	1190	1190
96	1687.96	1357.33504	1360	1360
120	1767.08	1420.957607	1420	1420

PMP VALUES (mm) – Winter (where applicable)

Duration (hours)	Initial Depth (D_w)	PMP Estimate $=D_w x TAF x DAF x MAF_w$	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24				
36				
48				
72				
96				

LOCATION INFORMATION				
Catchment Name Cavehill		State QLD		
GTSMR zone(s) Coastal				
CATCHMENT FACTORS				
Topographical Adjustment Factor			**TAF** = 1.066 (1.0 – 2.0)	
Decay Amplitude Factor			**DAF** = 0.960 (0.7 – 1.0)	
Annual Moisture Adjustment Factor			MAF_a = $EPW_{catchment}$/120.00	
Extreme Precipitable Water ($EPW_{catchment}$) = 95.473			**MAF_a** = 0.796 (0.4 – 1.1)	
Winter Moisture Adjustment Factor (where applicable)			MAF_w = $EPW_{catchment\_winter}$/82.30	
Winter EPW ($EPW_{catchment\_winter}$) = ………..			**MAF_w** = ……………… (0.4 – 1.1)	

PMP VALUES (mm) - Annual

Duration (hours)	Initial Depth (**D_a**)	PMP Estimate =**D_axTAFxDAFxMAF$_a$**	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24	1026.92	836.6688489	840	840
36	1198.11	976.1435308	980	980
48	1356.30	1105.026643	1110	1110
72	1640.44	1336.525773	1340	1340
96	1872.18	1525.332729	1530	1530
120	1970.68	1605.584240	1610	1610

PMP VALUES (mm) – Winter (where applicable)

Duration (hours)	Initial Depth (**D_w**)	PMP Estimate =**D_wxTAFxDAFxMAF$_w$**	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24				
36				
48				
72				
96				

Appendix C Temporal pattern files

TIME (HOURS)	TIME (%)	DAGWORTH: STANDARD AREA OF 20,000km^2		GREENHILLS: STANDARD AREA OF 10,000km^2		CAVEHILL: STANDARD AREA OF 5,000km^2	
		INCREMENTAL RAINFALL (%)	CUMULATIVE RAINFALL (%)	INCREMENTAL RAINFALL (%)	CUMULATIVE RAINFALL (%)	INCREMENTAL RAINFALL (%)	CUMULATIVE RAINFALL (%)
24 HOURS							
3	12.5	7.15	7.15	6.96	6.96	8.71	8.71
6	25	9.01	16.16	11	17.96	6.77	15.47
9	37.5	15.44	31.61	17.2	35.15	17.15	32.62
12	50	22.2	53.8	22.93	58.08	24.98	57.61
15	62.5	12.72	66.53	12.39	70.47	11.91	69.52
18	75	11.26	77.79	4.99	75.46	4.89	74.41
21	87.5	17.06	94.85	15.82	91.28	14.7	89.11
24	100	5.15	100	8.72	100	10.89	100
36 HOURS							
3	8.33	6.62	6.62	7.18	7.18	7.13	7.13
6	16.67	10.28	16.91	5.12	12.31	3.03	10.16
9	25	7.95	24.85	4.53	16.83	5.19	15.35
12	33.33	2.31	27.17	3.17	20	4.65	20
15	41.67	6.06	33.22	5.79	25.79	9.29	29.29
18	50	5.38	38.6	5.36	31.15	5.76	35.04
21	58.33	12.44	51.05	7.77	38.92	9.97	45.02
24	66.67	17.86	68.91	17.48	56.4	18.05	63.07
27	75	13.6	82.51	11.87	68.27	11.52	74.59
30	83.33	9.53	92.04	9.28	77.55	5.34	79.93
33	91.67	4.31	96.35	12.4	89.95	12.39	92.32
36	100	3.65	100	10.05	100	7.68	100
48 HOURS							
3	6.25	4.76	4.76	2.25	2.25	2.24	2.24
6	12.5	4.32	9.07	5.18	7.43	3.78	6.02
9	18.75	4.79	13.86	5.94	13.36	6.5	12.52
12	25	9.22	23.08	8.07	21.43	5.65	18.17
15	31.25	15.39	38.47	14.77	36.21	15.46	33.63
18	37.5	6.01	44.49	2.62	38.82	5.17	38.79
21	43.75	2.68	47.17	3.88	42.7	3.81	42.6
24	50	1.83	48.99	7.44	50.14	8.13	50.73
27	56.25	7.22	56.21	5.52	55.65	4.41	55.14
30	62.5	8.32	64.53	3.26	58.91	2.62	57.77
33	68.75	3.94	68.47	3.58	62.5	1.61	59.38
36	75	10.93	79.4	10.38	72.87	8.9	68.27
39	81.25	7.71	87.11	8.71	81.58	9.64	77.91
42	87.5	5.96	93.07	9.39	90.97	11.01	88.92
45	93.75	3.91	96.98	6.39	97.36	7.6	96.52
48	100	3.02	100	2.64	100	3.48	100
72 HOURS							
3	4.17	2.29	2.29	1.44	1.44	1.19	1.19
6	8.33	3.94	6.23	4.62	6.06	6.18	7.37
9	12.5	8.36	14.6	6.76	12.81	5.13	12.51
12	16.67	10.1	24.69	7.02	19.83	4	16.51
15	20.83	7.39	32.08	5.54	25.37	3.24	19.75
18	25	5.39	37.48	7.75	33.11	5.57	25.33
21	29.17	3.41	40.88	3.44	36.55	6.8	32.12
24	33.33	4.24	45.12	4.13	40.68	7.62	39.74
27	37.5	7.05	52.17	1.45	42.14	3.58	43.32
30	41.67	4.84	57.02	6.33	48.47	8.2	51.52
33	45.83	5.93	62.95	5.05	53.52	4.54	56.06
36	50	2.87	65.82	9.93	63.45	7.13	63.19
39	54.17	2.45	68.27	3.99	67.44	3.8	67
42	58.33	1.59	69.86	2.93	70.37	1.87	68.86
45	62.5	2.06	71.92	2.21	72.58	1.62	70.48
48	66.67	1.86	73.78	2.66	75.24	4.28	74.77
51	70.83	6.5	80.29	2.86	78.1	2.52	77.29
54	75	3.76	84.05	1.66	79.76	1.37	78.66
57	79.17	4.75	88.8	4.31	84.06	2.92	81.58
60	83.33	2.88	91.68	4.79	88.86	10.48	92.05
63	87.5	2.43	94.11	2.75	91.6	2.65	94.71
66	91.67	1.16	95.27	2.11	93.72	0.98	95.68
69	95.83	1.48	96.75	3.9	97.62	2.05	97.74
72	100	3.25	100	2.38	100	2.26	100
96 HOURS							
3	3.13	0.9	0.9	1.99	1.99	1.79	1.79
6	6.25	1.15	2.05	4	5.99	1.07	2.86
9	9.38	4.1	6.15	3.51	9.5	3.21	6.07
12	12.5	2.18	8.33	1.66	11.16	1.92	7.99
15	15.63	5.6	13.93	5.16	16.32	4.37	12.36
18	18.75	6.35	20.28	4.29	20.61	4.03	16.39
21	21.88	8.52	28.8	5.92	26.53	5.6	21.99
24	25	5.86	34.66	6.79	33.32	6.77	28.76
27	28.13	3.18	37.84	3.72	37.04	3.39	32.14
30	31.25	2.6	40.44	2.78	39.82	2.97	35.12
33	34.38	3.69	44.13	1.42	41.24	1.34	36.46
36	37.5	2.1	46.23	3.21	44.45	4.75	41.2
39	40.63	3.89	50.12	6.2	50.65	5.82	47.03
42	43.75	6.94	57.06	7.93	58.58	7.98	55.01
45	46.88	5.09	62.15	5.74	64.32	6.2	61.21
48	50	2.78	64.93	4.68	69	3.85	65.05
51	53.13	1.65	66.57	0.85	69.85	0.45	65.5
54	56.25	1.44	68.01	1.05	70.9	0.82	66.32
57	59.38	4.58	72.59	2.77	73.67	2.18	68.51
60	62.5	3.29	75.88	3.2	76.87	2.79	71.3
63	65.63	3.52	79.4	1.21	78.08	2.35	73.65
66	68.75	1.73	81.13	3.96	82.03	2.52	76.17
69	71.88	2.98	84.11	2.22	84.25	5.26	81.42
72	75	1.83	85.95	1.39	85.64	3.57	84.99
75	78.13	0.85	86.79	0.75	86.39	2.11	87.09
78	81.25	1.26	88.05	2.04	88.43	1.76	88.86
81	84.38	3.08	91.13	2.72	91.15	1.48	90.34
84	87.5	1.39	92.52	0.96	92.11	1.08	91.42
87	90.63	1.16	93.69	1.13	93.24	2.71	94.13
90	93.75	1.75	95.43	2.31	95.56	2.03	96.16
93	96.88	2.65	98.08	2.91	98.47	2.58	98.74
96	100	1.92	100	1.53	100	1.26	100

TIME (HOURS)	TIME (%)	DAGWORTH: STANDARD AREA OF 20,000km^2		GREENHILLS: STANDARD AREA OF 10,000km^2		CAVEHILL: STANDARD AREA OF 5,000km^2	
		INCREMENTAL RAINFALL (%)	CUMULATIVE RAINFALL (%)	INCREMENTAL RAINFALL (%)	CUMULATIVE RAINFALL (%)	INCREMENTAL RAINFALL (%)	CUMULATIVE RAINFALL (%)
120 HOURS							
3	2.5	0.23	0.23	1.38	1.38	1.44	1.44
6	5	2.81	3.04	1.54	2.92	0.45	1.9
9	7.5	2.97	6.01	2.77	5.69	0.73	2.63
12	10	0.86	6.87	1.44	7.13	0.65	3.27
15	12.5	2.42	9.29	1.66	8.79	2.1	5.38
18	15	2.59	11.88	2.53	11.32	3.57	8.94
21	17.5	4.6	16.47	4.1	15.43	2.57	11.51
24	20	1.7	18.17	2.67	18.09	1.01	12.52
27	22.5	3.16	21.33	4.51	22.6	1.93	14.45
30	25	7.38	28.71	5.85	28.46	6.73	21.18
33	27.5	8.36	37.07	3.01	31.47	1.82	23
36	30	2.19	39.26	2.45	33.92	1.64	24.64
39	32.5	1.58	40.84	1.3	35.22	1.53	26.17
42	35	1	41.84	3.76	38.98	2.74	28.91
45	37.5	6.39	48.22	3.35	42.33	2.52	31.44
48	40	3.56	51.79	2.03	44.36	4.72	36.16
51	42.5	5.5	57.29	9.42	53.77	7.39	43.55
54	45	4.93	62.23	7.35	61.13	9.39	52.95
57	47.5	3.37	65.59	2.24	63.36	3.07	56.02
60	50	1.84	67.43	0.96	64.32	2.44	58.46
63	52.5	4.09	71.53	6.33	70.65	5.48	63.94
66	55	3.78	75.3	3.24	73.89	1.32	65.26
69	57.5	0.69	75.99	1.01	74.9	0.26	65.52
72	60	1.1	77.09	0.66	75.56	0.9	66.42
75	62.5	0.33	77.42	0.5	76.07	1.37	67.79
78	65	1.47	78.89	0.83	76.9	5.08	72.87
81	67.5	0.81	79.7	1.2	78.1	1.06	73.93
84	70	5.89	85.59	5.54	83.63	3.33	77.26
87	72.5	1.18	86.77	1.91	85.55	4.21	81.47
90	75	1.43	88.2	1.03	86.58	2.25	83.72
93	77.5	1.75	89.95	0.77	87.35	1.2	84.93
96	80	0.75	90.7	0.74	88.09	0.53	85.46
99	82.5	1.87	92.57	4.99	93.08	2.94	88.4
102	85	1.22	93.79	1.74	94.82	3.79	92.18
105	87.5	2.14	95.93	3.6	98.43	6.17	98.36
108	90	0.41	96.34	0.37	98.8	0.43	98.78
111	92.5	0.62	96.96	0.2	99	0.16	98.94
114	95	0.56	97.52	0.14	99.14	0.12	99.06
117	97.5	0.12	97.65	0.27	99.41	0.35	99.41
120	100	2.35	100.00	0.59	100.00	0.59	100

Appendix D Design inflow and outflow hydrographs

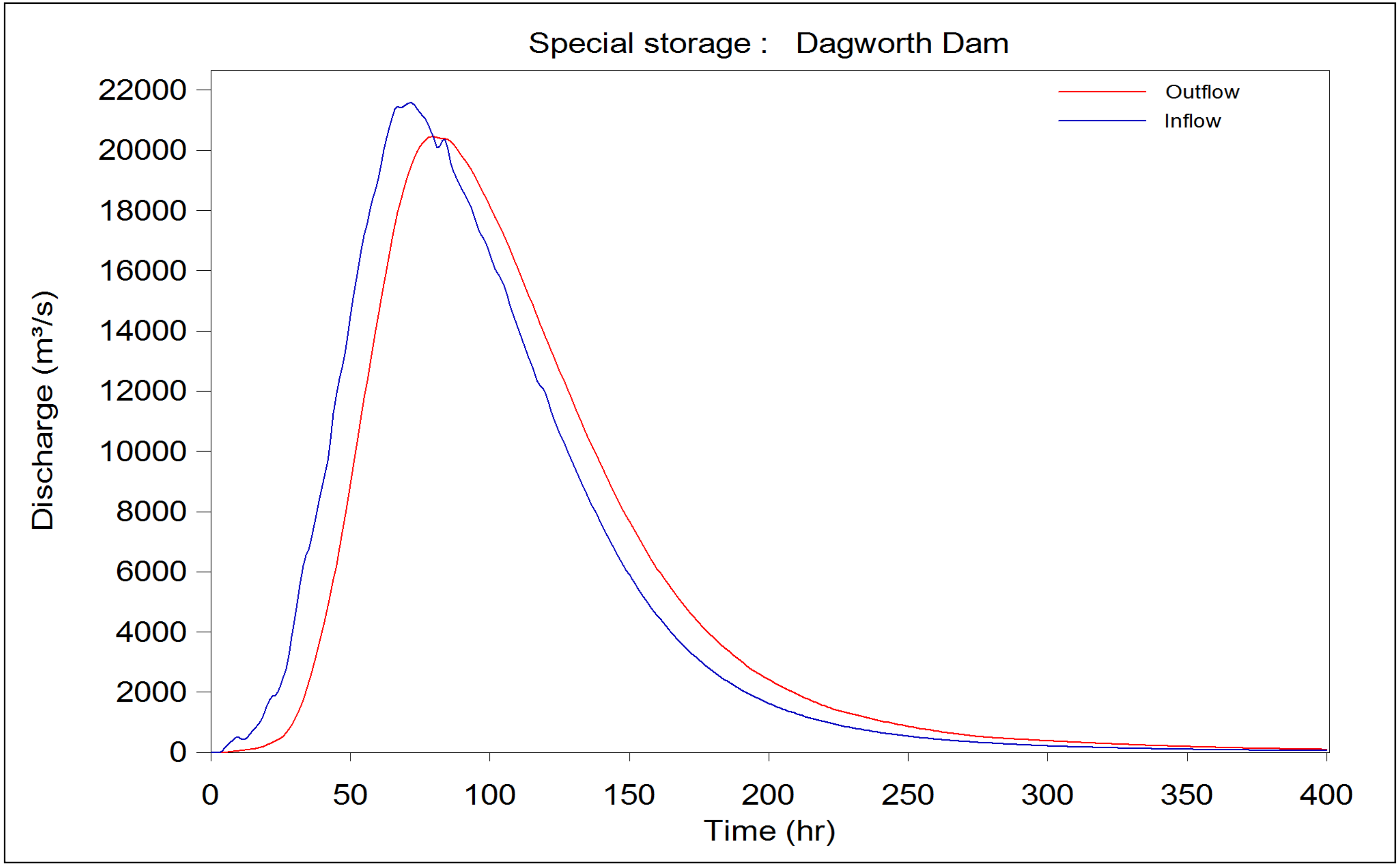


Figure D.1 Dagworth – AEP 1 in 1,000 Years – 120 hour

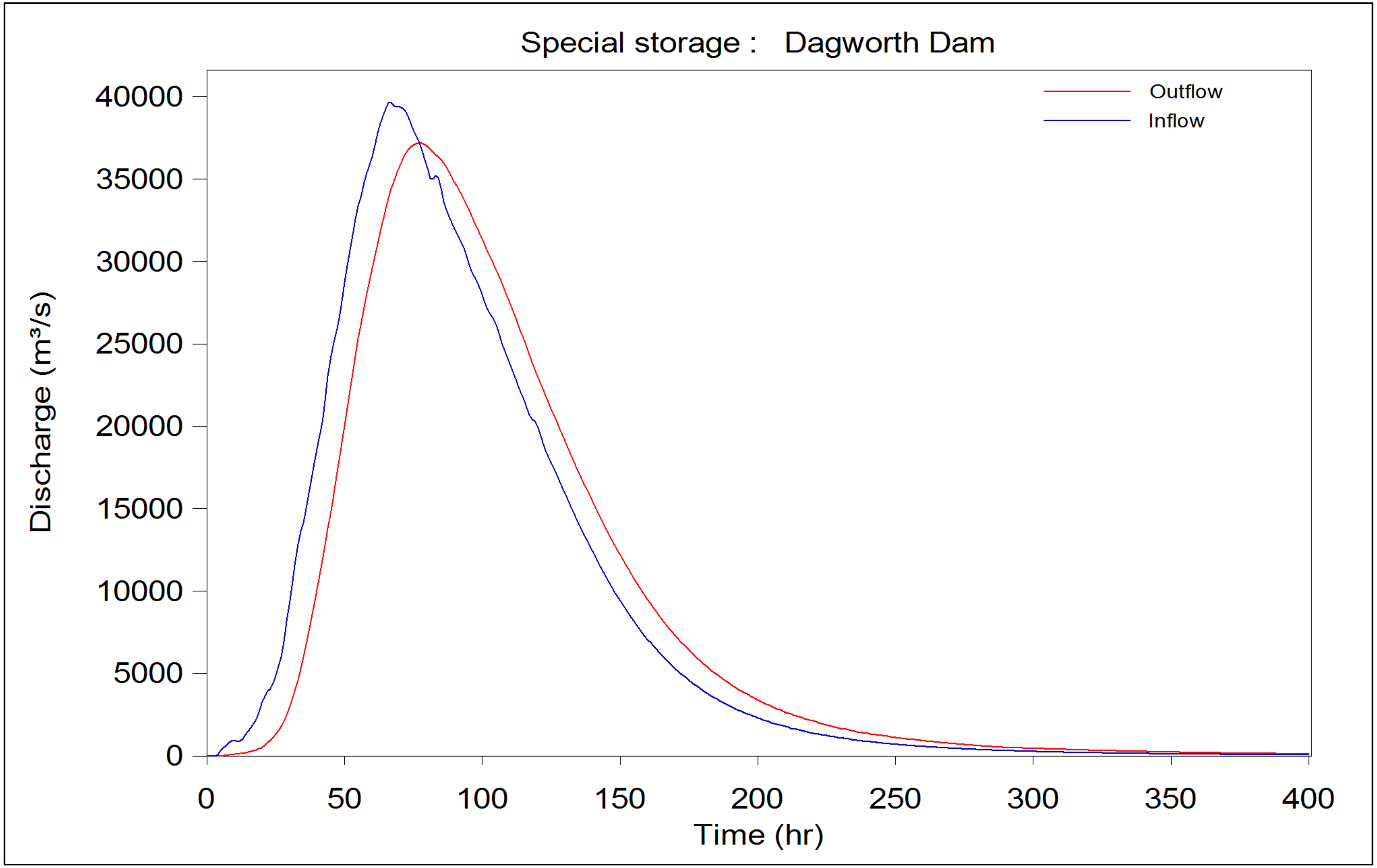


Figure D.2Dagworth – AEP 1 in 10,000 Years – 120 hour

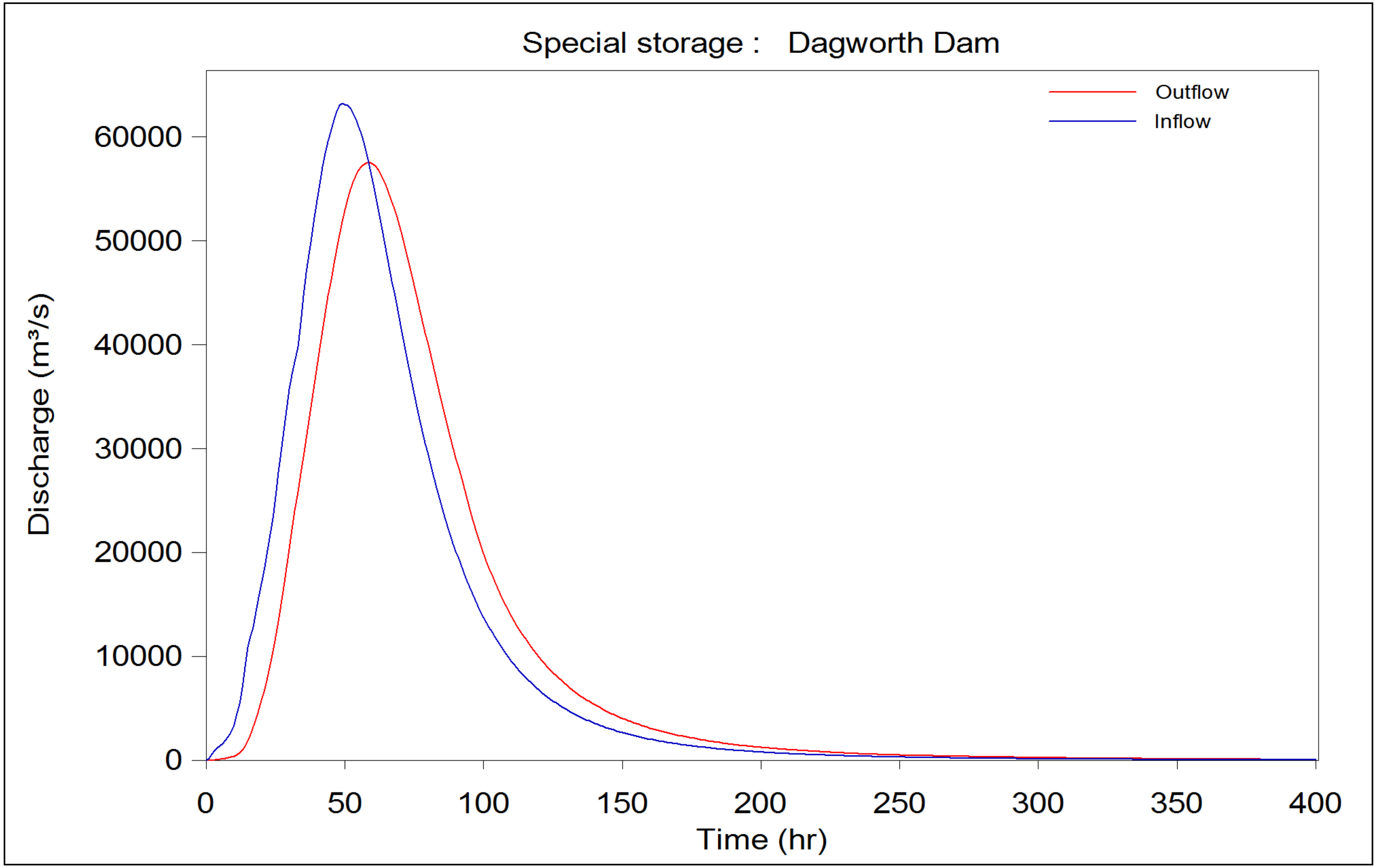


Figure D.3 Dagworth – AEP 1 in 55,556 Years – 48 hour

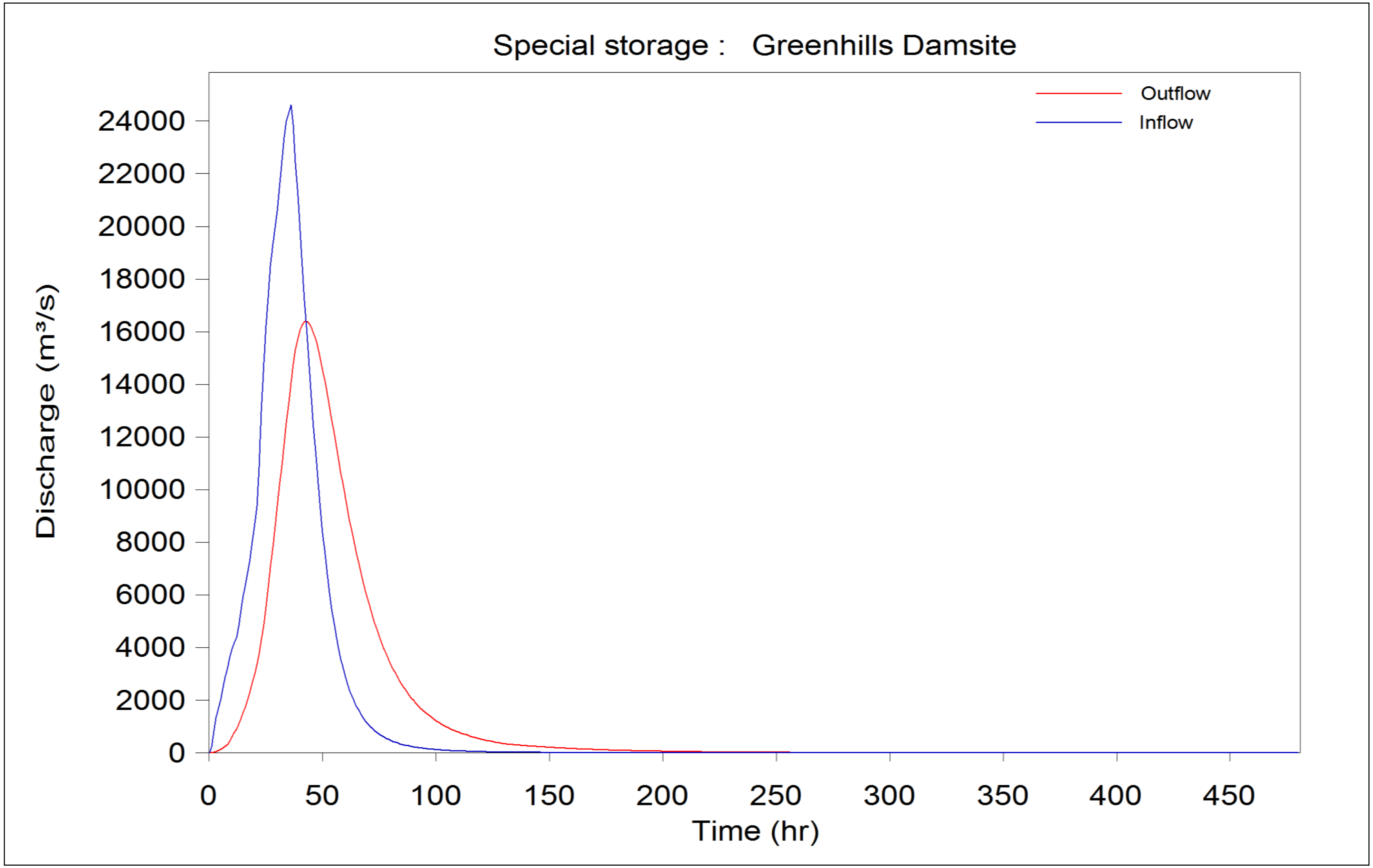


Figure D.4 Greenhills – AEP 1 in 1,000 Years – 36 hour

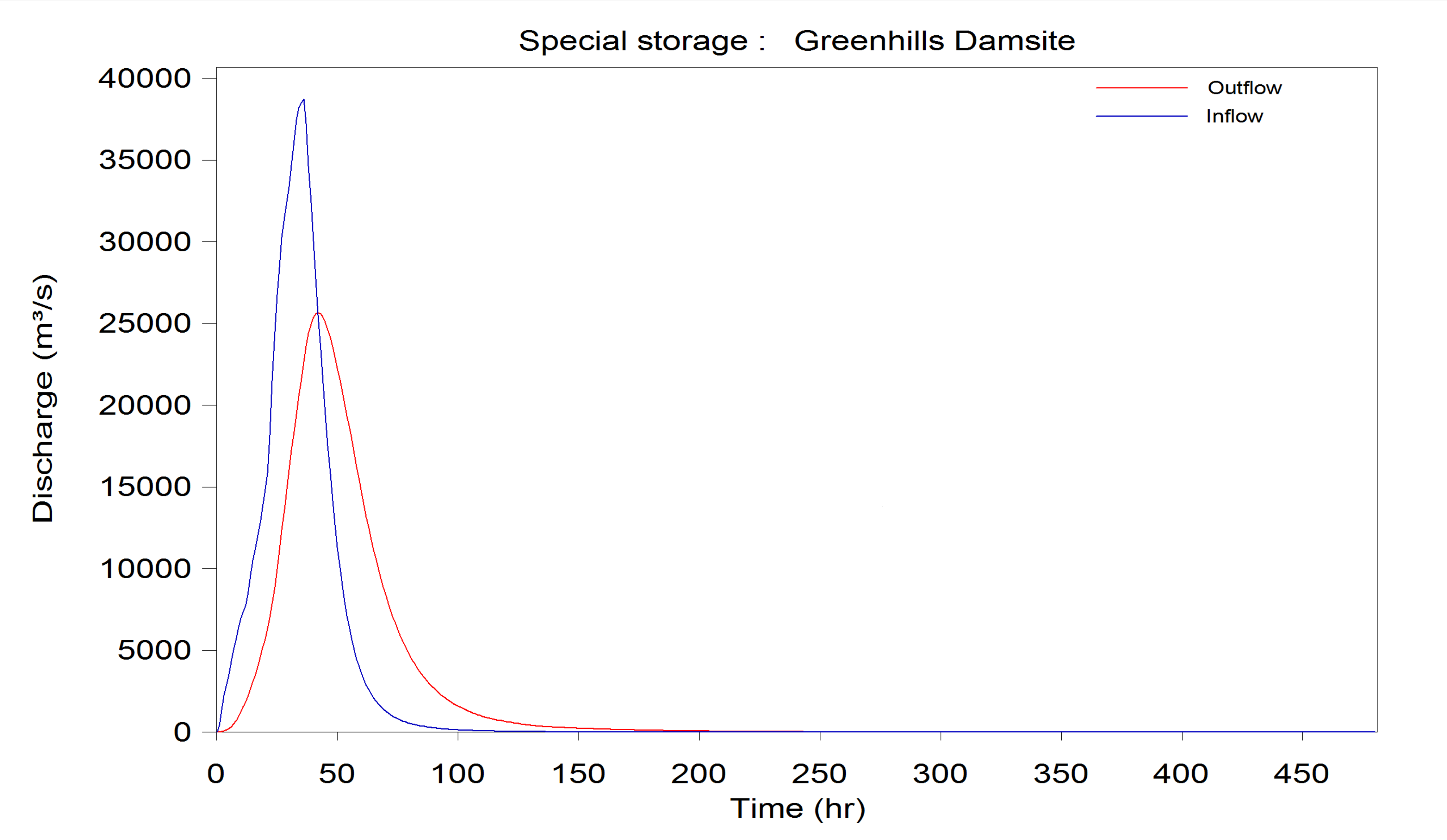


Figure D.5 Greenhills – AEP 1 in 10,000 Years – 36 hour

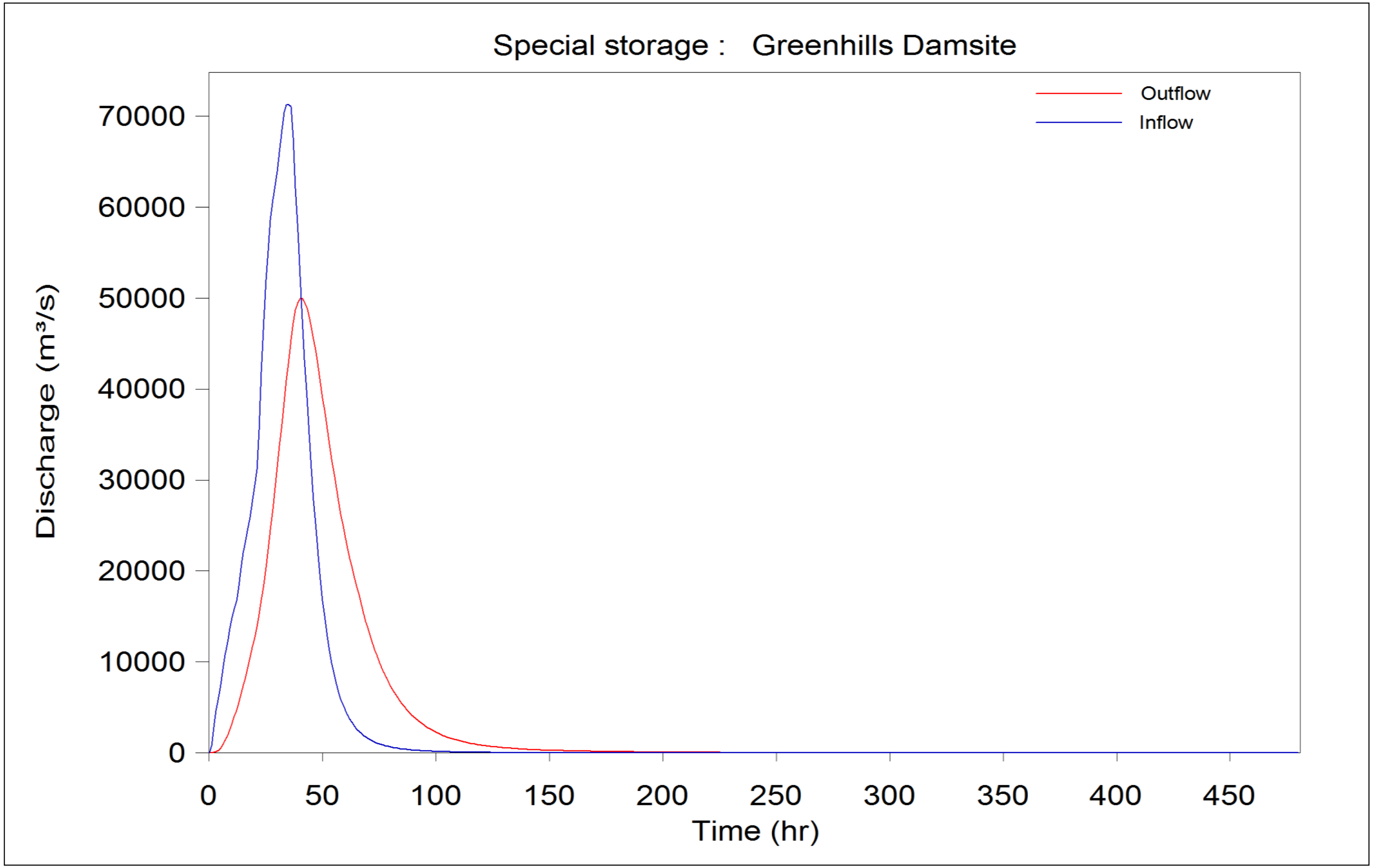


Figure D.6 Greenhills – AEP 1 in 90,909 years – 36 hour

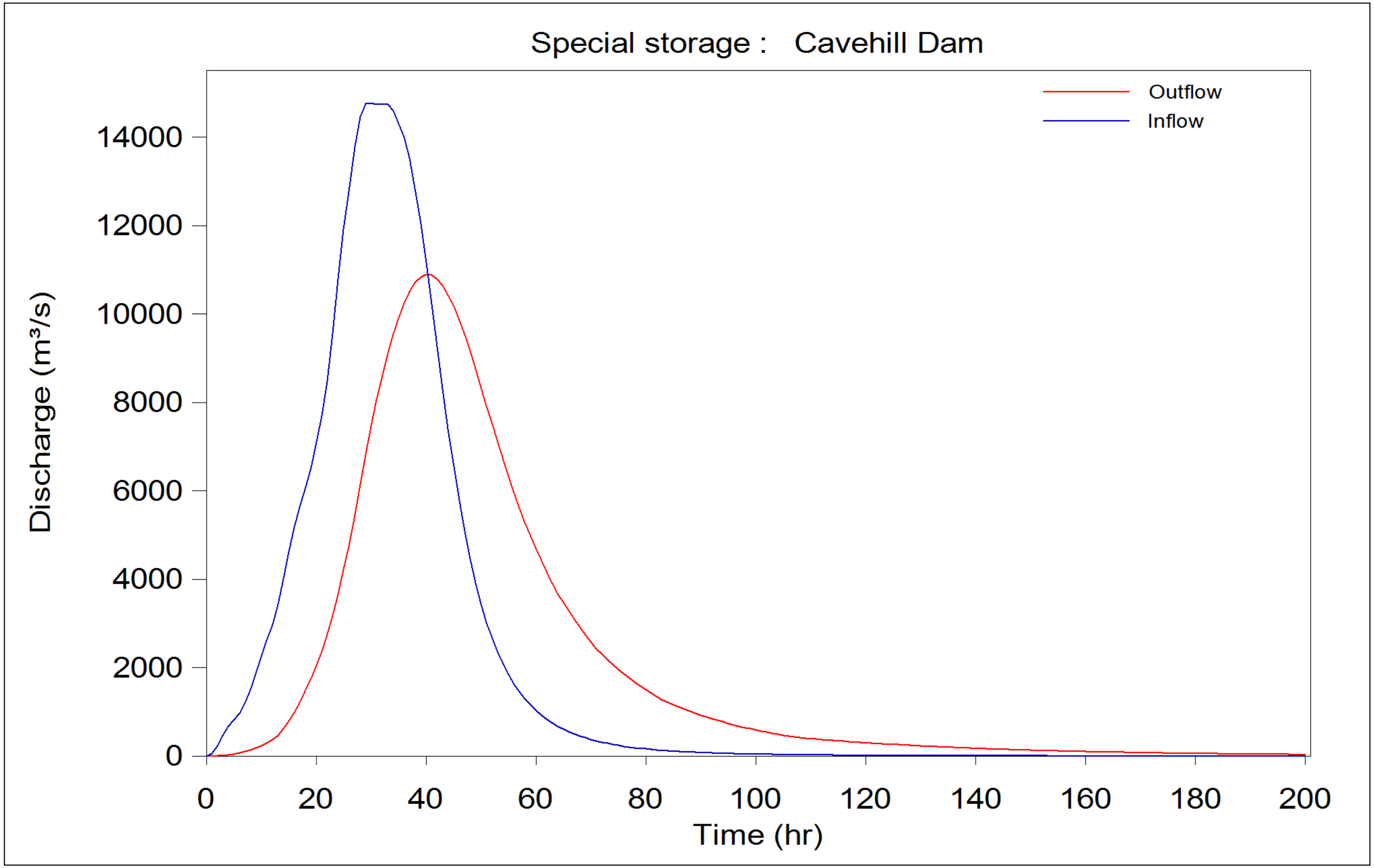


Figure D.7 Cavehill – AEP 1 in 1,000 Years – 36 hour

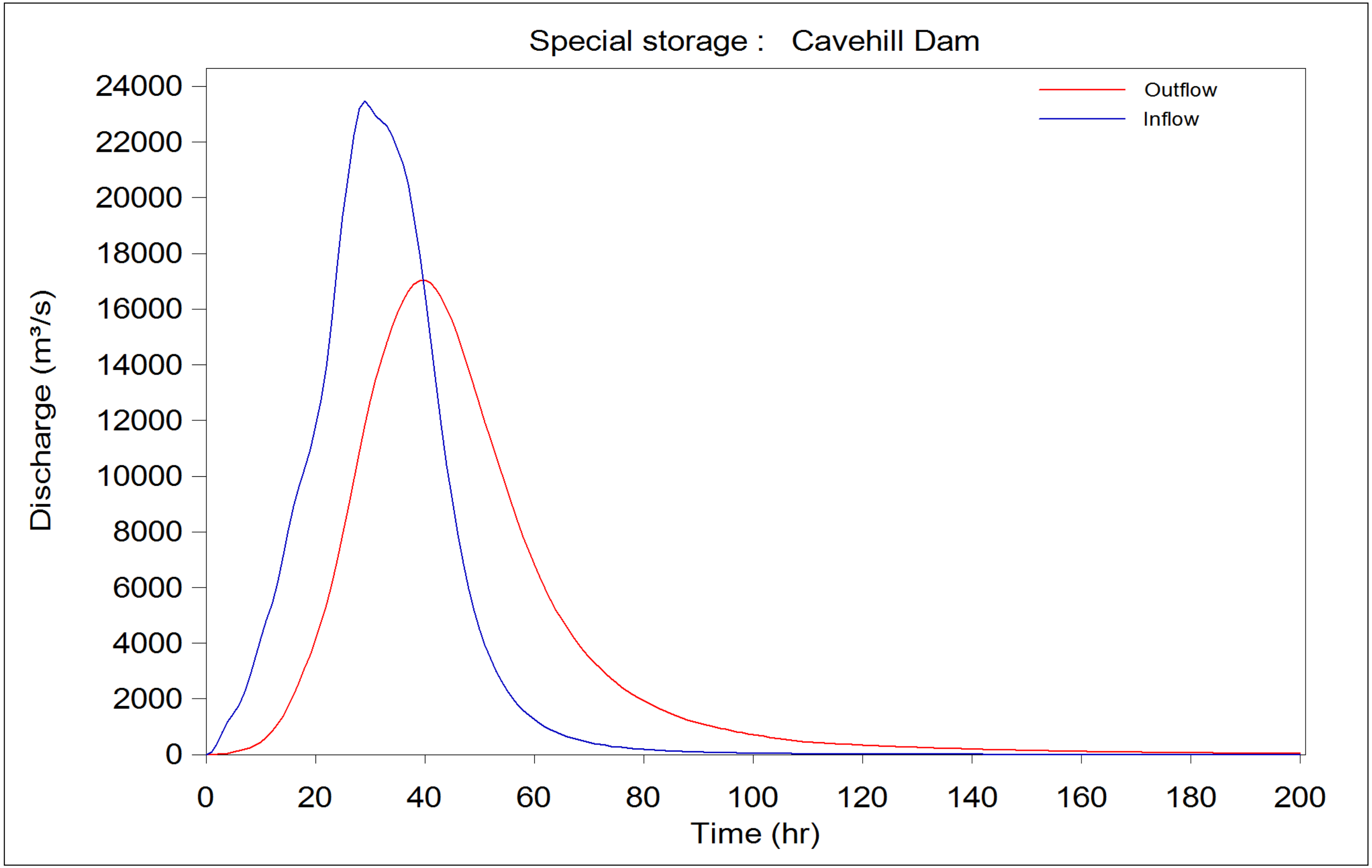


Figure D.8 Cavehill – AEP 1 in 10,000 Years – 36 hour

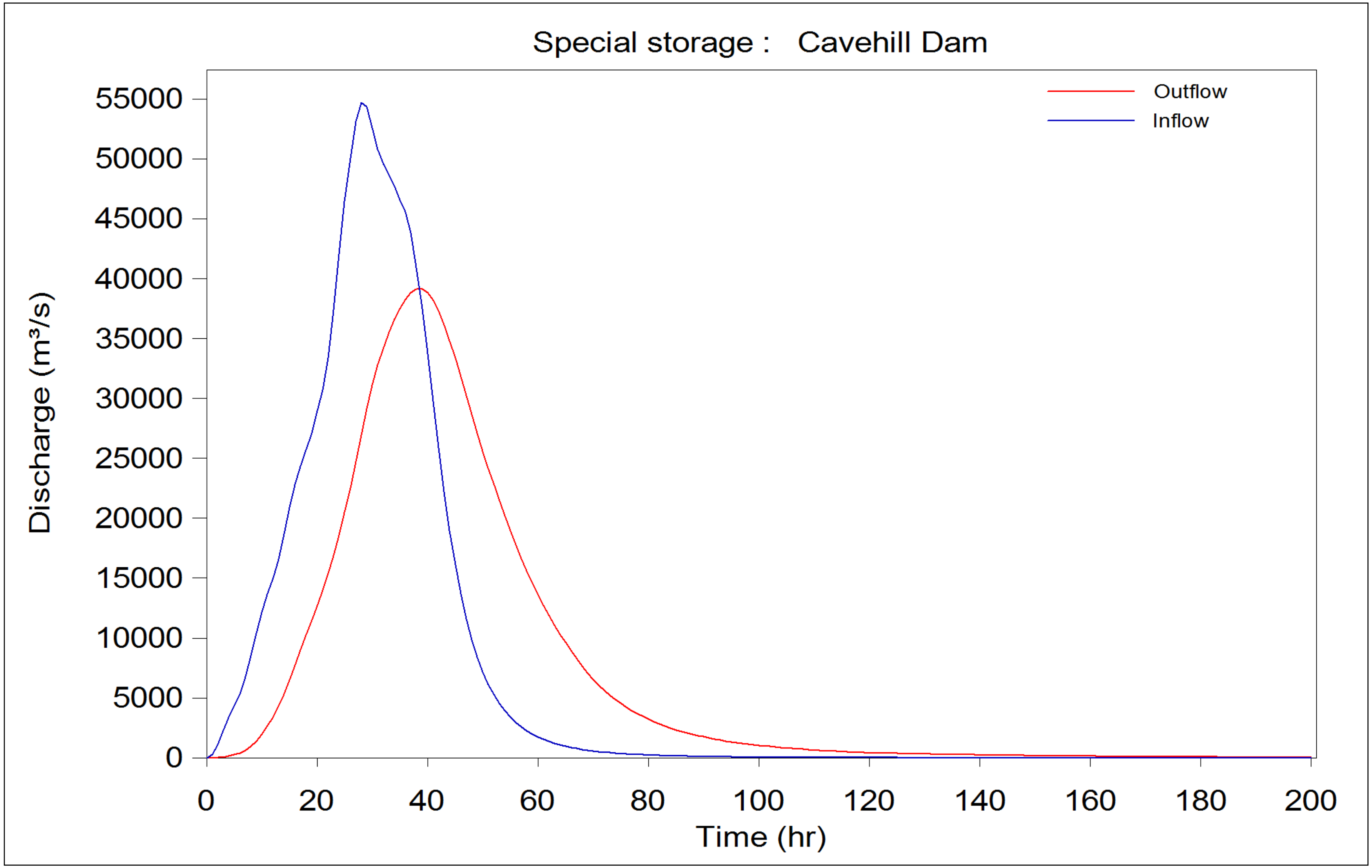


Figure D.9 Cavehill – AEP 1 in 166,667 Years – 36 hour

Appendix E Fitted distribution and confidence limit flood frequency curves

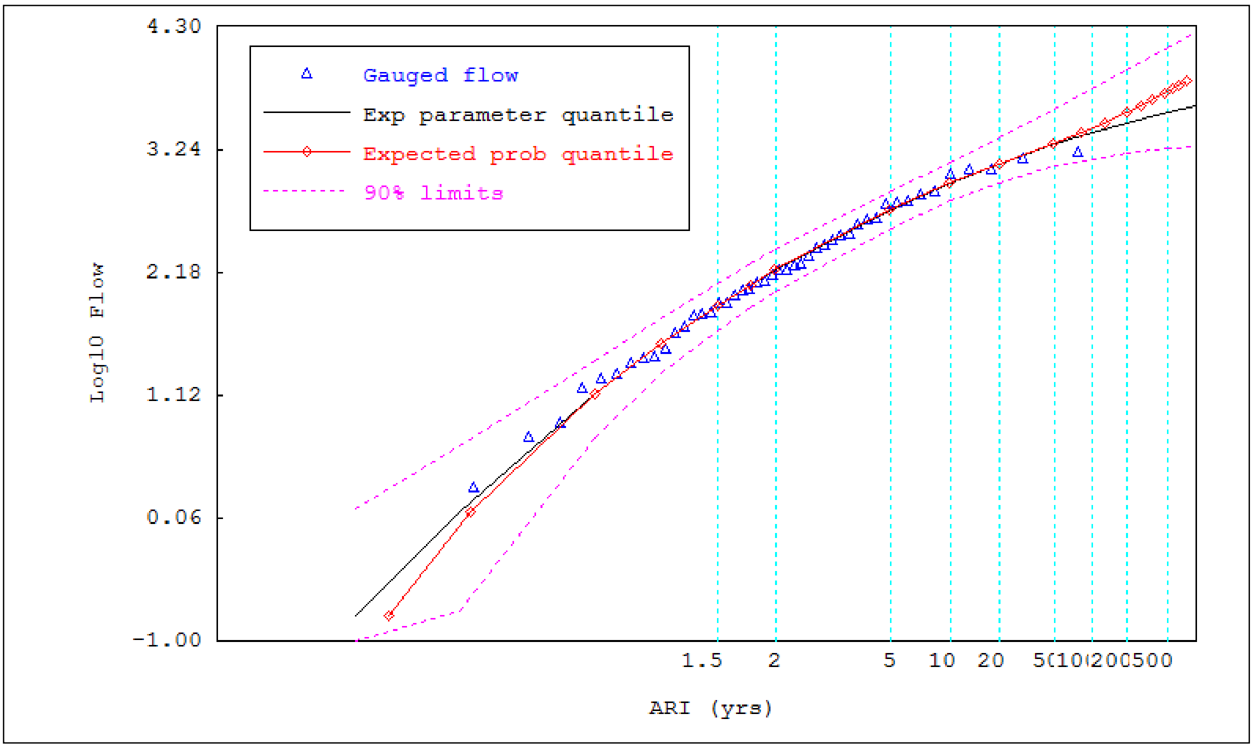


Figure E.1 Dagworth flood frequency plot

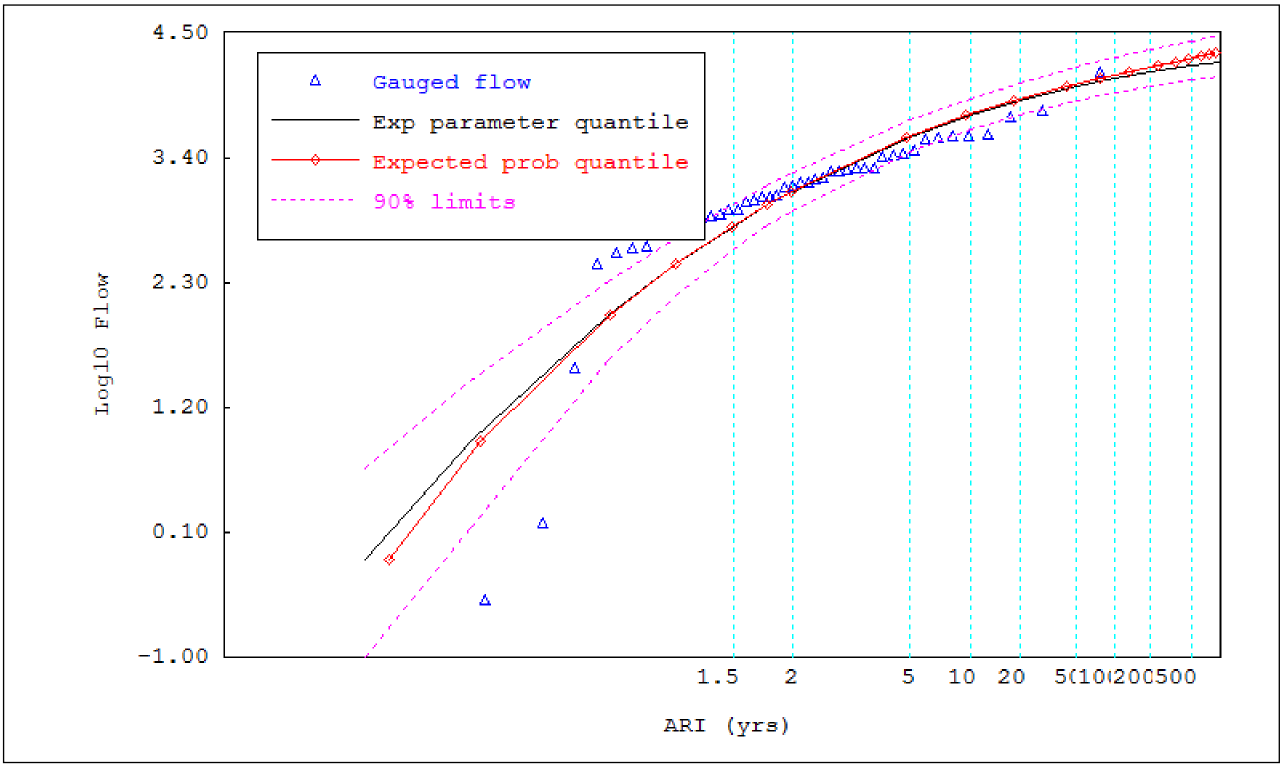


Figure E.2 Greenhills flood frequency plot

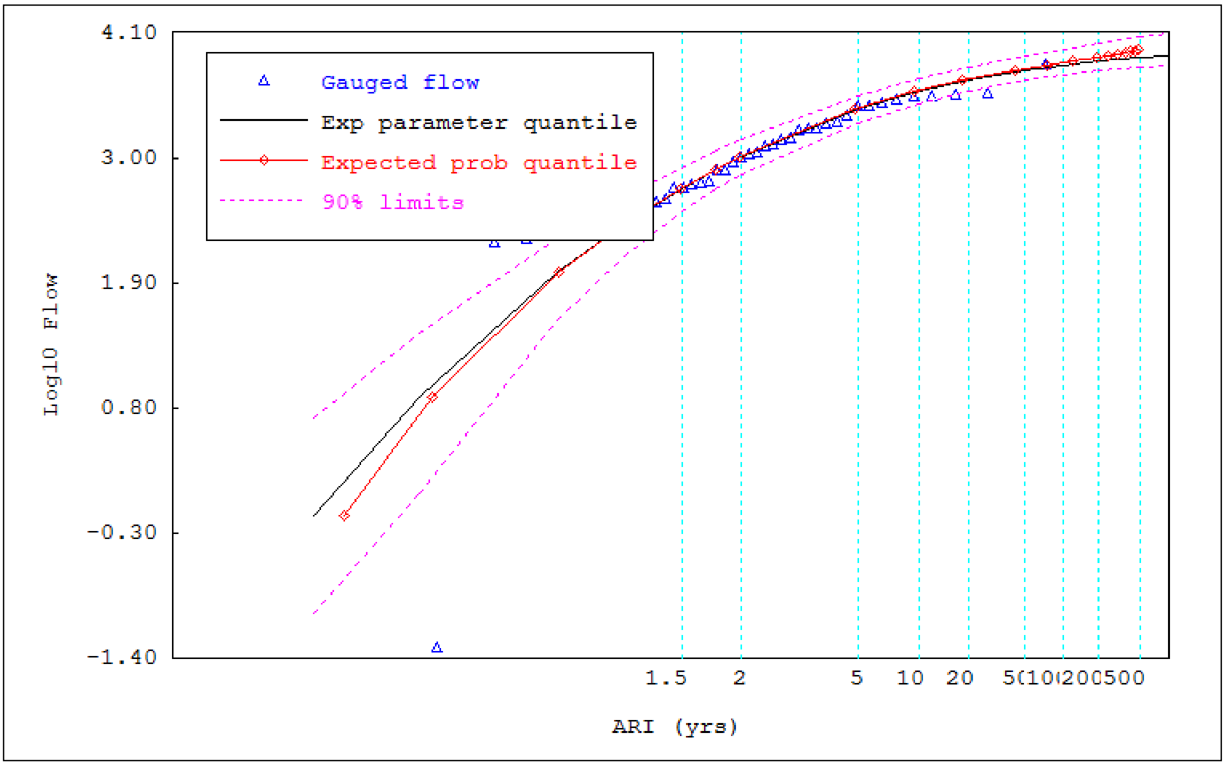


Figure E.3 Cavehill flood frequency plot

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