Appendix A

Document List

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
1	Chief medical Officer of Health's Recommendations concerning Shale Gas Development in New brunswick	2012	Chief medical officer - New Brunswick			Canada	82	This report outlines the recommendations for the protection of Public Health in New Brunswick in light of a changing social and physical environment. The report discusses the guiding principles for protection of public health and the risks associated with UGEE activities.	Recommended in public submission	Y							Y	Y			Y		
2	The Unconventional Hydrocarbon Resources of Britain's Onshore Basins - Shale gas	2013	Department of Energy & Climate Change	British Geological Survey		UK	40	This document outlines a geological framework to examine the potential for shale gas exploration in the UK. Environmental concerns are also discussed.	Recommended in public submission	Y													Y
3	The Economic Consequences of marcellus Shale Gas Extraction: Key Issues	2011	Susan Chrisopherson (Cornell University)			US	20	A review of the econmomic consequences of UGEE activties. The report examins the impacts on water resources, tourism, employment and public health issues.	Recommended in public submission	Y		Y	Y		Y								

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
4	Shale gas: a provisional assessment of climate change and environmental impacts	2011	Wood et al. (Tyndall Centre)			UK	87	This report reviews UGEE activities in the US and the development of shale gas in the UK. The potential impacts of GHG emissions from UGEE activities are highlighted as well as the impacts on groundwater, surface water, the visual landscape, traffic and noise.	Recommended in public submission	Y		Y			Y		Y						
5	Importance of Farming and the Agri-Food Industry - Leitrim	n/a	The Irish Farmers Association			Ireland	2	Summary of the agri-food industry in Leitrim	Recommended in public submission	Y					Y								
6	The Costs of Fracking - The Price Tag of Dirty Drilling's Environmental Damage	2012	Environment America Research & Policy Centre			US	49	This report provides a review of the UGGE process and examines the potential impacts of fracking on water resources, public health, ecosystems, wildlife, agriculture, the visual landscape, public infrastructure and services and seismicity.	Recommended in public submission	Y		Y	Y		Y		Y						

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
7	Ireland and the Climate Change Challenge: Connecting 'How Much' with 'How to'	2012	National Economic & Social Council			Ireland	104	A framwork to transform Ireland into a carbon neutal society and economy.	Recommended in public submission	Y													Y
8	Methane and the greenhouse-gas footprint of natural gas from shale formations	2010	Howarth et al.		Climatic Change	US	12	This article evaluates the GHG footprint of natural gas obtained by high-volume hydraulic fracturing from shale formations with a specific focus on methane emissions.	Recommended in public submission	Y					Y	Y		Y		Y			
9	City of Forth Worth Natural Gas Air Quality Study	2011	ERG & SAGE	City of Forth Worth, Texas		US	320	This report examines the impact of UGEE activities on air quality. The report outlines the processes involved in ambient air monitoring, point source testing, air dispersion modelling, public health eveluation and regulatory assessment.	Recommended in public submission	Y					Y	Y			Y				

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
10	Golden Rules for a Golden Age of Gas - World Energy Outlook - Special Report on Unconventional Gas	2012	International Energy Agency			France	150	The report proposes a set of "golden rules" which adhere to the highest practical social and environmental standards. Examples are given from North America, China, Europe and Australia.	Recommended in public submission	Y		Y	Y	Y	Y		Y		Y			Y	
11	World Energy outlook 2012 - Executive Summary	2012	International Energy Agency			France	12	Projections of energy trends through to 2035 with a close examinaition of the Iraqi energy sector and the growing strain on water resources.	Recommended in public submission	Y													Y
12	Fracking: The New Global Water Crisis	2012	Food and Water Watch			US	20	A review of the risks and costs associated with UGEE activities.The reports questions the vaidity of industry-backed claims of economic gains and examines the current status of UGEE in six selected countries.	Recommended in public submission	Y		Y			Y		Y						

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
13	Review of Phase II Hydrogeologic Study	2008	Geoffrey Thyne	Garfield County (USA)		US	26	A review of the water and geological data obtained in Grafield County (USA)	Recommended in public submission	Y		Y					Y		Y				
14	A Review of the Processes of preparation and Distribution of the Report "Fact-Based Regulation for Environmental Protection in Shale Gas Development"	2012	Augustine et al.	University of Texas at Austin		US	42	A review prepared in response to COI claims which were found to be true.	Recommended in public submission	Y													Y
15	State of the Art and proressive Approaches in Flowback Disposal (abstract)	2012	Prof. Karl-Heinz Rosenwinkel			Ger-many	3	The report examines the potential forms of pollution from the storage, transport and disposal of waste water from fracking.	Recommended in public submission	Y		Y		Y			Y						

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
16	Hydrofracking Risk Assessment - Executive Summary	2012	Ewen et al. (panel of experts)			Germany	75	An assessment of the environmental and health impacts of UGEE. Risk mgmt options are offered for the following areas: Monitoring, safety, chemical selection, liability and accountability and statutory considerations.	Recommended in public submission	Y		Y		Y	Y		Y	Y	Y			Y	
17	Impacts of Gas Drilling on Human and Animal Health	2012	Bamberger, M. and Oswald R.		Scientific Solutions	US	27	This study examines the potential impact of fracking on human health by assessing the effects on animals which have been exposed to UGEE activities. Practices for avoiding exposure to environmental toxicants are proposed.	Recommended in public submission	Y		Y		Y	Y		Y						
18	The Unanswered Questions About the Economic Impact of Gas Drilling in the Marcellus Shale: Don't Jump to Conclusions	2010	Jannette M. Barth			US	15	The author questions the assumption that UGEE will provide economic benefits in New York. Several case studies are provided.	Recommended in public submission	Y		Y			Y								

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
19	Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers	2012	Tom Myers		Ground-water	US	11	The article examines two potential contaminant pathways - advective transport through bulk media and preferential flow through fractures.	Recommended in public submission	Y		Y				Y	Y			Y			
20	Preese Hall Shale gas Fracturing - Review & Recommendations for Induced Seismic Mitigation	2012	Green et al.	DECC		UK	26	In light of sesmic events possibly caused by fracking in the UK, this report outlines recommendations for mitigating seismic risks.	Recommended in public submission	Y					Y								
21	Environmental Impacts of Shale gas and Shale Oil Extraction Activities	2011	European Parliament			EU	12	European Paliament resolution concerning: 1) General framework - regulation, implementation, monitoring and cooperation. 2) Environmental aspects of hydraulic fracturing. 3) Public participation and local conditions.	Recommended in public submission	Y		Y			Y				Y				

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
22	Natural Gas Operations from a Public Health Perspective	2011	Colburn et al.		Human and Ecological Risk Assessment	US	19	The study examines the impact of chemicals used in fracking on human health. A list of 944 products containing 632 chemicals was compiled and a literature search was conducted to determine potential health effects of 353 chemicals.	Recommended in public submission	Y					Y		Y		Y				
23	Impacts of Shale Gas Extraction on the Environment and on human Health - 2012 update	2012	European Parliament			EU	34	This report which is updating a study published in 2011 discusses the potential impacts of fracking on environmental and human health.	Recommended in public submission	Y		Y		Y	Y		Y						
24	Climate Action and Low Carbon Bill 2015	2015	Irish Government			Ireland	26	The bill outlines the national objective of transitioning to a low carbon, climate resilient and environmentally sustainable economy by 2050.	Recommended in public submission	Y													Y

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
25	An Exploratory Study of Air Quality near Natural Gas Operations	2012	Colburn et al.		Human and Ecological Risk Assessment	US	26	The study assessed air quality in western Colorado before, during and after drilling and hydraulic fracturing.	Recommended in public submission	Y					Y				Y				
26	The Environmental and Occupational Health Impacts of high Volume Hydraulic Fracturing of Unconventional Gas Reserves	2014	American Public Health Association			US	13	This report discusses the potential environmental and health impacts from UGEE activities and proposes recommendations in response.	Recommended in public submission	Y		Y	Y		Y		Y	Y					
27	Human health risk assessment of air emissions from development of unconventional natural gas resources	2012	McKenzie et al.		Science of the Total Environment	US	9	The study estimated the impacts of UGEE activities on human health in Garfield County, Colorado and found that risk assessment can be used in HIAs to direct health risk prevention strategies.	Recommended in public submission	Y					Y		Y		Y				

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
28	Health and Strategic Environmental Assessment	2009	World Health Organisation			EU	102	This report summaries the conclusions of an international consultation meeting on "Health and strategic environmental assessment". The overall theme is including health in strategic environmental assessments.	Recommended in public submission	Y													Y
29	The Irish EPA Preliminary Assessment of Fracking: A Good Start but a Long Way to Go	2012	Robert Emmet Hernan	Irish Environment article		Ireland	n/a	A review of the report issued by the EPA: "Hydraulic Fracturing or ‘Fracking’: A Short Summary of Current Knowledge and Potential Environmental Impacts"	Recommended in public submission	Y		Y											
30	The European Commission's Three Studies on Fracking: On Risks, Climate Impacts, and Market Possibilities.	2012	Unknown	Irish Environment article		US	n/a	A review of three studies commissioned by the EC: 1) Environmental and health Risks. 2) Climate Change implications. 3) Energy market Impacts.	Recommended in public submission	Y		Y	Y		Y								

No.	Title	Year	Authors	Agency report prepared for	Journal	Country/ Region	Pages	Content description	Other comments	Reviewed the document	Applicability to our evaluations:	Task B.1	Task B.2	Task B.3	Task B.4	Task B.5	Task B.6	Task B.7	Task B.8	Task B.9	Task B.10	Task B.11	Not relevant to any tasks in Project B
31	International Energy Agency's Golden Age of Gas and Golden Rules on Fracking	2012	Robert Emmet Hernan	Irish Environment article		Ireland	n/a	A review of the report: "Golden Rules for a Golden Age of Gas - World Energy Outlook - Special Report on Unconventional Gas"	Recommended in public submission			Y			Y								

Task B.1 Water Impacts and Mitigation Measures.

Task B.2 An assessment of the direct and indirect impacts of the use of local water sources.

Task B.3 Assessment of recycle and re-use of flowback water.

Task B.4 Other Potential Impacts and Mitigation Measures.

Task B.5 Life-Cycle Assessment.

Task B.6 Chemicals used: impacts and mitigation measures.

Task B.7 Identify and assess the success of treatment and disposal methods for flowback and production waters.

Task B.8 Links with Projects A1, A2, A3 and C: best practices for monitoring and mitigation.

Task B.9 Examination of validity and range of existing and potential monitoring and mitigation techniques.

Task B.10 Any other issues.

Task B.11 Effective dissemination of the research findings and deliverables.

Appendix B

Project Report A5

Sources: Figures 3.1 and 4.1 are reproduced from: Met Éireann, 2015 (1981–2010 rainfall grids. Available online: http://www.met.ie/climate-ireland/30year-averages.asp); and Walsh, 2012 (A summary of climate averages, 1981–2010 for Ireland. Climatological Note 14, Met Éireann, Dublin).

UGEE Joint Research Programme

Environmental Impacts of Unconventional Gas Exploration and Extraction (UGEE)

(2014-W-UGEE-1)

Interim Report A1-5:

Task 8: Quantitative Assessment of Water Resources

by

CDM Smith Ireland Ltd

Authors:

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This report is published as part of the Joint Research Programme on the Environmental Impacts of Unconventional Gas Exploration and Extraction. This Research Programme is being administered by the EPA and steered by a committee with representatives from the Department of Communications, Climate Action and Environment [DCCAE, formerly the Department of Communications, Energy and Natural Resources (DCENR) and the Environment Division of the Department of the Environment, Community and Local Government (DECLG)], the Commission for Energy Regulation (CER), An Bord Pleanála (ABP), the Geological Survey of Ireland (GSI), the Northern Ireland Environment Agency (NIEA), the Geological Survey of Northern Ireland (GSNI) and the Health Service Executive (HSE) of Ireland.

The authors would like to thank each of the public bodies who provided data and were available for consultations during the preparation of this report.

DISCLAIMER

References to government departments (DCENR and DCELG) throughout the report use the names of these departments prior to July 2016. References to the Department for the Economy (DfE) throughout the report use the name of its predecessor, the Department of Enterprise Trade and Investment (DETI), the department responsible for petroleum licensing in Northern Ireland until May 2016.

UGEE Joint Research Programme

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Table of Contents

Attachments

List of Figures

List of Tables

Executive Summary

Unconventional Gas Exploration & Extraction (UGEE) involves hydraulic fracturing (fracking) of low permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources such as shale gas deposits, coal seams and tight sandstone. The Environmental Protection Agency (EPA), the Department of Communications, Energy and Natural Resources (DCENR) and the Northern Ireland Environment Agency (NIEA) awarded a contract in August 2014 to a consortium led by CDM Smith Ireland Limited, to carry out a 24-month research programme looking at the potential impacts on the environment and human health from UGEE projects and operations (including construction, operation and after-care).

The UGEE Joint Research Programme (JRP)[1] is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity) as well as an extensive desk-based literature review of UGEE practices and regulations worldwide. The UGEE JRP has been designed to produce the scientific basis from which regulators – both North and South – can make informed decisions about whether it is environmentally safe to allow fracking. As well as research in Ireland, the UGEE JRP is looking at and collating evidence from other countries.

Project A1 of the UGEE JRP, which is the subject of this Interim Report A1-5, specifically addresses groundwater, surface water and associated ecosystems. Interim Report A1-5 is the fifth deliverable of Project A1, and:

- Summarises water use requirements for UGEE project/operations based on the ‘probable commercial scenarios’ developed in Task 2 of Project B of the UGEE JRP;
- Describes the available water resources in the two case study areas; and
- Discusses the estimated maximum water demand for a hydraulic fracturing event or programme in context of the available water resources, as a means of identifying potential impacts from water abstractions.

The ‘probable commercial scenarios’ for UGEE development indicate a potential wide range of water use requirements during assumed build-out scenarios for future UGEE projects. In the context of water resources availability and potential impacts from abstractions, it is the short-term demand for water during individual hydraulic fracturing events that define maximum use requirements. From the ‘probable commercial scenarios’, a total demand of 15,000 m^3 is assigned per well, per hydraulic fracturing programme at one well pad. Assuming that the hydraulic fracturing programme would be carried out over a 3-day period (conservatively short), the water demand for that programme would be 5000 m^3/d. This figure is provided for guidance purposes only, as actual demands would be case-specific, and would have to be declared and identified during future planning and review processes.

More significantly, if identical programmes are carried out at multiple wells concurrently, the total daily demand becomes significantly greater. For the peak build-out scenario defined by the ‘probable commercial scenarios’ in Project B of the UGEE JRP, there would theoretically be approximately 130 wells for the moderate build-out scenario drilled and hydraulically fractured per year in the NCB study area. Assuming a 3-day duration for each hydraulic fracturing programme, this equates to 390 days of hydraulic fracturing, each requiring 5000 m^3/d in the example given. Thus, the total demand is driven by how many wells are hydraulically fractured in the same time period, and the potential risk of impact from supply (i.e. abstraction of available water resources) is determined by *how* and *where* the water is sourced.

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1 www.ugeeresearch.ie

The quantitative assessment of available water resources in the two study areas document that future proposals for UGEE-related abstractions would have to be assessed on a case-by-case basis, with detailed and specific information provided about drilling and hydraulic fracturing schedules, in order to assess temporal and cumulative impacts, particularly on small streams and lakes in the study areas. In likelihood, and to mitigate against potential abstraction impacts, any proposed abstraction scheme would have to emphasise demand management, i.e. reducing demands, and sourcing waters from larger streams and lakes, moreover, abstracting water from multiple sources. In turn, case-specific review of abstraction proposals would need input from relevant stakeholders and regulatory bodies, as well as specialists in relevant scientific and technical fields.

Available water resources are represented by rainwater, lakes and reservoirs, streams and rivers, and groundwater in bedrock aquifers. Existing abstraction pressures are currently low. There is capacity to supply water use requirements of potential future UGEE development in both study areas, but this would ultimately be conditioned and influenced by *how* and *where* the development would proceed, both spatially and temporally. Local supply options are considerably wider in the NCB study area compared to the CB study area. Capacity of any given source would have to be judged by actual total demand, with a clear understanding of timelines of total demands.

Risks of *volumetric impacts* from surface water abstractions (to supply the demand) are lower in large lakes and streams, and higher in small lakes and streams. Identifying and documenting volumetric impact is relevant in a regulatory context, but it is *ecological impact* which ultimately determines if an abstraction authorisation should be granted or not. This is recognised by the methods that are applied by both the EPA and NIEA in classifying the ecological status of surface water bodies for WFD implementation purposes, and the existing prior authorisation procedures that are in place.

- In lakes, this relates to maintaining water level cycles within natural or regulated ranges so as not to adversely impact on reference conditions in littoral zones.
- In streams, this relates to maintaining ‘environmental flows’, i.e. the critical flow below which stringent flow standards may apply, so as not to adversely impact on the reference conditions required by macroinvertebrates, macrophytes, and fish.
- In aquifers, this relates to: understanding the hydraulic relationship between ground water and surface water bodies with an objective to avoid impact to reference conditions in surface water bodies; maintaining the natural supporting conditions of groundwater dependent terrestrial ecosystems (GWDTEs), and avoiding interference with other groundwater supplies.

With regard to groundwater, the bedrock aquifers in both study areas are viable sources of water to meet demands, at least in part. However, the ability to develop a sufficient supply to meet demands locally for hydraulic fracturing programmes would require prior exploration and testing, and supply would depend on case-specific circumstances of both hydrogeology and actual water demands.

Potential future UGEE-related abstractions would have to be evaluated at local level (local impact) and catchment level (water body impact). Special attention should be given to the requirements of existing statutory instruments and efforts by the EPA and NIEA to maintain “good quantitative” and “good ecological” status of water bodies. As UGEE activity is rarely confined to single locations, abstractions may have a cumulative impact which would need to be addressed by appropriate monitoring.

For logistical and cost reasons, future UGEE operations would try to obtain water from sources that are easily accessible, i.e. as close to the drill sites as possible. The water needed might be accessed via surface water or groundwater resources, and the water may either be developed by the UGEE companies directly or be purchased from existing supply sources.

Large abstractions in small lakes and streams increases the risk of impact. Concentrated abstractions in small subcatchments and abstractions in or near ecologically sensitive habitats also increase the potential for impacts. Even short-duration abstractions can cause environmental stresses and impact, depending on the source, abstraction rate and reference conditions of the source at the time of abstractions. The distinction between “small” and “large” is subjective, and cannot be made without consideration of surface water ecology and following lines of evidence.

In the licencing or prior authorisation of future UGEE-related abstractions, environmental reference conditions would have to be identified on a case by case basis, using site- and case-specific inputs (e.g. flow data and ecological datasets), and requiring technical judgement by specialists in related fields. Proper impact assessment can only be done once the details of proposed future abstractions become known, with scoping and technical review by relevant specialists representing public regulatory bodies in both the ROI and NI.

1 Introduction

Unconventional Gas Exploration & Extraction (UGEE) involves hydraulic fracturing ('fracking') of low permeability rocks to permit the extraction of natural gas on a commercial scale from unconventional sources such as unconventional gas deposits, coal seams and tight sandstones. The Environmental Protection Agency (EPA), the Department of Communications, Energy and Natural Resources (DCENR) and the Northern Ireland Environment Agency (NIEA) awarded a contract in August 2014 to a consortium led by CDM Smith Ireland Limited to carry out a 24-month research programme looking at the potential impacts on the environment and human health from UGEE projects and operations (including construction, operation and after-care).

The UGEE Joint Research Programme (JRP)[2] is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity) as well as extensive desk-based literature reviews of UGEE practices and regulations worldwide. The UGEE JRP has been designed to produce the scientific basis from which regulators – both North and South – can make informed decisions about whether it is environmentally safe to permit UGEE projects/operations involving fracking. As well as research in Ireland, the UGEE JRP is looking at and collating evidence from other countries.

The environmental impacts of UGEE projects/operations to be considered are those arising from UGEE projects/operations in their totality, not just from fracking activities. All stages of UGEE projects/operations must be considered (i.e. including construction, commissioning, operation, decommissioning and aftercare, as well as off-site and other developments).

1.1 Context

In the Republic of Ireland (ROI), Onshore petroleum Licensing Options were awarded in March 2011, as preliminary authorisations, to three exploration companies seeking to assess the shale gas potential within the Northwest Carboniferous Basin (NCB) and the Clare Basin (CB). In Northern Ireland (NI), one exploration company secured a Petroleum Licence from the Department of Enterprise, Trade and Investment (DETI) to explore the potential for shale gas reserves in Co. Fermanagh, within the NCB. The specific UGEE exploration areas are shown in *Figure 1.1* based on the licences that were held until recently.

In the ROI, exploration drilling, including drilling that would involve hydraulic fracturing, is not allowed under current Licensing Options. Nonetheless, two of the three companies have submitted applications for follow-on licences, which would include exploration drilling. The DCENR is not considering these applications further until the findings of this UGEE Joint Research Programme have been published. Also, the DCENR will not consider any applications for exploration authorisations in other onshore areas until the UGEE Research Programme has concluded. In NI, the referenced DETI licence was terminated as the licence conditions (a 'drill or drop' work programme requiring specified exploration, including drilling a stratigraphic borehole, in the first three years and, before the end of Year Three, a commitment to drilling an exploration well within the following two years) were not met.

2 www.ugeeresearch.ie

Figure 1.1. Overview of the case study areas of the UGEE Joint Research Programme.

In May 2012, the Environmental Protection Agency (EPA) released the report from a preliminary study “Hydraulic Fracturing or ‘Fracking’: A Short Summary of Current Knowledge and Potential Environmental Impacts”[3]. This short desk study was conducted for the EPA by the University of Aberdeen and provided an introduction to the environmental aspects of UGEE projects/operations including a review of regulatory approaches used in other countries and areas for further investigation and research.

In brief, some of the key findings of the study were:

- The importance of adequate knowledge of local geology in order to assess potential impacts on groundwater quality and the possibility of induced seismic activity;
- The importance of well integrity for preventing groundwater contamination;
- The uncertainty regarding the “carbon footprint” of shale gas in comparison to conventional natural gas. This is an important climate change issue;
- Baseline studies are needed before drilling begins (surface water; groundwater; seismic); and

3 http://www.epa.ie/pubs/reports/research/sss/epa-strivesmallscalestudyreport.html

- UGEE is a relatively new area of research (i.e. only a limited number of published, peer-reviewed, scientific studies are available in this area).

The information provided by the preliminary research project was used along with other sources, such as European Commission reports[4], to develop the Terms of Reference for a more comprehensive Research Programme. Between the 11th January and 8th March 2013, the EPA administered a Public Consultation[5] in relation to the draft Terms of Reference[6] for this Research Programme. Submissions[7] were assessed and relevant comments taken into account, when finalising the document.

In order to assist government bodies in making informed decisions about any potential future licensing and management of UGEE projects/operations on the island of Ireland, comprehensive knowledge of the potential impacts of this process on the environment and human health is required. This knowledge will be generated from a number of sources including EU and international research and through this programme of research.

The key questions to be addressed by the UGEE JRP are:

1. Can UGEE projects/operations be carried out in the island of Ireland whilst also protecting the environment and human health?
2. What is 'best environmental practice' in relation to UGEE projects/operations?

The Joint Research Programme is funded by the EPA, DCENR and NIEA. It is managed by a steering committee comprising the EPA, the Department of Environment, Community & Local Government; DCENR; the Geological Survey of Ireland; Commission for Energy Regulation; An Bord Pleanála; NIEA, the Geological Survey of Northern Ireland and the Health Services Executive.

1.2 Overview of the UGEE Joint Research Programme

The main aim of the UGEE Joint Research Programme is to further the understanding of potential impacts on the environment and human health from UGEE projects/operations. It comprises five separate but interlinked projects as follows:

- Baseline Characterisation:
  - Project-A1 (Groundwater, Surface Water and Associated Ecosystems)
  - Project-A2 (Seismicity)
  - Project-A3 (Air Quality)
- Impacts & Mitigation Measures:
  - Project-B: UGEE Projects/Operations: Impacts & Mitigation Measures
- Regulatory Framework:
  - Project-C: Regulatory Framework for Environmental Protection

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4 http://ec.europa.eu/energy/studies/energy_en.html

5 http://www.epa.ie/researchandeducation/research/researchpillars/water/ugee%20research/2013publicconsultation/

6 http://www.epa.ie/pubs/reports/research/ugeejointresearchprogramme/drafttermsofreferenceforugeeresearchprogramme.html

7 http://erc.epa.ie/public_consultation/

1.3 Project A1: Groundwater, Surface Water and Associated Ecosystems

Project A1, summarised by its scope in *Figure1.2* has two primary components:

Characterisation of the case study areas to help understand the 3-dimensional relationship between potential sources of contamination and potential receptors in the near-surface environment; and

Baseline monitoring of groundwater, surface water and associated ecosystems, informed by results of the characterisation and conceptual hydrogeological models.

Baseline characterisation of groundwater, surface water and associated ecosystems is required to enable potential impacts to be assessed. The research covered by Project A1 includes:

- The importance of geology and hydrogeology in environmental protection and considerations of human health (e.g. drinking water).

- Assessment of existing baseline monitoring and recommendations for future development of the baseline monitoring network in order to inform best practice, in the island of Ireland context.

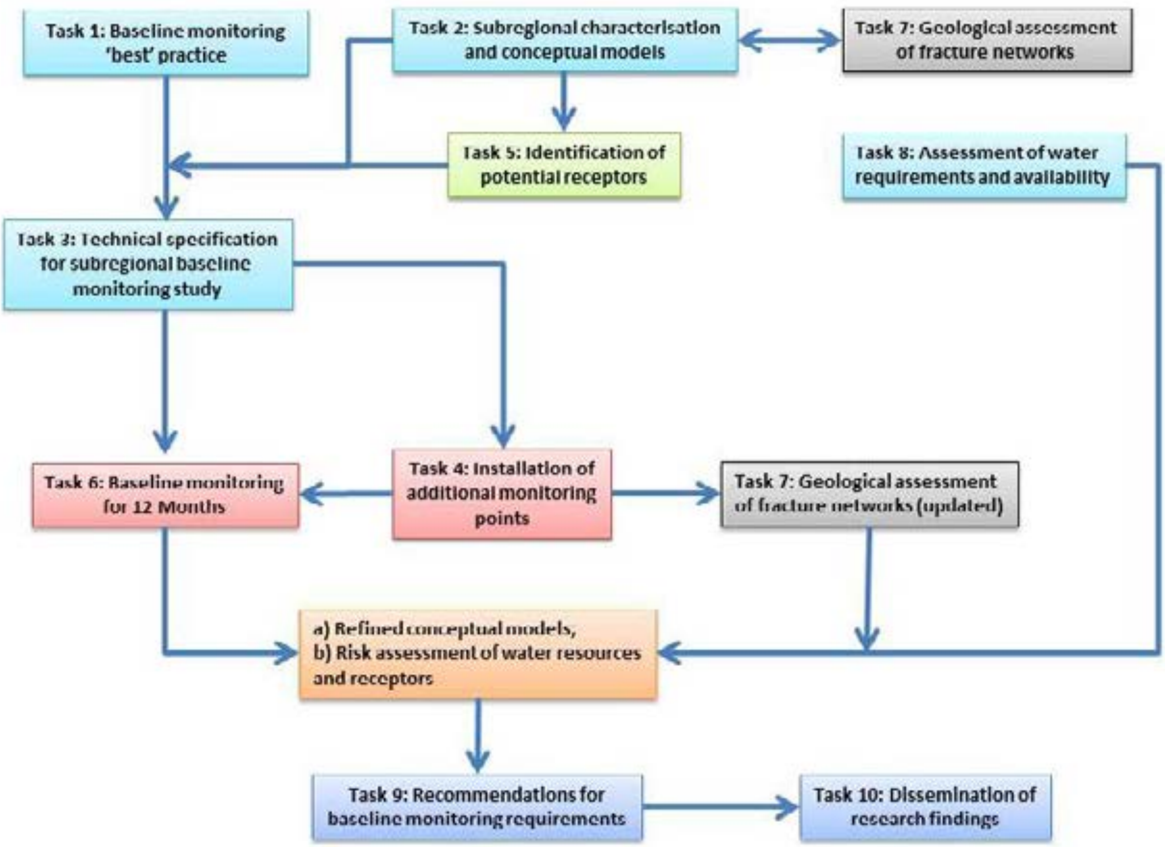


Figure 1.2. Tasks of Project A1 of the UGEE Joint Research Programme.

- Increasing geological and hydrogeological knowledge and developing a conceptual understanding, in the context of the case study areas.

- Evaluation of the connectivity between the unconventional gas source rocks and water resources.
- Evaluation of the water requirements of UGEE projects/operations (for an individual, typical pad and for each permit area) in the context of the study areas and assess if the local catchments could meet these requirements without adverse environmental impacts.

The research and implementation of Project A1 is guided by the source-pathway-receptor (S-P-R) model of environmental risk assessment which has served as the basis for most other water resources and environmental protection programmes on the island of Ireland, notably the river basin district projects led by EPA and NIEA, as well as the groundwater source protection work led by the EPA and GSI in the ROI. These efforts are supported by statutory instruments which were enacted in connection with the EU Water Framework Directive (WFD).

The following reports will be produced from Project A1:

- Interim Report A1-1: Assessment of Existing Baseline Monitoring (Best) Practice
- Interim Report A1-2: Sub-regional Geological/Hydrogeological Characterisation and Conceptual Models
- Interim Report A1-3: Technical Specifications for Sub-Regional Baseline Monitoring
- Interim Report A1-4: Refined Conceptual Model
- Interim Report A1-5: Quantitative Assessment of Water Resources
- Interim Report A1-6: Baseline Monitoring Results To Date
- Final Technical Report
- Non-Technical Summary Report

Combined, Interim Reports A1-1, A1-2 and A1-3 define the baseline monitoring programme which is intended to be carried out over an anticipated 12-month period under Tasks 4 and 6 of Project A1, and possibly beyond the life of the UGEE JRP.

1.4 Objectives and Goals of Interim Report A1-5

Interim Report A1-5 describes the work in Task 8 of Project A-1. It provides an overview of water use requirements for UGEE projects/operations and water resource availability in the two case study areas. This report supplements Interim Reports A1-1 (CDMS, 2015a), A1-2 (CDMS, 2015b) and A1-3 (CDMS, 2015c) of Project A1, and has been prepared in parallel with Interim Report B (CDMS, 2015d). The latter examines probable commercial scenarios of future UGEE development and outlines applicable and best practice mitigation measures to minimise water use in UGEE-related operations.

The overall *objective* of this Interim Report A1-5 is to assess whether the available water resources in the two case study areas can meet the defined demands of potential future UGEE projects/operations. The overall *goal* of the assessment is to document the potential risks that UGEE-related abstractions pose on catchment water requirements, including water supply schemes and the supporting conditions for surface water bodies and associated ecosystems.

1.5 Methodology and Information Sources

The methodology that has been followed in this Interim Report A1-5 has three main components:

- Definition of water use requirements for UGEE project/operations, with regard to the 'probable commercial scenarios' in Task 2 of Project B;
- Description of available water resources in the two case study areas, based on analysis of hydrometric data obtained from relevant information sources (see below) and the conceptual hydrogeological models developed in Interim Report A1-2 (CDMS, 2015b); and
- Comparison of water use requirements and available water resources, as a means of identifying potential impact.

The comparison is contextualised with respect to existing legislation and regulations that currently govern the technical assessment of future UGEE-related abstractions, as well as the metrics that are used by regulatory bodies in describing and reporting on the ecological status objectives of the European Union Water Framework Directive (WFD).

Information sources on hydrometrics are many:

- Rainfall/meteorology: Met Éireann in the ROI and Met Office in NI
- Lakes water levels: EPA, NIEA and Rivers Agency (RA)
- Stream levels and flows: EPA, OPW, Waterways Ireland (WI) and RA
- Groundwater recharge: GSI and GSNI
- Groundwater levels: EPA, GSI and GSNI

Additional data was also sourced from the ESB and Waterways Ireland, and research was conducted into past hydrometric studies of both study areas, including flood studies, and catchment management plans. Reference sources, documents and information which have been used are cited as appropriate, and references are listed in Section 8.

2 Water Use Requirements

UGEE projects require water for several purposes, including drilling operations, well construction, hydraulic fracturing, sanitation and equipment washing.

Concrete plans and details of future UGEE projects/operations in both the ROI and NI are as yet not known. Accordingly, the actual volumes of water that are needed for operations are uncertain. Case-specific circumstances would determine actual water demands at any given well pad. For guidance purposes, ranges of water use requirements for UGEE projects/operations were researched from published international literature. The highest water use requirements at any given well are associated with the hydraulic fracturing programme, over relatively short periods of time, normally measured in days. In the US, cited water demands for this purpose are 100 to 12,000 m^3 per well (Meiners et al., 2013), 10,800 to 35,000 m^3 per well (NYSDEC, 2011) and up to 23,000 m^3 per well (USEPA, 2015). Vengosh *et al* (2014) report an average water consumption for a single hydraulic fracturing well in the US of approximately 15,000-20,000 m^3. In Europe, a review of reported demand numbers generally range between approximately 5000 and 15,000 m^3 per well (JRC, 2013; Amec, 2014), though higher and lower values can apply depending on case-specific circumstances.

2.1 Development of Water Use Scenarios

The volumes of water that are required for the development of UGEE operations at a given site or in a given area depend on:

- Demands for general water use purposes (e.g. sanitation, equipment washing);
- Drilling methods and progress, total drilled vertical depths and lengths of horizontal boreholes, and degree to which water may be needed for dealing with losses of circulation during drilling;
- The number of well pads in a given area;
- The number of horizontal fracturing wells per well pad;
- Details of the hydraulic fracturing programme (e.g. the number of hydraulic fracturing stages (as function of horizontal length) in each well and the actual volumes used in each stage); and
- Timing and duration of build-out scenarios of UGEE projects/operations.

Other factors which directly influence UGEE-related water usage are the proportions of flowback and production waters that are generated from the operations and the degree to which these can be treated and recycled, thus reducing the volumes of water that would otherwise be abstracted from local sources and/or ‘imported/transported’ from other available sources.

Estimated water use requirement scenarios for the NCB and CB study areas are summarised in *Tables 2.1 and* 2.2 based on the ‘probable commercial scenarios’ described in Task 2 of Project B of the UGEE JRP (CDMS, 2015d).

Table 2.1 Water use requirement scenarios for the total licence area – NCB study area

Description	Unit	Low	Moderate	High
Well pads	No.	75	105	180
Wells per pad	No.	8	12	16
Total wells per study area	No.	600	1260	2880
Required volume of water per well/fracture programme	m^3	5000	10,000	15,000
Flowback of fracture fluid per well/fracture programme	%	25	32.5	40
Recycling rate for flowback water	%	80	40	0

Table 2.2 Water use requirement scenarios for the total licence area – CB study area

Description	Unit	Low	Moderate	High
Well pads	No.	20	30	50
Wells per pad	No.	8	12	16
Total wells per study area	No.	160	360	800
Required volume of water per well/ fracture programme	m^3	5000	10,000	15,000
Flowback of fracture fluid per well/fracture programme	%	25	32.5	40
Recycling rate for flowback water	%	80	40	0

Each item listed in the above tables are described below.

2.1.1 Number of well pads

The number of well pads that can be accommodated and/or developed in a licence area would in reality be determined by constraints placed on the developers. Constraints can be of a regulatory nature (e.g. authorisations) and a practical nature (e.g. landowner agreements, cost of development/operations). The theoretical maximum number of well pads that can be accommodated is a function of horizontal well lengths and the spatial configuration of the licence area. With regard to horizontal well lengths, there is no specific guidance materials for the two study areas, but on the basis of published plans in England and the US, lengths of 1500 m can be anticipated. On this basis, an estimated maximum (theoretical) of 180 well pads can be accommodated within the NCB licence area and 50 well pads can be accommodated in the CB licence area. Accordingly, this maximum theoretical development represents the 'high' water use scenario in *Tables 2.1 and 2.2*.

In reality, certain areas are not favourable or practical for well pad development. Examples are lakes and areas where the unconventional gas target formations are either absent or too shallow for consideration of hydraulic fracturing. A minimum depth limit of 500 m for the latter was indicated by Tamboran (2012) in the NCB. Accordingly, mapped outcrop areas of the Ballyshannon Limestone, Bundoran Shale and Mullaghmore Sandstone Formations and a 3 km buffer in an approximate downdip direction were removed from practical consideration, reducing the number of well pads that can be accommodated to 105 in the NCB, and focussing the likely development scenarios towards the Lough Allen Basin subdivision (CDMS, 2015b) of the NCB. A comparable reduction in the number of well pads to 30 in the CB was assigned by similarly eliminating areas where the interpreted depth to the unconventional gas target formation (i.e. the Clare Shale Basin) is less than 500 m (CDM Smith, 2015a). This represents the 'moderate' water use scenario in *Tables 2.1 and 2.2*.

A third low water use scenario was also defined by reducing the number of well pads arbitrarily to 75 in the NCB and 20 in the CB. This reflects a scenario whereby further spatial constraints are imposed on the developers in terms of where well pads might be considered. Examples would be restrictions to development within boundaries of Special Areas of Conservation (SACs), groundwater Source Protection Zones (SPZs), and other environmentally sensitive locations.

Until prospective UGEE plans become known, there is no accurate way to predict or judge precisely how water use requirements would emerge in the future. The three scenarios in *Tables 2.1 and 2.2* provide ranges which can guide the assessment of water resources availability in respective case study areas. However, the 'high' scenario is not considered realistic, simply because it includes well pads in locations where UGEE development would not be attempted. The 'moderate' and 'low' scenarios are more realistic, and the actual future scenario could even be somewhere in between.

2.1.2 Number of wells per well pad

Technology is sufficiently advanced that oil and gas companies can drill multiple wells from single well pads. For the three water use scenarios, the number of wells drilled per pad is 8, 12 and 16, as defined by the 'probable commercial scenarios' in Project B of the UGEE JRP (CDMS, 2015d).

2.1.3 Total wells per licence area

The total wells per licence area was calculated by multiplying the number of wells per well pad by the total number of well pads in each licence area.

2.1.4 Required volume per hydraulic fracturing programme

The required volume of water for a hydraulic fracturing programme at a single well is guided by published values from UGEE applications in Europe (CDMS, 2015d), i.e. 5000 m^3 for the low water use scenario, 10,000 m^3 for the moderate water use scenario, and 15,000 m^3 for the high water use scenario.

2.1.5 Flowback volumes of fracture fluid per fracturing event or programme

Based on the 'probable commercial scenarios' (CDMS, 2015d), an estimated range of flowback volumes between 25 and 40% of the water used is considered realistic: 25% for the low water use scenario, 32.5% for the moderate water use scenario, and 40% for the high water use scenario.

2.1.6 Recycling of flowback water

Flowback water may be treated and recycled to reduce the water supply from local resources. Up to 80% recycling can be accomplished as described in Task 3 of Project B (CDMS, 2015d). For the water use scenarios, the 80% is used with the low water use scenario, 40% is used for the moderate water use scenario, and 0% (no recycling) is used for the high water use scenario. There is an increasing trend worldwide of recycling some proportion of the flowback water (CDMS, 2015d), and the degree of recycling is determined by technical considerations (feasibility), cost considerations (treatability of flowback water vs. access to local water sources), and regulatory considerations (e.g. authorisation and ability to discharge wastewater effluents to local water bodies).

There is also a temporal aspect that must be considered, specifically how development proceeds in time, both at an individual well pad and on a cumulative basis across a given licence area. The 'build-out' period of UGEE projects/operations cannot be predicted with any certainty, but for purposes of this report, it has been assumed that build-out would occur in each lease area over a 15-year period beginning gradually, peaking in Years 7 to 11, and subsequently declining to Year 15. There are 3 lease areas in the NCB, and it is assumed that development (by different licencees) in each would proceed concurrently. Without knowledge of how UGEE would be planned and developed in the future, this is a 'worst case' or maximum development scenario. The resulting total annualised water use (m^3/yr) for the build-out period are presented in *Figures 2.1 and 2.2* for the NCB and CB licence areas, respectively. The corresponding estimated annualised maximum water use requirements, expressed in m^3/d, for years 7 through 11 of the build-out scenario, are summarised in *Table 2.3*.

2.2 Maximum Daily Water Demand for UGEE Operations

The annualised water use requirements presented above indicate the progression of total and maximum water use requirements for the 15-year build-out scenario. They do not define the maximum daily water demand on any given day, which is defined by the number of hydraulic fracturing stages and the volumes of water needed for each stage. Using the maximum water requirement for a hydraulic fracturing programme at a single well of 15,000 m^3 (see Section 2.1), the water demand for a single well would be determined by how the programme is implemented, specifically how many fracturing stages are undertaken and the total duration of programme.

For a single well, a hydraulic fracturing programme is typically completed within a few (3-10) days (CDMS, 2015d), but the duration of the programme is subject to case-specific circumstances and objectives. Accordingly, if the programme requires 15,000 m^3 of water over a 3-day implementation period, the maximum daily water demand is 5000 m^3/d for the single well. If the duration is shorter, or greater volumes of water are required, the daily demand rises. More significantly, if identical programmes are carried out at multiple wells concurrently, the total daily demand becomes significantly greater. For the peak build-out scenario presented in *Figures 2.1 and 2.2*, there would theoretically be approximately 130 wells for the moderate build-out scenario drilled and hydraulically fractured per year in the NCB study area. Assuming 3 days per hydraulic fracturing programme, this equates to 390 days of demand at 5000 m^3/d in the example given above. Such development and demand would have to be supplied from multiple sources. Accordingly, all future proposed UGEE-related abstraction plans would have to be carefully reviewed to understand the timeline of total demands, individually and cumulatively, with the involvement of relevant stakeholders and regulatory bodies.

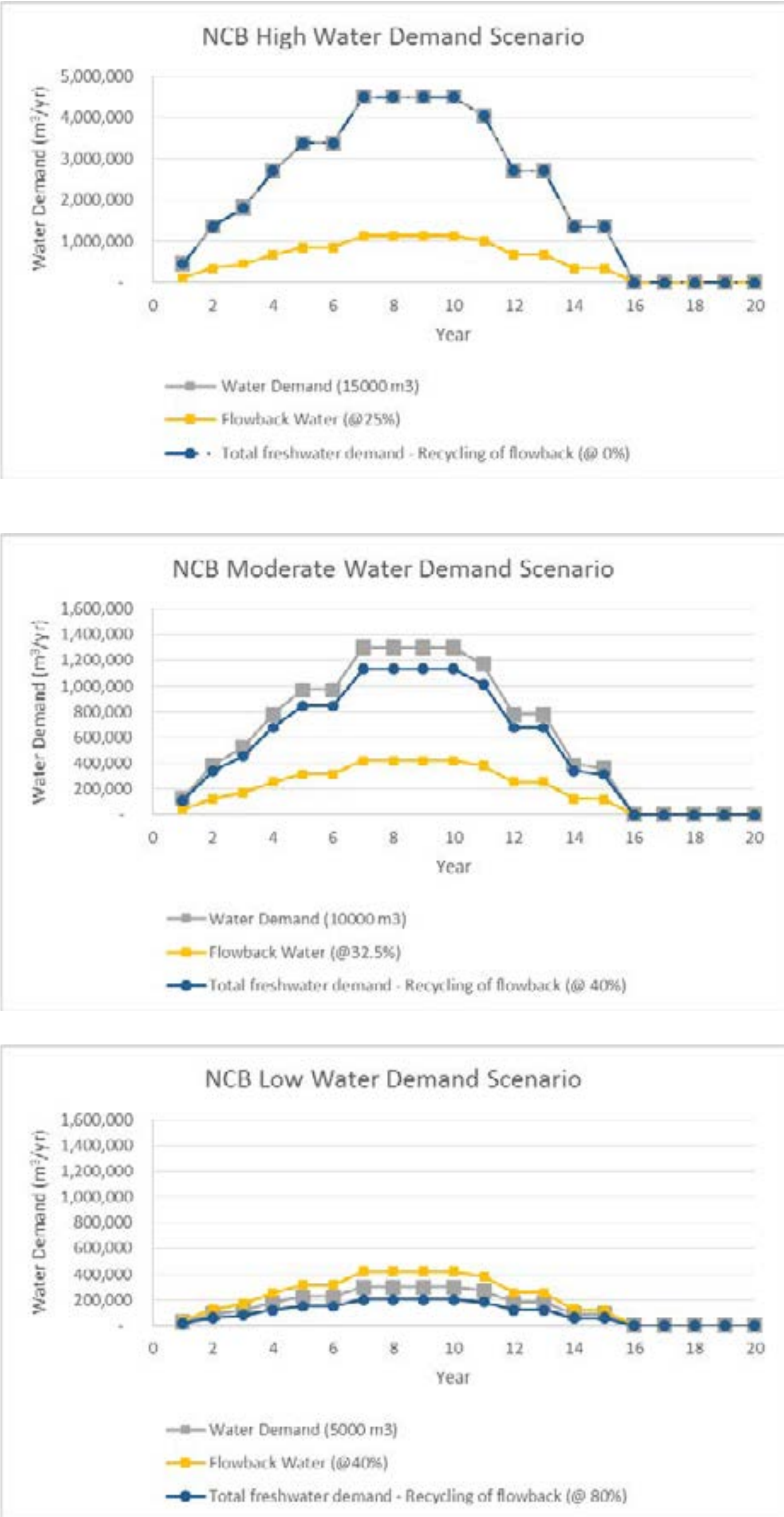
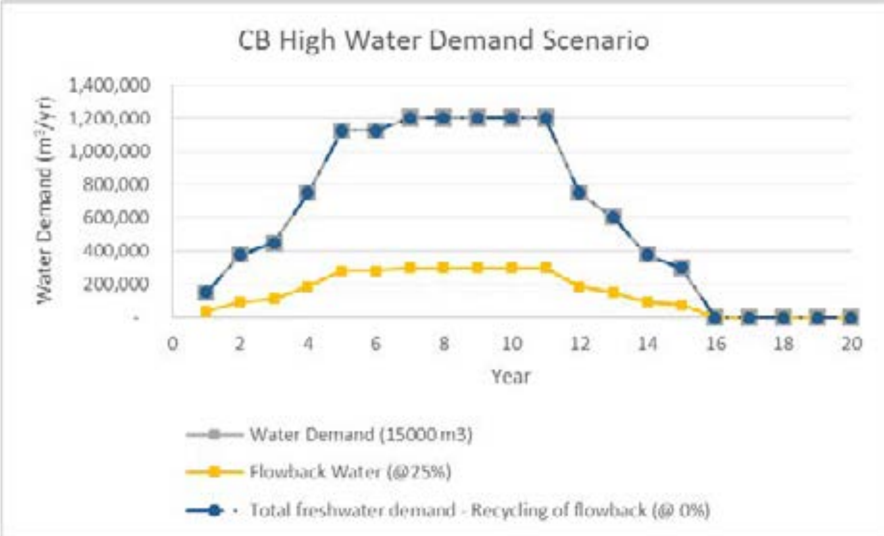
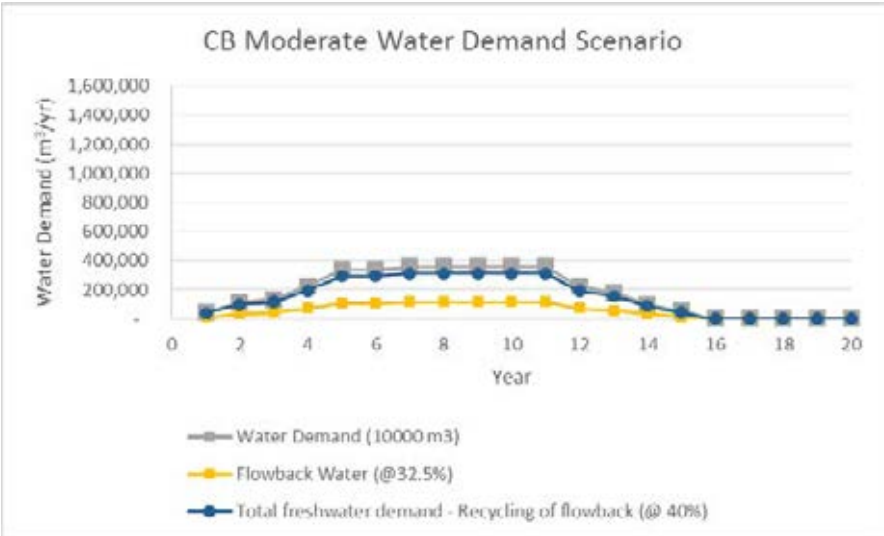


Figure 2.1. UGEE water use requirement – NCB study area.





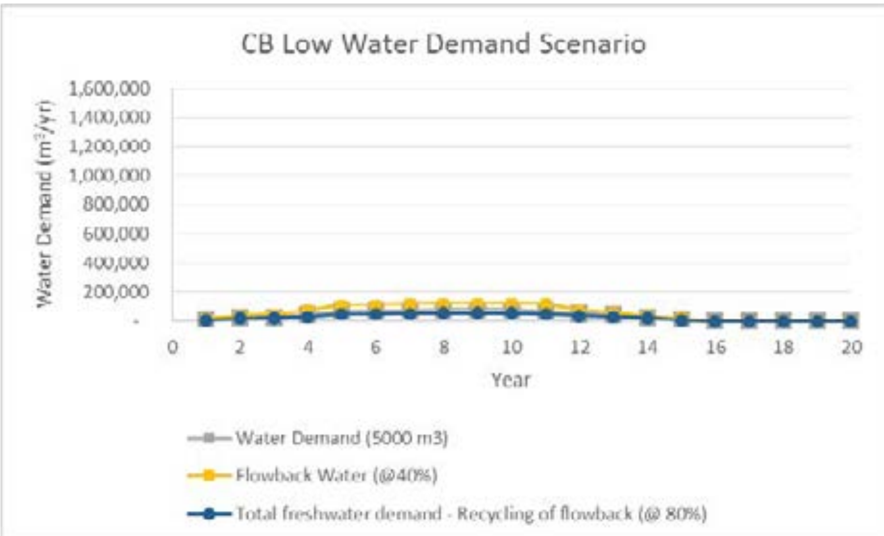


Figure 2.2. UGEE water use requirements – CB study area.

Table 2.3. Estimated annualised water use requirements during the assumed build-out scenario

Water Use Requirement	Clare Basin	Northwest Carboniferous Basin		
		Demand per lease area	No, of lease areas in NCB	Demand for NCB licence area
High	3288 m^3/d	4110 m^3/d	3	12,330 m^3/d
Moderate	858 m^3/d	1032 m^3/d		3096 m^3/d
Low	149 m^3/d	186 m^3/d		558 m^3/d

2.3 Sourcing of Water to Meet Demands

It is anticipated that the water required for UGEE projects/operations would be sourced from available water resources within or close to the licence areas in each basin. It is further expected that UGEE developers would try to source water as close as possible to individual wells pads. Precisely how and where the water would be sourced would be determined by practical considerations and cost – specifically the costs of planning, licensing, constructing and maintaining abstraction points versus the costs of purchase and transport of water from existing water supply schemes in the region.

Given the high rainfall in both case study areas, rainwater harvesting is an option to help reduce demands from water abstraction sources. The use of recycled treated wastewater can also reduce water demands, but the ability to recycle treated wastewater effluent from UGEE operations is influenced by the volumes of the available flowback water as well as the chemical nature and treatability of same. Thus, establishing and subsequently monitoring the volumes and quality of flowback and production water become important operational controls (Nicot et al., 2014). There is a trend in the industry towards increasing the proportion of recycled flowback and produced water, especially in areas where freshwater resources are limited (Nicot et al., 2014; Hunter, 2012). This is also described in Tasks 3 and 7 of Project B of the UGEE JRP (CDMS, 2015d).

Any UGEE-related abstractions would be subject to existing control measures (systems of “prior authorisation”) in both the ROI and NI. In the ROI, abstraction controls are currently defined by: a) the Environmental Impact Assessment (EIA) Directive (85/337/EEC), which is included in statutory instrument (S.I.) No. 93 of 1999 (EC (EIA) (Amendment) Regulations, 1999) and referred to in Part 2 of Schedule 5 of the Planning and Development Regulations, 2001; b) the Water Supplies Act 1942, as amended by the Planning and Development Act (S.I. 30 of 2000); and by c) the Planning and Development Regulations (2001) for groundwater abstraction proposals for water supply to Local Authorities. In NI, abstractions of all waters are licenced under the Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006.

Article 11.3(e) (Programme of Measures) of the European Union (EU) Water Framework Directive (WFD) (2000/60/EC) requires a system of “prior authorisation” for water abstractions. It also includes provision for measures to be introduced to mitigate potential abstraction impacts on water resources. Different water bodies can be impacted in different ways, e.g. by changes in water levels, flow/discharge, quality, and/or the status/health of associated aquatic ecosystems. With regard to the latter, the European Court of Justice (ECJ) has ruled that Article 6(3) of the EC Habitats Directive (EC 92/43/EEC) applies to abstraction projects, whereby an Appropriate Assessment is required where the potential for impact to Natura 2000 sites is identified (EC, 2006). In the ROI, the need for control measures for groundwater abstractions are specifically addressed by the recently enacted Groundwater Regulations [S.I. No. 9 of 2010].

Within the UGEE licence areas in the NCB, several surface water and groundwater bodies cross the border between the ROI and NI. Such water bodies are part of formally designated international river basins under the EU WFD, e.g. the Northwestern and Neagh-Bann International River Basin Districts. In cross-border river basins, Article 3 (Coordination of administrative arrangements within river basin districts) of the WFD requires Member States to coordinate water resources management. Accordingly, the study and prior authorisation of future abstractions of shared water resources and associated ecosystems in the NCB study area would require coordination amongst the relevant regulatory bodies in the ROI and NI.

3 Available Water Resources in the NCB Study Area

The available water resources of the NCB study area are represented by rainwater, lakes and reservoirs, streams and rivers, and groundwater (including springs), as described below. The main physiographical, geological and hydrogeological characteristics of the NCB study area were described in detail in Interim Report A1-2 (CDMS, 2015b), and key descriptors are referenced as appropriate in the following sections.

3.1 Rainfall/Meteorology

The 30-year annual average rainfall distribution for the period 1981-2010 (Met Éireann, 2015) is shown in *Figure 3.1*, and ranges from 800 to 2400 mm/yr across the study area. The wide range in average rainfall reflect topography, and the higher rainfall values correlate with upland areas, notably the Benbulben/Truskmore, Cuilcagh and Slieve an Iarainn Mountains which receive between 2000 and 2400 mm/yr.

Rainfall varies considerably between summer and winter. The 30-year average winter rainfall (December through January) ranges between 200 and 700 mm/yr, whilst the 30-year average summer rainfall (June through August) ranges between 200 and 500 mm/yr.

In 2014/2015, the estimated monthly potential evapotranspiration (PE) rate at the recently established Finner weather station (located approximately 5.5 km NW of the study area) ranged between approximately 10 mm/month in November and 80 mm/month in June, as shown in *Figure 3.2*. The total monthly rainfall in the same period ranged between 39.1 mm/month to 197.9 mm/month.

3.2 Lakes

There are numerous lakes in the NCB study area, ranging in size from 0.004 km^2 (Lough Nacroagh) to 103.8 km^2 (Lower Lough Erne). The largest lakes, see *Figure 3.3*, are located in lowland, valley settings whilst smaller lakes tend to be located in uplands. Lakes that are present in valleys occupy inter-drumlin areas which form a complex hydrological system of interconnected lakes, bogs and wet meadows (wetlands) in which flooding occurs frequently.

The largest lakes and drainage systems are associated with Upper and Lower Lough Erne, Lough Allen, and Lough Melvin. The Lough Erne catchment also incorporates Upper and Lower Lough Macnean.

Lakes are important for recreational uses, including fisheries (Kelly *et al.*, 2012), hosting several important species of trout, salmon, and char. Lakes are also abstracted for public and private water supplies and *Table 3.1* summarises the abstracted lakes within or adjoining the UGEE licence boundaries, indicating respective lake surface areas, approximate storage volumes, delineated catchment areas, estimated daily mean inflows, abstraction rates, and ratios of abstractions and estimated daily mean inflows.

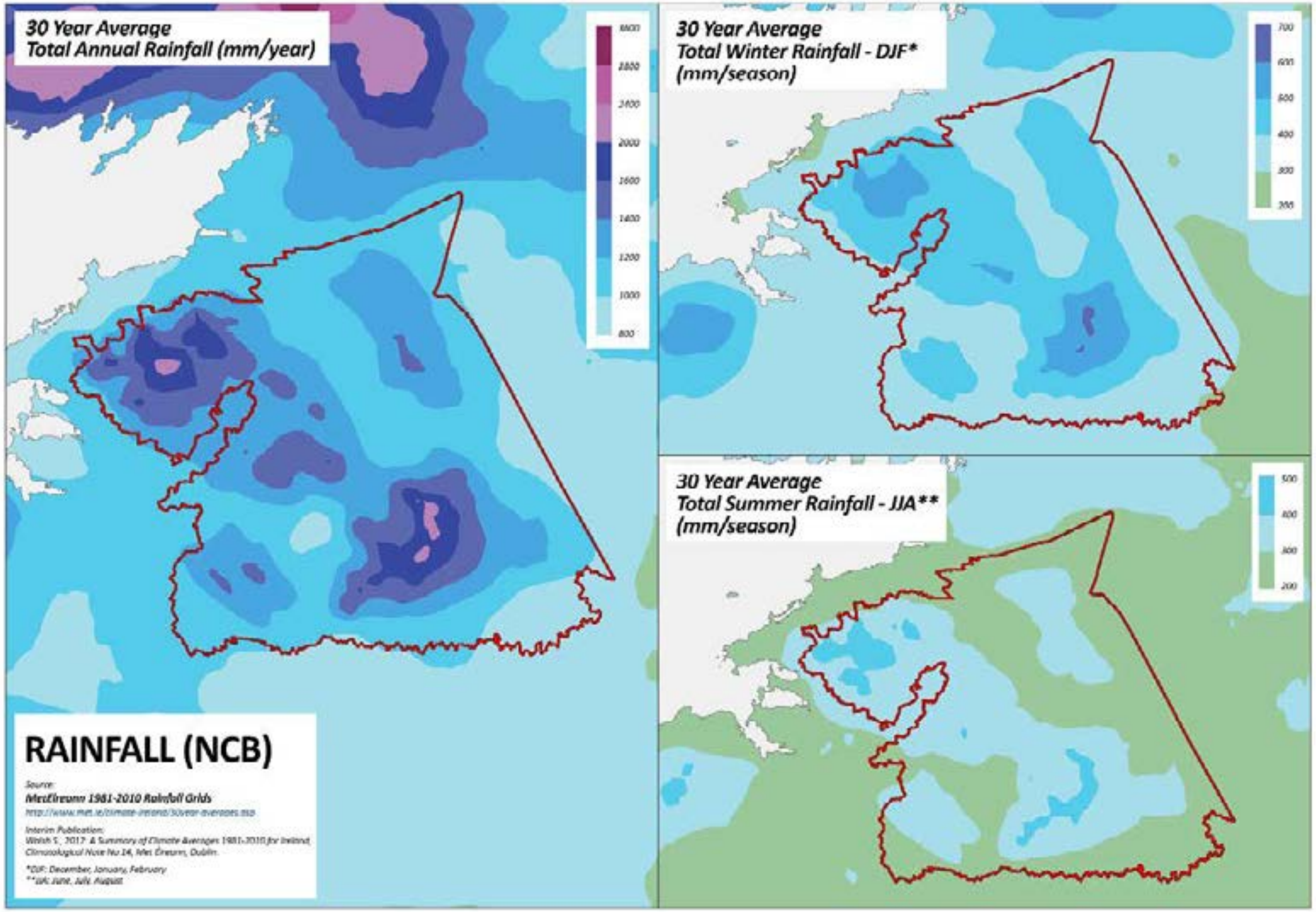


Figure 3.1. Average annual rainfall distribution (1981-2010) – NCB study area.

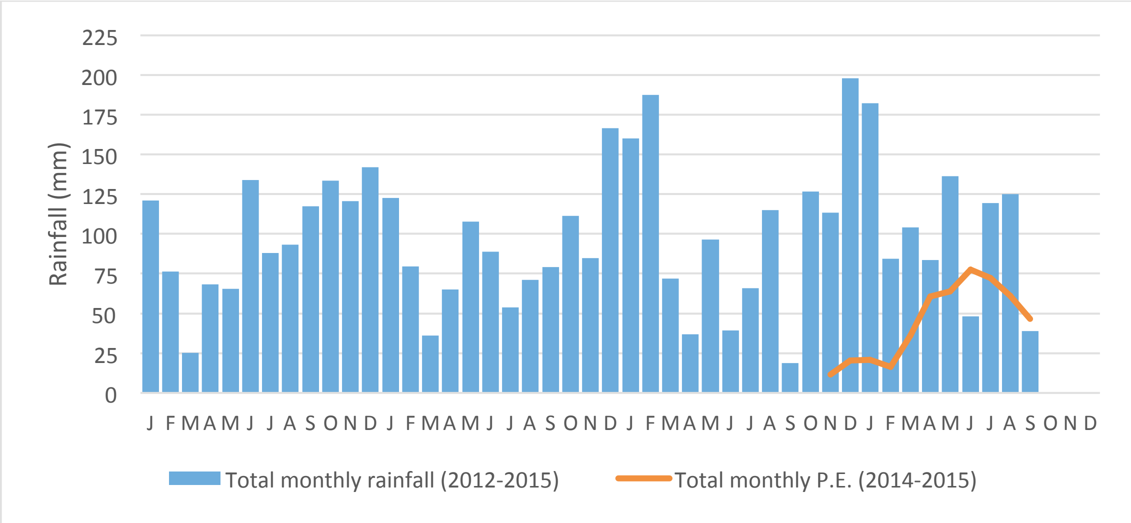


Figure 3.2. Total monthly rainfall and P.E. at Finner weather station.

Table 3.1. Summary of abstracted lakes – NCB study area

Name	Lake Area	Lake Volume[a]	Estimated Lake Catchment Area	Daily Mean Inflow[b]	Abstraction Rate	Abstraction as % of Daily Mean Inflow
	(km^2)	(km^3)	(km^2)	(m^3/d)	(m^3/d)	(m^3/d)
Aghalough	0.01	0.04	1.4	2805	50	1.8
Anarry Lough	0.11	0.26	0.8	2963	135	4.6
Annagh Lough	0.35	1.20	1.5	2424	1455	60.0
Clonty Lough	0.11	0.12	10.8	23,590	740	3.1
Drumlane Lough	0.64	3.32	8.8	15,545	250	1.6
Lackagh Lough[c]	0.07	0.15	0.6	1262	236	18.7
Lough Arrow	12.47	134.17	50.5	106,938	432	0.4
Lough Erne Lower	103.8	n/a[d]	4106.6	14,299,645[e]	2600[f]	0.0
Lough Erne Upper	32.18	n/a[d]	3296.9	12,427,664[e]	44,000[f]	0.4
Lough Gill	13.81	160.63	375.2	1439,439	18,902	1.3
Lough Kilsellagh	0.04	0.20	8.7	15,751	4594	29.2
Lough Melvin	22.06	185.69	226.1	705,621	7000	1.0
Lough Nabellbeg	0.01	0.01[d]	0.2	814	83	10.2
Lough Nambrack	0.07	n/a[d]	0.3	656	141	21.5
Lough Naweleian	0.05	0.02	0.5	1138	60	5.3

[a]Estimated from bathymetry data.

[b]Calculated by multiplying catchment areas and estimated specific runoff values.

[c]Flagged as WFD 'at-risk' from over abstraction (CDM, 2009).

[d]Bathymetric maps were not obtained but exist. Upper Lough Erne: mean depth 2.3 m, max. depth 27 m (NIEA, 2015). Lower Lough Erne: mean depth 11.9 m, max. depth 69 m (NIEA, 2015).

[e]From water balance table received from NI Water.

[f]Maximum licenced. Actual abstractions are less.

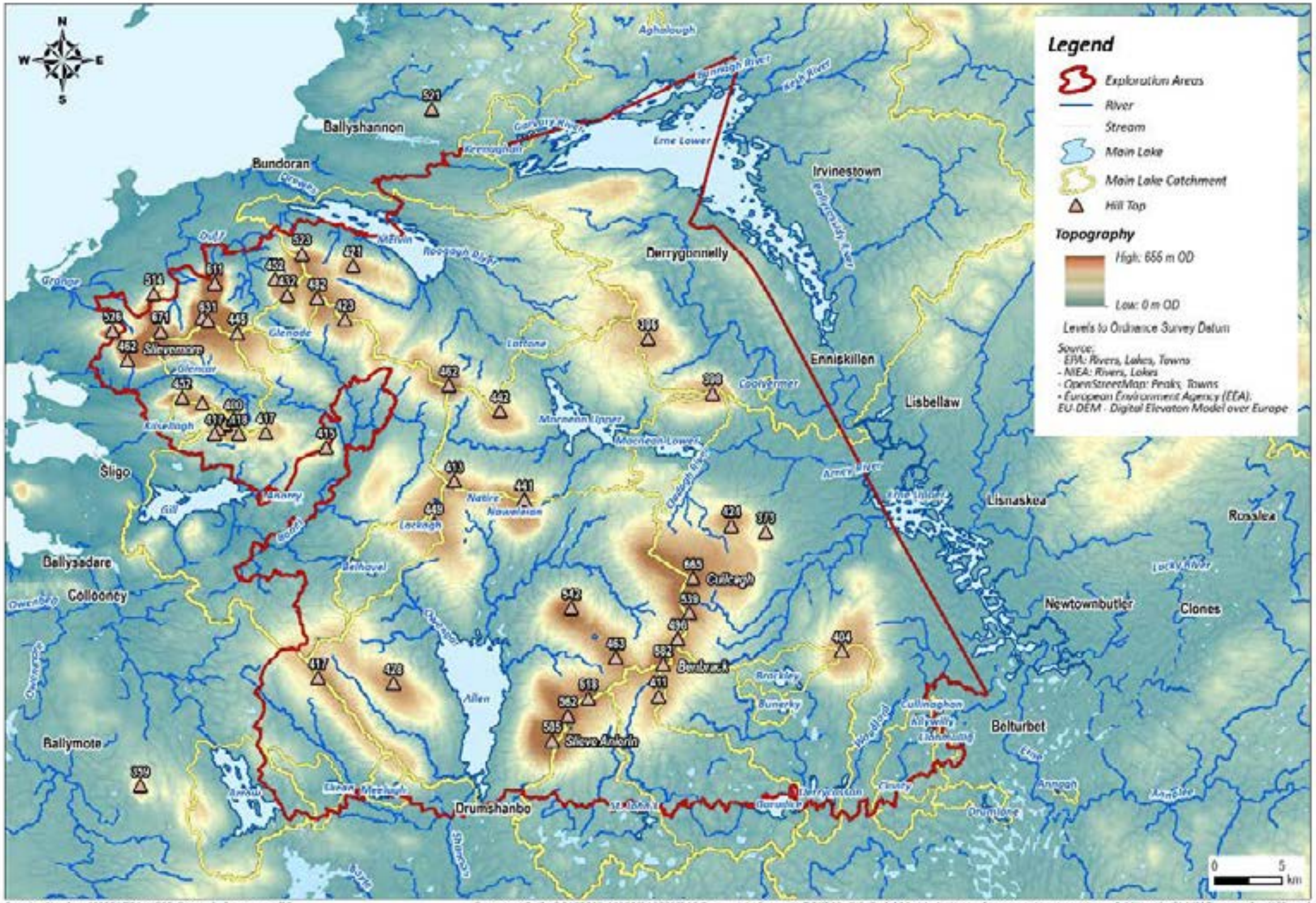


Figure 3.3. Overview of lakes – NCB study area

The single largest abstraction from lakes is associated with Lough Erne, where the Fermanagh regional water scheme is supplied from two pump stations at Belleek and Killyhevlin. Information obtained from the NIEA indicates that the maximum permissible (i.e. licenced) abstraction from each station are 2600 m^3/d and 44,000 m^3/d, respectively, and that in 2014, the actual abstraction from each station averaged 1640 m^3/d and 24,810 m^3/d, respectively (NIEA, 2015). In the ROI, the single largest lake abstraction is from Lough Gill, where approximately 18,900 m^3/d is abstracted to supply three public water schemes and one private supply. The largest abstraction (8000 m^3/d) supplies the North Leitrim Regional Supply Scheme.

For the majority of abstracted lakes, water balance and/or design studies have been researched with relevant public bodies, but few details have emerged. Bathymetry has been mapped for 33 lakes within or adjoining the UGEE licence area, see *Attachment A*, and information on lake volumes can be assigned for the surveyed lakes. Upper and Lower Lough Erne, Lough Melvin, Lough Gill, Lough Arrow, Upper and Lower Lough Macnean, and Lough Allen are all equipped with staff gauges for water level measurements, and hydrographs are presented in *Attachment B*. Hydrographs show relatively stable water levels over time, with the possible exception of the station at Rosscor (236001) which is associated with Lower Lough Erne. This station shows slightly lower water tables, but the same range of seasonal fluctuations, in the period from 2010 to present compared to the period of record 1999-2009. Hydrographs for Gowly (36071), Wood Island (36073) and Ballinacur (36091) display a considerable change in water level regimes in 1994 which are linked with the dredging and opening of the Shannon-Erne Waterway.

Loughs Erne and Allen are regulated water bodies. Water levels in Lough Erne are managed in context of the Ballyshannon hydroelectric power scheme, and the temporal variability of water levels is gauged and controlled to maintain the ecological significance ('value') of the lake system. The regulatory schemes are described in relevant flood and fish studies (e.g. ESBI, 2003, IFI, 2010; JBA 2013). The Lough Erne system includes a designated RAMSAR site, Area of Special Scientific Interest, and Special Area of Conservation (NIEA, 2010). Water levels and outlows from Lough Allen are managed according to "The Regulations and Guidelines for the Control of the River Shannon" (ESB, November 2003 with minor revision in 2008).

3.3 Streams/Rivers

Drainage patterns in the NCB study area are influenced by the underlying geology and the landforms which have resulted from past glacial action (CDMS, 2015b). The majority of streams originate on high-rainfall, peat-covered hilltops which are mostly underlain by low-permeability bedrock formations, but some streams also originate at springs in limestone terrains. Drainage patterns tend to be radial where low-permeability bedrock is present, and dendritic where limestones are present, with streams discharging to lakes in valley settings or westward directly to the sea (CDMS, 2015b).

The Lough Erne and Lough Allen drainage systems account for approximately 43% and 36% of the total UGEE license area, respectively. Both systems are regulated by dams, lock gates or sluices, and since 1994, the Upper Lough Erne is connected with the River Shannon via the Shannon-Erne Waterway (SEW), see *Figure 3.4*.

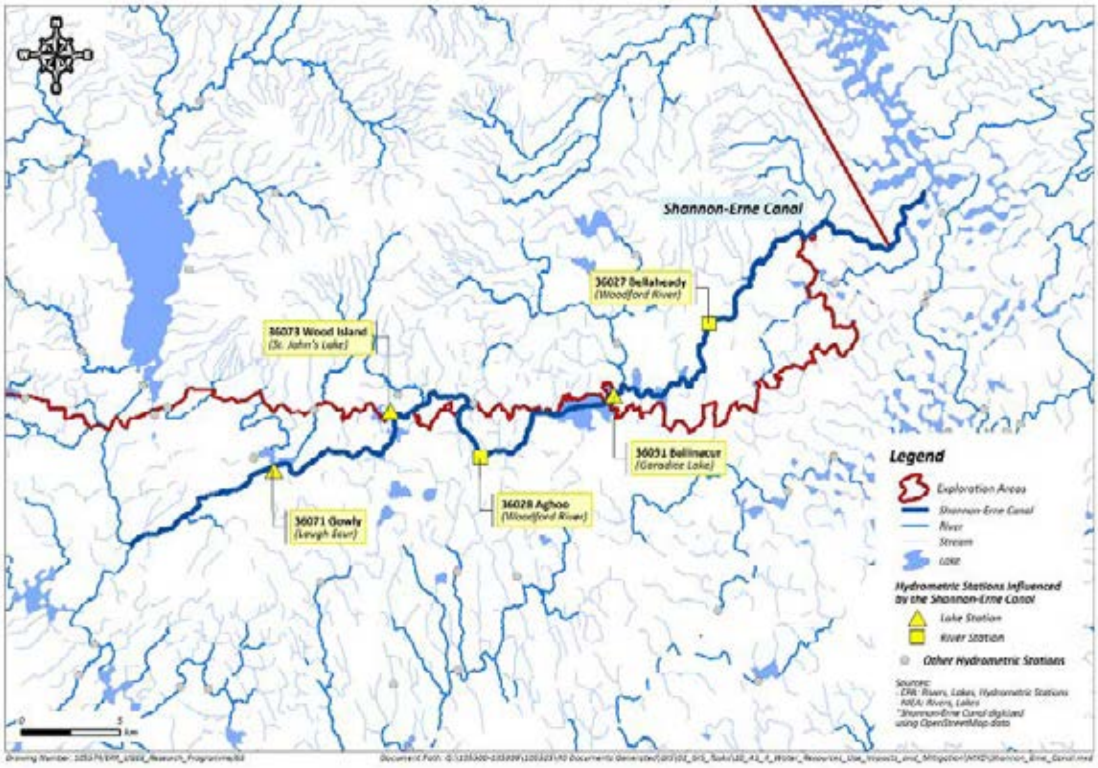


Figure 3.4. Shannon–Erne Waterway.

There are 33 active gauging stations in the NCB study area, see *Figure 3.5*, of which 28 are stream flow recorder sites and 5 are equipped with staff gauges for water level recording. Hydrographs and flow duration curves (FDCs) are depicted in *Attachment B* for stations with more than 6 years of continuous record. Using the hydrometric data obtained from the EPA and Office of Public Works (OPW) in the ROI, and the Rivers Agency (RA) in NI, the daily mean and 95-percentile (Q_{95}) flows (i.e. the flow that is exceeded 95% of the time) are summarised in *Table 3.2* from stations with long-term records. Flow statistics for ungauged catchments in the ROI were estimated using the EPA's HydroTool. Flow statistics for ungauged catchments in NI were estimated by transposing specific runoff estimates from gauging stations in neighbouring catchments that have similar physical characteristics. Flow statistics in ungauged catchments that cover karstified limestones are assigned low confidence given the dynamic nature and range of flows that characterise such catchments, and which cannot be captured with simplified estimation methods.

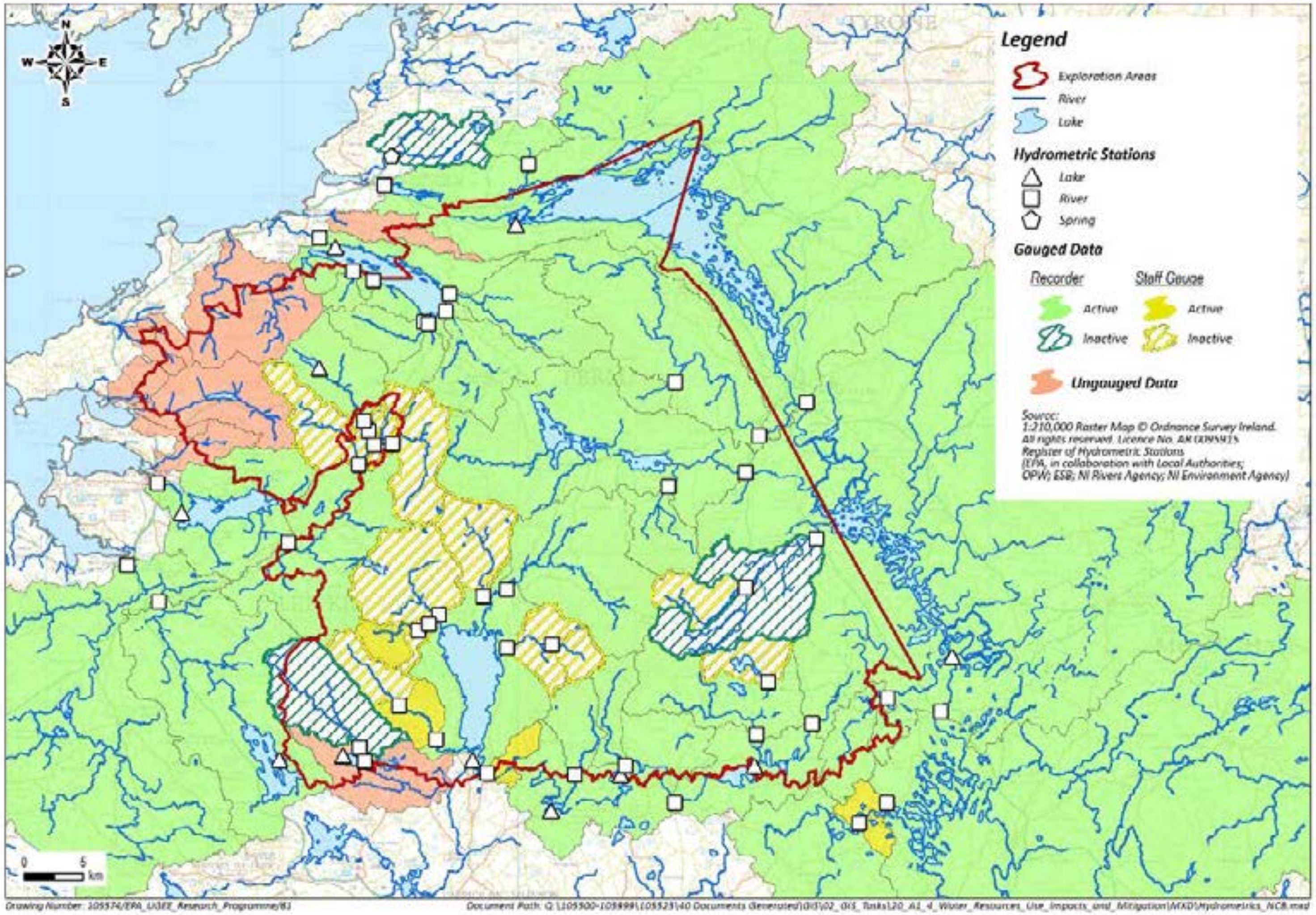


Figure 3.5. Gauging stations – NCB study area.

Table 3.2. Summary of estimated flows in the NCB and CB study areas

Gauged Catchments (derived from measured data)									
		Northwest Carboniferous Basin				Clare Basin			
Parameter	Unit	Min	Max	Mean	Median	Value	–	–	–
Q_{95} Flow	m^3/s	0.06	2.17	0.80	0.34	0.171	–	–	–
Mean Flow	m^3/s	0.89	28.56	8.44	4.86	3.039	–	–	–
Specific Runoff (Q_{95})	$m^3/s/km^2$	0.0011	0.0066	0.0035	0.0034	0.0016	–	–	–
Specific Runoff (mean)	$m^3/s/km^2$	0.0191	0.0777	0.0386	0.0372	0.028	–	–	–
Ungauged Catchments (derived from HydroTool)									
		Northwest Carboniferous Basin				Clare Basin			
Parameter	Unit	Min	Max	Mean	Median	Min	Max	Mean	Median
Q_{95} Flow	m^3/s	0.02	1.045	0.2165	0.105	0.011	0.15	0.0548	0.038
Mean Flow	m^3/s	0.12	6.634	1.3807	0.54	0.08	1.17	0.4128	0.2805
Specific Runoff (Q_{95})	$m^3/s/km^2$	0.0024	0.0063	0.0039	0.0038	0.0007	0.003	0.0019	0.0021
Specific Runoff (mean)	$m^3/s/km^2$	0.0165	0.0255	0.0209	0.021	0.0097	0.0222	0.0143	0.0143

Gauged:

NCB: Based on 11 gauging stations with long-term continuous records (period 1946-2015)

CB: Based on Doonbeg gauging station (period 1972-2015)

Ungauged:

NCB: Result from HydroTool in 11 catchment. Not used in catchments with karst limestone.

CB: Result from HydroTool in 12 catchments.

Figures 3.6–3.9 depict the hydrographs and FDCs for four representative gauging stations in four separate catchments:

- Glenaniff gauging station, which measures flow in a dominantly limestone catchment near Lough Melvin;
- Bellaheady gauging station, which measures flow in a dominantly limestone catchment in the upper parts of the Lough Erne drainage system;
- Kiltybardan gauging station, which measures flow in a dominantly shale and sandstone catchment near Lough Melvin; and
- Dowra gauging station, which measures flow in a mixed shale and sandstone catchment which drains into Lough Allen.

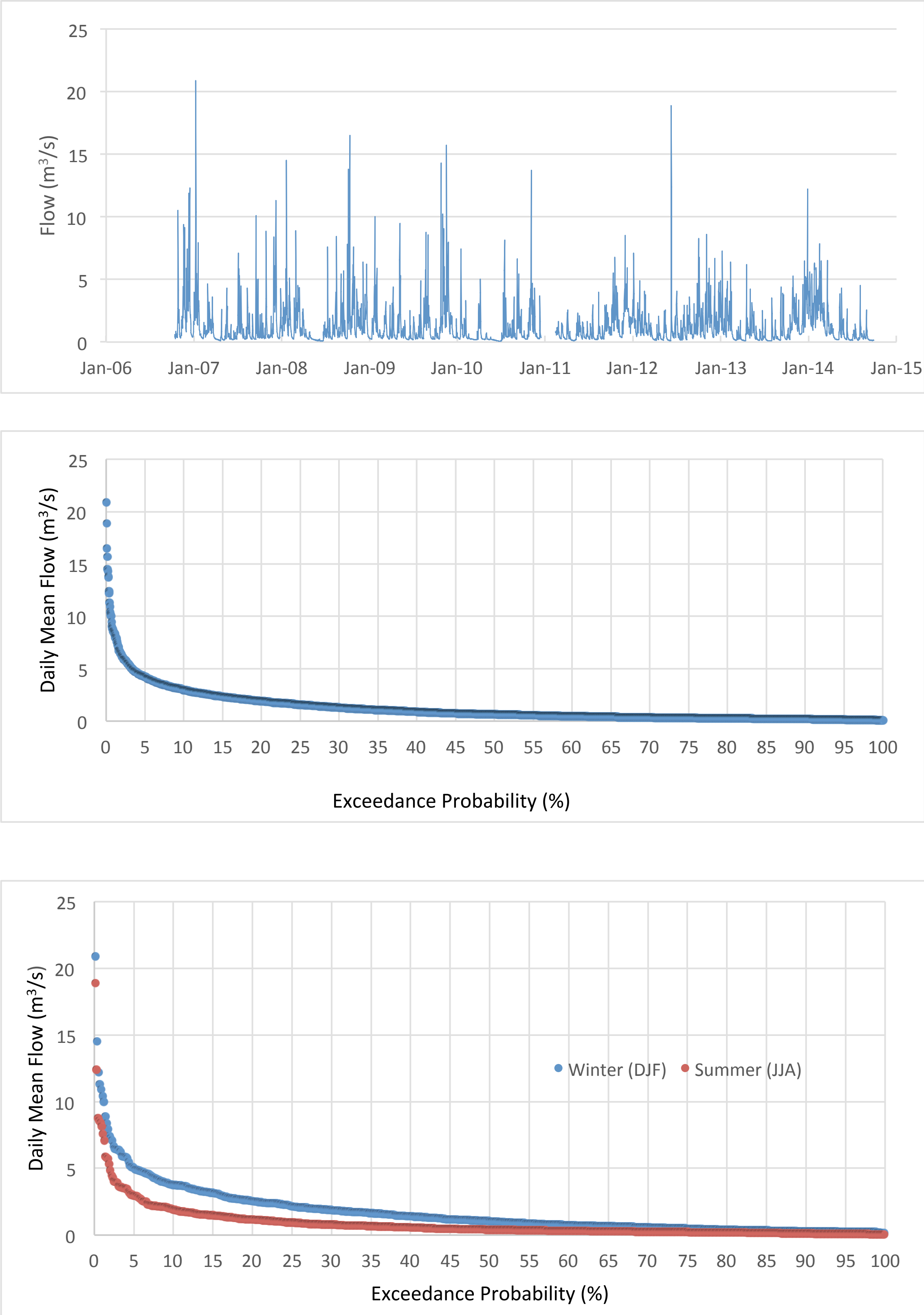
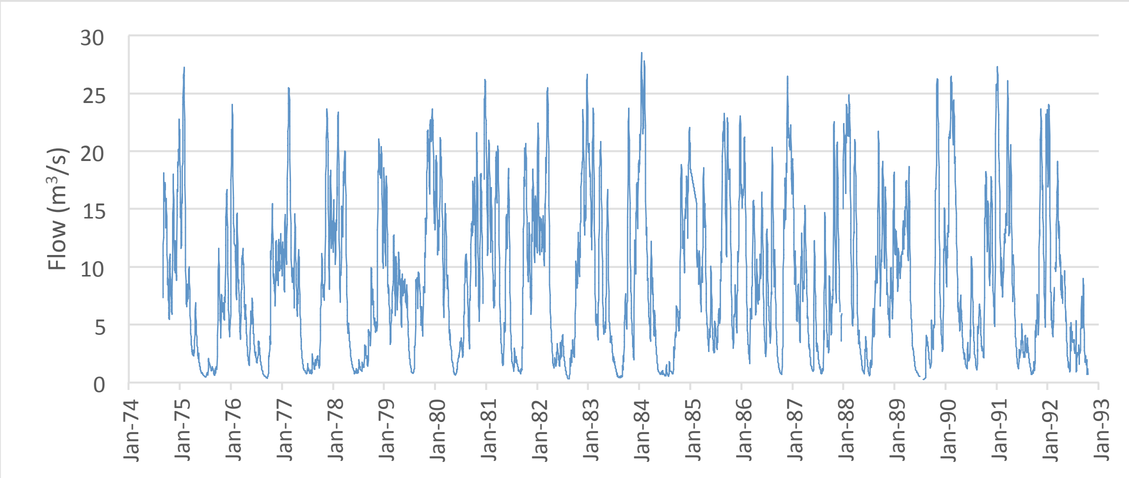
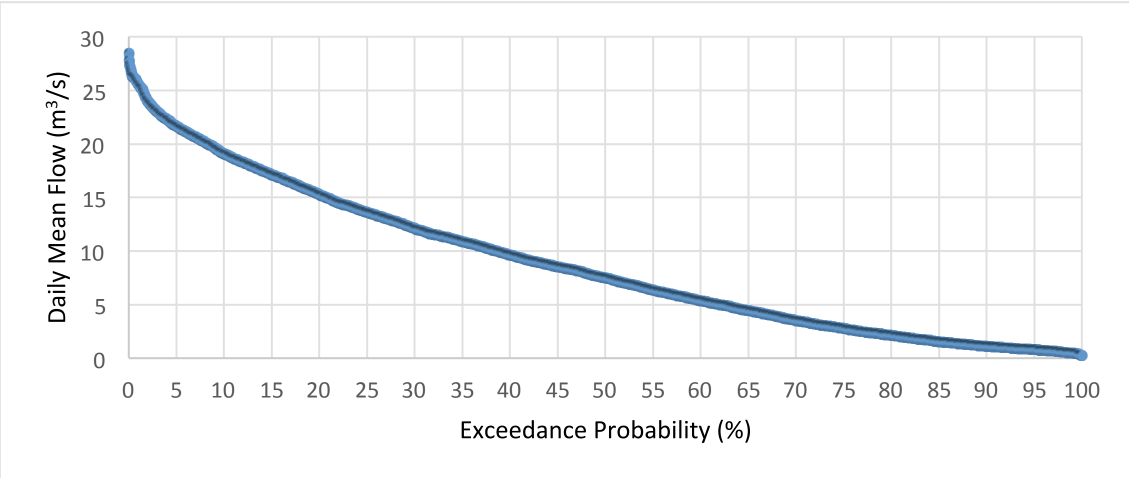


Figure 3.6. Hydrograph and flow duration curves – Glenaniff.





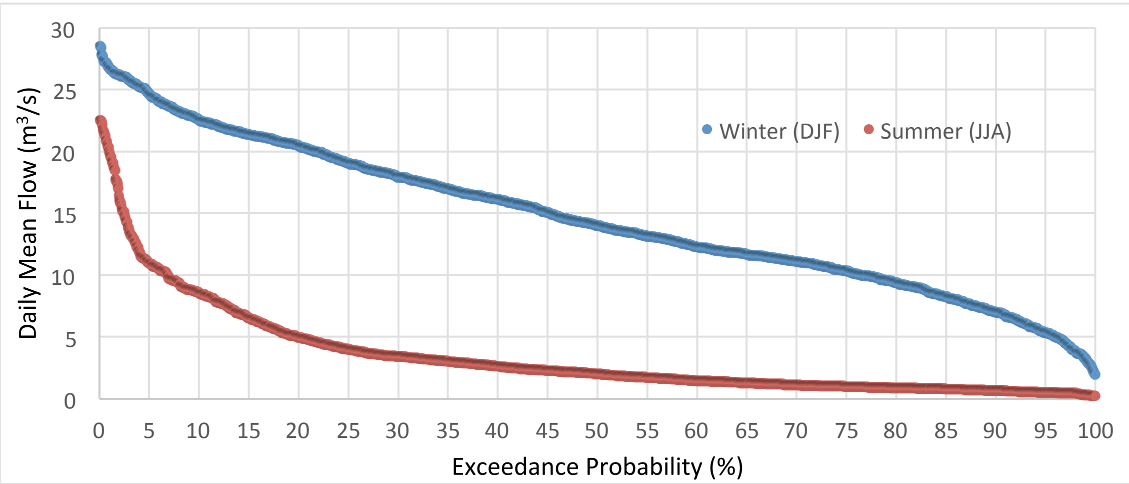


Figure 3.7. Hydrograph and flow duration curves – Bellaheady.

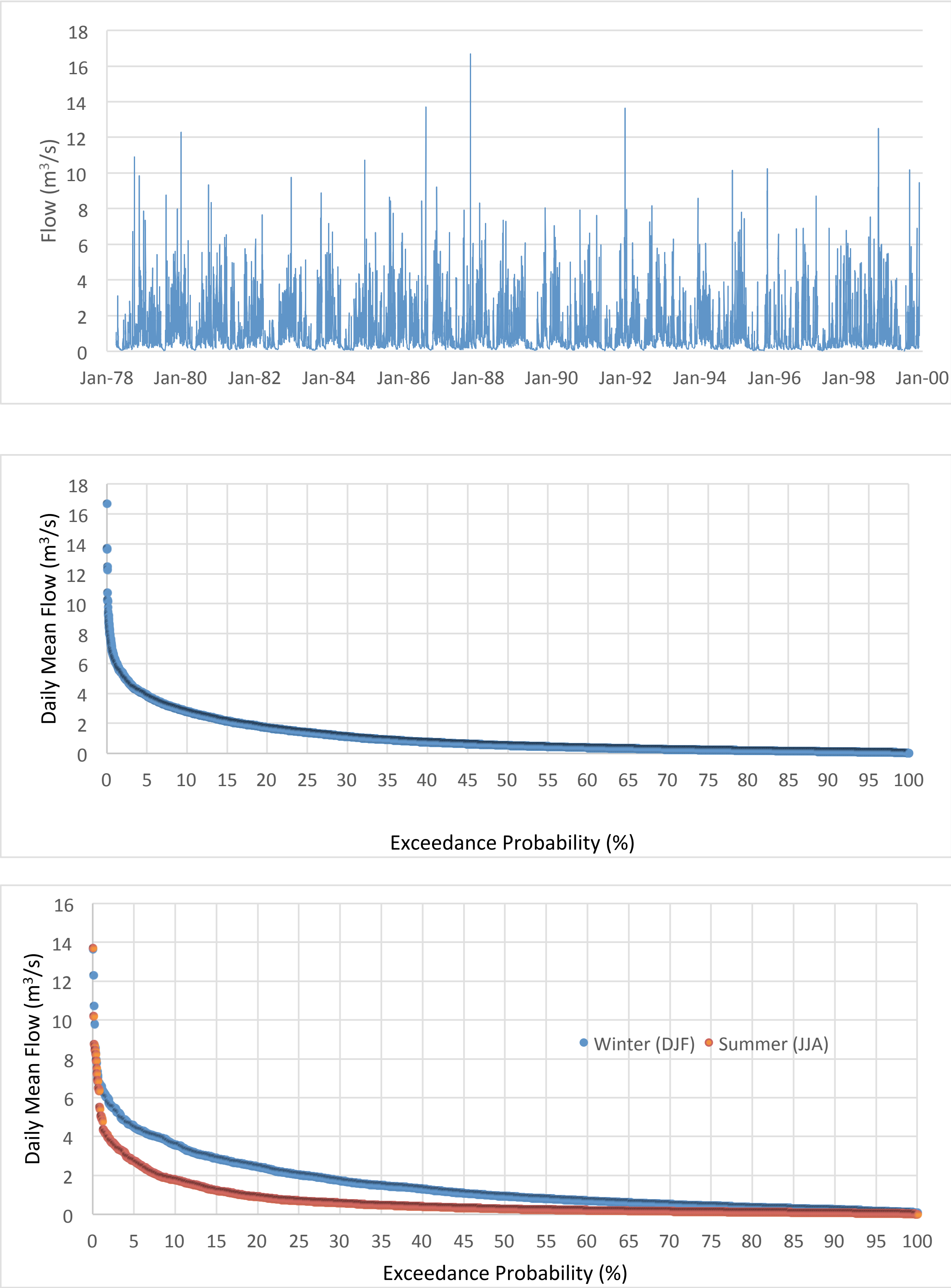
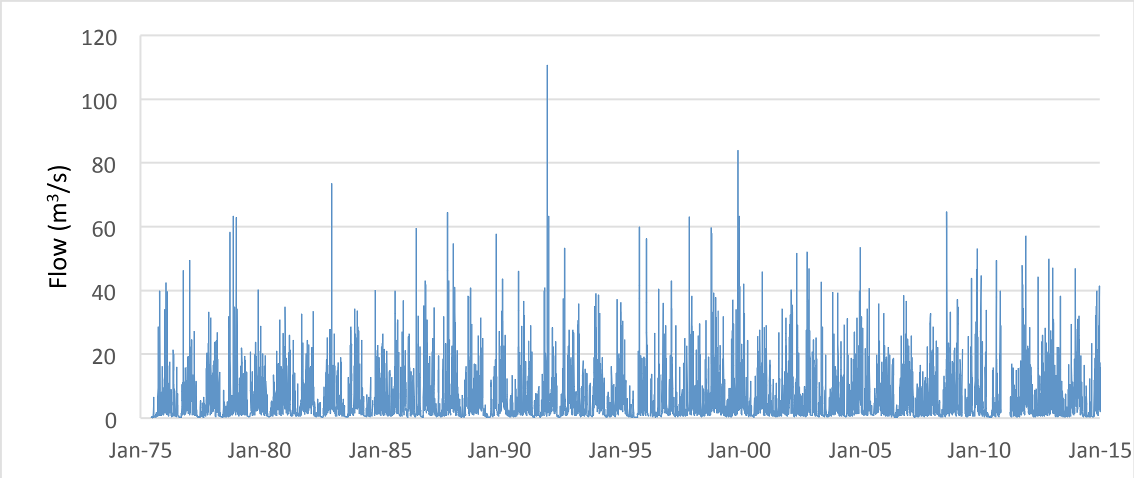
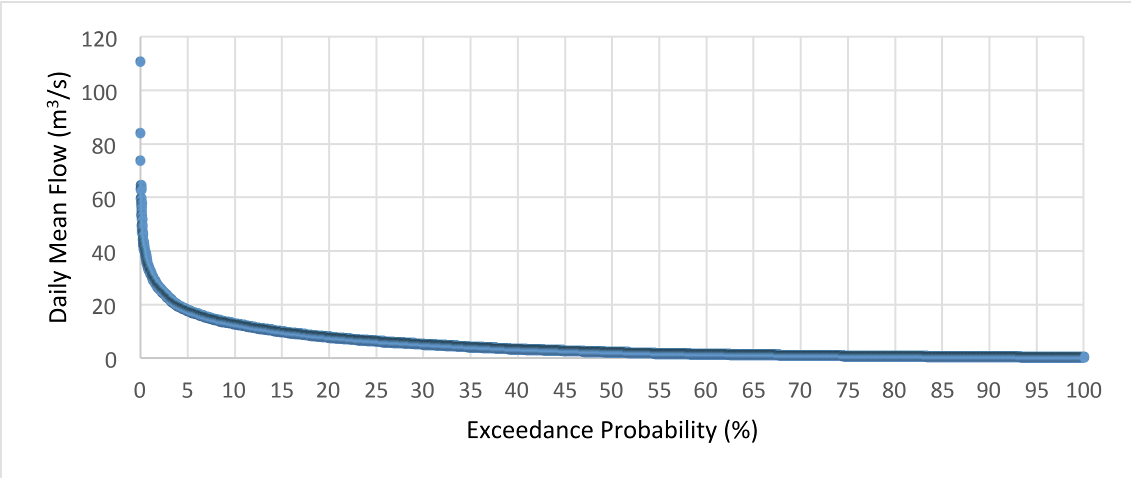


Figure 3.8. Hydrograph and flow duration curves – Kiltybardan.





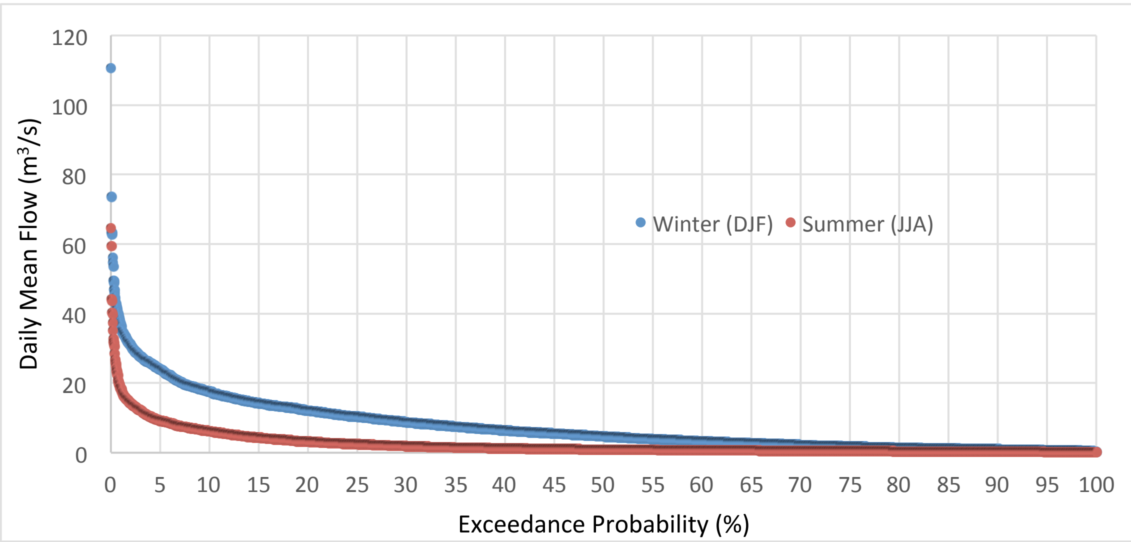


Figure 3.9. Hydrograph and flow duration curves – Dowra.

These gauging stations are highlighted because they illustrate different hydrological responses to rainfall and flow in the NCB study area:

- Glenaniff – this is a quick response catchment in which the steeper slope section of the FDC reflects surface runoff and near-surface pathways of water movement, and the flatter low-flow section of the curve represents inferred groundwater contributions to the measured stream flow. The latter are sustained, but the contributions are volumetrically small (per unit area of discharge to the stream) compared to the shorter-duration peak runoff contributions during rainfall events.
- Bellaheady – this is also a quick response catchment, but the hydrograph shows a distinct seasonality with sustained higher flows in the winter months, which indicates that water is stored. The gauging station is situated on the Woodford River (see station 35054 in *Figure 3.4*) and is likely influenced by the regulating mechanism of the Shannon-Erne Waterway. The significant difference between summer and winter flows is reflected in the seasonally separated FDC
- Kiltybardan – this is another quick response catchment, but compared to other hydrographs, the hydrograph recessions are equally steep and quick *between* individual rainfall events, reflecting rapid runoff and a very small volumetric baseflow component. The hydrograph response is explained by the steep-sided nature and low-permeability of the bedrock within the catchment, which enhances runoff via overland pathways.
- Dowra – this gauge displays a similar behaviour to Kiltybardan, but the flashy response at Dowra may also partly be influenced by flow contribution from 'Shannon Pot', a karst spring which discharges from the underlying Dartry Limestone aquifer at the top of the gauged catchment. The hydraulic behaviour of the Shannon Pot spring is poorly quantified, and its overall influence on the gauge is uncertain. The spring has been recommended for further study in the recommended baseline monitoring programme of the UGEE JRP (CDMS, 2015b).

The implication is that rainfall runoff coefficients are high and groundwater baseflow contributions are, on the whole, small, even if the latter are important in maintaining baseflow during prolonged dry weather conditions. This characteristic is typical of 'poorly productive bedrock' settings which are present across most of the NCB study area (CDMS, 2015b), and which are described further below.

Streams that originate as large karst springs in the Cuilcagh Mountains (e.g. at Marble Arch caves) are relatively poorly quantified in terms of their hydrological responses, end-member flows, and discharge characteristics. The nearest gauging station in a karst catchment is Tilery Bridge downstream of Lower Lough Macnean. As shown in *Figure 3.10***,** the hydrograph and flow duration curve shows influence of storage, and is located downstream from Lower Lough Macnean, which acts as the natural storage regulating mechanism for discharges from contributing catchments.

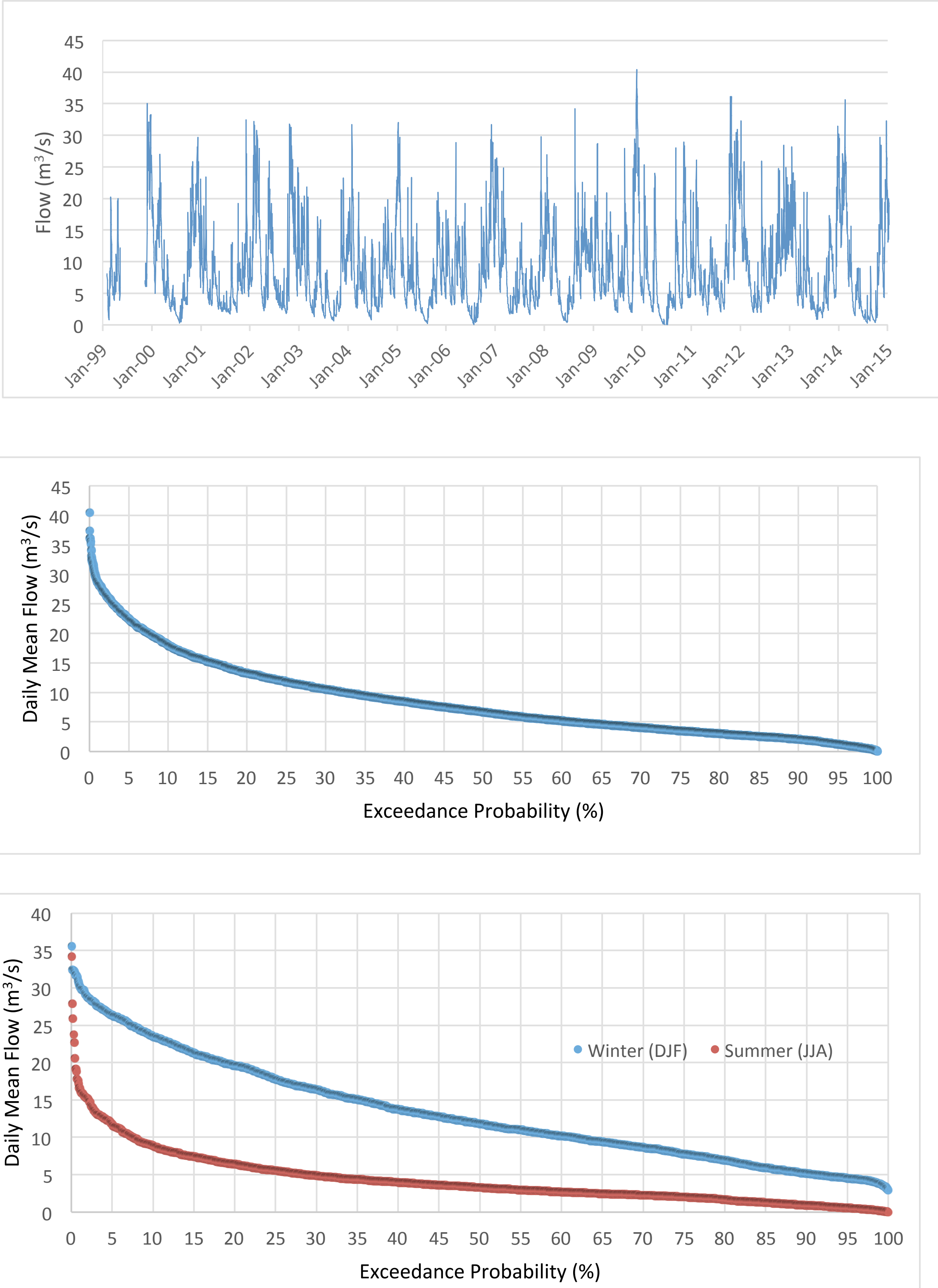


Figure 3.10. Hydrograph and flow duration curves – Tilery Bridge.

The hydrological behaviour of the large karst springs in the Cuilcagh Mountains is not well quantified or documented, and spring discharge monitoring was recommended for the intended baseline monitoring programme under the UGEE JRP (CDMS, 2015c).

3.4 Groundwater

The available groundwater resources of the NCB study area are primarily represented by bedrock aquifers (CDMS, 2015b). Alluvial sediments are present along stream courses, and mapped sand and gravel bodies are also present, but these are of limited spatial extent.

All bedrock aquifers are sourced for public or private water supply (see Section 5.3) and all aquifers provide baseflow to streams, lakes and groundwater dependent wetlands (CDMS, 2015b,c). Groundwater in bedrock aquifers flows via fractures and fissures. Storage is limited and the water-transmissive capacities of the various bedrock aquifers vary according to the geometry and degree of connectivity of open fracture networks. Certain limestone formations are also karstified, whereby groundwater flows preferentially through open solution conduits. The extensively karstified Dartry Limestone Formation (and its chronostratigraphic equivalent formations) is considered to be the principal aquifer and groundwater resource in the NCB study area (CDMS, 2015b).

All bedrock formations are by definition aquifers, but some are of greater hydrogeological significance, or 'value', than others, and this is recognised by the aquifer classification schemes of the GSI (DELG/EPA/GSI, 1999) and GSNI (Ball *et al.*, 2005). The majority of the bedrock formations in the NCB study area are mapped as 'poorly productive' by the GSI and GSNI. The related aquifer type designations are slightly different in the ROI and NI, and for the purposes of this report, the terms 'poorly productive aquifers' (PPAs) is used.

In the NCB, PPAs are represented by shale, sandstone and mudstone formations, as well as argillaceous limestones and volcanic rocks (CDMS, 2015b). They have low storage and low-permeability characteristics, and tend to be associated with small, localised groundwater flow systems (GSI, 2006). Accordingly, boreholes drilled in PPAs tend to result in low yields, except in fault zones where the probability of enhanced fracturing and permeability can increase the transmissive capacities of the same rocks.

Although the groundwater flux through bedrock aquifers can be small, especially in PPAs, the baseflow components they provide to surface water bodies (e.g. streams) are important for aquatic biota, especially during prolonged dry weather events. Groundwater baseflow to streams may account for 100% of stream flows in such periods (e.g. drought of the summer in 2010), but only represent a very small percentage during peak flow conditions (Misstear *et al*, 2009; O'Brien *et al*, 2013). Actual contributions depend on catchment-specific characteristics, pathways and flow systems. This is supported by recharge and hydrograph separation studies, using rainfall-runoff modelling techniques, which were carried out in support of WFD implementation projects in the ROI and NI (e.g. GWG, 2005; RPS, 2008).

Besides the hydraulic properties of bedrock formations, groundwater availability is also a function of:

- Depth, e.g. whether formations store and/or transmit groundwater at depth and whether boreholes can be drilled within limits of technical feasibility and reasonable cost;
- Recharge from rainfall, i.e. the extent to which groundwater is replenished; and
- Groundwater quality, i.e. whether the formation waters can be naturally exploited without extensive treatment.

As documented in Interim Report A1-2 (CDMS, 2015b), the primary aquifers become deeply buried towards the central parts of the UGEE licence area, within the 'Lough Allen Basin; subdivision of the NCB. Accordingly the aquifers become increasingly inaccessible for water supply purposes. Certain formations are also known to store (and possibly transmit) variably saline formation waters at depth (CDMS, 2015b), which implies that the 'resource value' is diminished with depth.

Bedrock aquifers are recharged by the proportion of rainwater that infiltrates into the groundwater environment. The principal factors that control recharge to an aquifer are effective rainfall (the available recharge), the nature and thickness of overlying soils and subsoils, slope and land use. The nature of bedrock is also important, and sections of bedrock aquifers with a greater storage and transmissive capacities have greater capacity to receive and accept the available recharge than sections of bedrock that are impermeable. These characteristics are summarised by Misstear and Fitzsimons (2007), Misstear *et al.* (2009) and are represented in the updated national recharge map which is prepared and published by the GSI for the ROI using existing hydrogeological and meteorological spatial datasets (Hunter-Williams *et al.*, 2013). Reproduced in *Figure 3.11*, the estimated long-term average recharge rates in the NCB study area range from <50 to approximately 900 mm/yr. The lower values apply to areas covered by peat and thick low-permeability subsoils. The higher values apply to areas where subsoils are thin or absent and where the underlying bedrock is mapped by the GSI as regionally important and productive (mostly karstified limestones in the NCB).

The ability of an aquifer to accept all of the recharge is a function of its hydraulic properties. For example, low storage and transmissive characteristics limit the amount of recharge that can be accommodated in the available bedrock volume. Thus, a portion of the available recharge is 'rejected'. In PPAs especially, this is most often translated to enhanced surface runoff and water movement along shallow pathways, including the 'transition zone' (GSI, 2003; Moe *et al.*, 2010) and transport to and via field drains to streams (Deakin, 2014). Accordingly, recharge 'caps' have been proposed and are typically considered for different types of PPAs (Hunter-Williams et al., 2013).

A similar recharge map has not been produced for the section of the NCB that is within NI, but the same principles apply – higher recharge rates are expected where infiltration potential is greater and bedrock aquifer can accept the available recharge.

Constraints that apply to the national recharge map in the ROI are:

- The map is intended as a guide for water balance estimation purposes at the groundwater body scale (i.e. catchment or sub-regional scale);

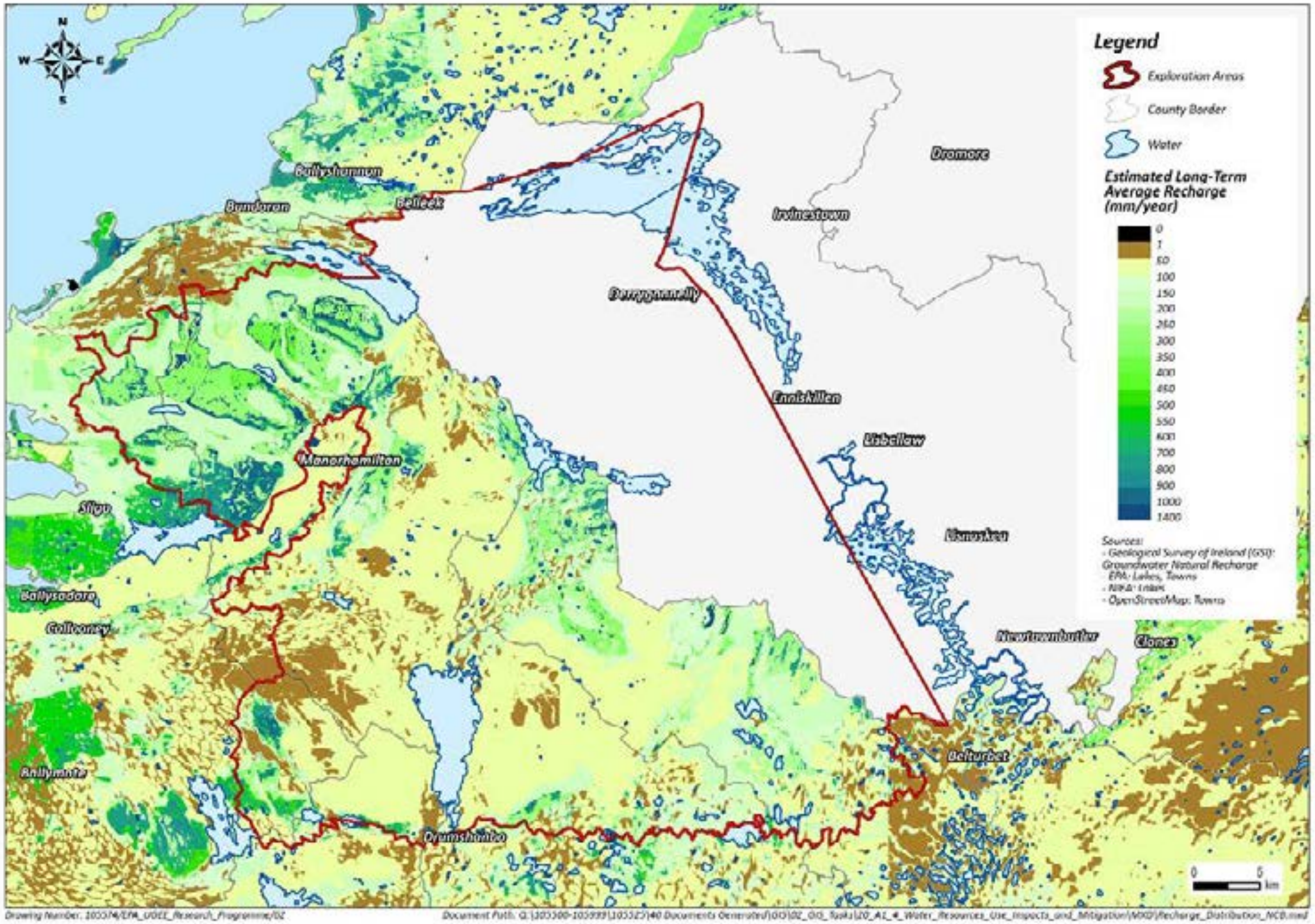


Figure 3.11. Estimated recharge distribution – NCB study area in the ROI.

- Local-scale differences should be expected, as determined by local-scale features and characteristics which cannot not be captured by the scale of spatial datasets used in the recharge estimation methodology (e.g. local subsoil thickness or permeability variations, presence of point recharge sources such as dolines in karstified limestones);
- The map represents long-term average recharge, and does not document seasonal variability (e.g. summer/winter); and
- Recharge values are not fixed. Lowering of water levels frees up 'space' for additional recharge if this is available.

With regard to bedrock hydraulic properties, the available 'space' for water storage and movement in fractured bedrock aquifers is limited to that offered by open fracture networks and primary or secondary porosities of sedimentary rocks. In the context of the hydrogeology of the NCB study area, values of 1-2% of the total formation volume are frequently cited, as indicated by aquifer test results and hydrographs from individual wells (Hunter Williams and Lee, 2011). Water level fluctuations in bedrock aquifers with low storage properties can be several metres over seasons, also displaying rapid responses to rainfall. Water level fluctuations in aquifers with more favorable characteristics as groundwater resources tend to be more subdued over time.

The transmissive capacity (transmissivity, T) of an aquifer is a function of its thickness and fracture permeability (hydraulic conductivity, K), which is a measure of the ease with which water can be transmitted. Based on aquifer testing, published values of T can range over several orders of magnitude, depending on the degree and extent of fracturing in a given aquifer *at any given location*. Bedrock aquifers are heterogeneous in three dimensions, and there is no means of predicting storage or transmissivity characteristics with certainty. The probability of intersecting water-bearing fracture networks and achieving higher well yields tends to increase near geological fault zones in limestone and sandstone formations, where the brittle nature of the rocks and structural deformation combine to increase the probability of enhancing fracturing and fracture permeability.

3.4.1 Springs

There are hundreds of springs present in the NCB study area, of which only a fraction are likely represented in available maps. They are an important source of water for both public and private regulated water supplies. Springs are groundwater discharge points which also give rise to stream flow throughout the study area. Accordingly, they play an important role in providing baseflow to surface water bodies and supporting conditions for groundwater-dependent ecosystems.

Springs are present everywhere and emerge from all bedrock types. They are both stratigraphically and structurally controlled. Despite their hydrogeological and ecological significance (CDMS, 2015b,c), spring discharge records are sparse to non-existent. Only one spring at Manorhamilton in the NCB is equipped for automatic discharge measurement. The general lack of spring discharge data represents a significant data gap, particularly where springs are used for water supply and where large springs discharge from karstified limestone aquifers. Discharges from the latter can be on the order of several hundred l/s (CDMS, 2015c).

4 Available Water Resources in the CB Study Area

The available water resources of the CB study area are defined primarily by small streams and groundwater, as described below. The main physiographical, geological and hydrogeological characteristics of the CB study area were described in detail in Interim Report A1-2 (CDMS, 2015b), and key descriptors are referenced as appropriate in the following sections.

4.1 Rainfall/Meteorology

The estimated 30-year annual average rainfall for the period 1981-2010 (Met Éireann, 2015) is shown in *Figure 4.1*, and ranges from 800 to 1400 mm/yr across the study area. Rainfall amounts increase with elevation and Slievecallan, 390 mOD to the northeast of the UGEE licence area, receives up to 2000 mm annually.

Rainfall in the winter months is generally 300 to 400 mm/yr with a small section on the eastern side of the study area receiving between 400 and 500 mm/yr. A similar trend is observed for the summer months with rainfall between 200 and 300 mm/yr increasing to between 300 and 400 mm/yr in upland areas.

The estimated 30-year monthly potential evapotranspiration (PE) rate at Shannon Airport (located approximately 24 kms east of the UGEE licence area) ranges between approximately 13 mm/month in December and 87 mm/month in June, as shown in *Figure 4.2*. The mean monthly rainfall in the same period ranged between 59.2 mm/month to 104.9 mm/month.

4.2 Lakes

Lakes are absent in the UGEE licence area. However, Doo Lough is located just east of and near the licence area and serves as the main source of public water supply for western Co. Clare. Water levels in Doo Lough are regulated (impounded), and the average daily abstraction of approximately 11,500 m^3/d is below its reported 'yield' (i.e. capacity) of approximately 48,400 m^3/d for its design storage (Bowman *et al.*, 1983).

Two smaller natural lakes, Lough Namina and Lough Acrow, are also located near but outside the UGEE licence area to the east, supplying the Inagh-Kilmaly and Lissacasey group water schemes (GWS), respectively (CDMS, 2015b).

4.3 Streams/Rivers

Several small streams flow west and south to the sea and Shannon Estuary from the upland areas in the east. On Loop Head peninsula, several localised catchments drain directly to the sea over short distances.

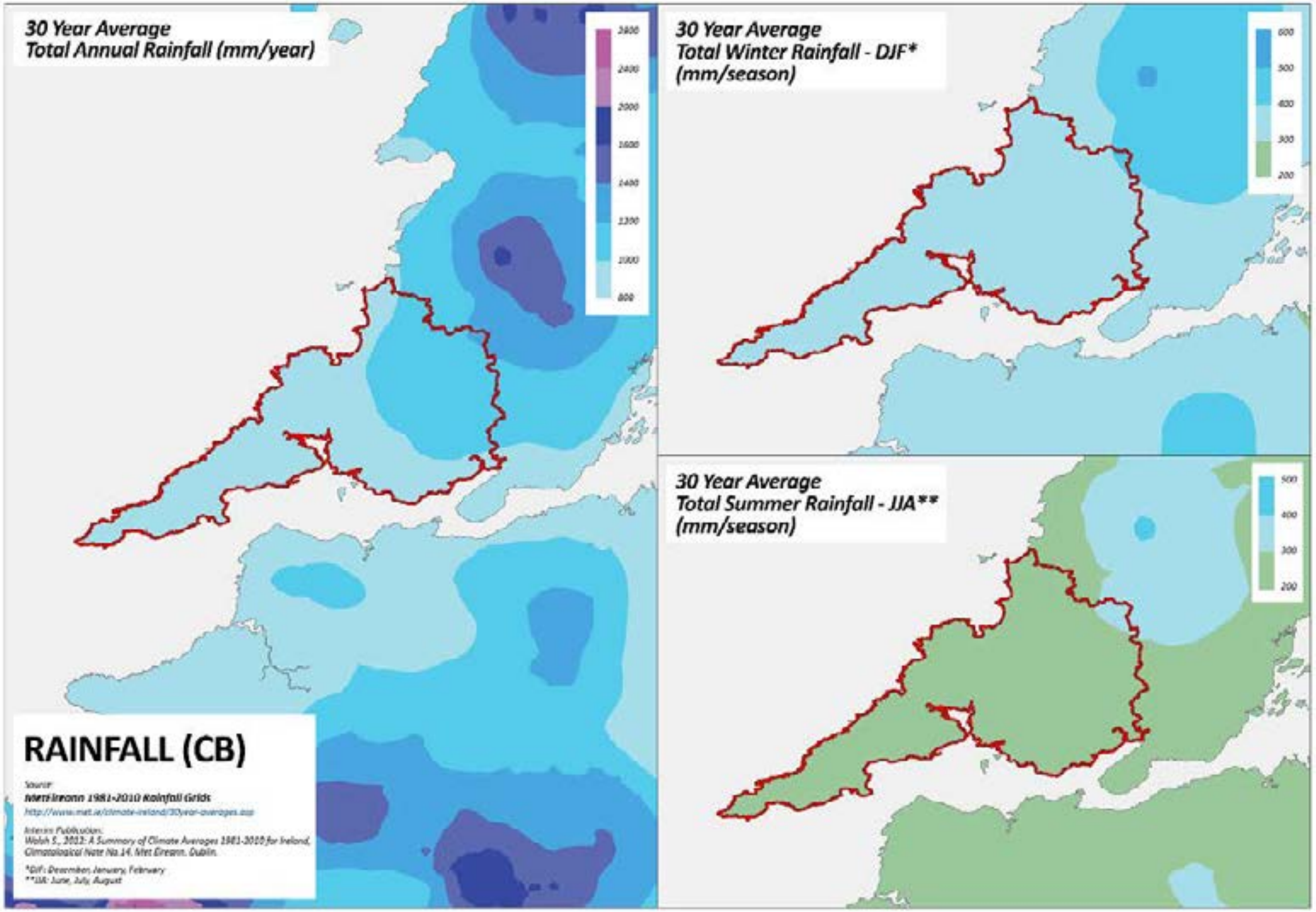


Figure 4.1. Average annual rainfall distribution (1981–2010) – CB study area.

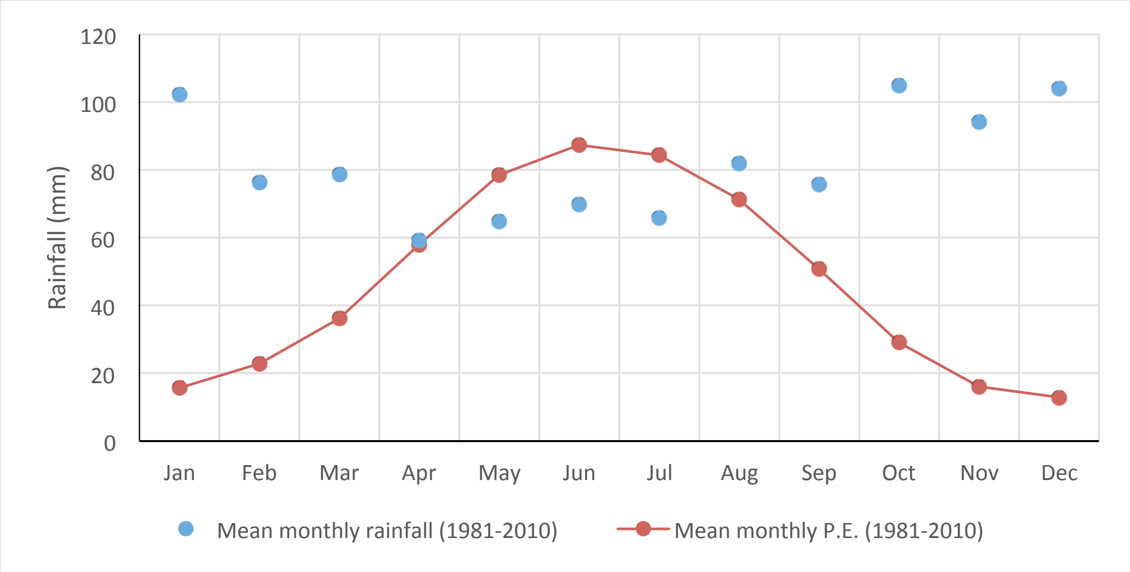


Figure 4.2. Mean monthly rainfall and P.E., Shannon Airport (1981–2010).

There is only one active gauging station, on the Doonbeg River. Operated by the OPW, the derived mean and Q_{95}-flows for this station are 3.04 and 0.17 m^3/s, respectively. However, the mean flows may be underestimated as peak flows are historically truncated (pre-2012), as indicated by its hydrograph and flow duration curve in Figure 4.3**.** Nonetheless, the hydrograph demonstrates a similar quick-response to rainfall as the catchments in the NCB study area.

Because the other catchments in the CB study area share similar physical and geological characteristics as the Doonbeg catchment, the Doonbeg gauge can be used as a surrogate for other catchments. As well, estimates of mean and Q_{95}-flow in ungauged catchments were derived using EPA's HydroTool (see *Table 3.2*)**.**

4.4 Groundwater

The available groundwater resources are represented by bedrock aquifers, primarily fractured sandstone units within the main formations in the study area (CDMS, 2015b), which are mapped as PPAs by the GSI. Although there are no public groundwater supplies within the UGEE licence boundaries, the bedrock aquifers provide water to single homes, farms and commercial facilities (e.g. hotels, water bottling plant). Reports of water strikes to 600 m in a gas exploration borehole drilled in the 1960s opens questions about the potential presence of a deeper regional groundwater flow component in the study area (CDMS, 2015b).

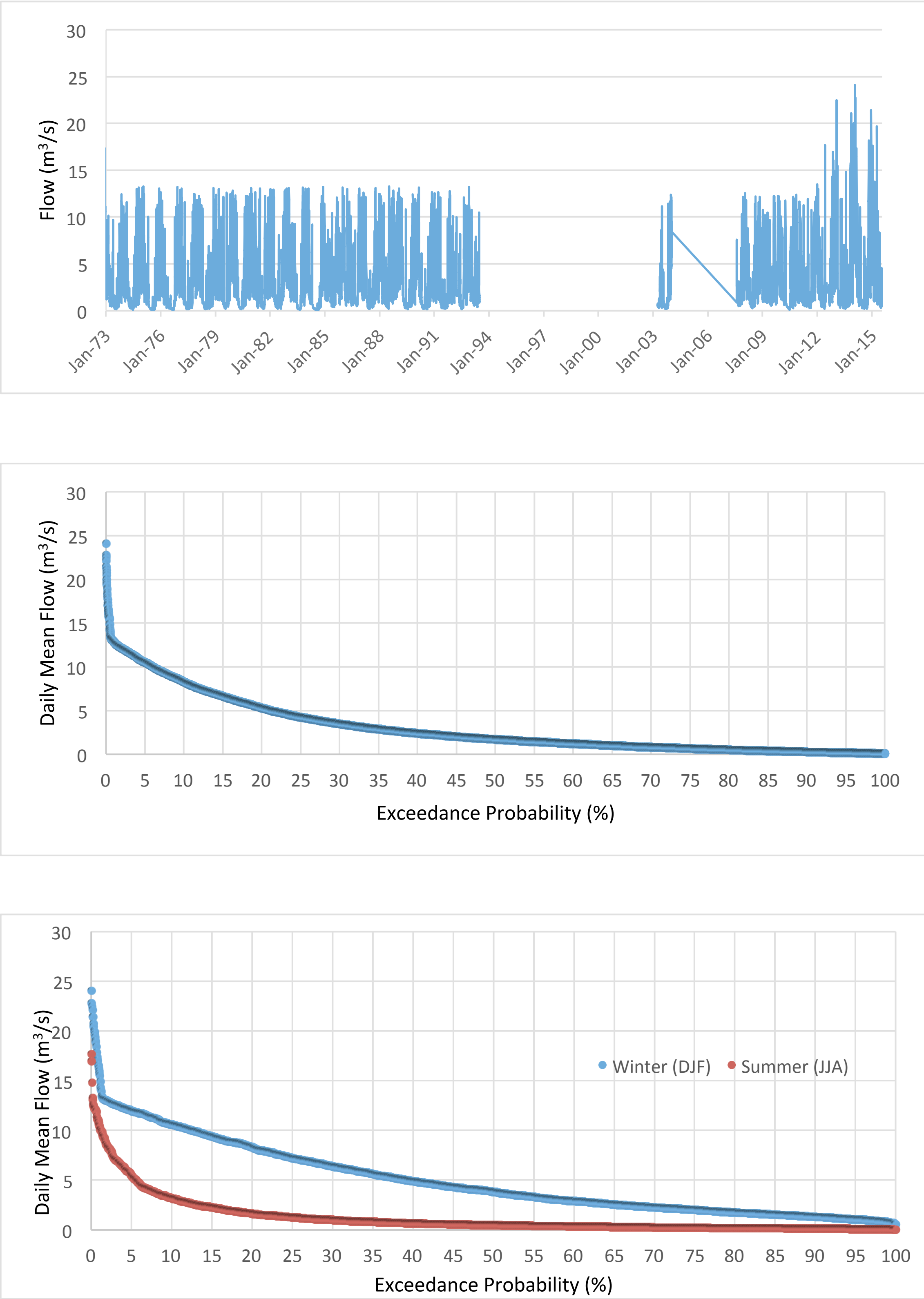


Figure 4.3. Hydrograph and flow duration curves – Doonbeg.

Very little is known about deeper hydrogeological conditions in both the NCB and CB study areas, and should be addressed as part of future UGEE-related planning and licensing, as described in Interim Reports A1-2 and A1-3 (CDMS, 2015b; CDMS, 2015c).

The estimated recharge distribution for the CB study area, based on the national recharge map, is shown in *Figure 4.4*, and range from <50 mm/yr to 150 mm/yr, the upper value representing a recharge cap which is based on the PPA classification, and which is subject to the same influences that were described in Section 3.4.

4.4.1 Springs

There are many small springs throughout the UGEE licence area, but these are small, generally discharging less than 5 l/s, and none are comparable to the significantly larger springs noted in the NCB. They can nonetheless be important in providing baseflow to streams and supporting conditions for groundwater-dependent ecosystems.

Figure 4.4. Estimated recharge distribution – CB study area.

5 Impact Assessment of Abstractions

Impacts from abstractions are described in terms of volumes of water per unit time but also by potential changes to water levels, flows, ecosystems and habitats, and water quality. Key descriptors are discussed below based on existing abstractions in the NCB and CB study areas and the potential UGEE-related water demand scenarios that were defined in Section 2.

5.1 Lakes

Abstraction pressures in lakes are manifested as changes in natural and/or or regulated water level cycles and residence times. Abnormally low water levels during periods of high net abstraction represent a particular risk of impact on the shallow littoral zones which support the main populations of macrophytes and macroinvertebrates (CDM, 2008). Changes from natural conditions, particularly changes in water level regimes, can cause the drying out of biota, increase exposure to wave action, and result in both freezing and changes in light penetration or water temperature. The significance of these effects depends largely on the extent, duration and timing of abstractions, as well as the ability of biota to recover from such changes. Assessing impacts of abstractions is, accordingly, a complex ecologically-based science, requiring the combined inputs from qualified hydrologists and aquatic ecologists on a case-by-case basis.

In the case of severe abstraction impacts, the volumes abstracted can exceed the ability of a lake's catchment to restore the water level to typical seasonal high levels, resulting in a longer-term decline in lake water levels. Based on the water level records obtained for the NCB study area, see *Attachment A*, such long-term declines are not apparent in available datasets, noting that not all of the currently abstracted lakes are monitored. With regard to Lower and Upper Lough Erne, lake levels are managed in the context of the Ballyshannon hydroelectric power scheme, and the temporal variability of water levels is gauged and regulated in context of the ecological significance of the lake system (e.g. as a designated RAMSAR site, Area of Special Scientific Interest, Special Area of Conservation, etc.).

The reporting of the 'ecological status' of lake water bodies for WFD implementation purposes (EPA, 2014 and NIEA, 2014a) does not identify current lake abstractions as a significant environmental pressure. Although several lakes in the NCB are classified as being at 'less than good' ecological status, none of these failed classification tests because of abstraction pressures. The majority of 'less than good' ecological status cases are based on other factors that relate to biological conditions and water quality, as a result of physical modifications (e.g. dredging) or elevated nutrient (phosphorus) loading. This is well documented in the published catchment management plan for Lough Melvin (Campbell and Foy, 2008).

Future risks of impact from UGEE-related lake abstractions under the water demand scenarios described in this report are also considered to be small. Volumetrically, the risks would be greater in 'small lakes' compared to 'large lakes'. Further distinction cannot be made or judged without lake-specific knowledge about ecosystems and related environmental sensitivities, as well as water balance studies that define inflows, outflows, and throughflow (turnover rates). It is noted that a study carried out in 2001 by Donegal County Council to investigate water supply options ruled out additional abstractions from Lough Melvin due to the recreational importance of the lake and its assigned ecological significance as a Special Area of Conservation (Campbell and Foy, 2008).

The importance of understanding water balances of lakes is evident from the data received by NI Water for the Lower and Upper Lough Erne, where the estimated maximum 'capacities' of Lower and

Upper Lough Erne are reported to be 40,856,000 m^3/d and 10,738,000 m^3/d, respectively (NIEA, 2015). The 'capacity' figures are based on estimation methods which are derived from the study of surface areas of 'habitable zones' in each lake, whereby allowable depth changes from abstractions are set to 0.40 and 0.35 m, respectively (NIEA, 2015). The methods account for both natural and induced fluctuations since water levels in both lakes are regulated. The referenced 'capacities' of the lakes are defined as the 'allowable volume changes (m^3/d) due to abstractions for less than 99% of days in a given year'. To be at "good ecological status' in WFD terms, the reference surface area (habitable zone) of the lakes must be maintained within 5% of natural conditions for 99% of the time (362 days per year) (NIEA, 2015).

The daily maximum water demand of 5000 m^3/d considered for a single well in Section 2.2 represents a negligible volumetric fraction of the above reported capacities, indicating a negligible risk of impact. However, the scenario of concurrent operations at multiple sites would change the reference point on potential impacts to lakes, and risks would be greater in small lakes. Accordingly, all future proposed UGEE-related abstractions would have to be carried out individually with the involvement of relevant stakeholders and regulatory bodies, as each lake is different and risks of impact are case-specific.

5.2 Streams/Rivers

The quick, flashy nature of stream hydrographs, as well as the flat slope of the low-flow sections of available flow duration curves, imply that the majority of streams are sensitive to stream abstractions. Impacts would be measured by the resulting changes to ecological conditions, including the stream biota, hydromorphology, and water quality (CDM, 2008). This is recognised by the UKTAG-derived methods which are applied by both the EPA and NIEA in classifying the ecological status of surface waters for WFD reporting purposes. In both the ROI and NI, the methods examine departures from reference conditions with regard to macroinvertebrates, hydromorphology and physico-chemical quality:

- Macroinvertebrates are biological indicators which are measured by counts, distributions and quality of colonies. These are judged by 'Q-scores' in the ROI and the 'Biological Monitoring Working Party (BMWP) biotic score system' in NI.
- Hydromorphological characteristics are described from field observation and survey, notably: channel morphology and flow types, channel vegetation, substrate diversity and condition, barriers to flow continuity (e.g. dams), bank structure and stability, bank and bank top vegetation, riparian land cover and floodplain interaction.
- Physico-chemical conditions are described by results of field and laboratory analysis of water samples.

As reported by the EPA (2014) and NIEA (2014a), several streams in both case study areas have been classified as being at 'less than good ecological status' in WFD reporting terms, but none failed WFD status objectives on the basis of abstraction pressures alone. The majority of streams which failed 'good ecological status' objectives did so on the basis of biological elements or indicators, in particular the quality of macroinvertebrate colonies. In many cases, the precise cause for the failed status objectives are not certain and subject to further study. Although abstractions may influence the ecological conditions in the related water bodies, it is not considered by the EPA and NIEA to be a single, direct cause of failed status objectives.

Using gauged or estimated flow data and hydrological pressure information (notably abstractions and effluent discharge data from existing licences and knowledge of impoundments), the NIEA also assign a status to the 'hydrological regimes' of rivers and streams in NI. The status is reviewed in the context of deviations of water levels or flows that occur from natural reference conditions according to standards that are tabulated in:

- The Water Framework Directive (Priority Substances and Classification) Regulations (Northern Ireland) 2011 – commencing 21 January 2011; and
- The Water Framework Directive (Priority Substances and Classification) (Amendment) Regulations (Northern Ireland) 2015 – commencing 10 February 2015.

In 2014, the 'hydrological regimes' within the NCB study area were mostly classified as either 'high' or 'good'. Streams or sections of streams where hydrological regimes were identified as requiring further study /assessment include:

- Lough Melvin and Arney Local Management Area (NIEA, 2014b): Lower Lough Macnean, Drunharrif Burn, Screenagh, Sillees;
- Lower Lough Erne Local Management Area (NIEA, 2014c): Ballinamallard, Ballycassidy, Lisnarick, Kesh, Glendurragh; and
- Upper Lough Erne Local Management Area (NIEA, 2014d): Newtownbutler, Swanlinbar (upper), Erne, Finn, Starraghen.

For cross-border water bodies, the status assignments have been jointly agreed by the EPA and NIEA. Heavily Modified Water Bodies (HMWBs) are subject to the environmental objectives of 'ecological potential' rather than status. In both jurisdictions, the assignment of ecological potential have been made based on UKTAG guidance methods, considering each HMWB on an individual basis. In an abstractions licensing context, HMWBs are considered in the same manner as any other water body (i.e. case by case basis).

Similar to lakes, the identification of potential abstraction impacts on streams requires survey work and the combined and coordinated assessment by suitably qualified hydrologists and aquatic ecologists. Without detailed study, only cursory or screening-level assessments can be carried out, based on volumetric considerations and/or published reports or records of catchments and their ecological characteristics (e.g. SAC synopsis reports of the National Parks and Wildlife Service (NPWS).

In this context, the Q_{95} flow is often cited as a 'critical' baseline characteristic which is used to identify potentially problematic abstractions. In NI, the concept of environmental flows for rivers (originally described by Acreman *et al*, 2006) have been adopted as standards in regulations in Statutory Rule No. 45 of 2015 (DOENI, 2015). In these regulations, permissible abstractions from rivers are judged by river 'size', where the relevant metric is a natural mean daily flow which exceeds a flow statistic (e.g. the Q_{95} flow), and river 'type' (i.e. its typology, which are also defined in the regulations by combinations of catchment areas, baseflow indices, and average annual rainfall over the catchment areas). Specifically, the permissible abstraction is defined as a percentage of the natural daily mean flow which exceeds a specified flow metric, for different river types. Accordingly, permissible abstractions can be judged by and take into consideration variable flow conditions (i.e. seasonality) and environmental sensitivity. As such, the environmental flow concept is risk-based (*i.e.* higher risks during low-flow periods).

This concept is further illustrated by *Tables 5.1 and 5.2*, which are reproduced from the 2015 regulations for categories of 'high' and 'good' environmental standards for river flows, respectively. Using *Table 5.2* for descriptive purposes, the permissible abstraction for a river type A1 when the natural mean daily flow exceeds the Q_{95} is 25% of the natural mean daily flow. The corresponding percentages decrease for smaller streams and increase for larger stream flow exceeding a specified larger flow metric (e.g. Q_{60} vs Q_{95})

Accordingly, environmental flows and permissible abstractions are risk-based and can be adjusted for flow conditions, thus accounting for seasonality and environmental sensitivity (i.e. higher risks apply during low-flow conditions, and vice versa). For this reason, the assessment of permissible abstractions requires knowledge of the natural flow characteristics of the river or stream, by way of flow duration curves, which can be derived from one or both of measured (gauged) data and/or modelling techniques.

In combination with other elements of river ecology (e.g. biological indicators, water quality, and hydromorphology), the environmental standard designations for river flows described above are used by the NIEA to classify the ecological status of rivers for WFD reporting purposes.

Table 5.1. Environmental standards for river flows for the 'High" category

Permitted abstraction per day as a percentage of the natural mean daily flow(Q)[(1)]		
High		
Column 1	Column 2	Column 3
	Maximum permitted % abstraction at Q exceeding Q_{95}[(2)]	Maximum permitted % abstraction at Q **not** exceeding Q_{95}
A1, A2 (downstream), A2 (headwaters), B1, B2, C2, D2	10	5

(1) 'Q' is the mean daily flow for a specified period of time

(2) 'Qx' is the Q that is expected to be exceeded by 'x' percent for a specified period of time

Source: DOENI.

Table 5.2. Environmental standards for river flows for the 'Good' category

Permitted abstraction per day as a percentage of the natural mean daily flow(Q)				
Good				
Column 1	Column 2	Column 3	Column 4	Column 5
River type	Maximum % abstraction at Q exceeding Q_{60}	Maximum % abstraction at Q exceeding Q_{70}	Maximum % abstraction at Q exceeding Q_{95}	Maximum % abstraction at Q **not** exceeding Q_{95}
A1	35	30	25	20
A2 (downstream), B1, B2	30	25	20	15
A2 (headwaters), C2, D2	25	20	15	10

Source: DOENI.

In the context of UGEE-related abstractions, the temporal aspect of stream flow behaviour is a particularly important variable to be considered:

- The demands for water for hydraulic fracturing programmes, as described in Section 2.2, are of limited duration, measured in days. Thus, the risk of impact from abstractions at any given location are influenced by the timing of the demands against the actual stream flow conditions;
- In both case study areas, the majority of streams are flashy, with quick hydrograph responses to rainfall and quick recessions to baseflow conditions. Thus, potential future abstraction schemes would have to be assessed against the actual hydraulic response to rainfall in any given catchment; and

- The Q_{95} flow is a useful low-flow metric which can be used to screen or flag potentially problematic abstractions.

For these reasons, prior authorisations of UGEE-related abstractions would have to be reviewed in context of catchment hydrological conditions, on a case by case basis. The review should be based on the principles of environmental flows, i.e. factoring in the reference conditions of water level- and flow-dependent ecosystems and habitats.

For purposes of this report, and as a screening exercise, the daily maximum water demand for a single hydraulic fracturing programme of 5000 m^3/d (see Section 2.2) was compared to the estimated Q_{95} flows in *Table 3.2.* The demand, alternatively expressed as 0.058 m^3/s, exceeds the minimum estimated Q_{95} flows of 0.02 m^3/s and 0.01 m^3/s for subcatchments in the NCB and CB licence areas, respectively. Accordingly, certain streams would likely not be able support the demand based on the estimated Q_{95}. Spatial representations to illustrate the same point are provided in *Figures 5.1* and *5.2* for the NCB and CB study areas, respectively. In both examples, several catchments would not be expected to be able to supply the demand under low-flow conditions, thus flagging potential risk of impact to stream biota and associated ecosystems, and warranting further detailed study.

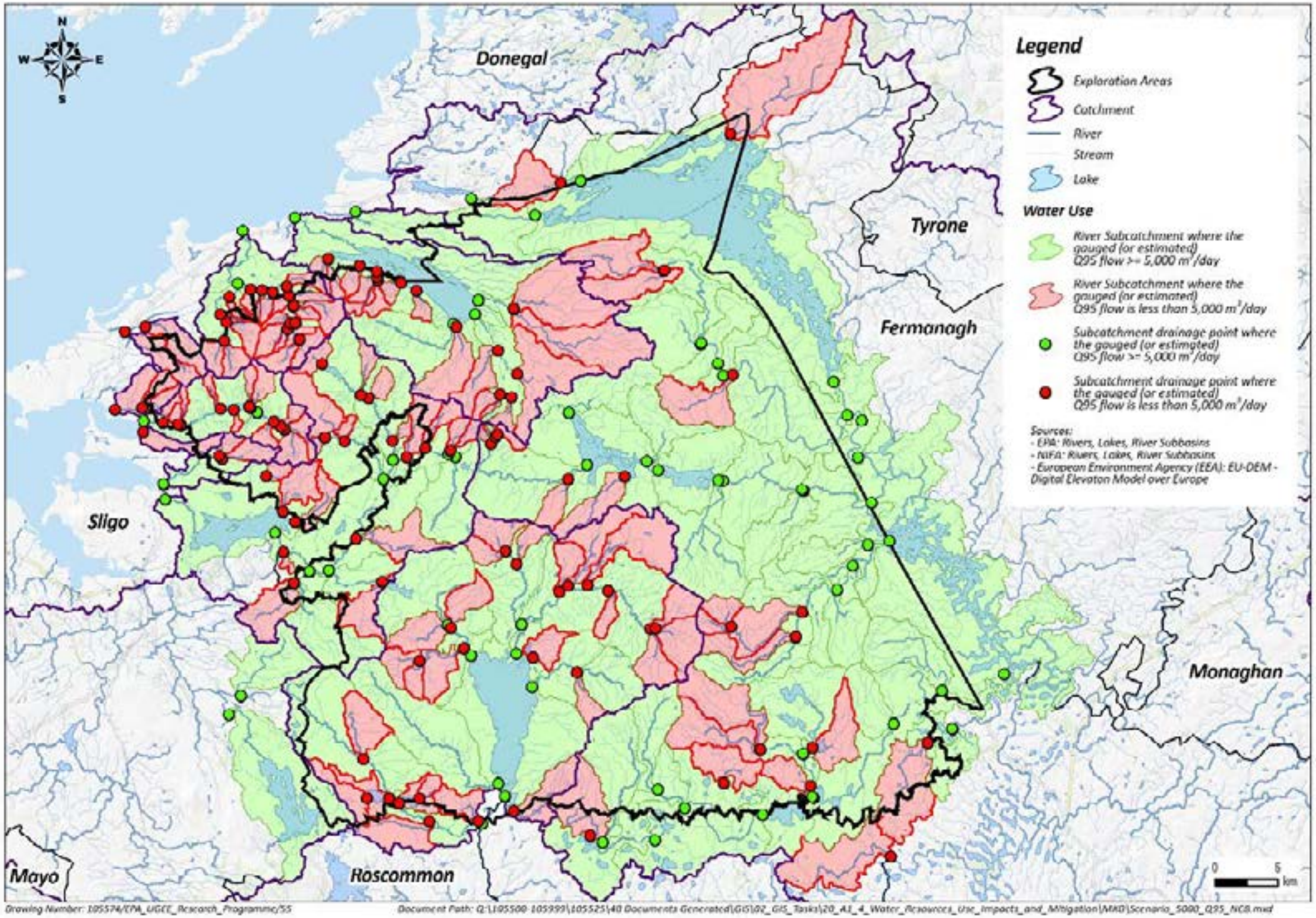


Figure 5.1. Comparison of daily water demand of 5000 m^3/d and estimated Q_{95} flows – NCB study area.

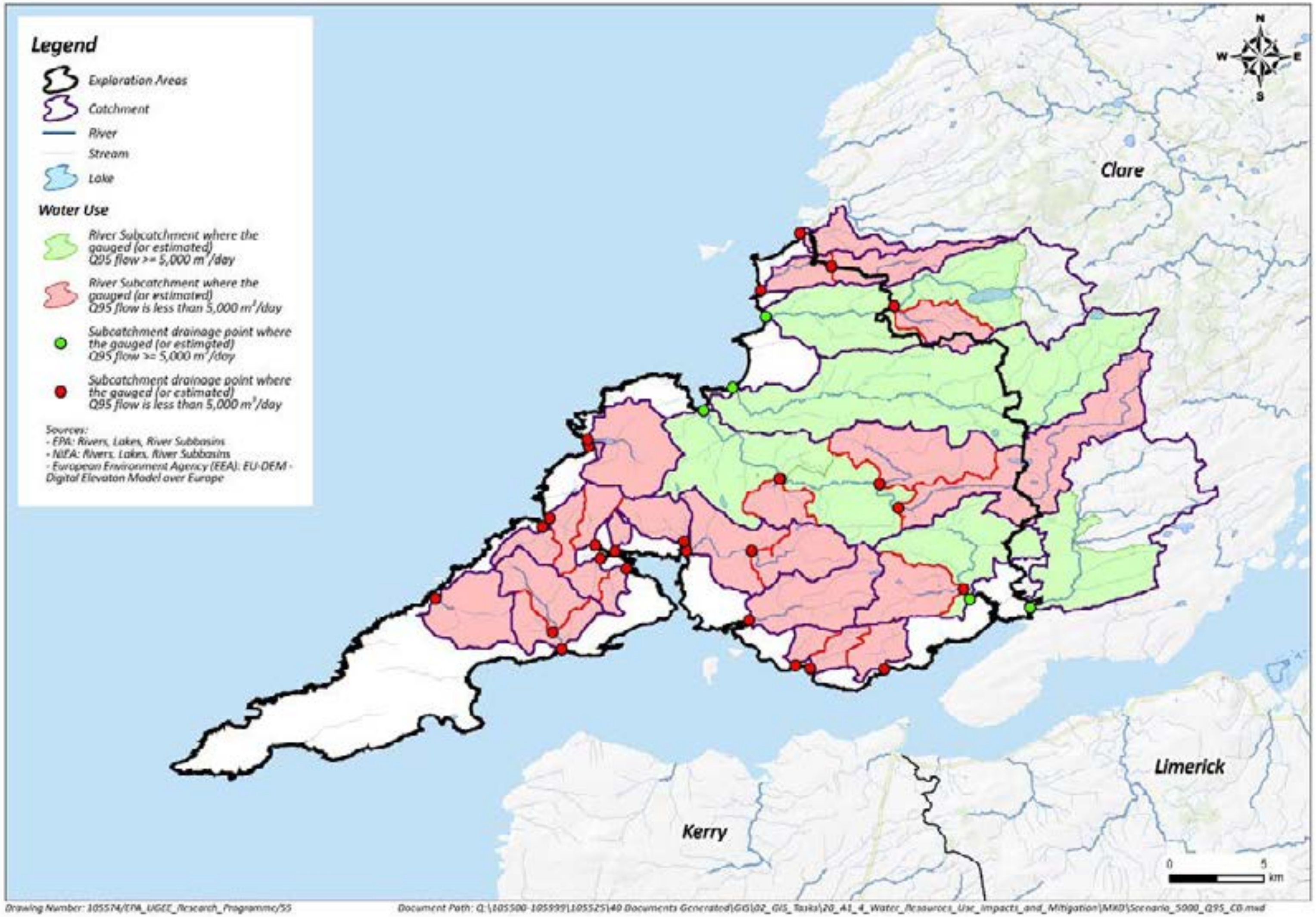


Figure 5.2. Comparison of daily water demand of 5000 m^3/d and estimated Q_{95} flows – CB study area.

In any future UGEE-related abstraction case, environmental flows would have to be established, based on case- and stream-specific circumstances, taking account of reference conditions of associated ecosystems. In any given case and circumstance, opportunities should also be sought to mitigate potential impacts of abstractions by:

- Reducing demands (e.g. re-cycling of flow-back waters);
- Spreading abstractions to multiple different sources of water;
- Directing abstractions towards lower sections of catchments (higher-order streams);
- Avoiding abstractions from ecologically sensitive catchments and streams; and
- Timing operations such as to avoid overlap between maximum demand periods and low-flow conditions.

Few streams in the NCB and no streams in the CB study areas are presently abstracted for public and private water supplies. As documented in *Table 5.3*, the single largest relevant abstraction from a stream is 12,000 m^3/d from the River Shannon, which supplies the South Leitrim Regional Water Supply Scheme. The abstraction is outside and downstream of the UGEE licence area in the NCB, but is considered relevant to the study area because Lough Allen, which is within the licence area, is regulated to maintain flow in the River Shannon. The daily mean discharge from Lough Allen is 14.4 m^3/s (Jacobs, 2012).

Table 5.3 illustrates the importance of deriving accurate flow estimates for streams. The abstraction from the North Sligo PWS is reportedly 1850 m^3/d distributed over two abstraction points on two separate streams. The distribution of abstraction between the two sources is not known, but assuming a 50-50 distribution, the abstraction rates exceed the estimated Q_{95} for the respective streams. This simple comparison highlights that the streams may at risk from over abstraction, notably during low-flow conditions, and further checks on actual flow conditions and related ecology would be recommended. In the case of North Sligo PWS, abstractions are repositioned downstream to the larger Grange River during low-flow conditions (EPA, 2013).

There are additional abstractions from streams in the NCB study area where the abstraction point is located immediately downstream of springs. Such abstractions can technically be considered as groundwater abstractions, but they are located at the headwaters of streams and, as such, reduce flows in streams. Spring discharges support baseflow to streams and related ecosystems further downstream in the same catchments, thus abstractions from headwaters require a larger geographical focus beyond the headwater location.

Table 5.3. Abstractions from streams – NCB study area

Supply Name	Supply type	Stream Name	Net Abstraction (m^3/d)	Q_{95} Flow [a] (m^3/d)	Mean Flow [a] (m^3/d)	Abstraction/ Q_{95} Flow %	Abstraction/ Mean Flow %
Belturbet P.W.S.	P.W.S.	Erne River	720	135,648	2467,860	0.5	0.03
Erne & Melvin Enhancement Co.	Private (industry)	Cladagh River	4806 (all returned)	14,274	97,244	31.2	4.6
Errington Trout Farm	Private (industry)	Ballycassidy River	1700	2767	211,838	61.4	0.8
North Sligo P.W.S.	P.W.S.	Gortnaleck Stream	925[b]	785	4811	117.9	19.2
North Sligo P.W.S.	P.W.S.	Lyle River	925[b]	553	3775	167.2	24.5
South Leitrim Regional Water Supply Scheme[c]	P.W.S.	River Shannon	12,000	36,754[d]	278,879[d]	32.6	4.3

[a]Estimated at position of abstraction.

[b]The total abstraction rate for North Sligo P.W.S. from the two rivers (Gortnaleck and Lyle) is approx. 1850 m3/d. The abstraction rates from the individual sources is not measured.

[c]Outside the UGEE licence area but connected to Lough Allen which is in the NCB. Flow estimation based on limited data.

[d]Underestimated values, as estimation does not include all tributaries which are located between abstraction point and Lough Allen. Thus, percentages are overestimated.

5.3 Groundwater

The hydrogeological characteristics of the bedrock aquifers in the two case study areas are complex. They are conceptually understood, but data gaps exist with regard to quantitative data and information. The complexity and, often, unpredictability of bedrock aquifers implies that well yields and influences of abstractions cannot be predicted with certainty without detailed study involving field investigations. In the UGEE-context, risks of impact from groundwater abstractions relate primarily to:

- Reduced baseflow to surface water bodies (if groundwater and surface water are hydraulically connected);
- Adverse influence on the supporting conditions of nearby groundwater dependent terrestrial ecosystems (GWDTEs); and
- Hydraulic interference with existing, neighbouring supply wells (public and private).

As part of the prior authorisation process, both desk study and field surveys should be carried out to identify potential features, ecologies, and/or populations that might be affected by the proposed abstractions. Following this, the case-specific risks and mitigation measures must be assessed through further study, testing, and monitoring. All such work should be scoped, carried out and reviewed by suitably qualified hydrogeologists, supported by other specialists in relevant fields.

As documented in Interim Report A1-3 of Project A1 (CDMS, 2015c), groundwater is used extensively for both public and private water supply across both study areas. Individual abstraction rates range from <10 m^3/d (small group water scheme) to approximately 500 m^3/d (public scheme). Accordingly, groundwater supplies are volumetrically smaller than abstractions from surface water bodies, but are no less important for supply purposes.

Overall, groundwater abstraction pressures in the two study area are low. The large number of private wells serving single homes and farms (in the CB study area especially) are of reduced consequence as the majority of the groundwater that is abstracted for private supply is returned back to the groundwater environment via septic tanks, percolation systems, and livestock.

All groundwater bodies in the two study areas are classified as being of ‘good’ or ‘high’ quantitative status with respect to groundwater abstraction pressures (EPA, 2014; NIEA, 2014). Thus, existing abstractions are considered to be sustainable and there are no identified adverse impacts on drinking water sources, surface water bodies, or groundwater dependent terrestrial ecosystems.

Reported yields from pump testing of wells results range from <50 to >400 m^3/d. In context of the UGEE water demand in Section 2.2, groundwater is a viable source of water to meet demands, at least in part. The ability to develop a sufficient supply to meet demands locally for hydraulic fracturing programmes would be subject to exploration and testing, and may require more than a single supply well at a single location. This would depend on location and case-specific circumstances of both hydrogeology and actual water demands. The chance of drilling productive wells in bedrock aquifers involves study, skill and a degree of good fortune, and is not always guaranteed at the first attempt.

6 Summary

Available water resources in the two case study areas are represented by rainwater, lakes and reservoirs, streams and rivers, and groundwater in bedrock aquifers. The surface water resources are reasonably well documented and quantified at the sub-regional scale, and although groundwater resources are less well quantified, the hydrogeological characteristics of the bedrock aquifers are conceptually understood. Accordingly, the conceptual hydrogeological models of the two study areas (CDMS, 2015b) document the significance of groundwater both as sources of water for supply purposes and providing supporting conditions for surface waters and groundwater dependent terrestrial ecosystems. Recommendations for supplementary hydrometric baseline monitoring have been made with regard to discharge contributions and characteristics of large karst springs, mostly in the Cuilcagh Mountains (CDMS, 2015c).

There is capacity to supply water use requirements of potential future UGEE development in both study areas, but this would ultimately be conditioned and influenced by *how* and *where* the development would proceed, both spatially and temporally. Local supply options are considerably wider in the NCB study area compared to the CB study area. Capacity would have to be judged by actual total demand, with a clear understanding of timelines of total demands.

The highest water demands associated with UGEE occur during the hydraulic fracturing programmes at individual wells. On the basis of a demand of 15,000 m^3 for an individual hydraulic fracturing programme implemented over 3 days, the maximum (conservative) daily demand is 5000 m^3/d for a single well. This figure is provided for guidance purposes only, as actual demands would be case-specific.

Although the maximum water demand associated with a hydraulic fracturing programme at an individual well is temporary, each well pad would consist of several wells, and each well would undergo fracturing operations. Accordingly, the total demands associated with a single well pad are greater and are also distributed in time. Actual plans, schedules and implementation of hydraulic fracturing programmes would, therefore, dictate how water demands develop and when and where the supplies are needed.

A scenario in which multiple hydraulic fracturing programmes are carried out concurrently would be where operations are carried out at multiple well pads in a given area. In this case, the total demand would be higher than indicated above, and the potential for abstraction impacts would equally be greater.

For the peak build-out scenario described in Section 2.1, there would theoretically be 130 wells for the moderate build-out scenario drilled and hydraulically fractured per year in the NCB study area. Assuming a 3-day duration for each hydraulic fracturing programme, this equates to 390 days of hydraulic fracturing, each requiring 5000 m^3/d in the example given. Thus, the total demand is driven by how many wells are hydraulically fractured in the same time period and the potential risk of impact from supply (i.e. abstraction of available water resources) is determined by how and where the water is sourced.

Such development and demand would have to be supplied from multiple sources. Accordingly, all future proposed UGEE-related abstraction plans will have to be carefully reviewed to understand the timeline of total demands, individually and cumulatively, with the involvement of relevant stakeholders and regulatory bodies.

As documented in this report, risks of *volumetric* impacts are lower in large lakes and streams, and higher in small lakes and streams. Identifying and documenting volumetric impact is relevant in a regulatory context, but ultimately what determines impact are changes in water levels and flows, the influence of such changes on reference conditions for ecosystems and habitats in the related water bodies. Impact from abstractions are more appropriately described by *ecological* impact. This is recognised by the methods that are applied by both the EPA and NIEA in classifying the ecological status of surface waters for WFD reporting purposes. In both the ROI and NI, the methods examine and monitor departures from reference conditions with regard to macroinvertebrates, hydromorphology and physico-chemical quality. Future assessment of potential abstraction impacts related to UGEE development would require inputs from qualified hydrologists, hydrogeologists and aquatic (freshwater) ecologists.

NI has adopted the concept of 'environmental flows' in the licencing scheme that governs prior authorisation of abstractions. This identifies the Q_{95} low-flow condition of a stream to be the critical flow below which more stringent standards are required. Different flow standards are established for invertebrates, macrophytes, and fish, and environmental flow standards are provided in the form of allowable abstractions as a percentage of natural flow, where the permitted change in the stream flow varies according to WFD ecological status objectives, stream typology, and seasonal flow. The environmental flow concept is risk-based, and higher abstractions may be permitted during higher natural flow conditions.

With regard to groundwater, the bedrock aquifers in both study areas are viable sources of water to meet demands, at least in part. However, the ability to develop a sufficient supply to meet demands locally for hydraulic fracturing programmes would require prior exploration and testing, and may require more than a single supply well at a single location, depending on location and case-specific circumstances of both hydrogeology and actual water demands. The complexity and, often, unpredictability of bedrock aquifers implies that well yields and influences of abstractions cannot be predicted with certainty, requiring detailed study involving field investigations. In the UGEE-context, risks of impact from groundwater abstractions are mainly:

- Reduced baseflow to surface water bodies (if groundwater and surface water are hydraulically connected);
- Adverse influence on the supporting conditions of nearby groundwater dependent terrestrial ecosystems (GWDTEs);
- Hydraulic interference with existing, neighbouring supply wells (public and private).

As part of the prior authorisation process, both desk study and field surveys should be carried out to identify potential features, ecologies, and/or populations that might be affected by the proposed abstractions. Following this, the case-specific risks and mitigation measures must be assessed through further study, testing, and monitoring. All such work should be scoped, carried out and reviewed by suitably qualified hydrogeologists, supported by other specialists in relevant fields.

Existing abstraction pressures are currently low throughout the two study areas. Future UGEE-related abstractions would have to be evaluated at two levels: a) local level (local impact) and b) catchment level (water body impact). Regarding the latter, special attention should be given to requirements of existing statutory instruments and efforts by the EPA and NIEA to maintain "good quantitative" and "good ecological" status of water bodies. As UGEE activity is rarely confined to single locations, abstractions may have a cumulative impact which would need to be addressed by appropriate monitoring.

For logistical and cost reasons, future UGEE operations would try to obtain water from sources that are easily accessible, i.e. as close to the drill sites as possible. The water needed might be accessed via surface water or groundwater resources and water may either be developed by the UGEE companies directly or be purchased from existing supply sources. Case-specific circumstances of actual demands would determine the sourcing of water.

Large abstractions in small lakes and streams increases the risk of impact. Concentrated abstractions in small subcatchments and abstractions in or near ecologically sensitive habitats also increase the potential for impacts. Even short-duration abstractions can cause environmental stresses and impact, depending on the source, abstraction rate and reference conditions of the source at the time of abstractions. The distinction between “small” and “large” is subjective, and cannot be made without consideration of surface water ecology and following lines of evidence.

In the licencing or prior authorisation of future UGEE-related abstractions, environmental reference conditions would have to be identified on a case by case basis, using site- and case-specific inputs (e.g. flow data and ecological datasets), and requiring technical judgement by specialists in related fields. Proper impact assessment can only be done once the details of proposed future abstractions become known, with scoping and technical review by relevant specialists representing public regulatory bodies in both the ROI and NI.

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Acronyms and Annotations

ABP	An Bord Pleanála
BGS	British Geological Survey
BMWP	Biological Monitoring Working Party
CB	Clare Basin
CER	Commission for Energy Regulation
DCENR	Department of Communications, Energy and Natural Resources
DECLG	Department of Environment, Community and Local Government
DEHLG	Department of the Environment, Heritage and Local Government
DETI	Department of Enterprise, Trade and Investment
DOENI	Department of the Environment Northern Ireland
EC	European Commission
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EU	European Union
GSI	Geological Survey of Ireland
GSNI	Geological Survey of Northern Ireland
GWDTE	Groundwater Dependent Terrestrial Ecosystem
GWS	Group Water Scheme
HMWB	Heavily Modified Water Body
HSE	Health Services Executive
JRP	Joint Research Programme
Km	Kilometres
m	Metres
m^3/d	Cubic metres per day
mOD	Metres Ordnance Datum
MRP	Molybdate Reactive Phosphorus
NCB	Northwest Carboniferous Basin
NI	Northern Ireland
NIEA	Northern Ireland Environment Agency
NPWS	National Parks and Wildlife Service
OPW	Office of Public Works
PAD	Petroleum Affairs Division
PPA	Poorly productive aquifers
PWS	Public Water Supply

RA	Rivers Agency
ROI	Republic of Ireland
SAC	Special Areas of Conservation
SC	Steering Committee
SEW	Shannon-Erne Waterway
STRIVE	Science, Technology, Research and Innovation for the Environment
TOR	Terms of Reference
UGEE	Unconventional Gas Exploration and Exploitation
USEPA	United States Environmental Protectoon Agency
USGS	United States Geological Survey
UKTAG	UK Technical Advisory Group
WFD	Water Framework Directive
WI	Waterways Ireland

Attachment A

Aghalough	
Lake Name	Aghalough
Lake Code	NW_36_142
Lake Area	0.01 km^2
Catchment Area	1.43 km^2
Easting	210,433
Northing	368,665

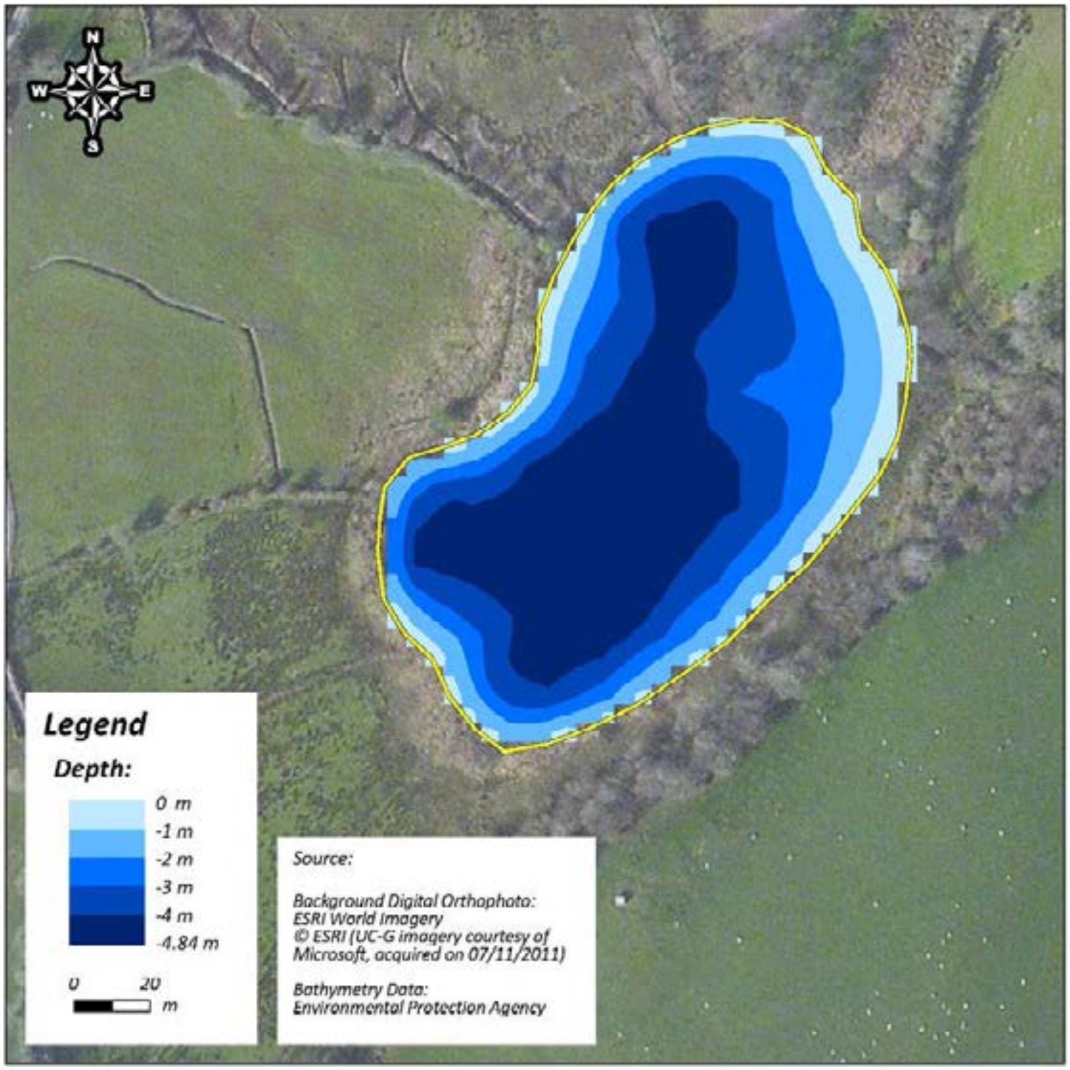


Figure A.1. Bathymetry (m).

Lough Allen	
Lake Name	Lough Allen
Lake Code	SH_26_716
Lake Area	33.46 km^2
Catchment Area	413.82 km^2
Easting	196,231
Northing	319,255

Hydrometrics

Station Name	Lough Allen U/S
Station Number	26073
Status	Active
Type	Recorder
Temporal Range	1932-2015
Easting	196,153
Northing	312,431

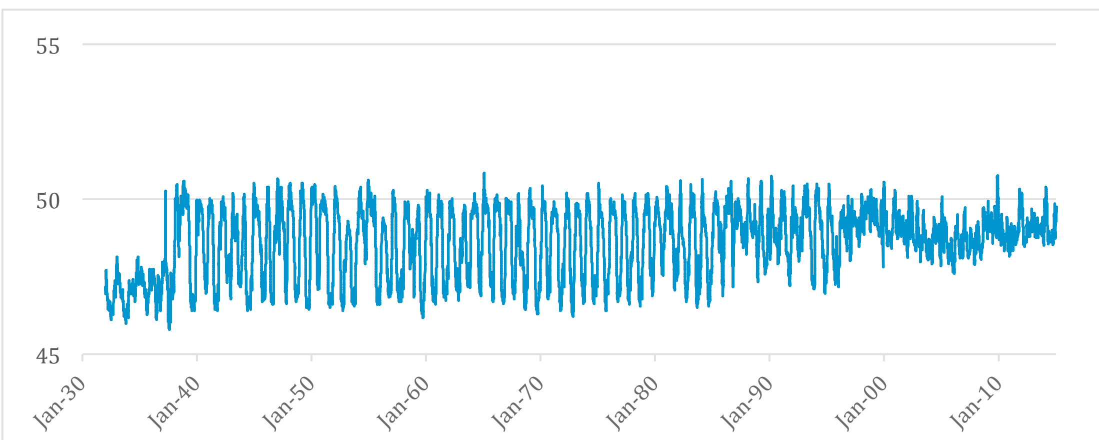


Figure A.2. Levels (m).

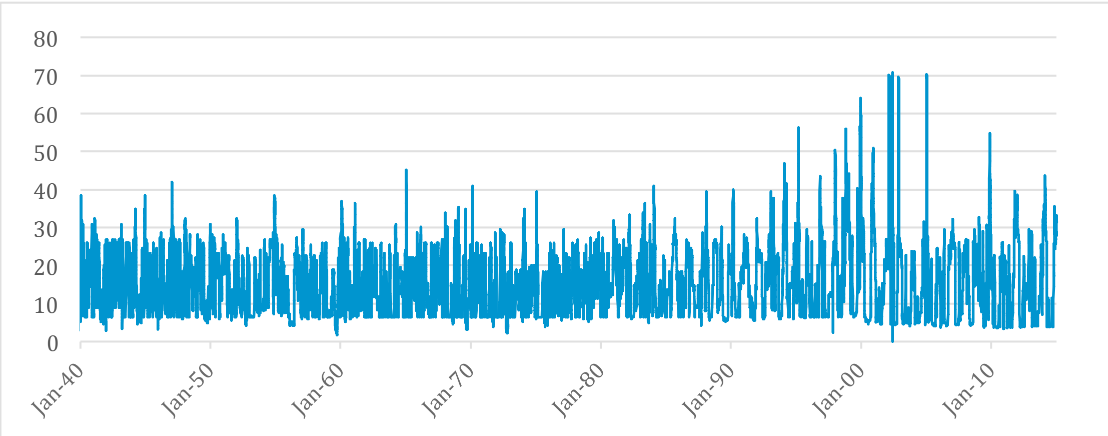


Figure A.3. Flow (m^3/s).

Station Name	Blackrock Lock
Station Number	26074
Status	Active
Type	Recorder
Temporal Range	1994-2004
Easting	196,747
Northing	310,977

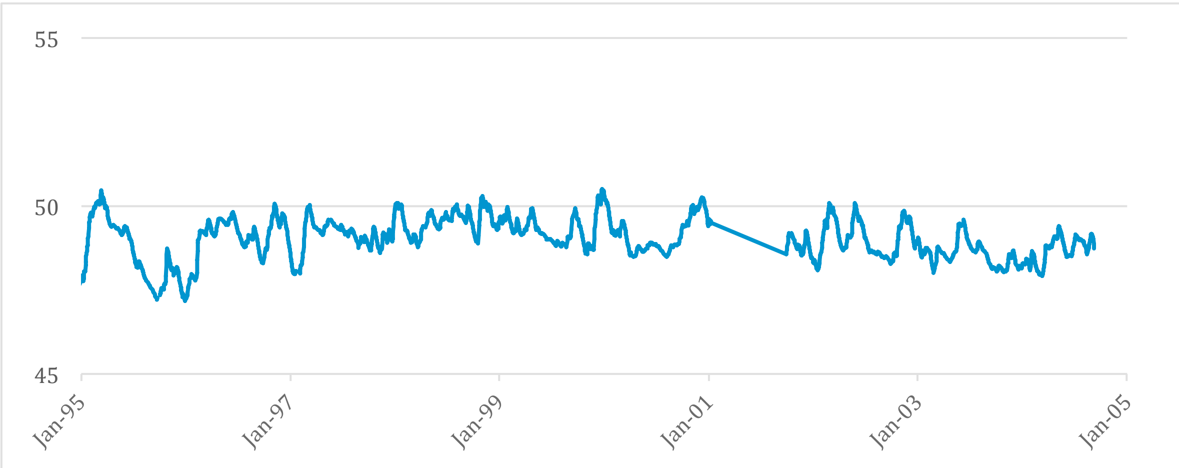


Figure A.4. Levels (m).

Anarry Lough

Lake Name	Anarry Lough
Lake Code	WE_35_131
Lake Area	0.11 km^2
Catchment Area	0.92 km^2
Easting	181,964
Northing	334,156

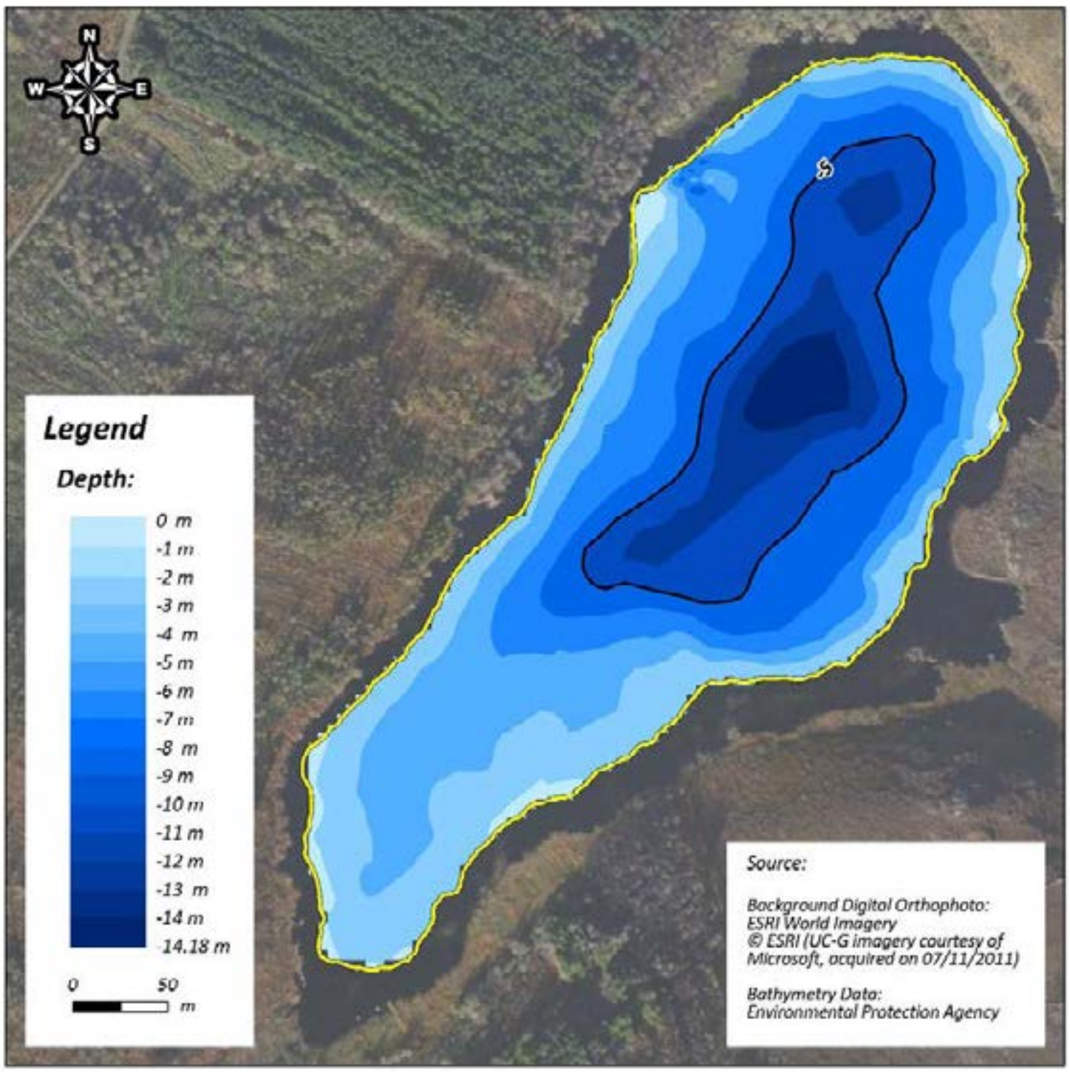


Figure A.5. Bathymetry (m).

Annagh Lough

Lake Name	Annagh Lough
Lake Code	NW_36_517
Lake Area	0.35 km^2
Catchment Area	1.82 km^2
Easting	239,542
Northing	312,489

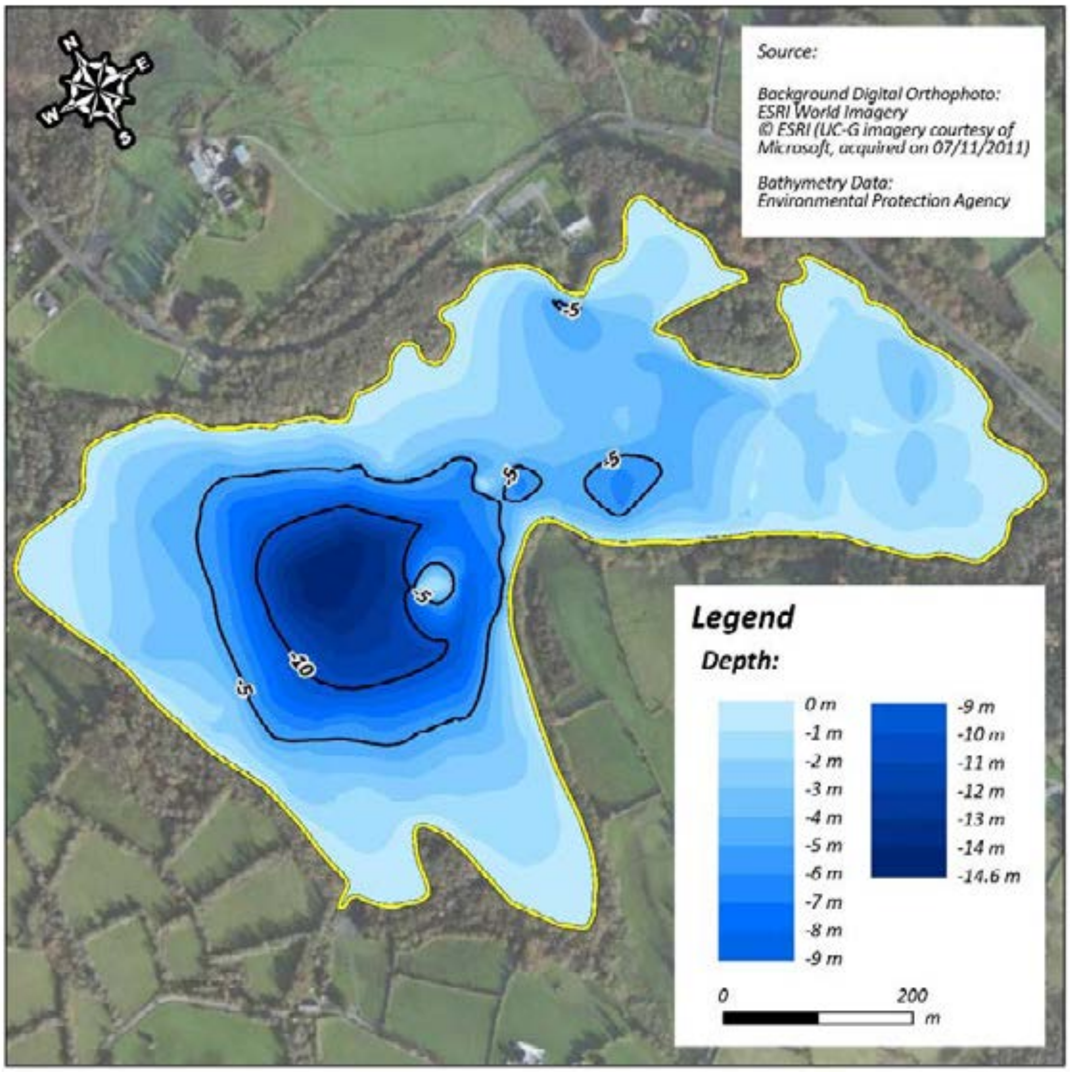


Figure A.6. Bathymetry (m).

Lough Arrow

Lake Name	Lough Arrow
Lake Code	WE_35_159
Lake Area	12.47 km^2
Catchment Area	63 km^2
Easting	178,991
Northing	312,053

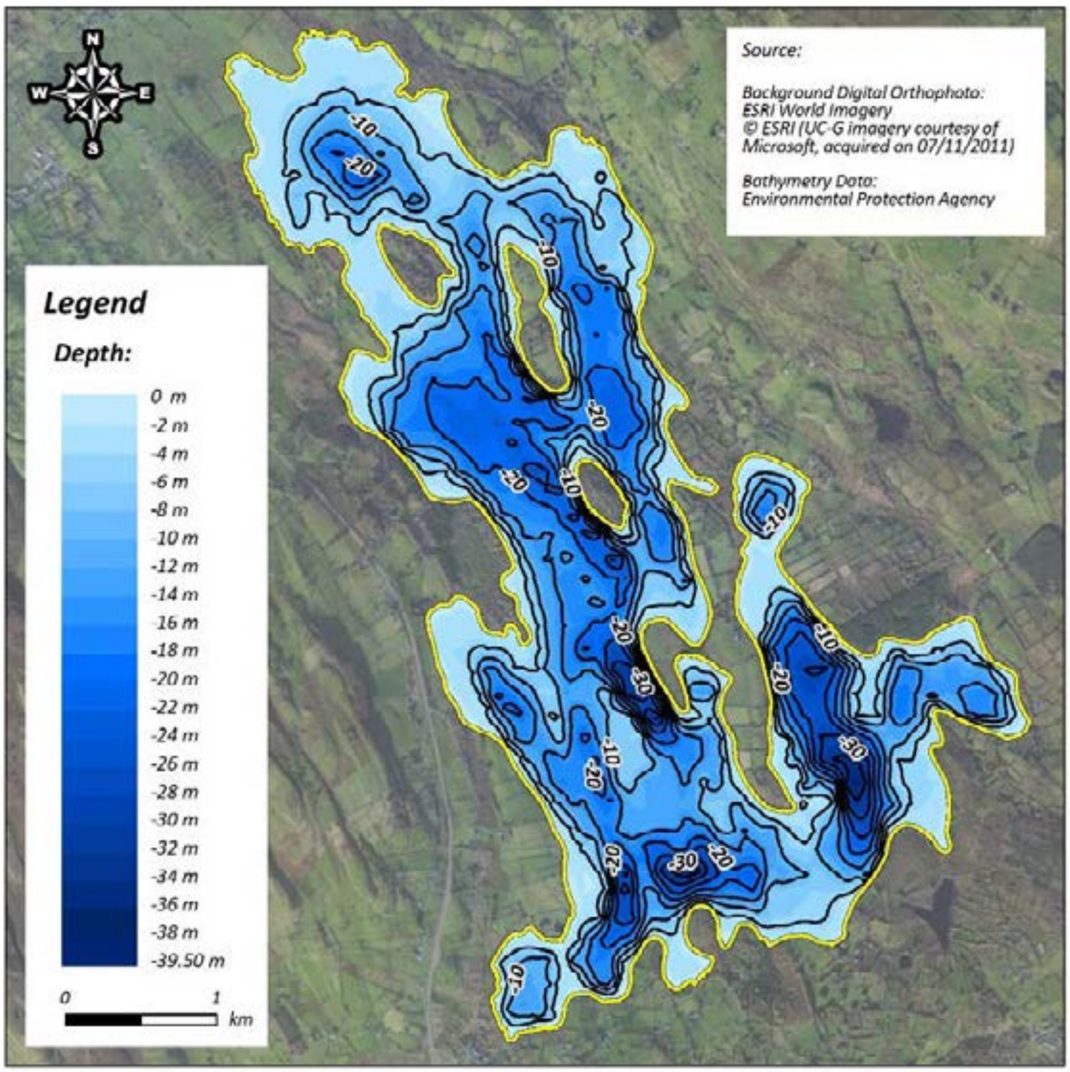


Figure A.7. Bathymetry (m).

Hydrometrics		
Station Name	Ballynary	
Station Number	35087	
Status	Active	
Type	Recorder	
Temporal Range	2008-2010	
Easting	179,748	
Northing	312,454	

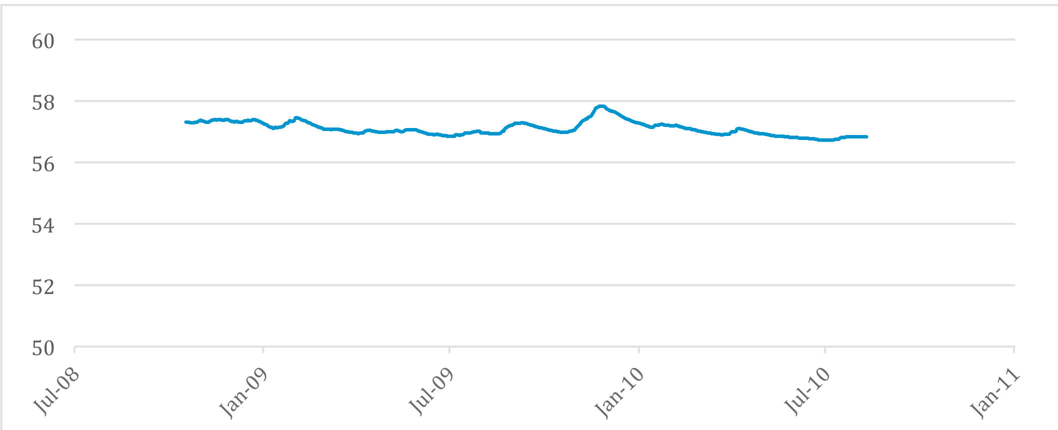


Figure A.8. Levels (m).

Belhavel Lough

Lake Name	Belhavel Lough
Lake Code	WE_35_155
Lake Area	1.01 km^2
Catchment Area	29.20 km^2
Easting	187,907
Northing	328,860

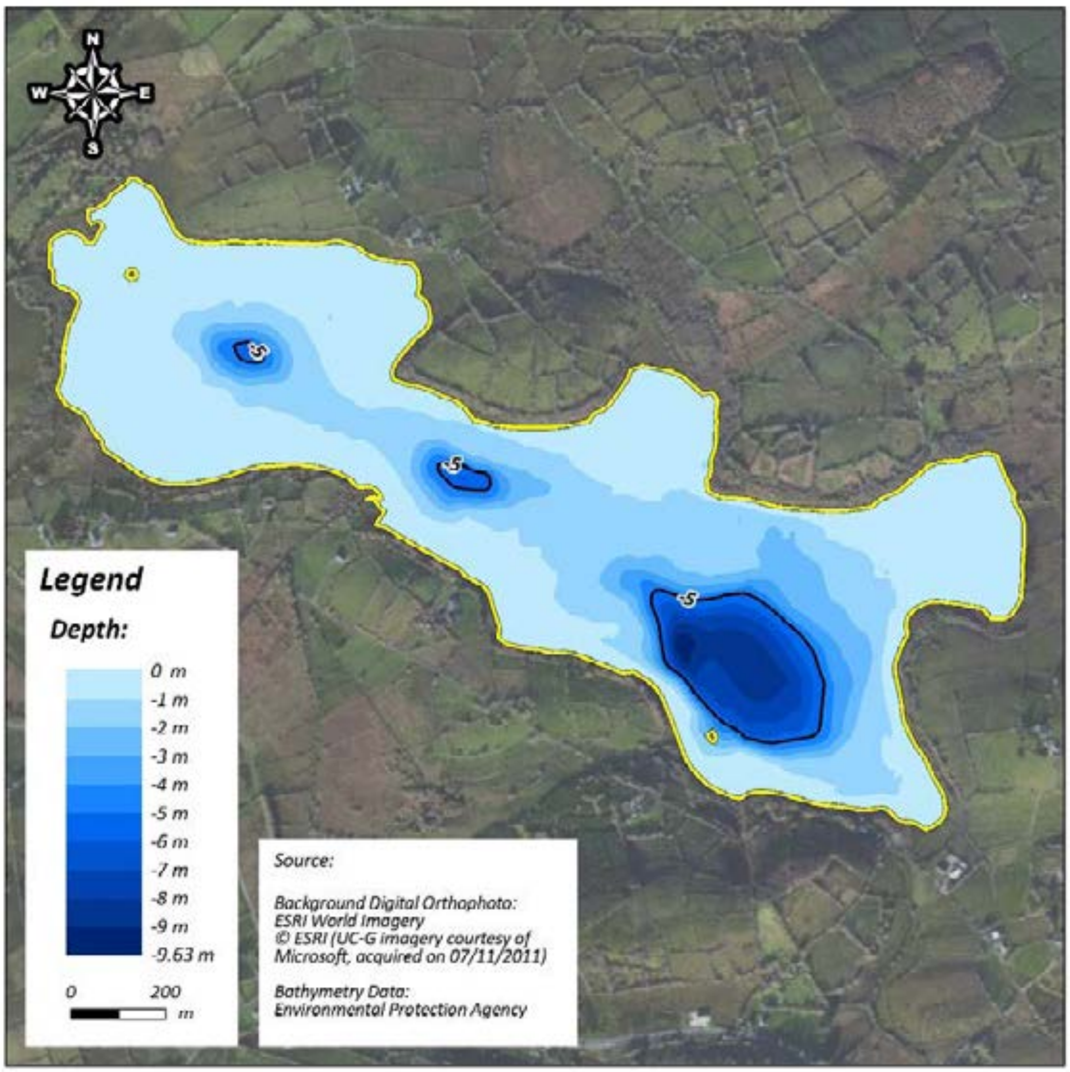


Figure A.9. Bathymetry (m).

Brackley Lough	
Lake Name	Brackley Lough
Lake Code	NW_36_577
Lake Area	1.67 km^2
Catchment Area	16.21 km^2
Easting	219,188
Northing	320,619

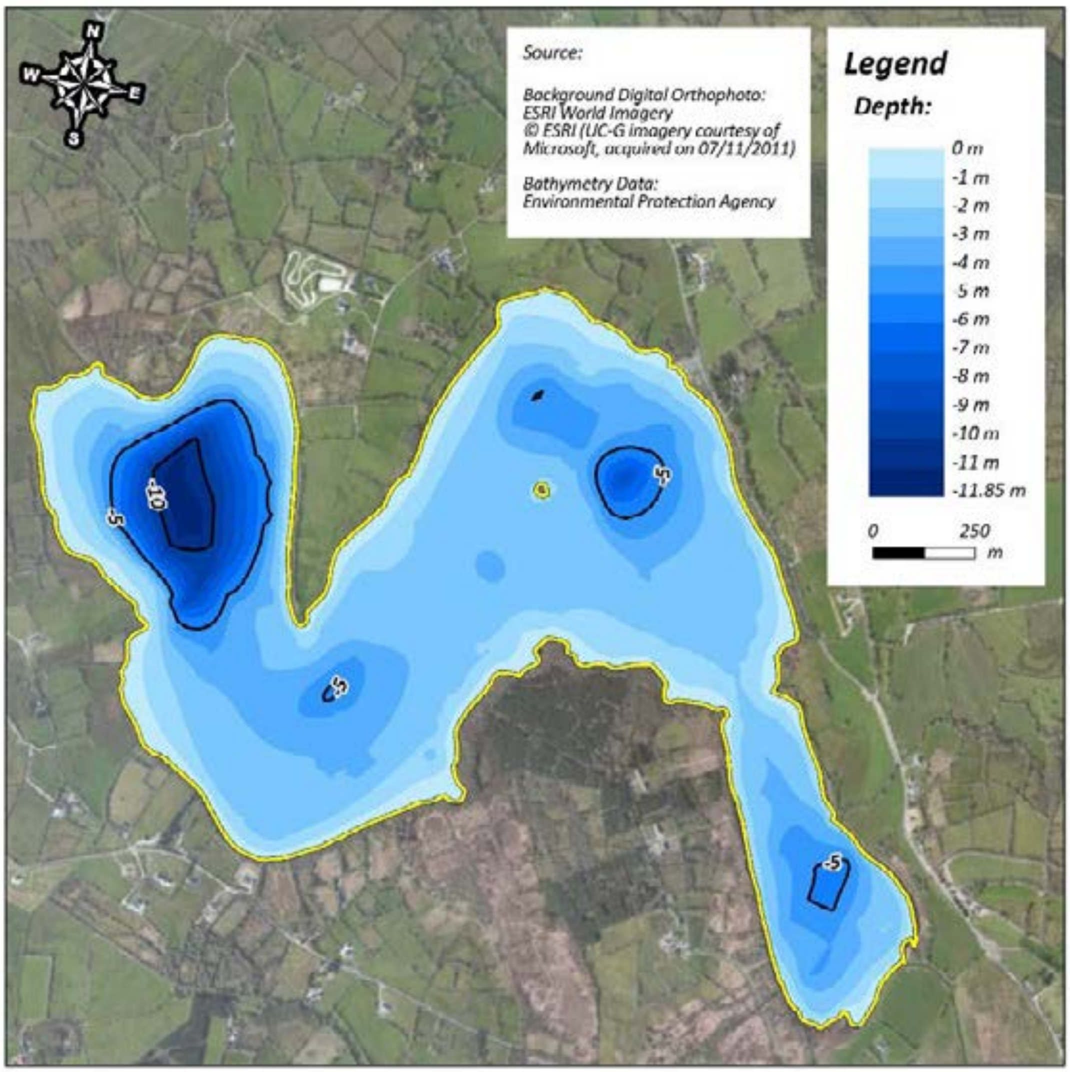


Figure A.10. Bathymetry (m).

Bunerky Lough	
Lake Name	Bunerky Lough
Lake Code	NW_36_624
Lake Area	0.75 km^2
Catchment Area	6.73 km^2
Easting	218,726
Northing	318,533

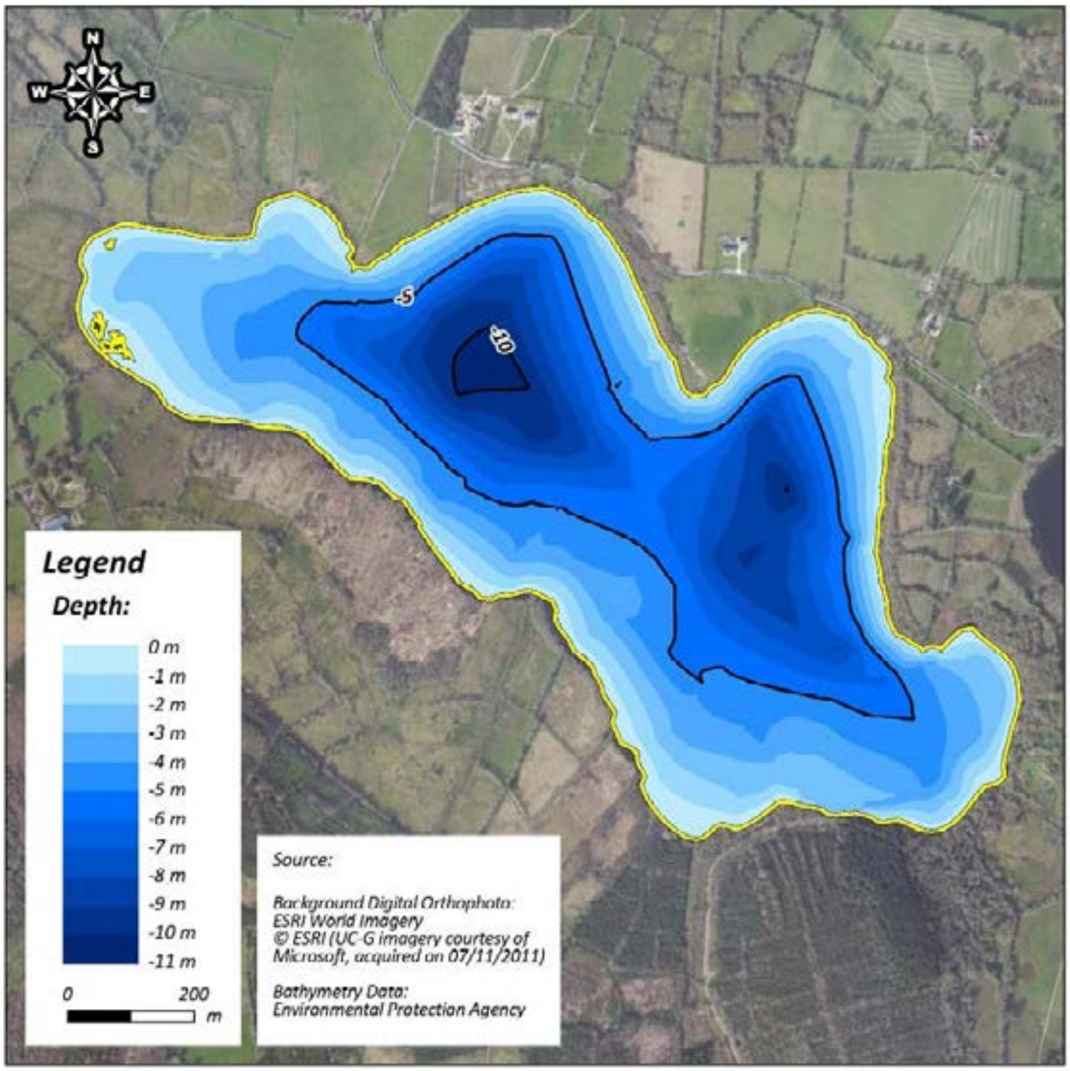


Figure A.11. Bathymetry (m).

Clonty Lough	
Lake Name	Clonty Lough
Lake Code	NW_36_468
Lake Area	0.11 km^2
Catchment Area	10.90 km^2
Easting	227,342
Northing	312,573

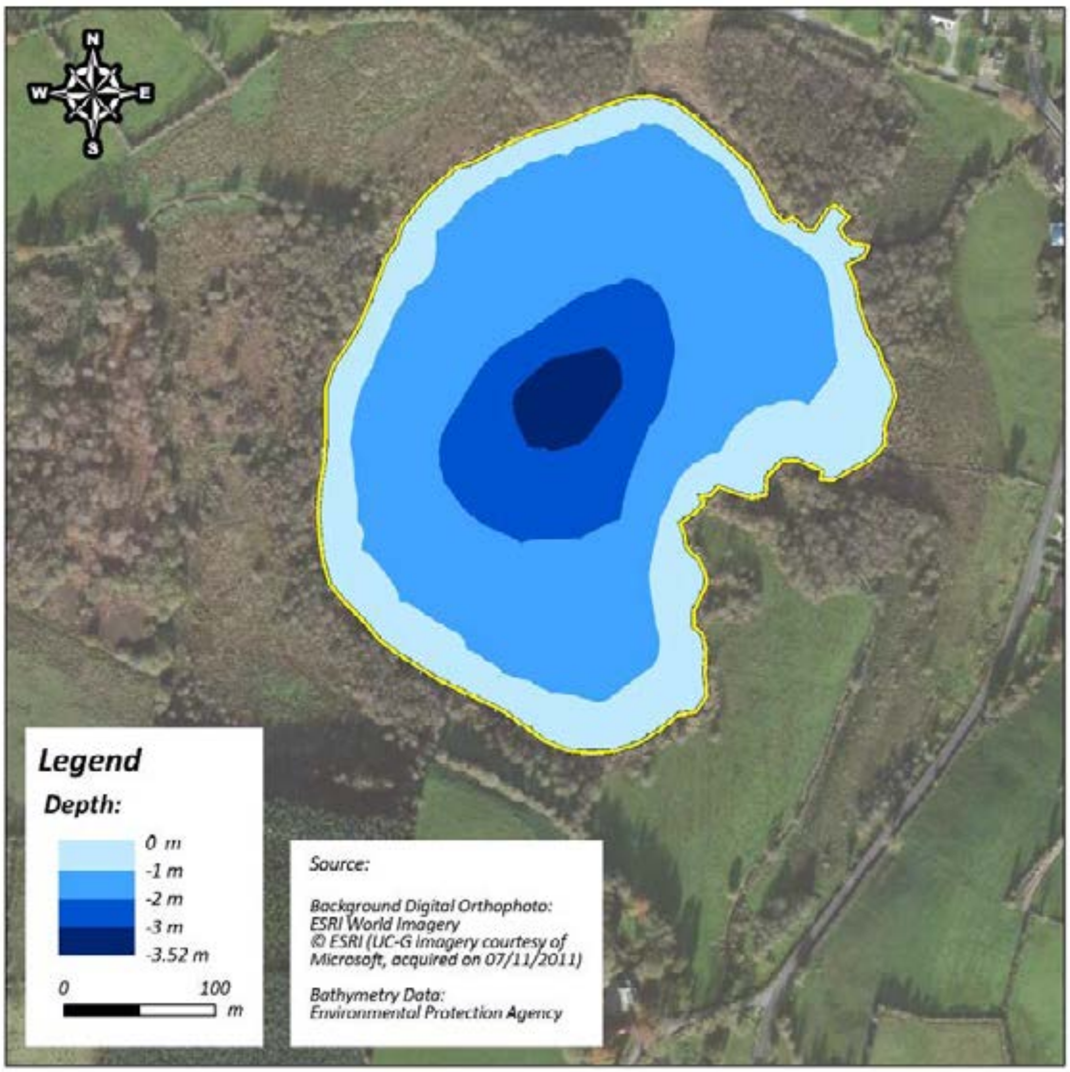


Figure A.12. Bathymetry (m).

Lough Coolyermer

Lake Name	Lough Coolyermer
Lake Code	NI3NW0028
Lake Area	0.18 km^2
Catchment Area	1.35 km^2
Easting	218,059
Northing	342,363

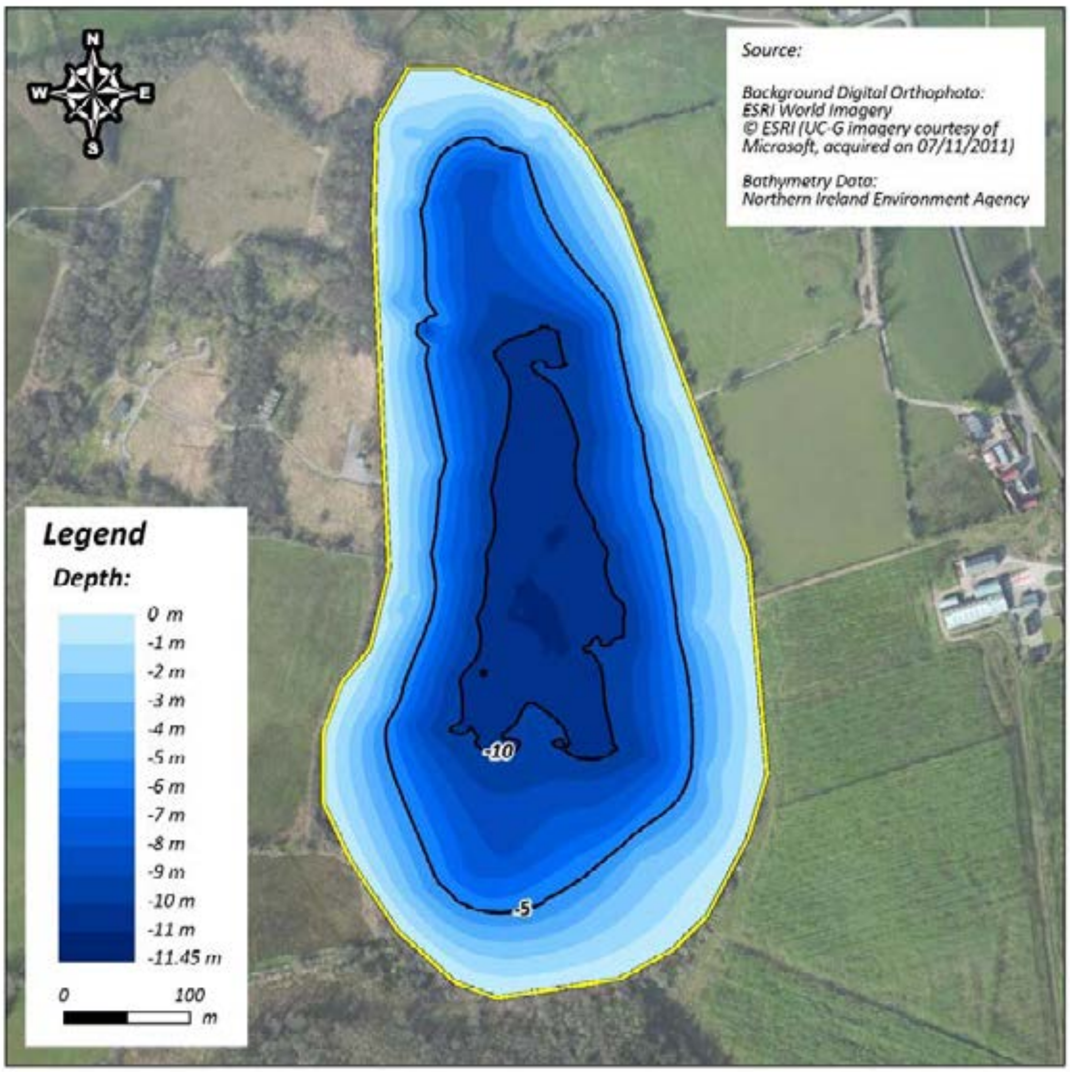


Figure A.13. Bathymetry (m).

Cullinaghan Lough		
Lake Name	Cullinaghan Lough	
Lake Code	NW_36_385	
Lake Area	0.29 km^2	
Catchment Area	35.43 km^2	
Easting	230,477	
Northing	318,329	

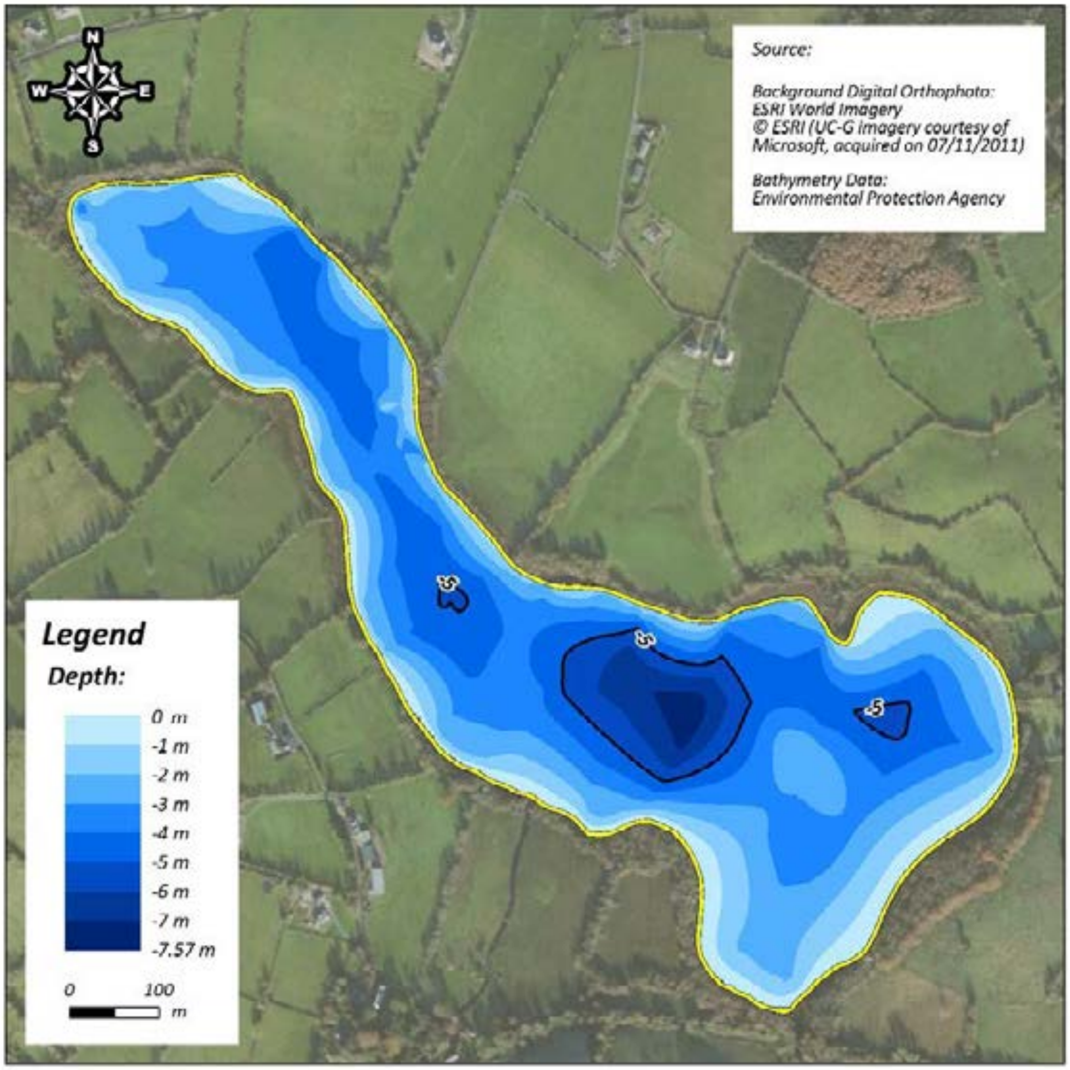


Figure A.14. Bathymetry (m).

Derrycassan Lough	
Lake Name	Derrycassan Lough
Lake Code	NW_36_514
Lake Area	1.62 km^2
Catchment Area	329.06 km^2
Easting	222,265
Northing	312,331

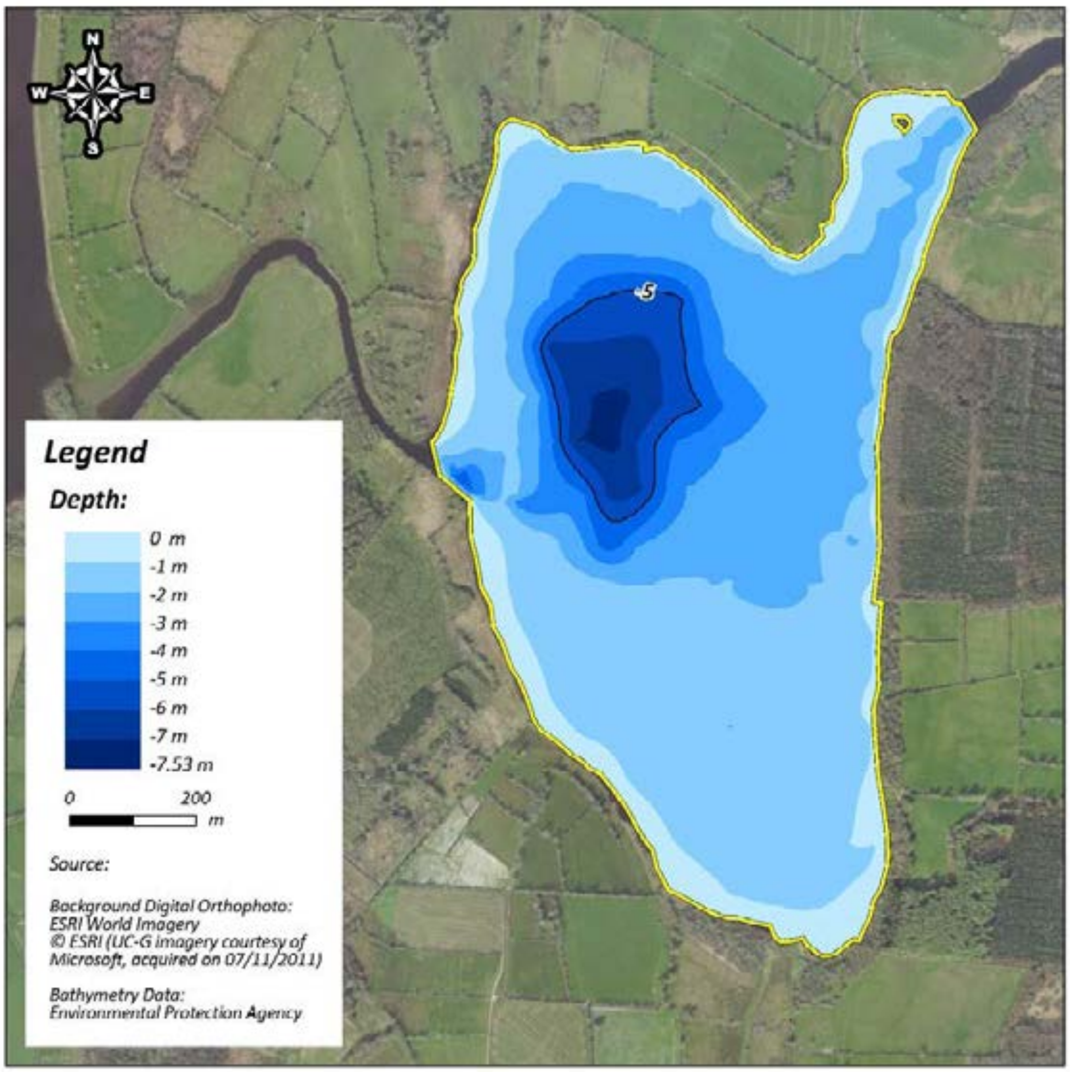


Figure A.15. Bathymetry (m).

Drumlane Lough	
Lake Name	Drumlane Lough
Lake Code	NW_36_504
Lake Area	0.64 km^2
Catchment Area	9.43 km^2
Easting	234,625
Northing	310,743

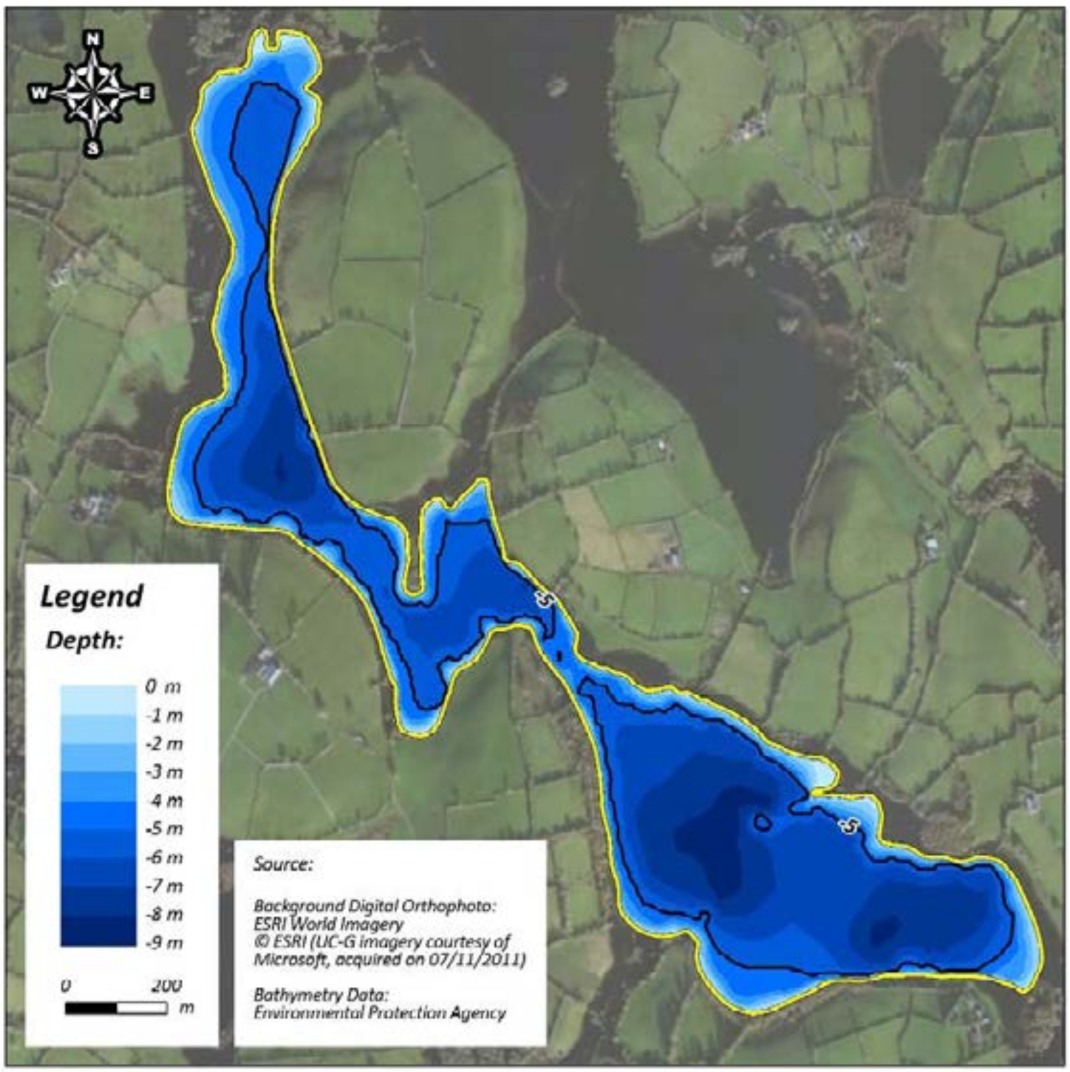


Figure A.16. Bathymetry (m).

Lower Lough Erne

Lake Name	Lower Lough Erne
Lake Code	NI3NW0006
Lake Area	103.8 km^2
Catchment Area	4,269.56 km^2
Easting	212,250
Northing	358,595

Hydrometrics

Station Name	Rosscor
Station Number	236601
Status	Active
Type	Recorder
Temporal Range	1999-2015
Easting	199,940
Northing	357,791

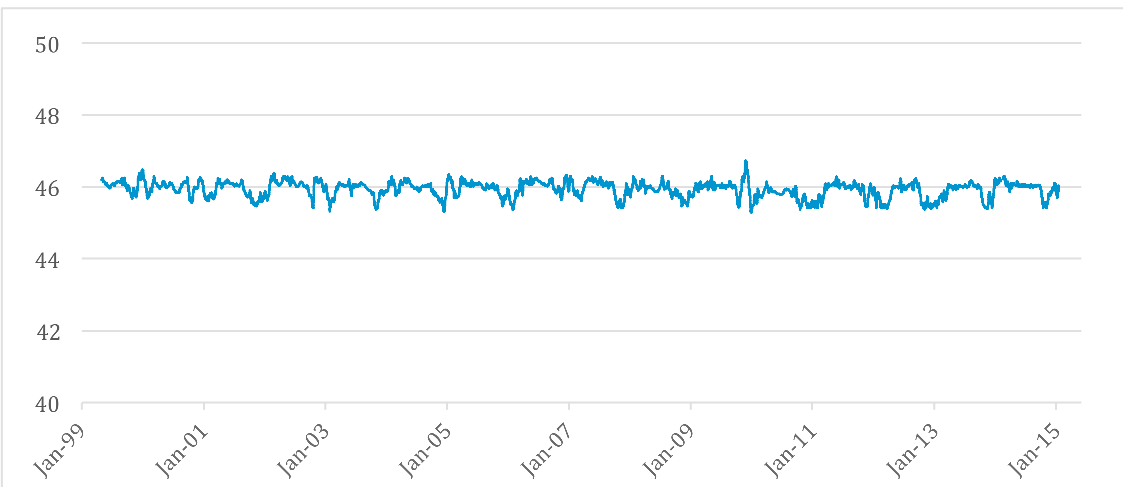


Figure A.17. Levels (m).

Station Name	Portora
Station Number	236002
Status	Active
Type	Recorder
Catchment Area	4,269.56 km^2
Temporal Range	1999-2015
Easting	222,353
Northing	345,292

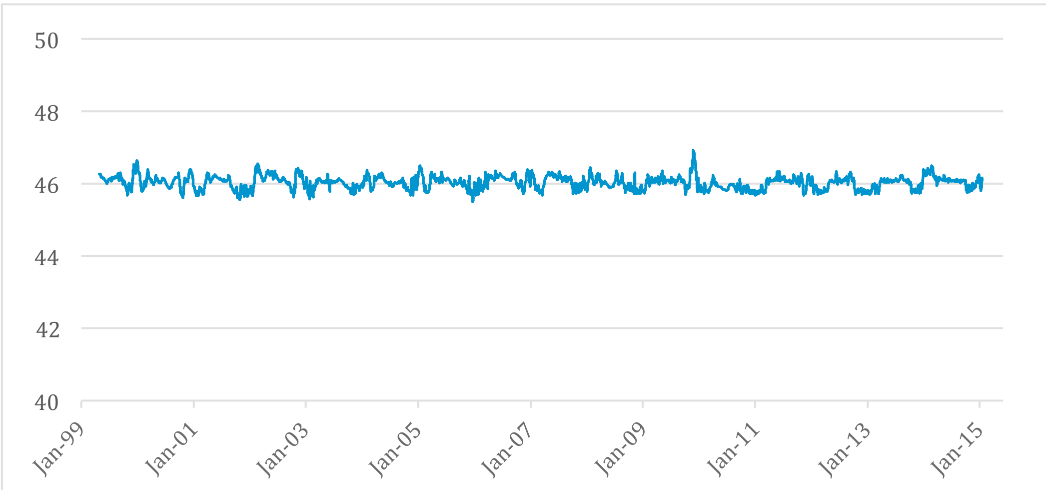


Figure A.18. Levels (m).

Upper Lough Erne

Lake Name	Upper Lough Erne
Lake Code	NI3NW008
Lake Area	32.18 km^2
Catchment Area	3,355.04 km^2
Easting	231,794
Northing	329,755

Hydrometrics

Station Name	Foalies Bridge
Station Number	36171
Status	Active
Type	Recorder
Temporal Range	1982-2010
Easting	236,872
Northing	321,219

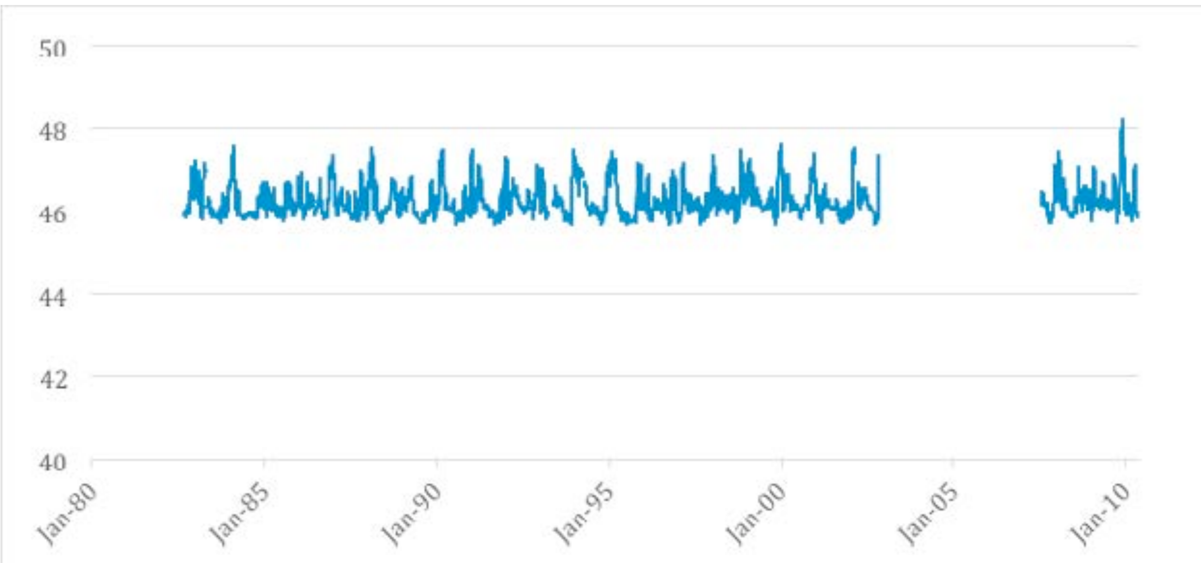


Figure A.19. Levels (m)

Station Name	Bellisle
Station Number	236603
Status	Active
Type	Recorder
Catchment Area	3,355.04 km^2
Temporal Range	1999-2015
Easting	228,350
Northing	334,523

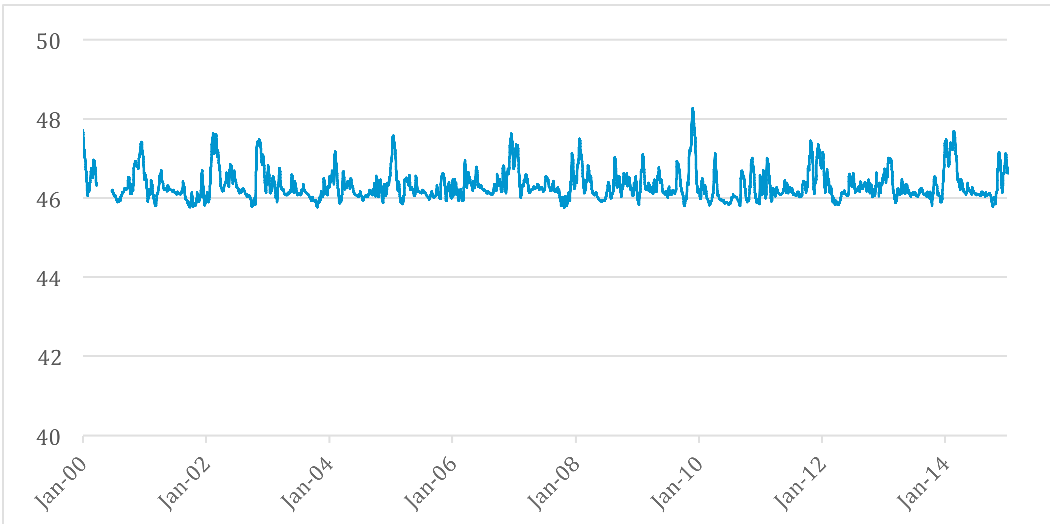


Figure A.20. Levels (m).

Garadice Lough

Lake Name	Garadice Lough
Lake Code	NW_36_648
Lake Area	3.89 km^2
Catchment Area	204.65 km^2
Easting	218,685
Northing	311,225

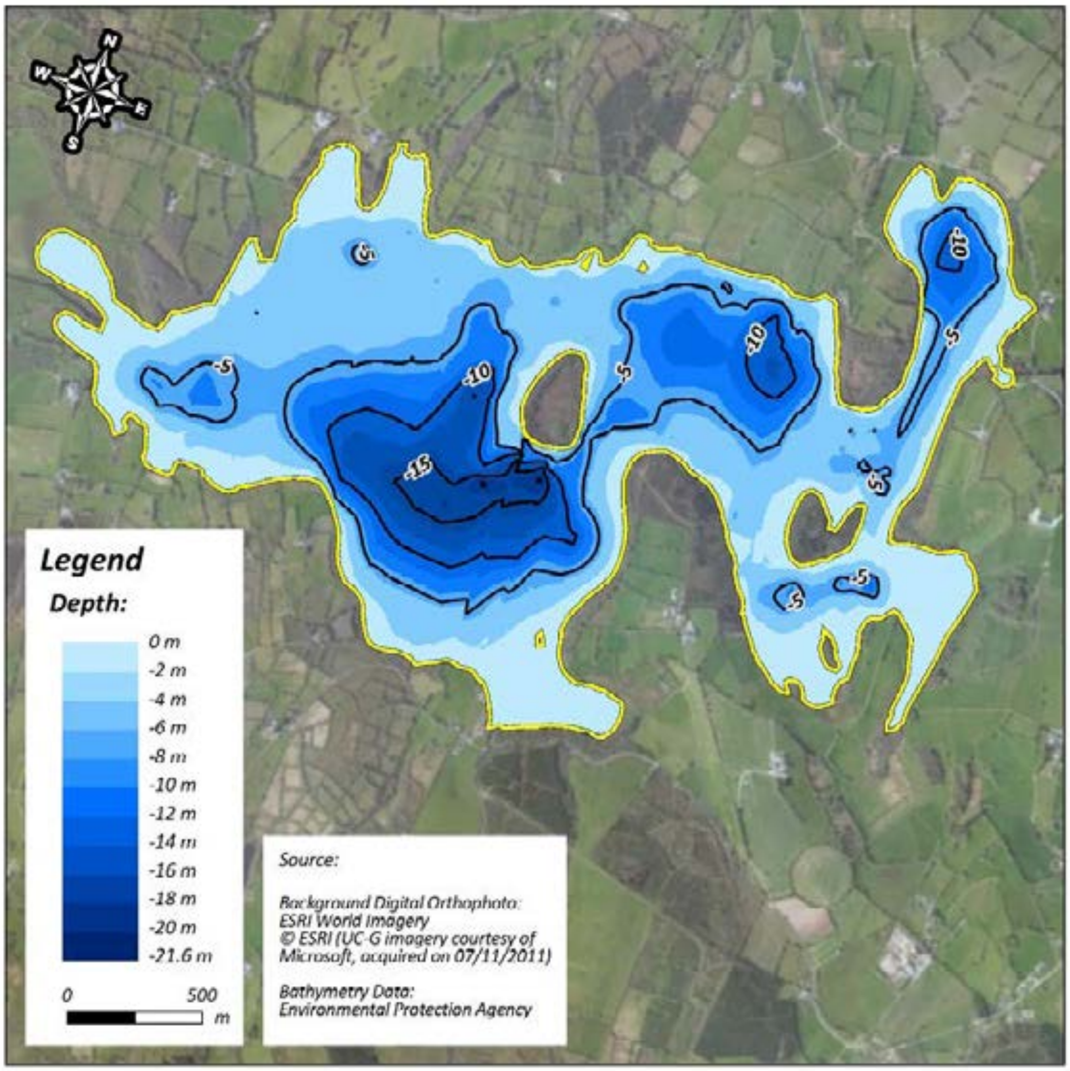


Figure A.21. Bathymetry (m).

Hydrometrics		
Station Name	Ballinacur	
Station Number	36091	
Status	Active	
Type	Recorder	
Temporal Range	1974-2010	
Easting	220,102	
Northing	311,959	

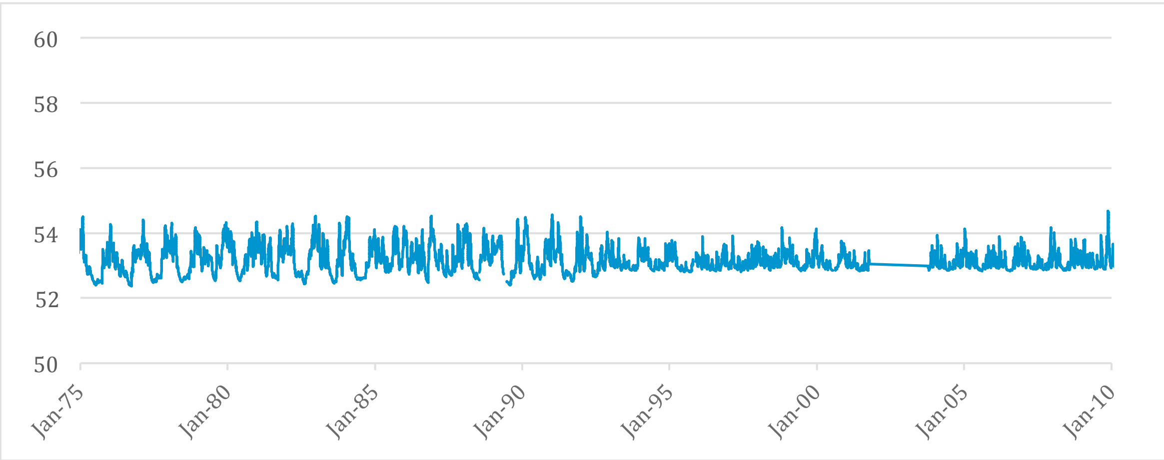


Figure A.22. Levels (m).

Lough Gill	
Lake Name	Lough Gill
Lake Code	WE_35_158
Lake Area	13.81 km^2
Catchment Area	391 km^2
Easting	175,023
Northing	333,693

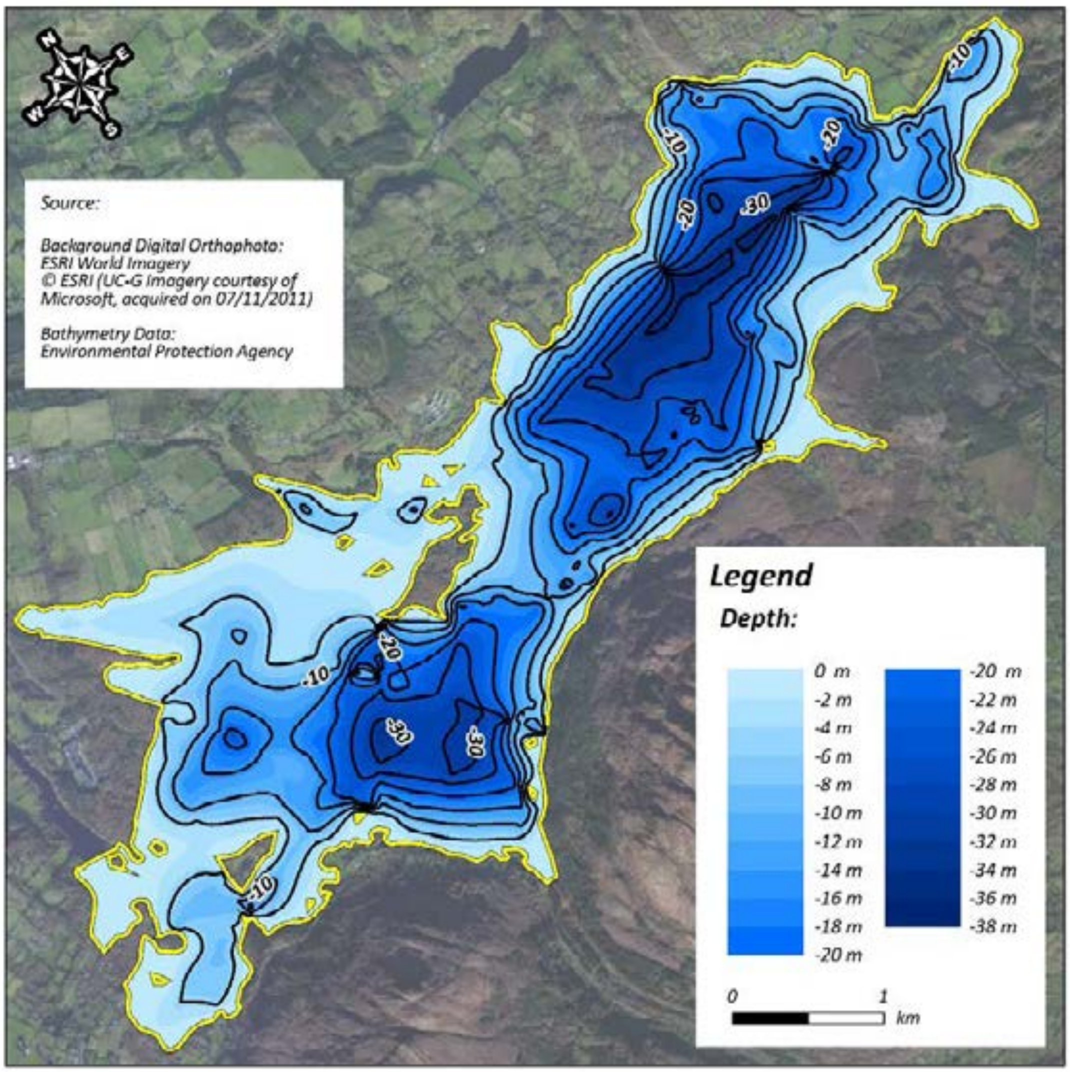


Figure A.23. Bathymetry (m).

Hydrometrics	
Station Name	Lough Gill
Station Number	35073
Status	Active
Type	Recorder
Temporal Range	1975-2014/1975-1997
Easting	171,439
Northing	333,444

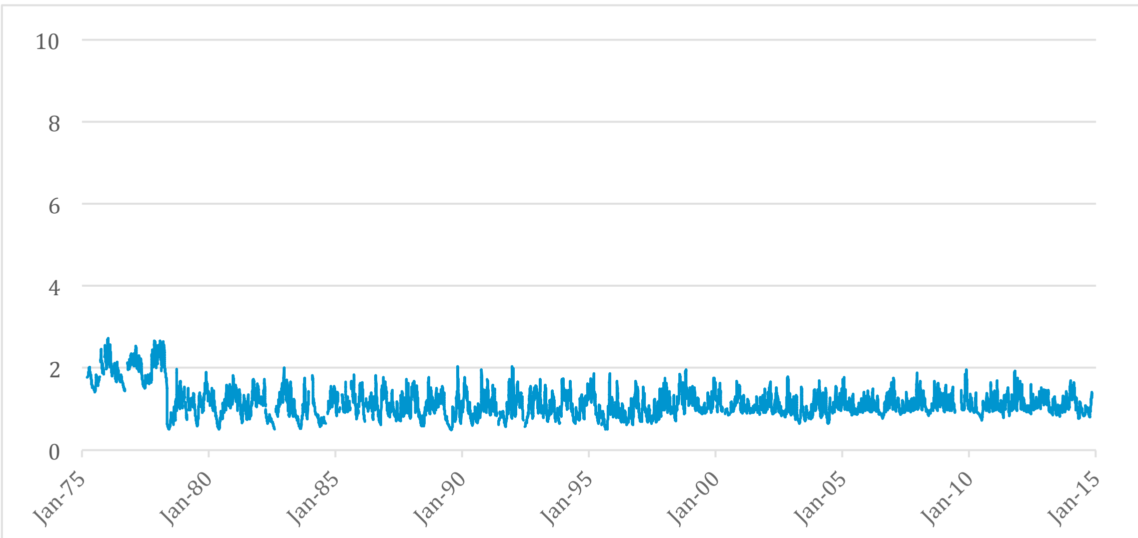


Figure A.24. Levels (m).

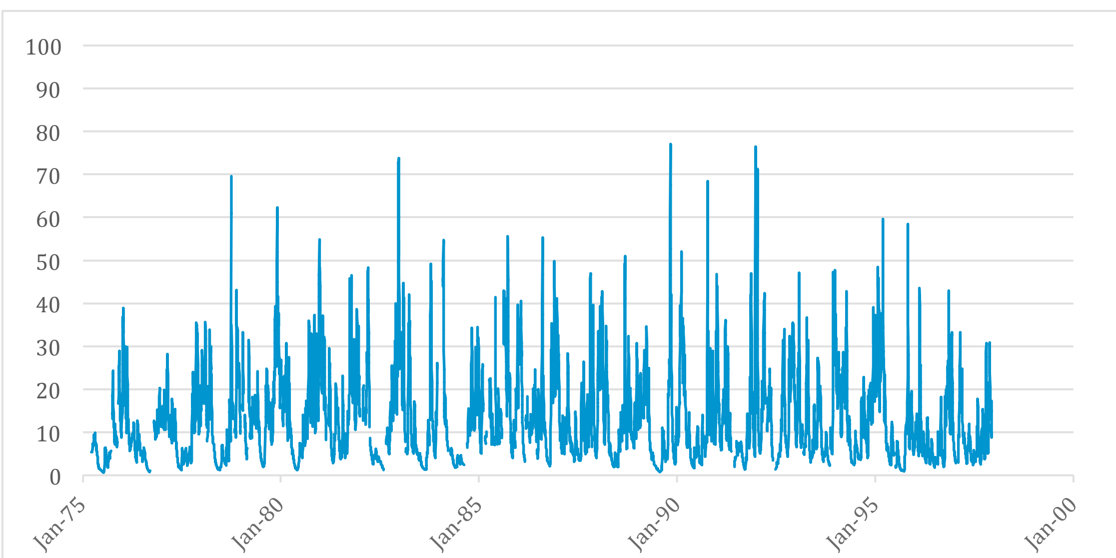


Figure A.25. Flow (m^3/s)

Glenade Lough		
Lake Name	Glenade Lough	
Lake Code	WE_35_156	
Lake Area	0.74 km^2	
Catchment Area	14.92 km^2	
Easting	182,429	
Northing	346,230	

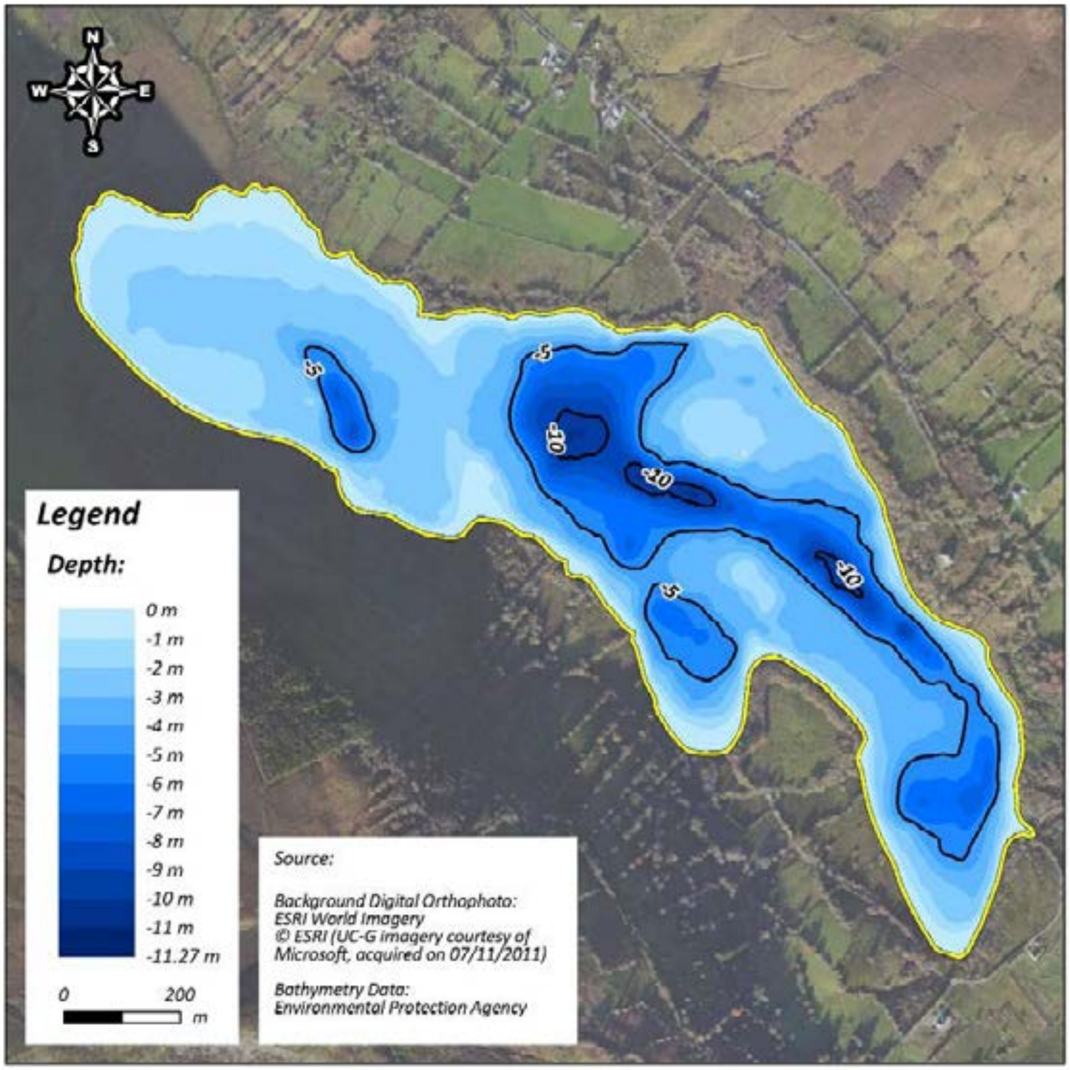


Figure A.26. Bathymetry (m).

Glencar Lough

Lake Name	Glencar Lough
Lake Code	WE_35_139
Lake Area	1.15 km^2
Catchment Area	39.45 km^2
Easting	174,919
Northing	343,333

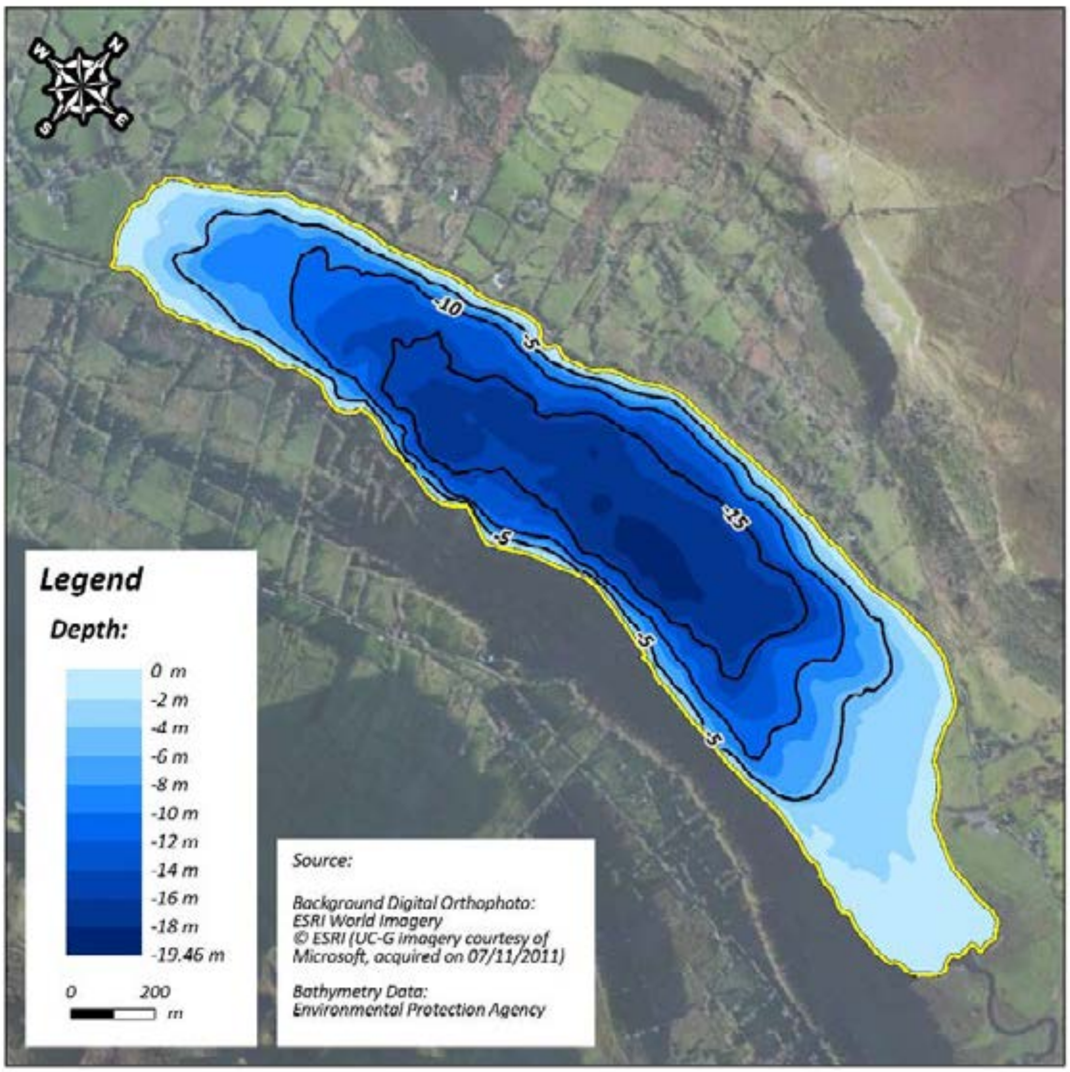


Figure A.27. Bathymetry (m).

Keenaghan Lough	
Lake Name	Keenaghan Lough
Lake Code	NI3NW0029
Lake Area	0.19 km^2
Catchment Area	4.83 km^2
Easting	197,466
Northing	359,880

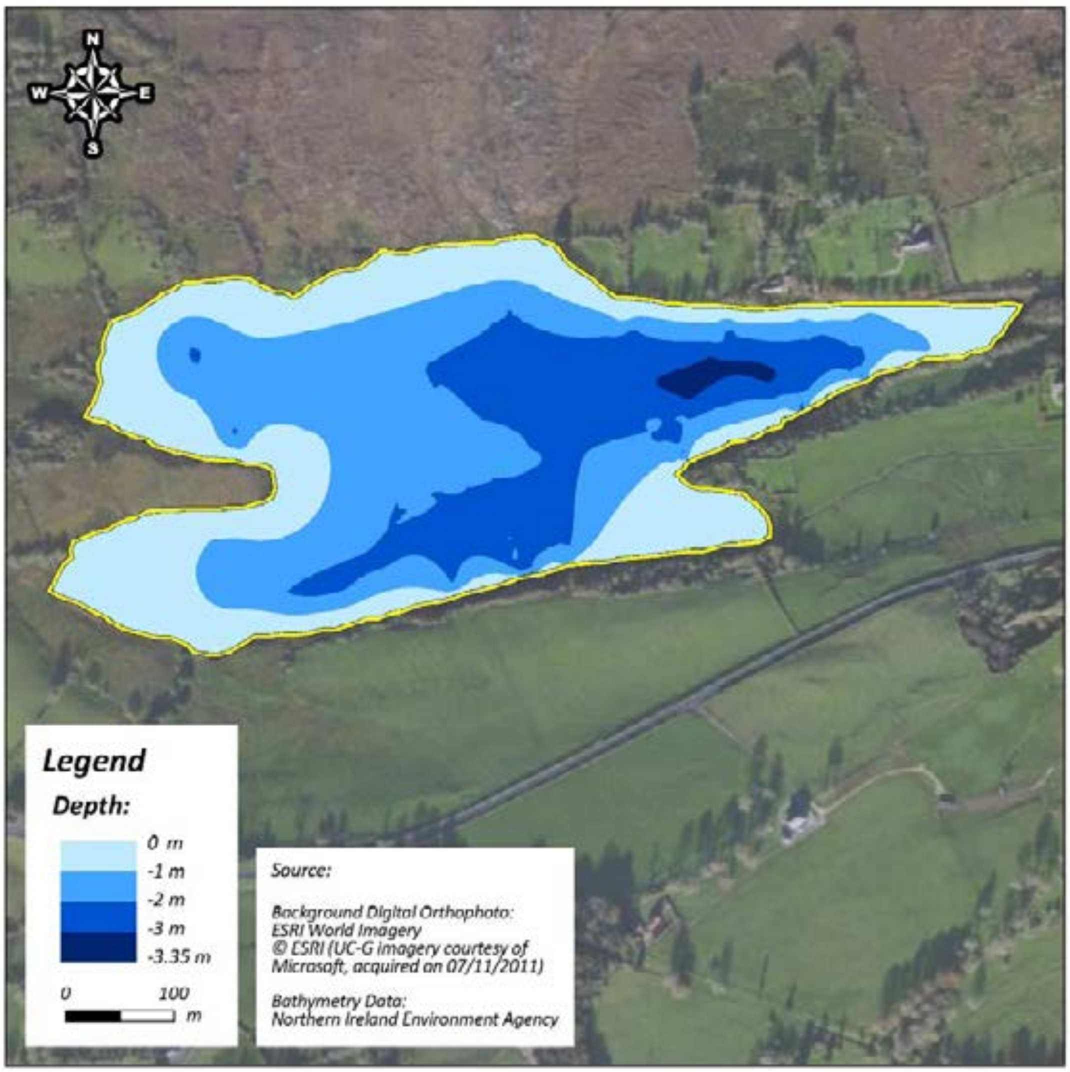


Figure A.28. Bathymetry (m).

Lough Killooman

Lake Name	Lough Killooman
Lake Code	SH_26_698
Lake Area	0.02 km^2
Catchment Area	0.19 km^2
Easting	195,403
Northing	330,768

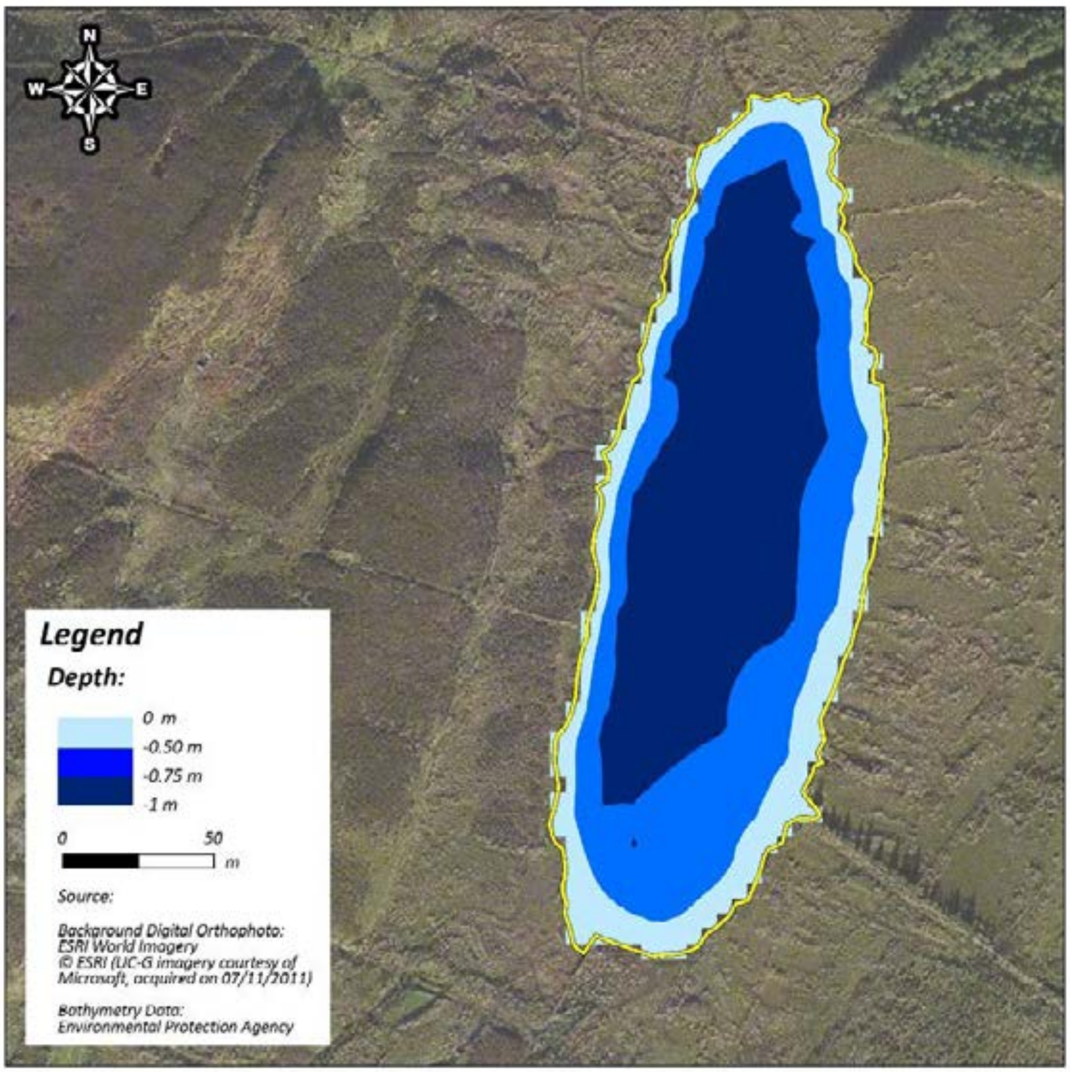


Figure A.29. Bathymetry (m).

Lough Kilsellagh	
Lake Name	Lough Kilsellagh
Lake Code	WE_35_17
Lake Area	0.04 km^2
Catchment Area	8.70 km^2
Easting	173,421
Northing	339,301

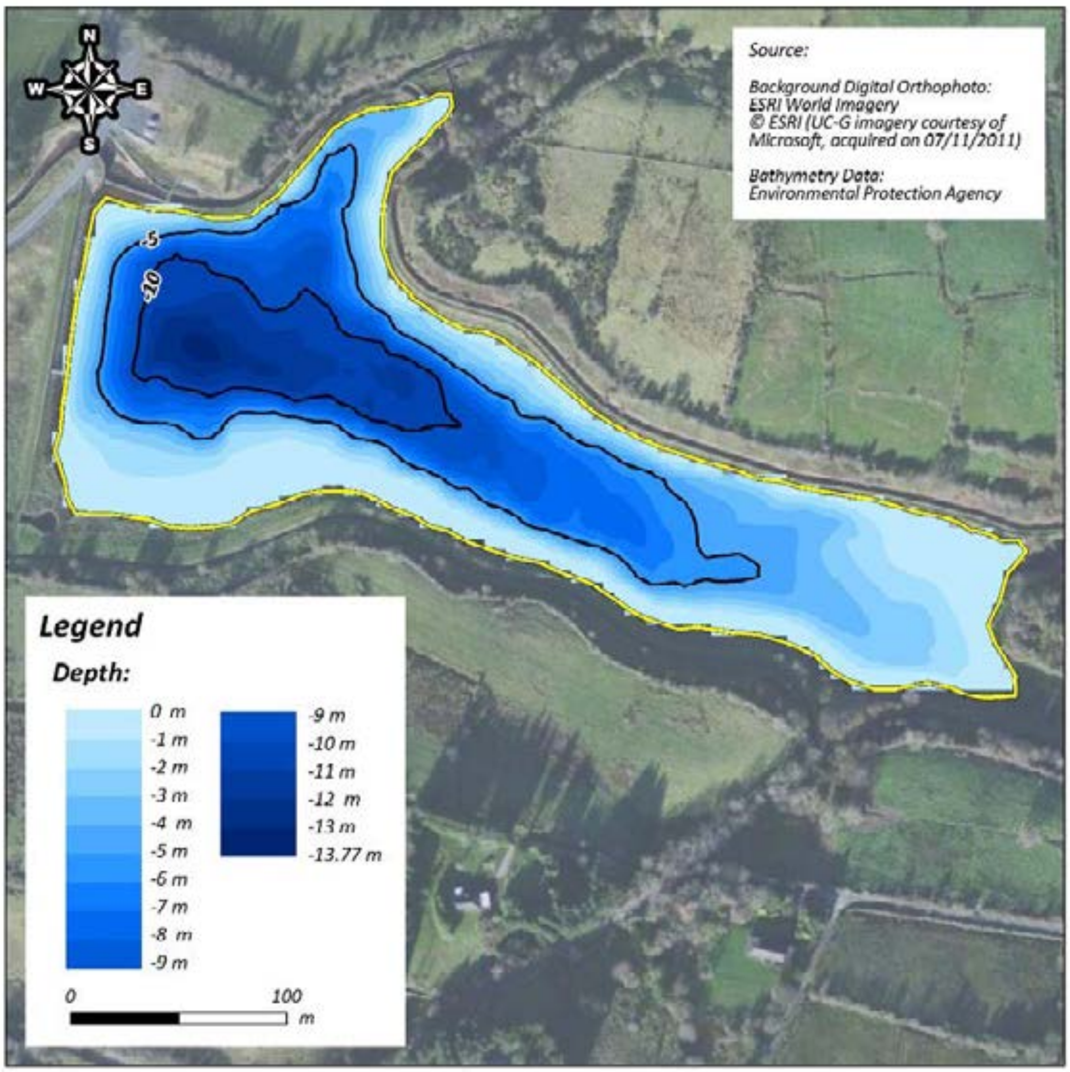


Figure A.30. Bathymetry (m).

Kilywilly Lough	
Lake Name	Kilywilly Lough
Lake Code	NW_36_513
Lake Area	0.56 km^2
Catchment Area	33.21 km^2
Easting	229,782
Northing	317,316

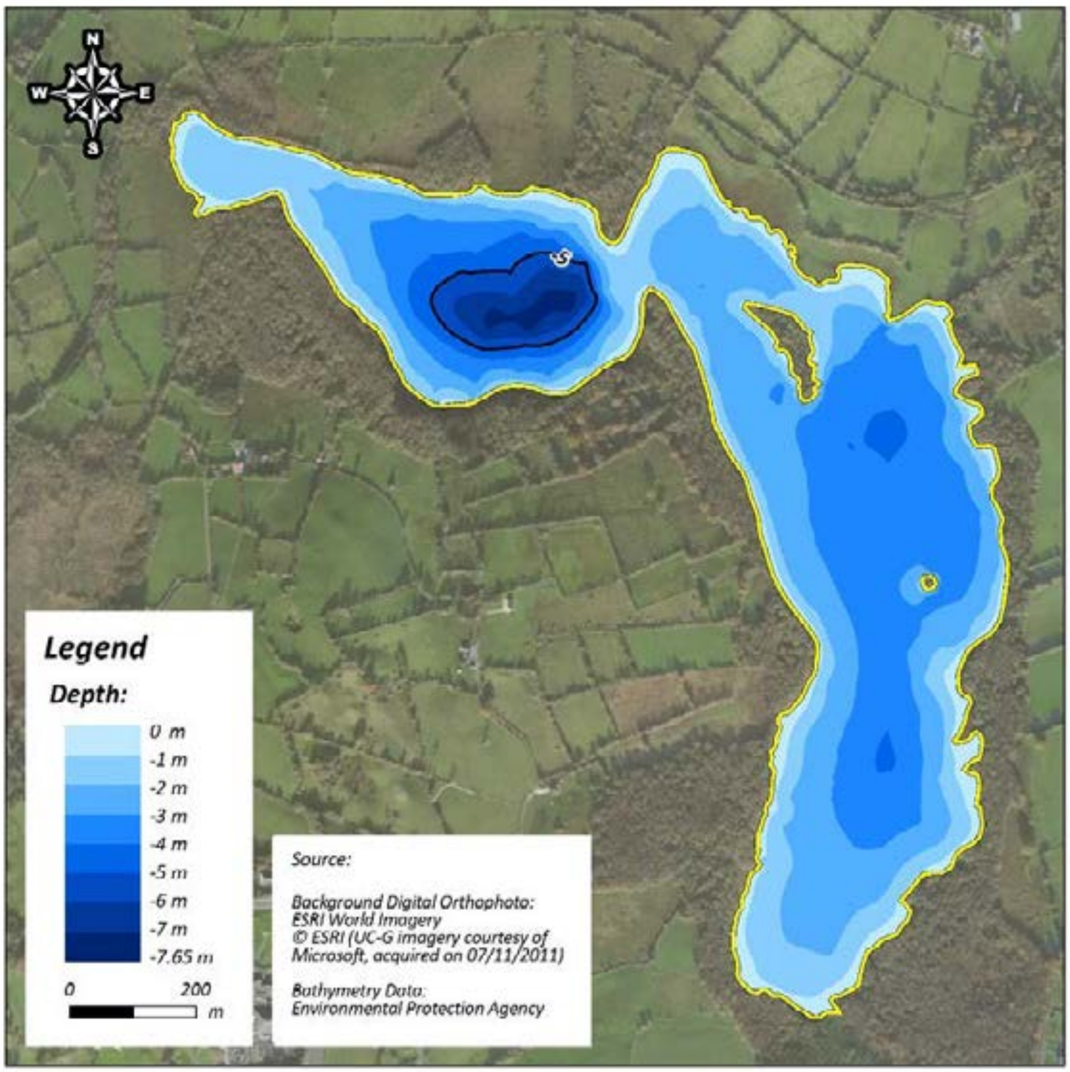


Figure A.31. Bathymetry (m).

Lackagh Lough	
Lake Name	Lackagh Lough
Lake Code	WE_35_96
Lake Area	0.07 km^2
Catchment Area	0.62 km^2
Easting	192,095
Northing	331,939

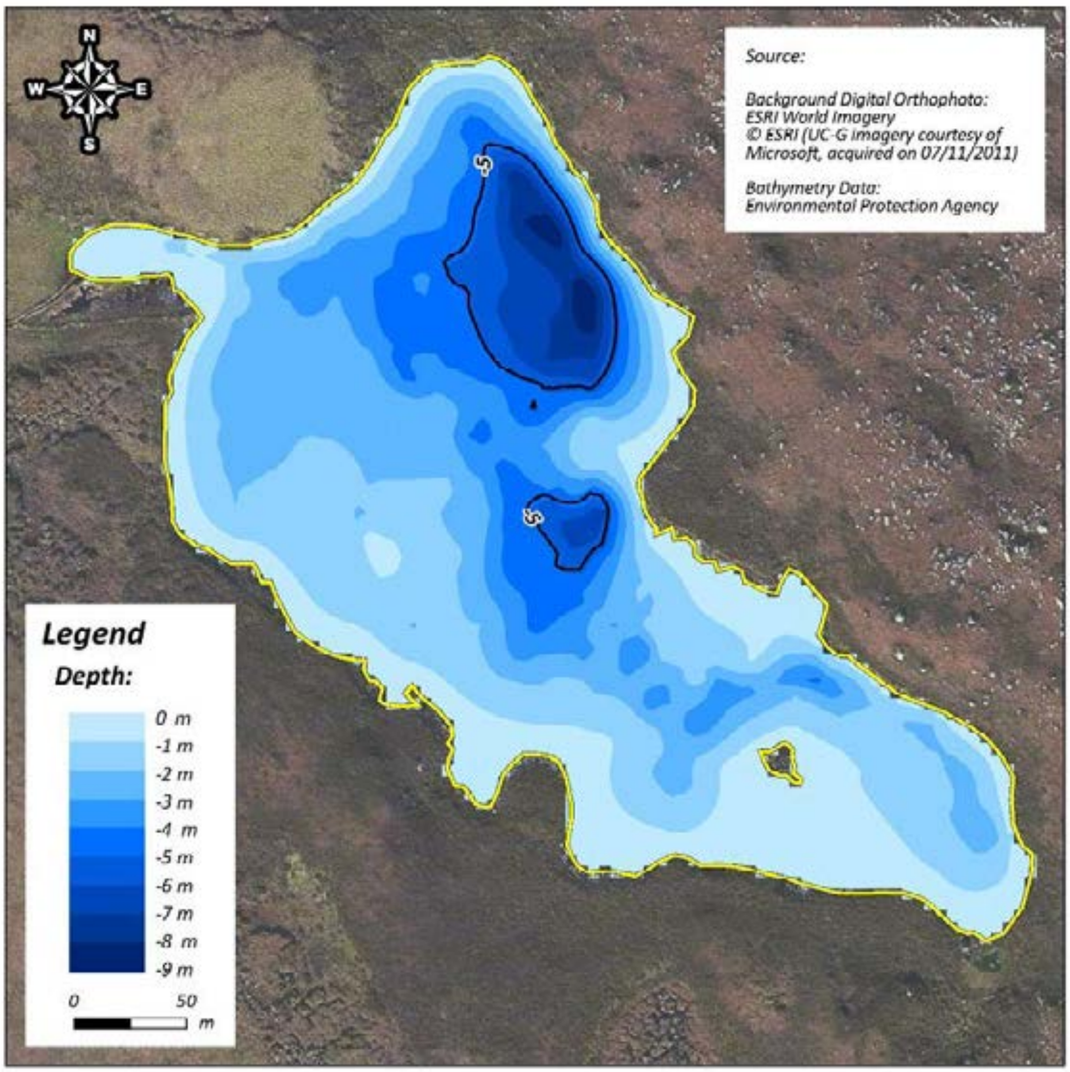


Figure A.32. Bathymetry (m).

Lattone Lough	
Lake Name	Lattone Lough
Lake Code	NI3NW0030
Lake Area	0.31 km^2
Catchment Area	9.01 km^2
Easting	200,041
Northing	345,401

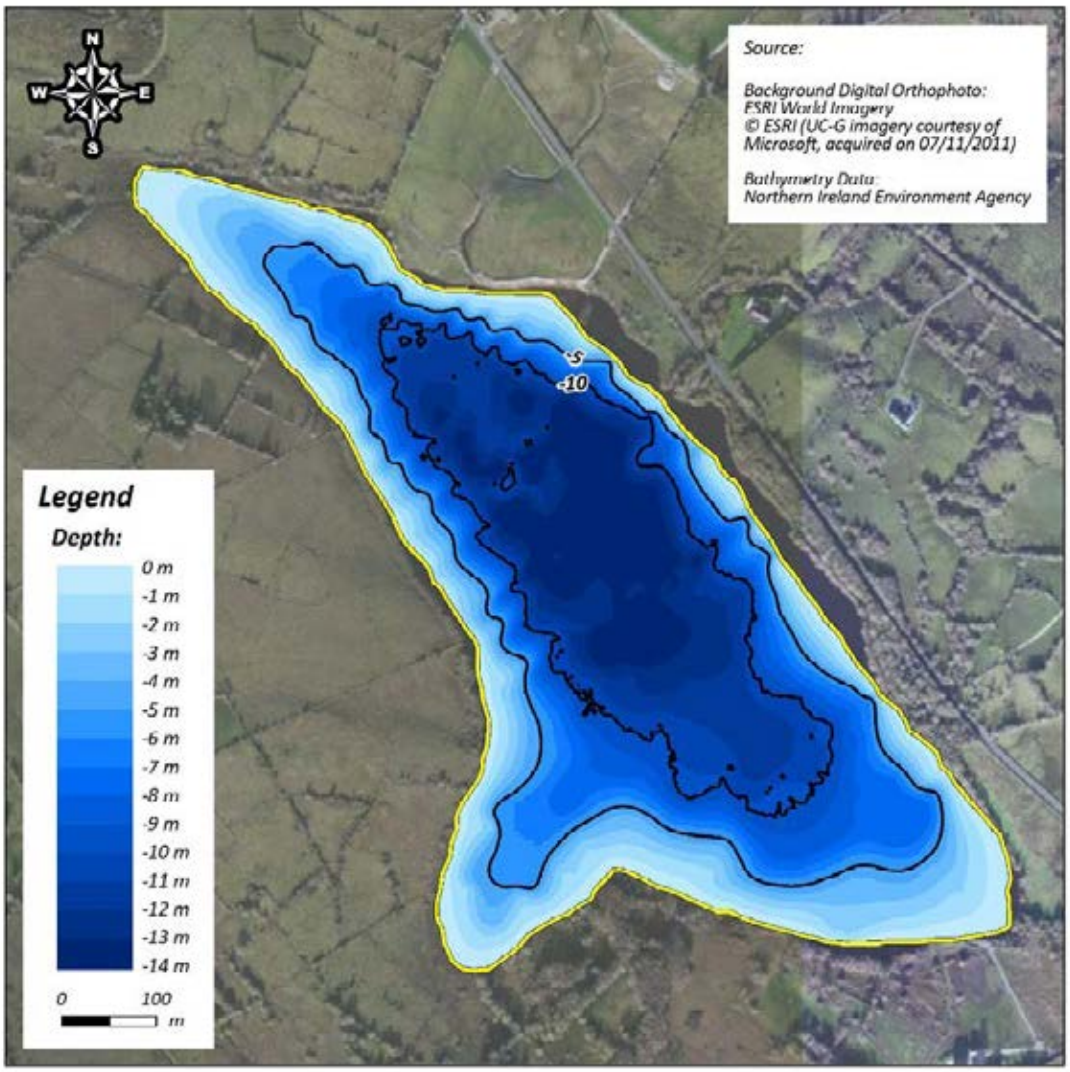


Figure A.33. Bathymetry (m).

Lough Macnean Lower

Lake Name	Lough Macnean Lower
Lake Code	NI3NW0014
Lake Area	4.44 km^2
Catchment Area	185.22 km^2
Easting	210,910
Northing	337,790

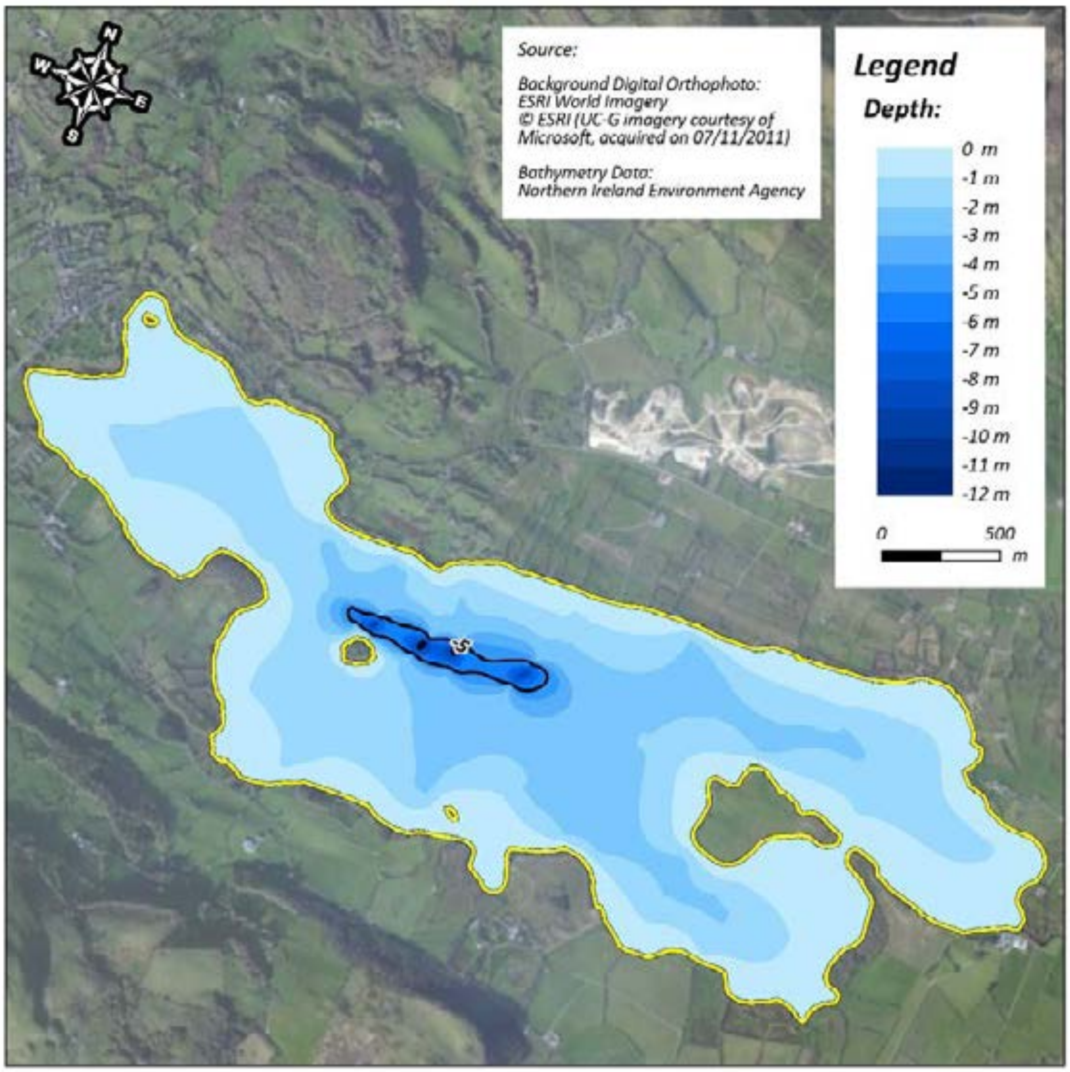


Figure A.34. Bathymetry (m)

Hydrometrics		
Station Name	Lough Macnean	
Station Number	236004	
Status	Active	
Type	Recorder	
Temporal Range	2014-2015	
Easting	213,147	
Northing	337,495	

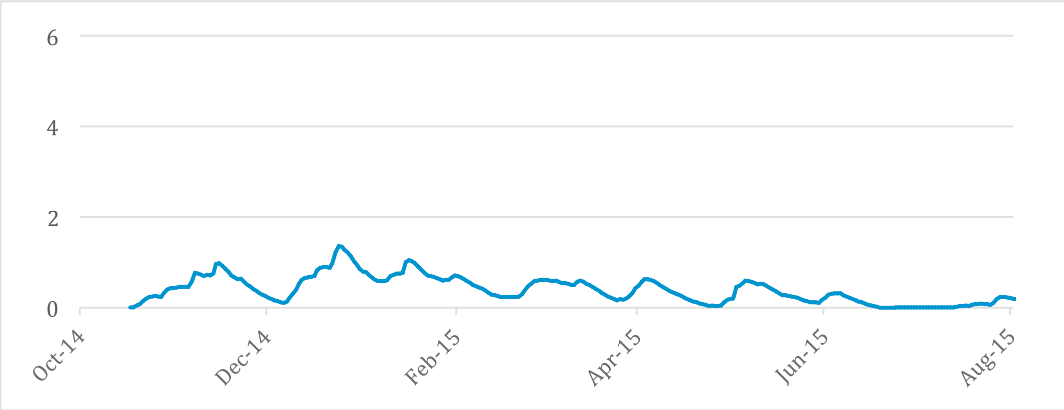


Figure A.35. Levels (m).

Lough Macnean Upper	
Lake Name	Lough Macnean Upper
Lake Code	NI3NW0011
Lake Area	9.91 km^2
Catchment Area	149.23 km^2
Easting	203,860
Northing	339,772

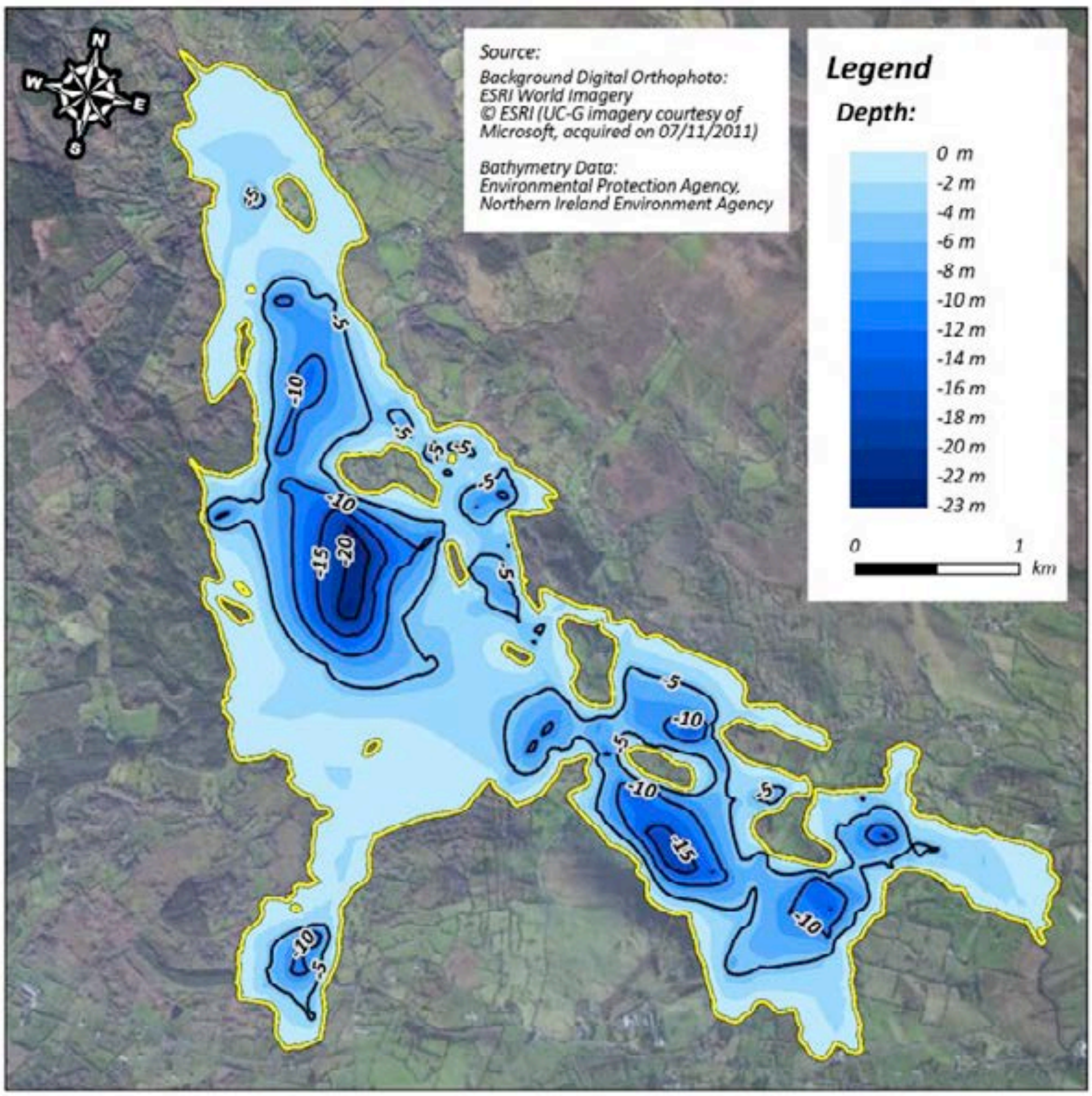


Figure A.36. Bathymetry (m).

Lough Meelagh

Lake Name	Lough Meelagh
Lake Code	SH_26_711
Lake Area	1.16 km^2
Catchment Area	7.86 km^2
Easting	189,010
Northing	312,066

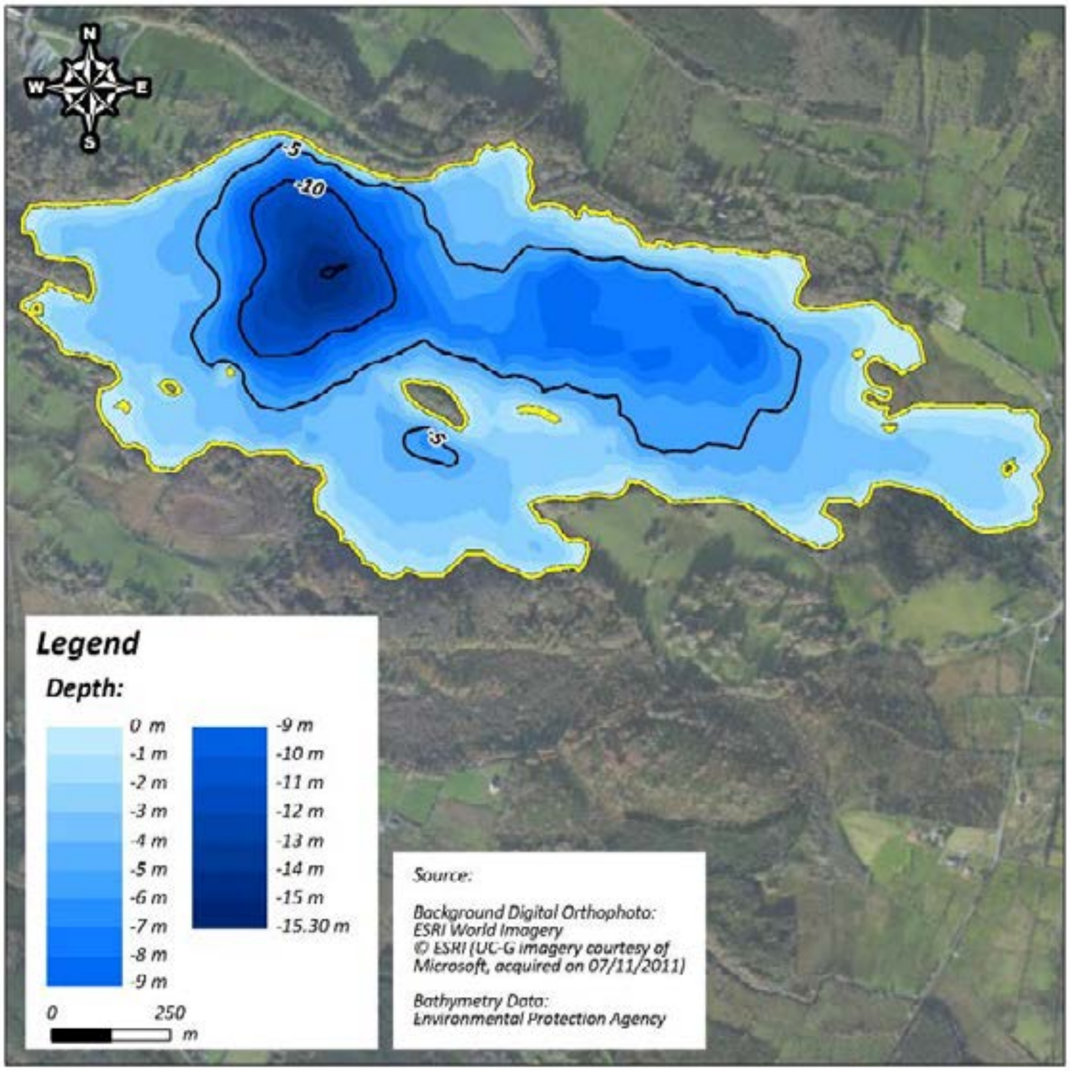


Figure A.37. Bathymetry (m).

Lough Melvin

Lake Name	Lough Melvin	
Lake Code	NW_35_160	
Lake Area	22.06 km^2	
Catchment Area	248.49 km^2	
Easting	189,476	
Northing	353,429	

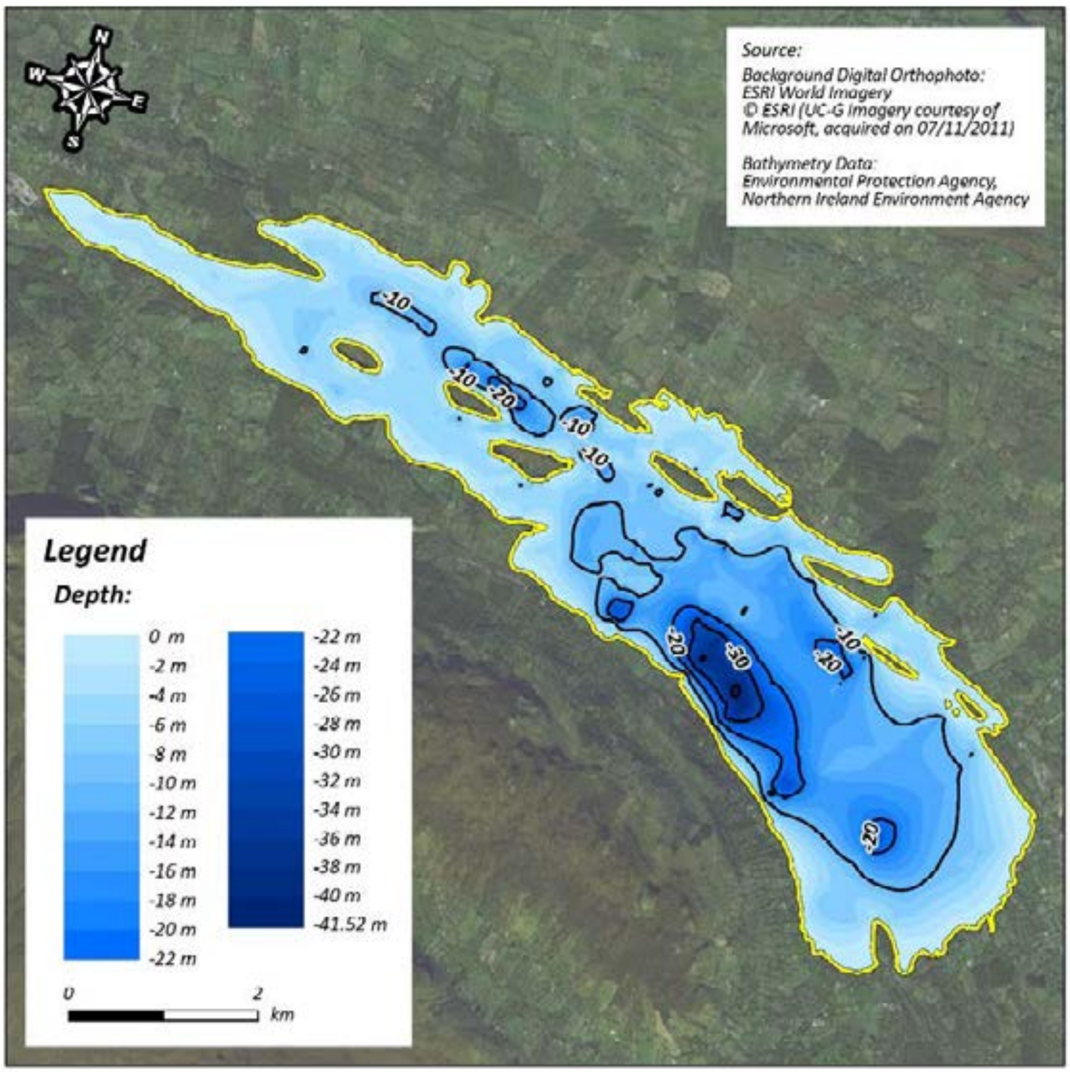


Figure A.38. Bathymetry (m).

Hydrometrics		
Station Name	Lareen	
Station Number	35071	
Status	Active	
Type	Recorder	
Temporal Range	1975-2003/1975-2010	
Easting	184,504	
Northing	355,971	

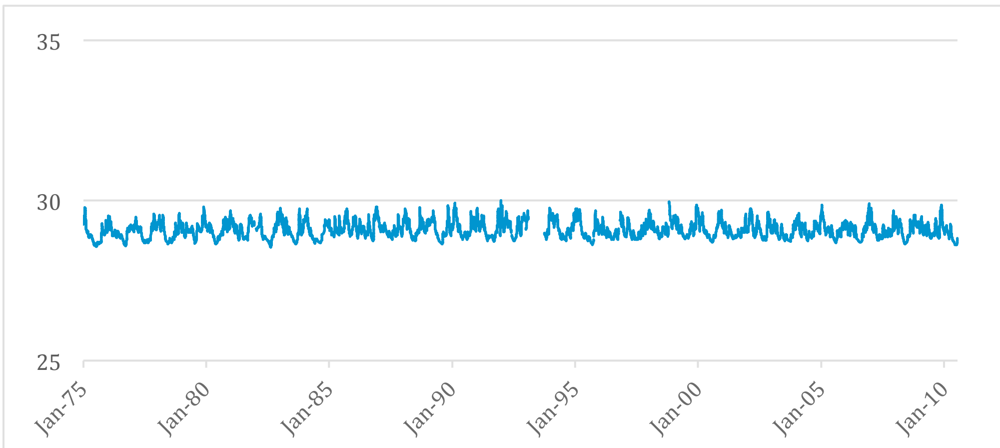


Figure A.39. Levels (m).

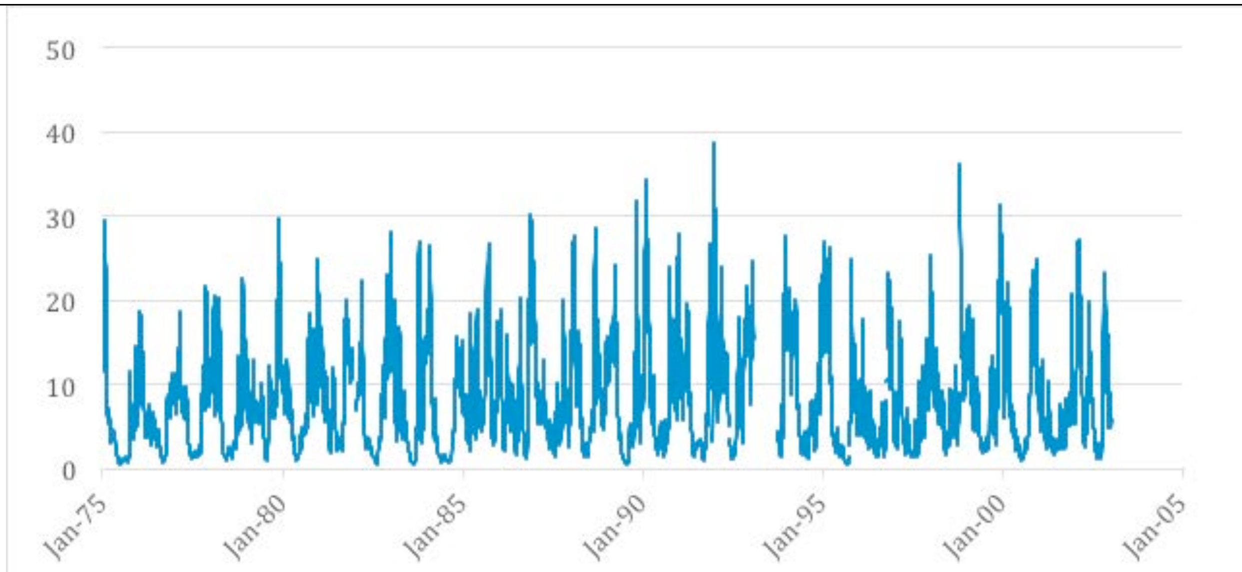


Figure A.40. Flow (m^3/s).

Lough Nabellbegh		
Lake Name	Lough Nabellbeg	
Lake Code	NW_36_201	
Lake Area	0.01 km^2	
Catchment Area	0.19 km^2	
Easting	203,267	
Northing	316,931	

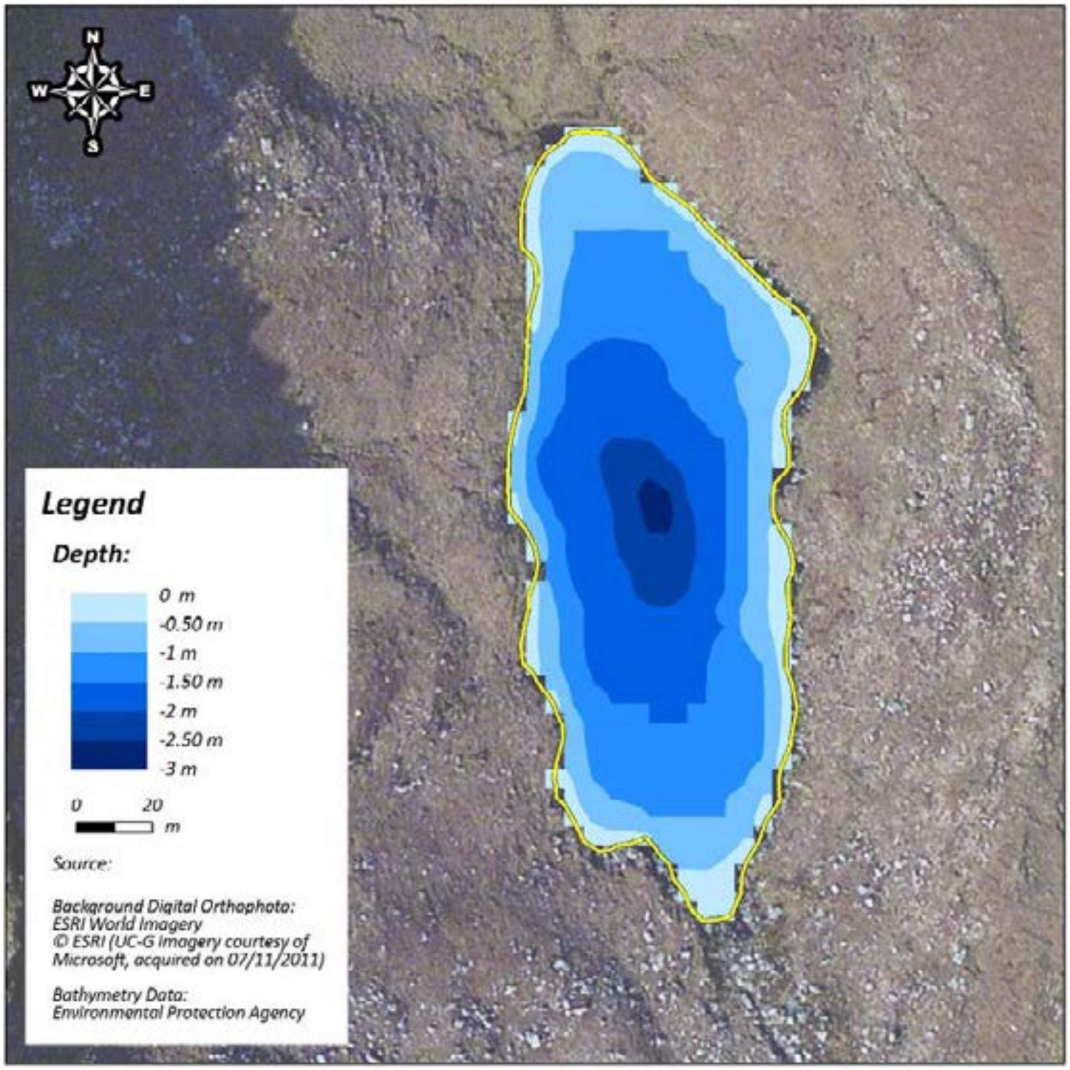


Figure A.41. Bathymetry (m).

Nacroagh Lough		
Lake Name	Nacroagh Lough	
Lake Code	WE_35_188	
Lake Area	0.004 km^2	
Catchment Area	0.07 km^2	
Easting	184,531	
Northing	323,495	

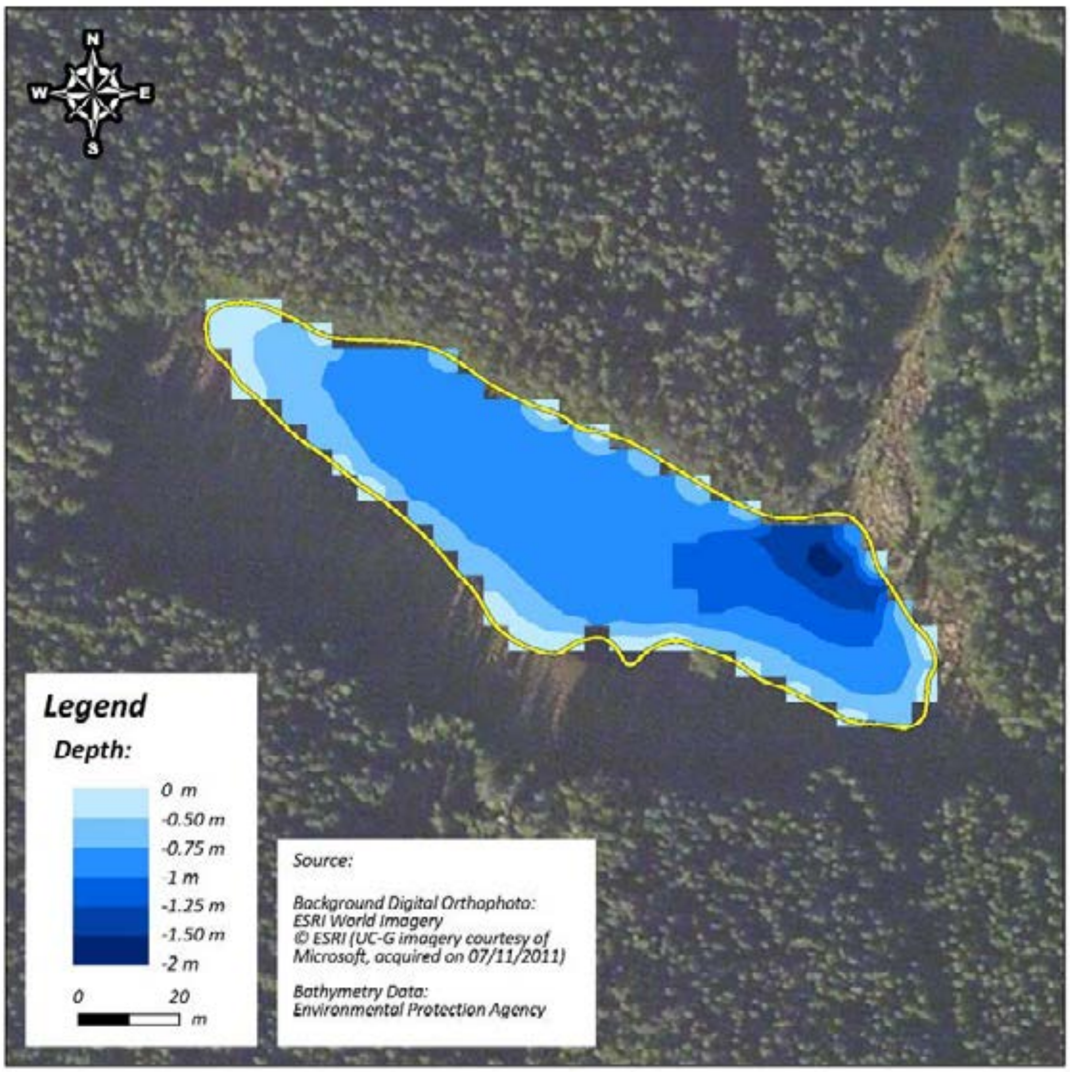


Figure A.42. Bathymetry (m).

Lough Natire	
Lake Name	Lough Natire
Lake Code	SH_26_410
Lake Area	0.06 km^2
Catchment Area	1.14 km^2
Easting	196,766
Northing	333,988

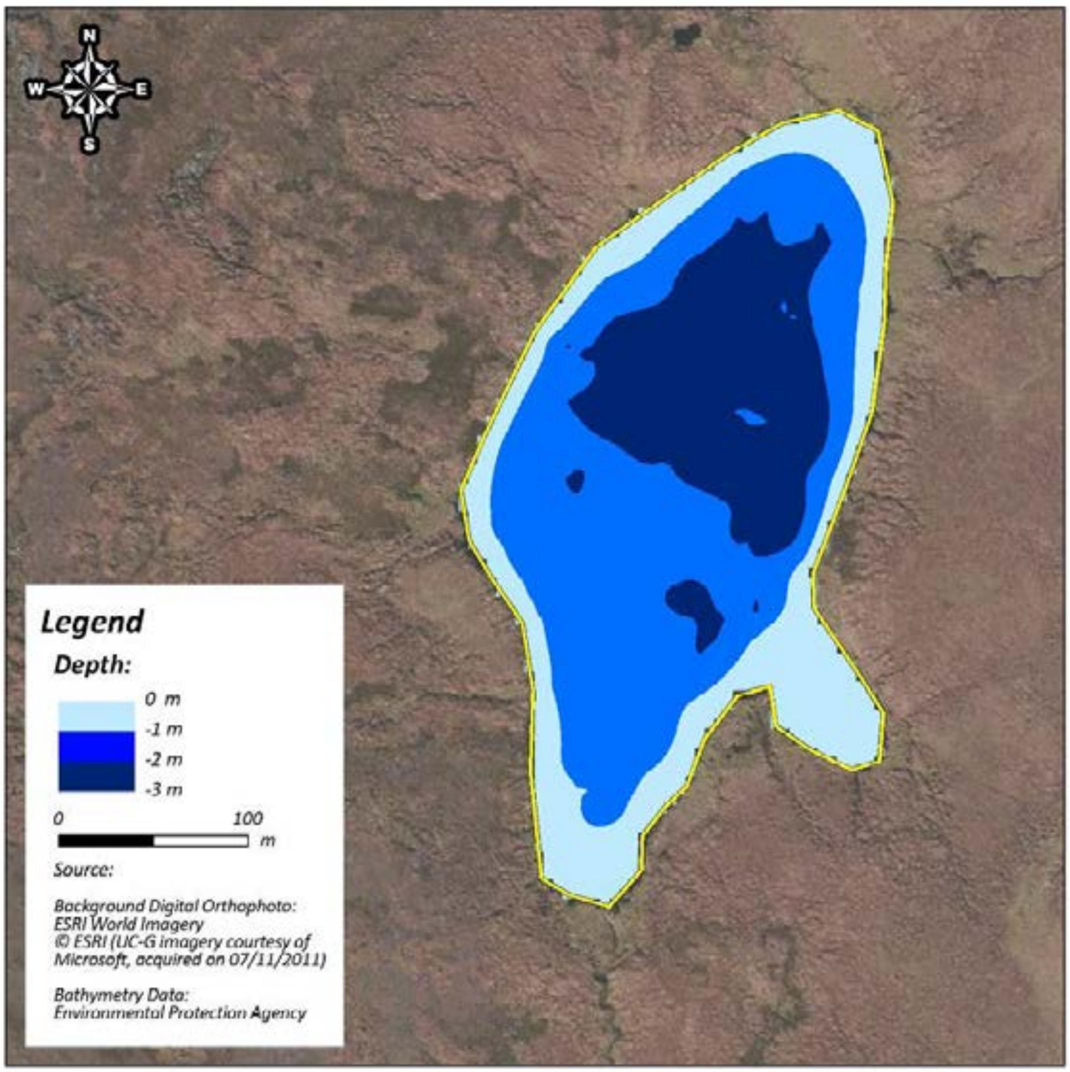


Figure A.43. Bathymetry (m).

Lough Naweleian	
Lake Name	Lough Naweleian
Lake Code	SH_26_411
Lake Area	0.05 km^2
Catchment Area	0.52 km^2
Easting	199,101
Northing	332,827

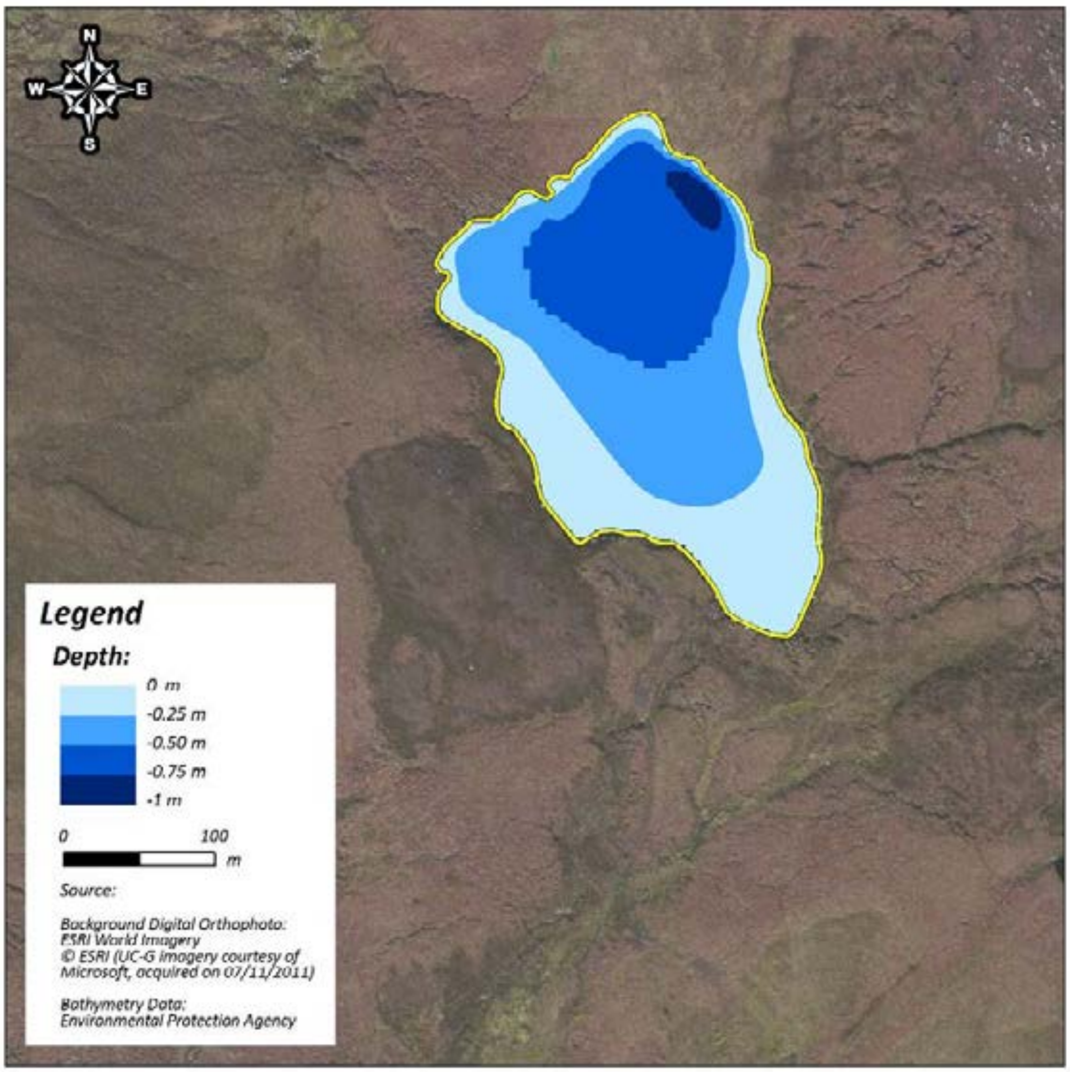


Figure A.44. Bathymetry (m).

Lough Scolban		
Lake Name	Lough Scolban	
Lake Code	NI3NW0022	
Lake Area	0.66 km^2	
Catchment Area	13.69 km^2	
Easting	199,620	
Northing	360,610	

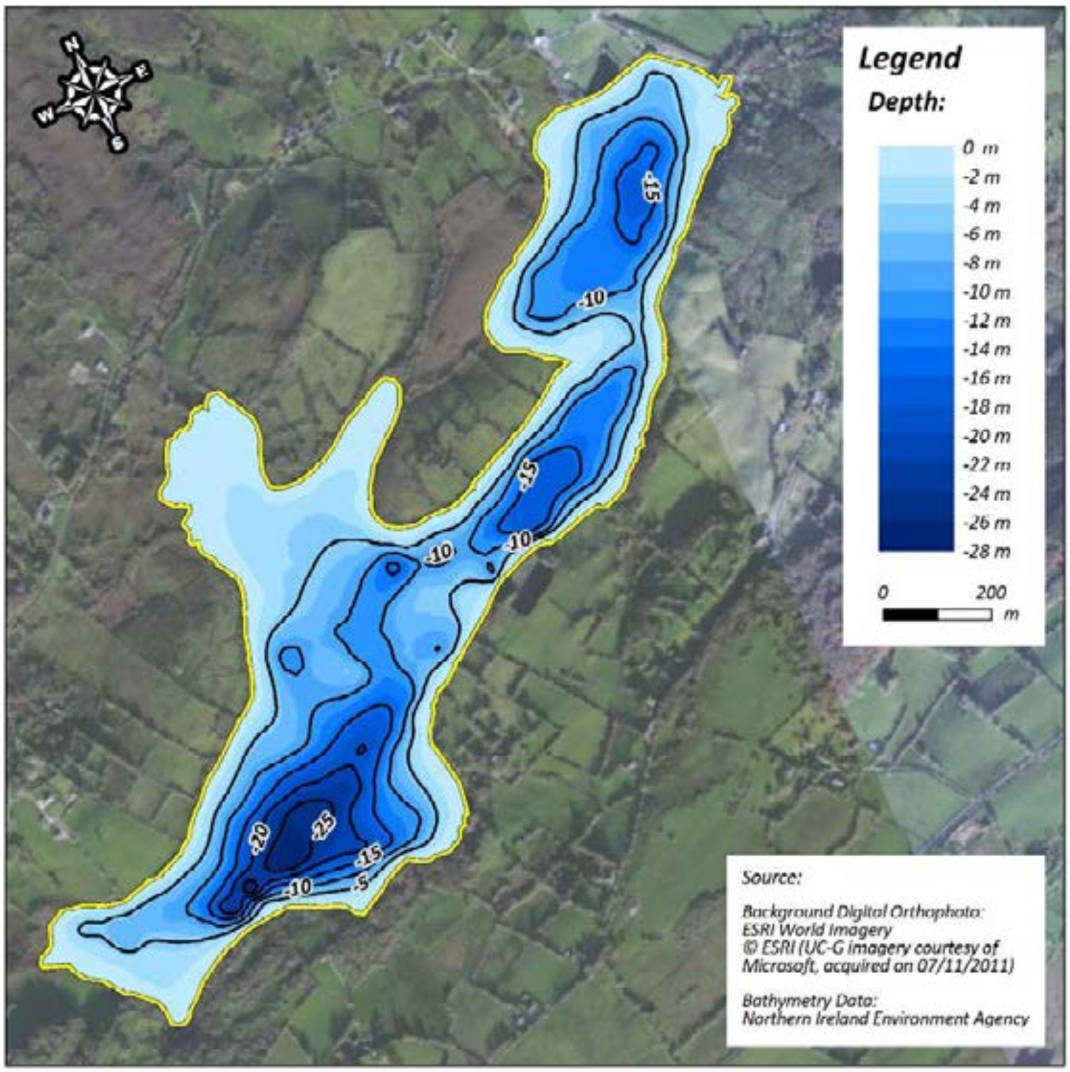


Figure A.45. Bathymetry (m).

<table>
<tr><th colspan="2">Lough Skean</th></tr>
<tr><td>Lake Name: Lough Skean
Lake Code: SH_26_673
Lake Area: 1.14 km^2
Catchment Area: 14.35 km^2
Easting: 185,888
Northing: 312,487</td><td>
</td></tr>
</table>

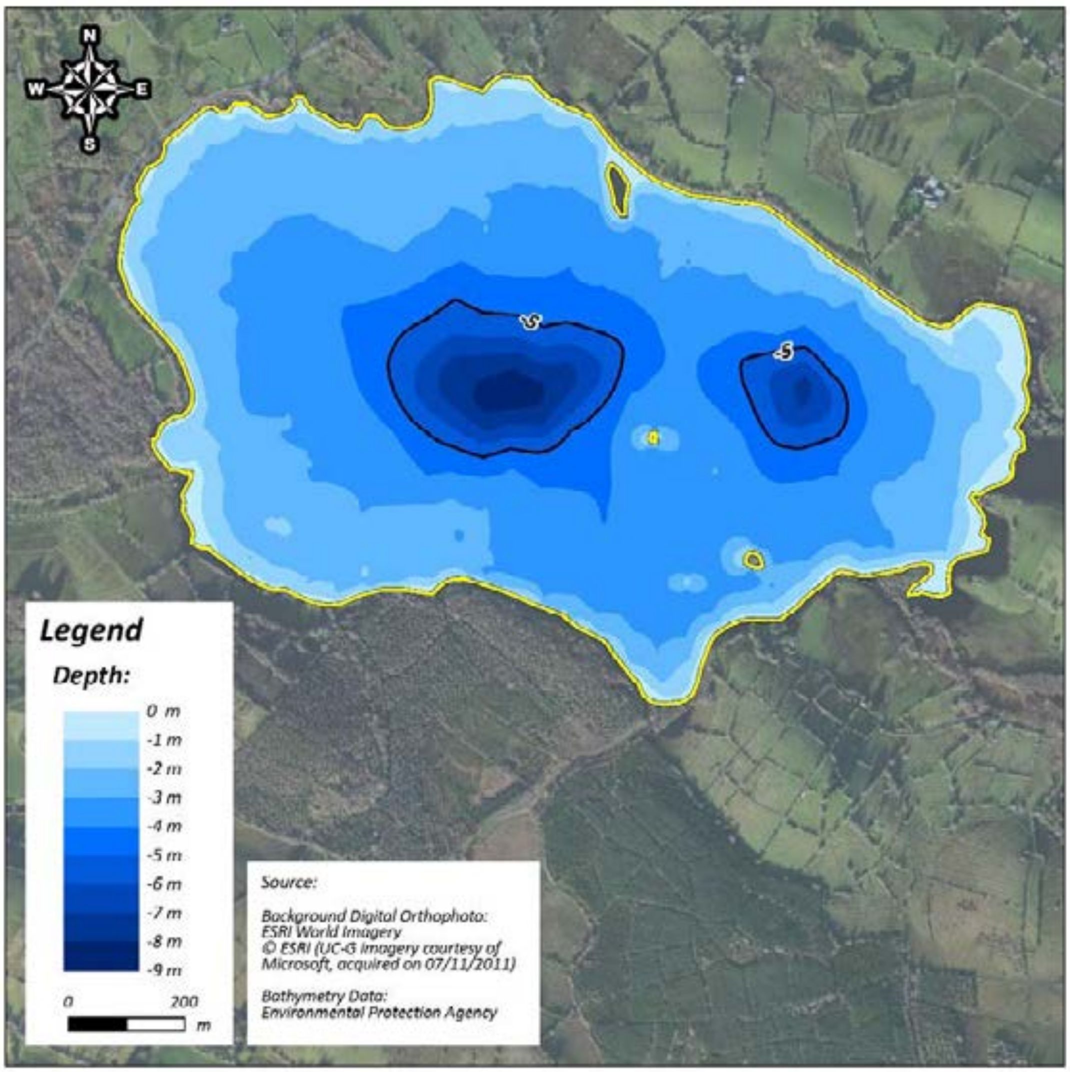


Figure A.46. Bathymetry (m).

Hydrometrics		
Station Name	Creevagh	
Station Number	26094	
Status	Inactive	
Type	Recorder	
Temporal Range	2005-2009	
Easting	185,140	
Northing	312,810	

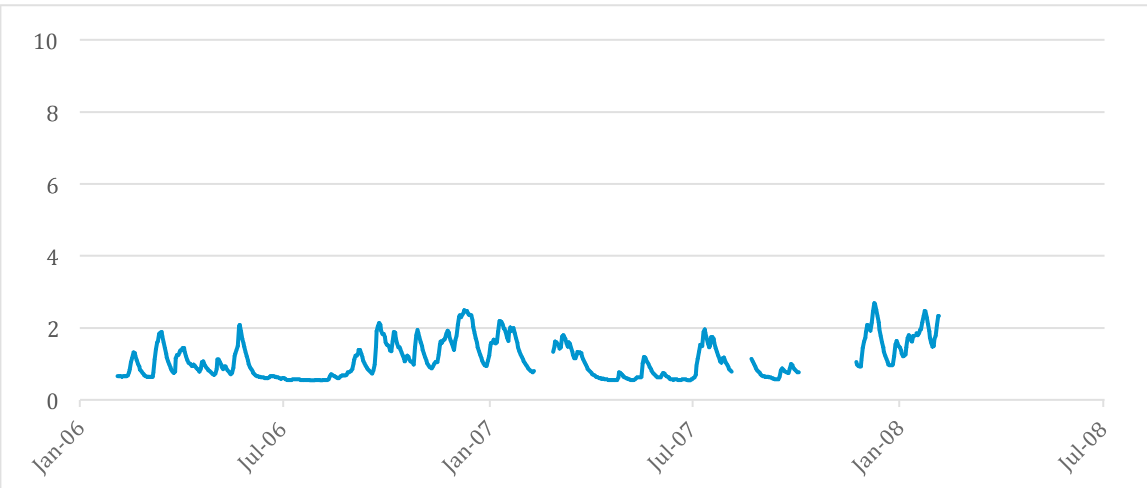


Figure A.47. Levels (m).

St. John's Lough	
Lake Name	St. John's Lough
Lake Code	NW_36_642
Lake Area	1.46 km^2
Catchment Area	101.7 km^2
Easting	208,633
Northing	310,337

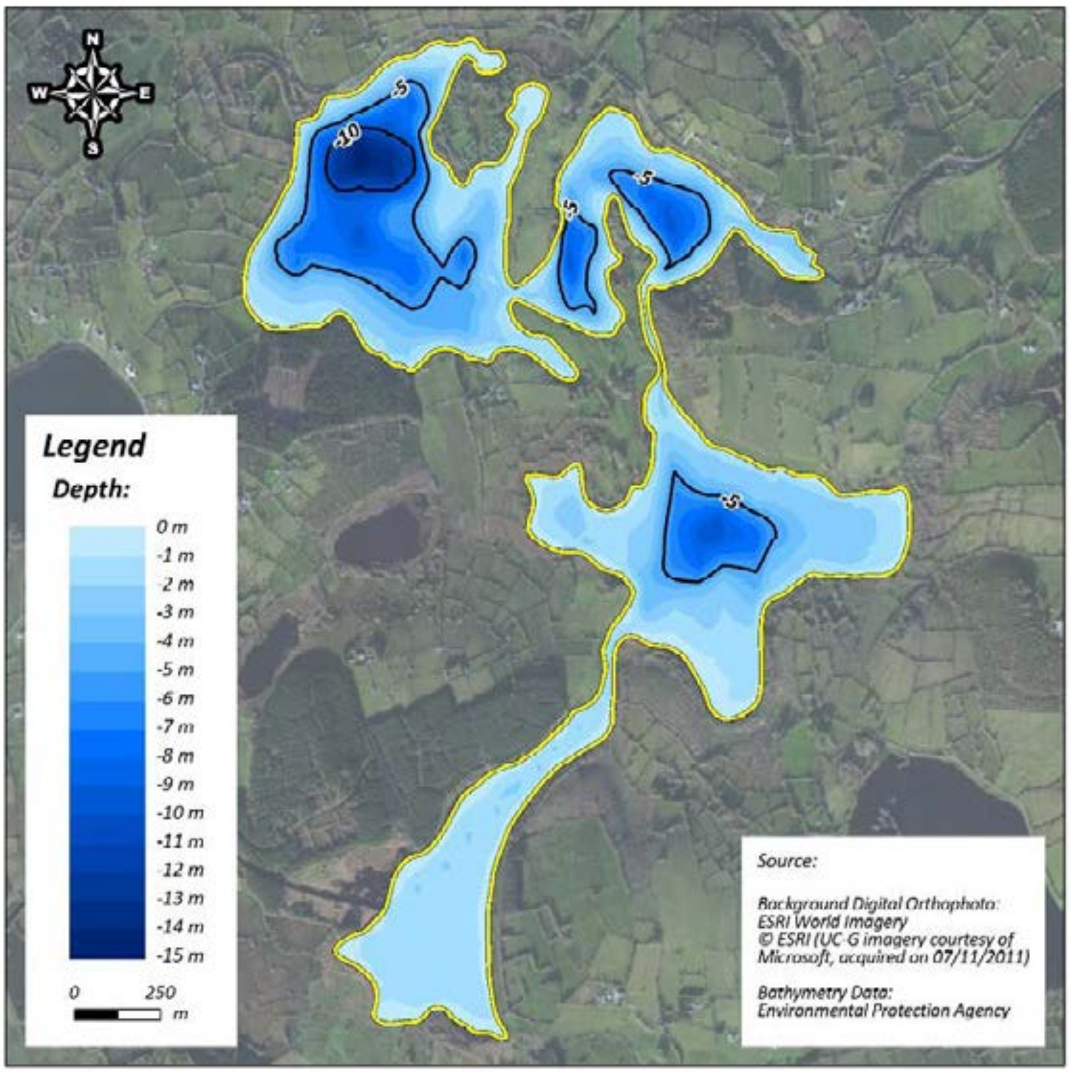


Figure A.48. Bathymetry (m).

Hydrometrics	
Station Name	Wood Island
Station Number	36073
Status	Active
Type	Recorder
Temporal Range	1974-2002
Easting	208,746
Northing	311,171

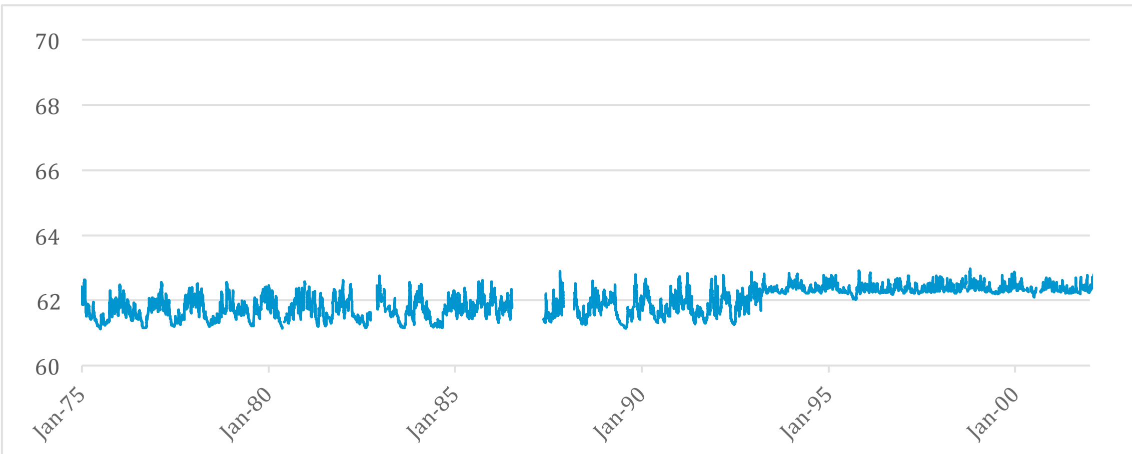


Figure A.49. Levels (m).

Doo Lough		
Lake Name	Doo Lough	
Lake Code	SH_28_82	
Lake Area	1.30 km^2	
Catchment Area	23.55 km^2	
Easting	112,032	
Northing	172,061	

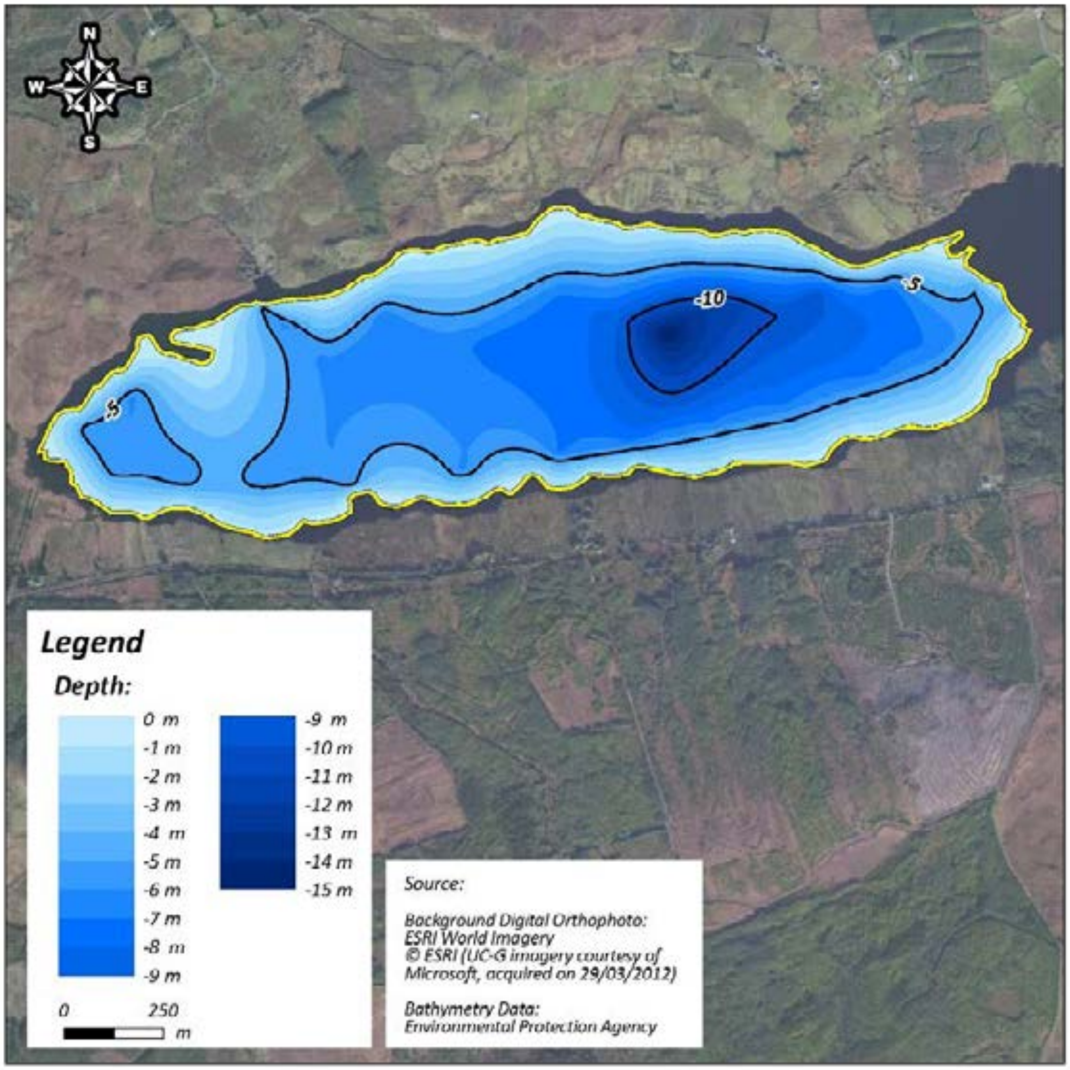


Figure A.50. Bathymetry (m).

Lough Naminna

Lake Name	Lough Naminna
Lake Code	SH_28_87
Lake Area	0.20 km^2
Catchment Area	0.91 km^2
Easting	117,702
Northing	170,992

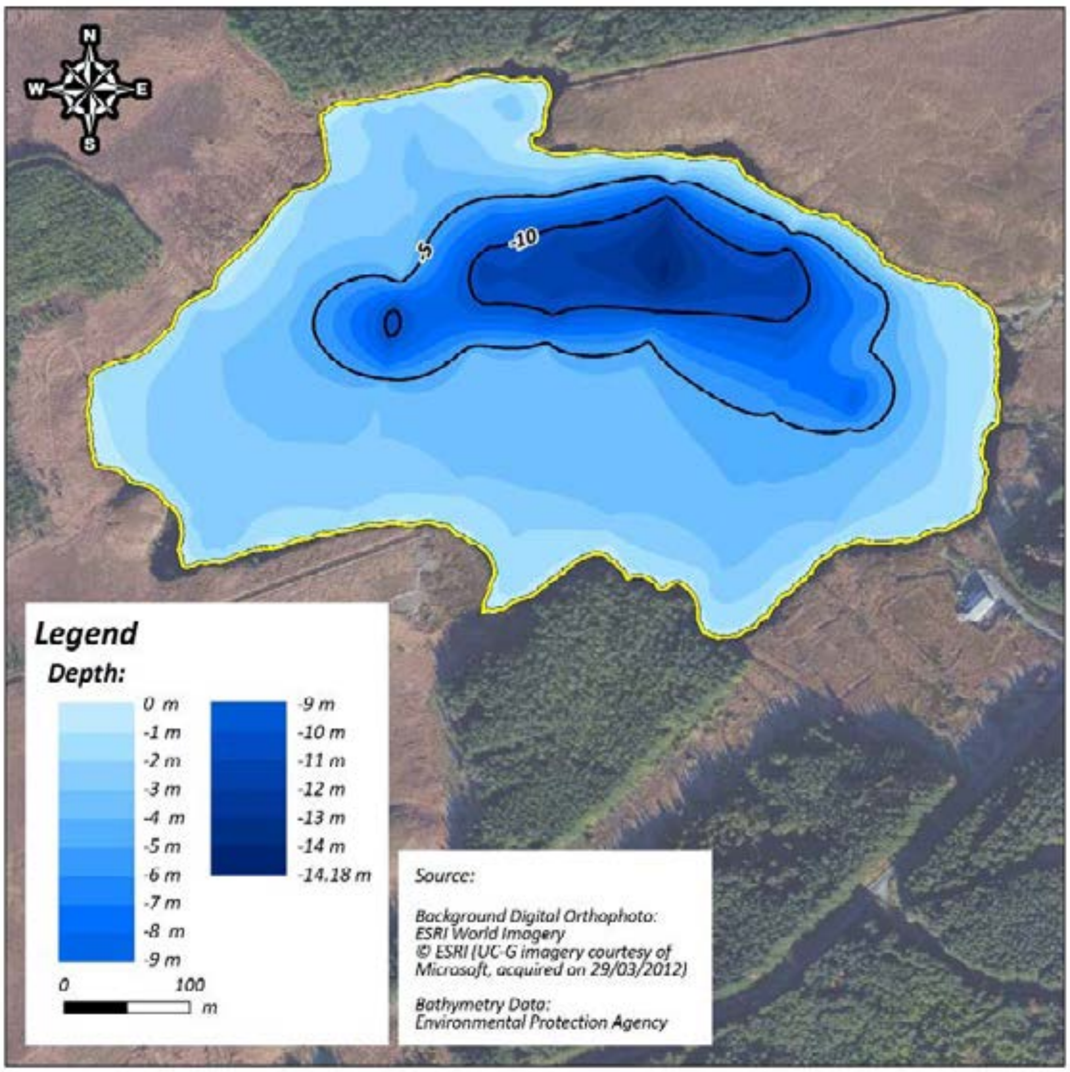


Figure A.51. Bathymetry (m).

Attachment B

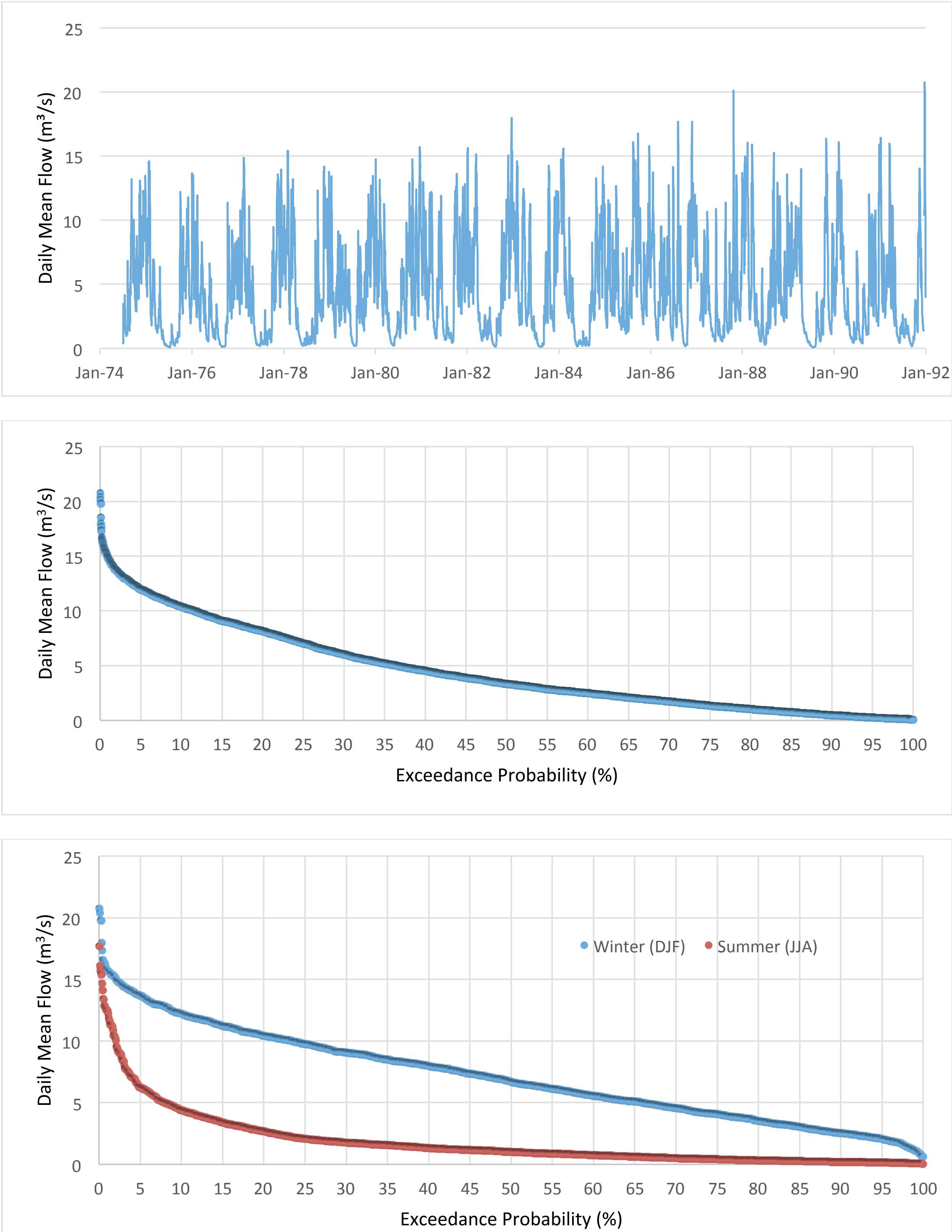


Figure B.1. Hydrograph and flow duration curve – Aghoo (36028).

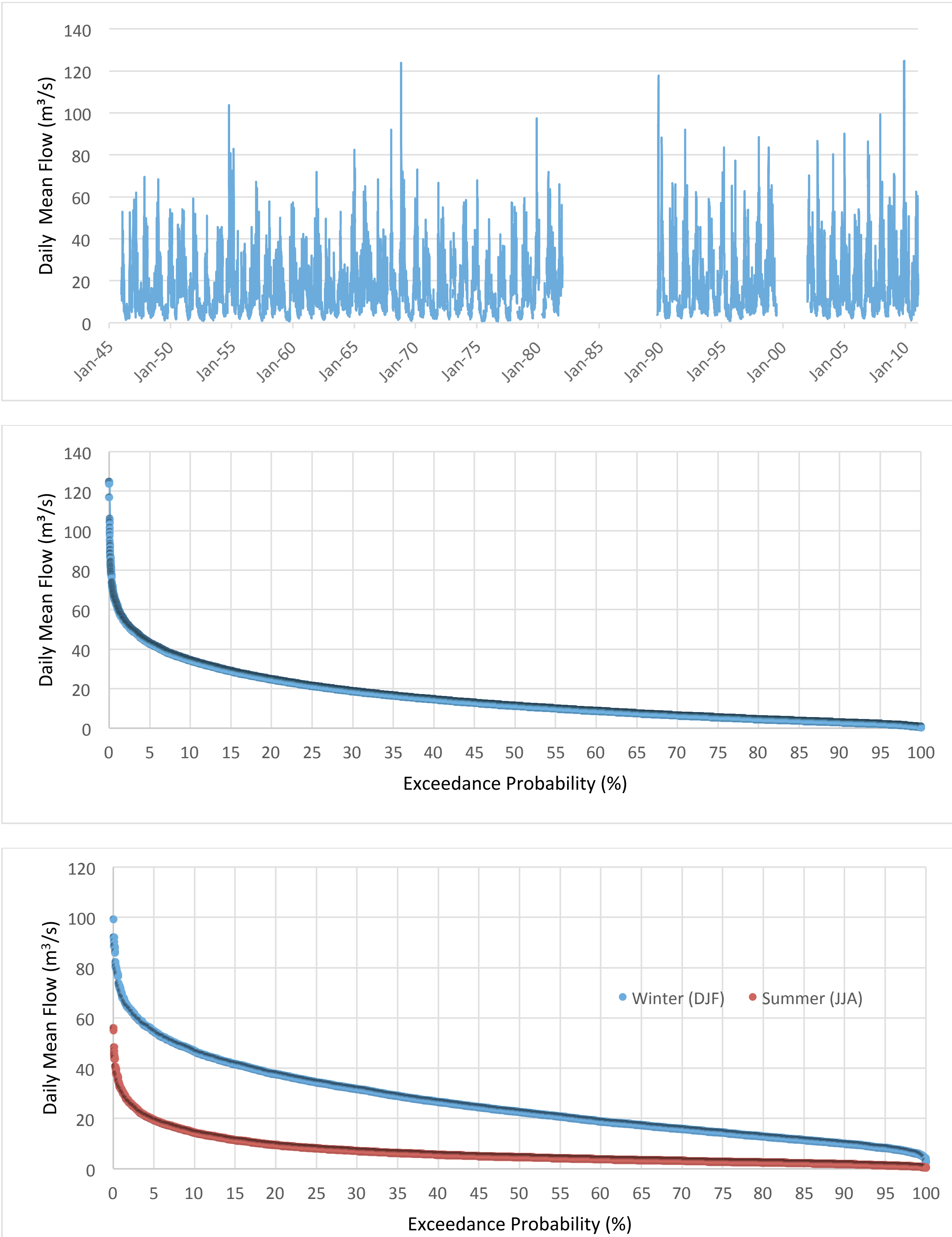


Figure B.2. Hydrograph and flow duration curve – Ballysadare (35005).

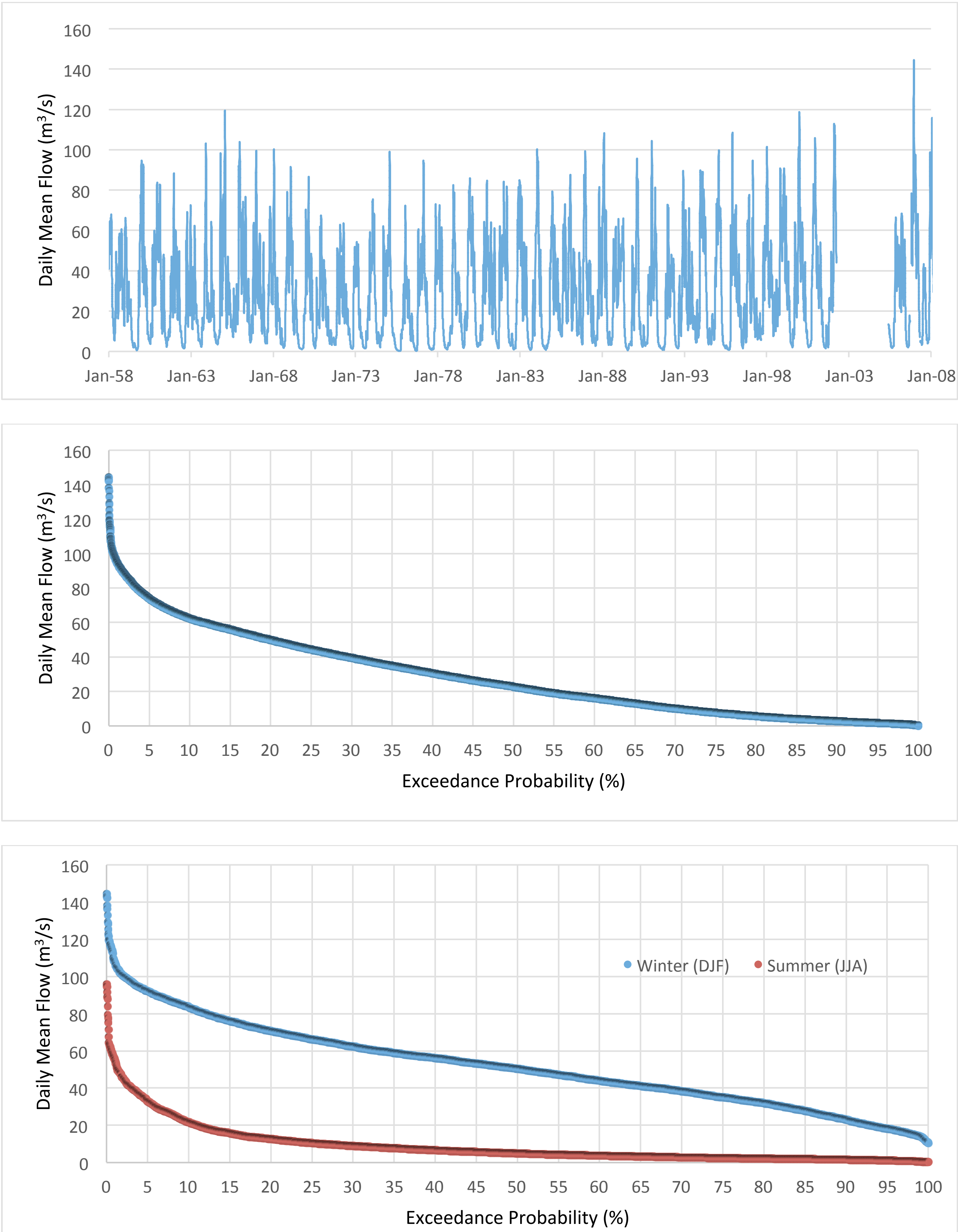


Figure B.3. Hydrograph and flow duration curve – Belturbet (36019).

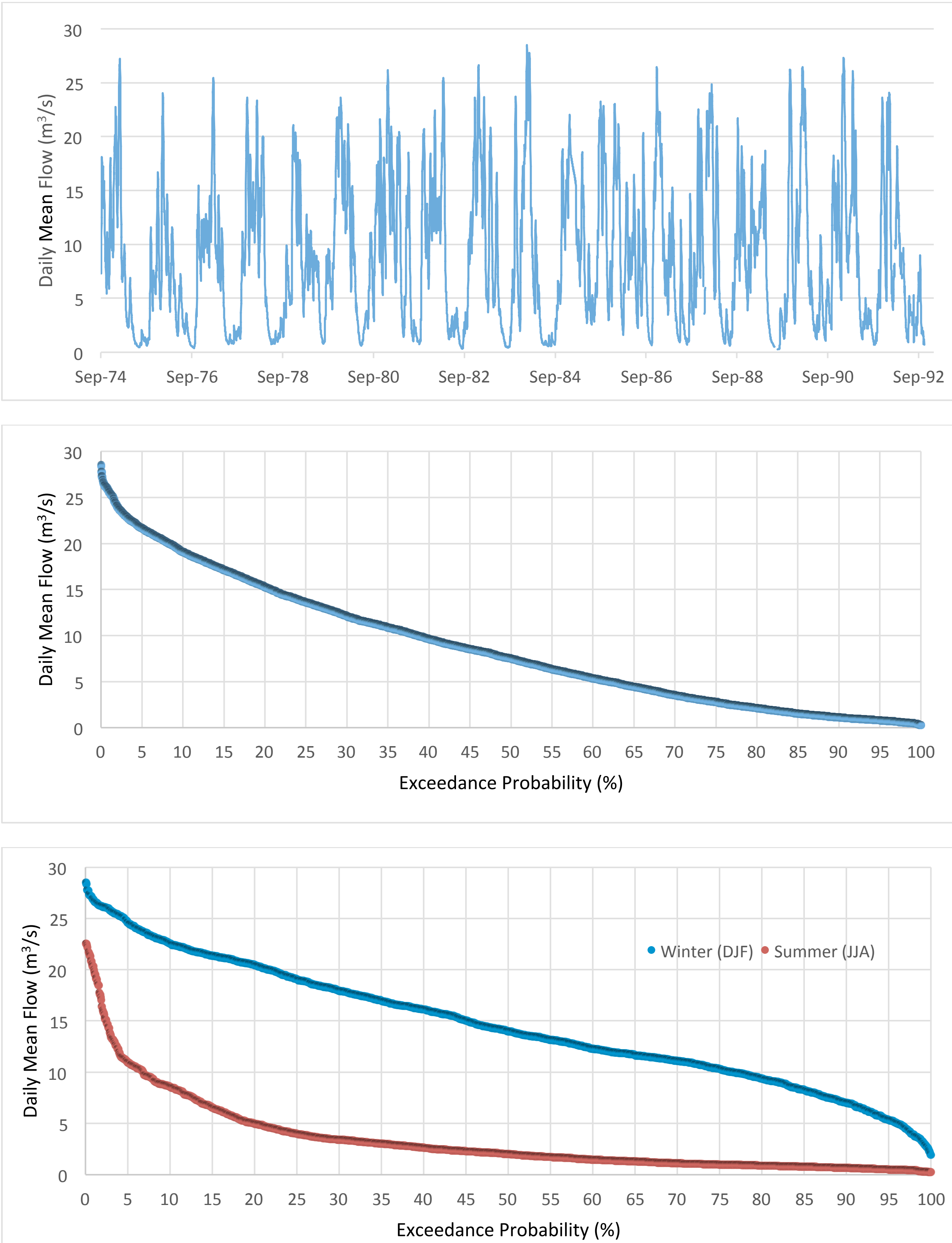


Figure B.4. Hydrograph and flow duration curve – Bellaheady (36027).

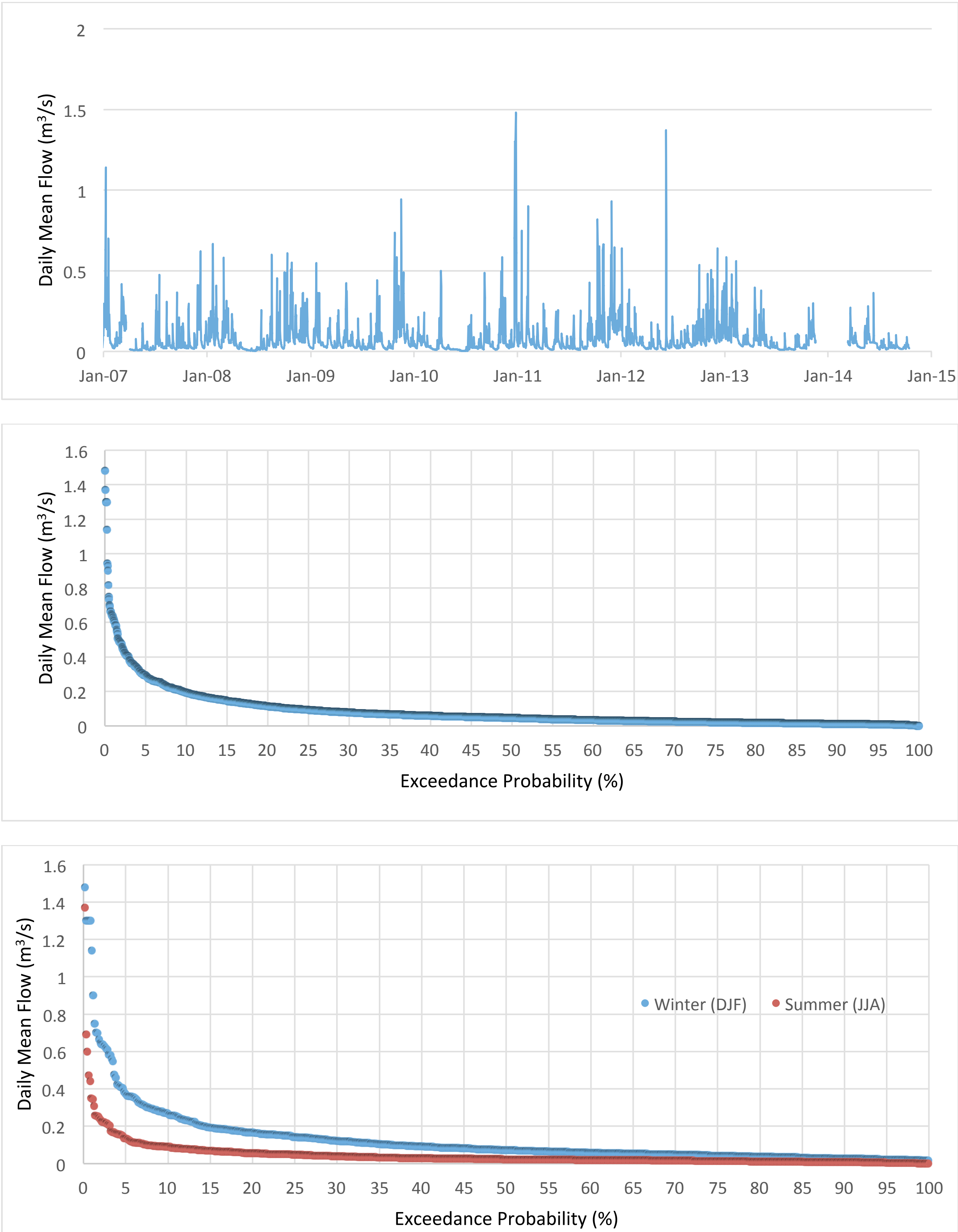
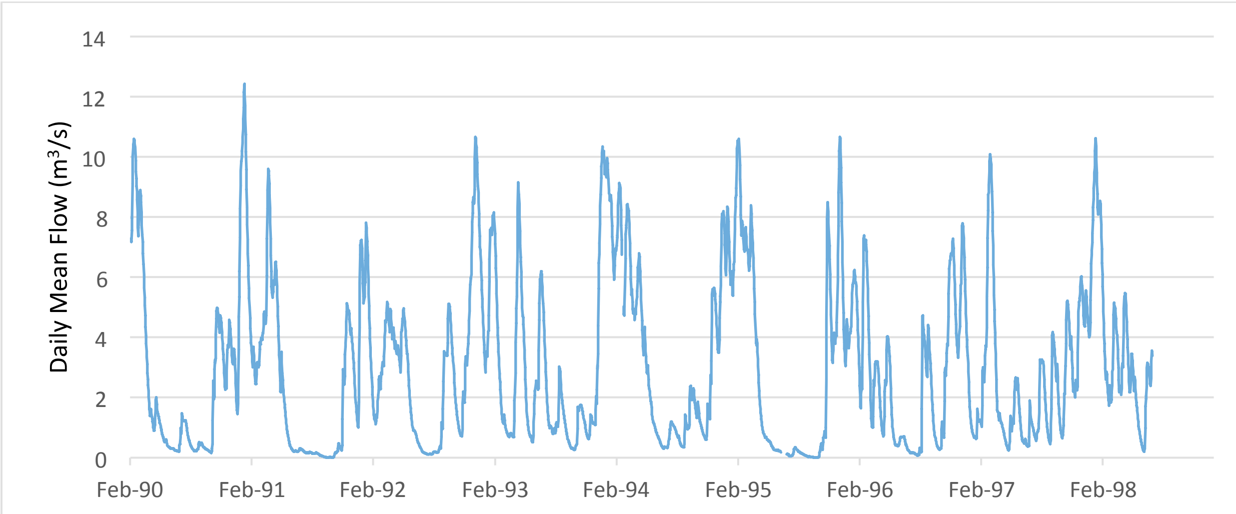
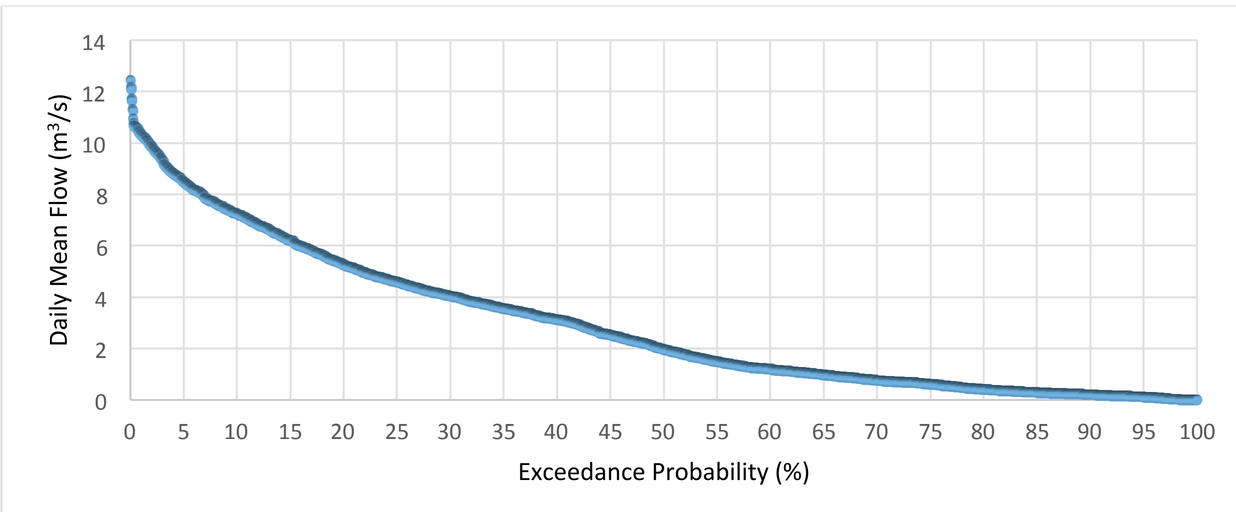


Figure B.5. Hydrograph and flow duration curve – Bomahas (35053).





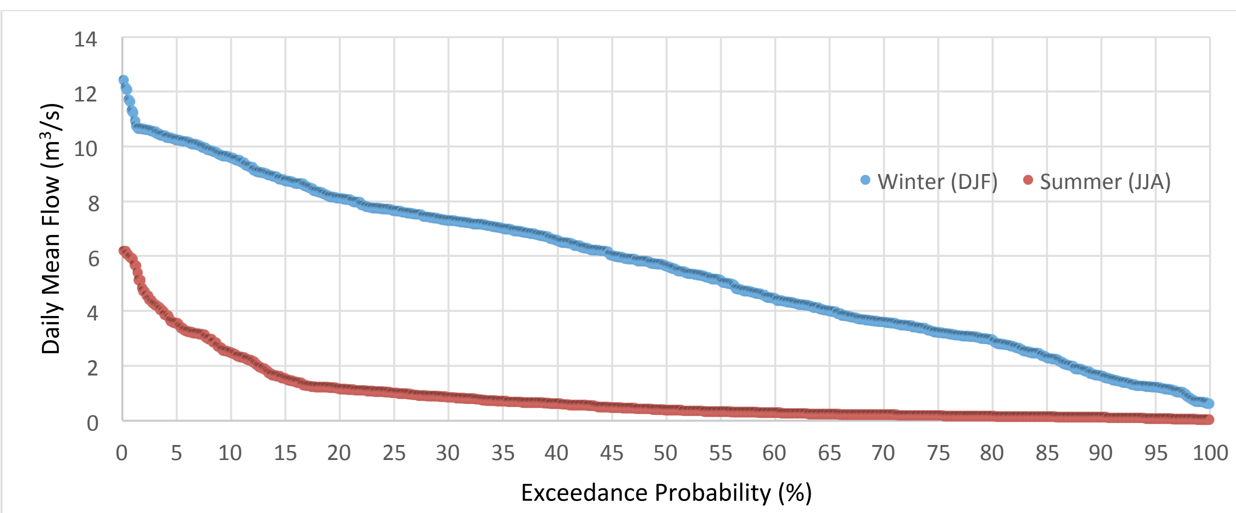


Figure B.6. Hydrograph and flow duration curve – Derreskit (36013).

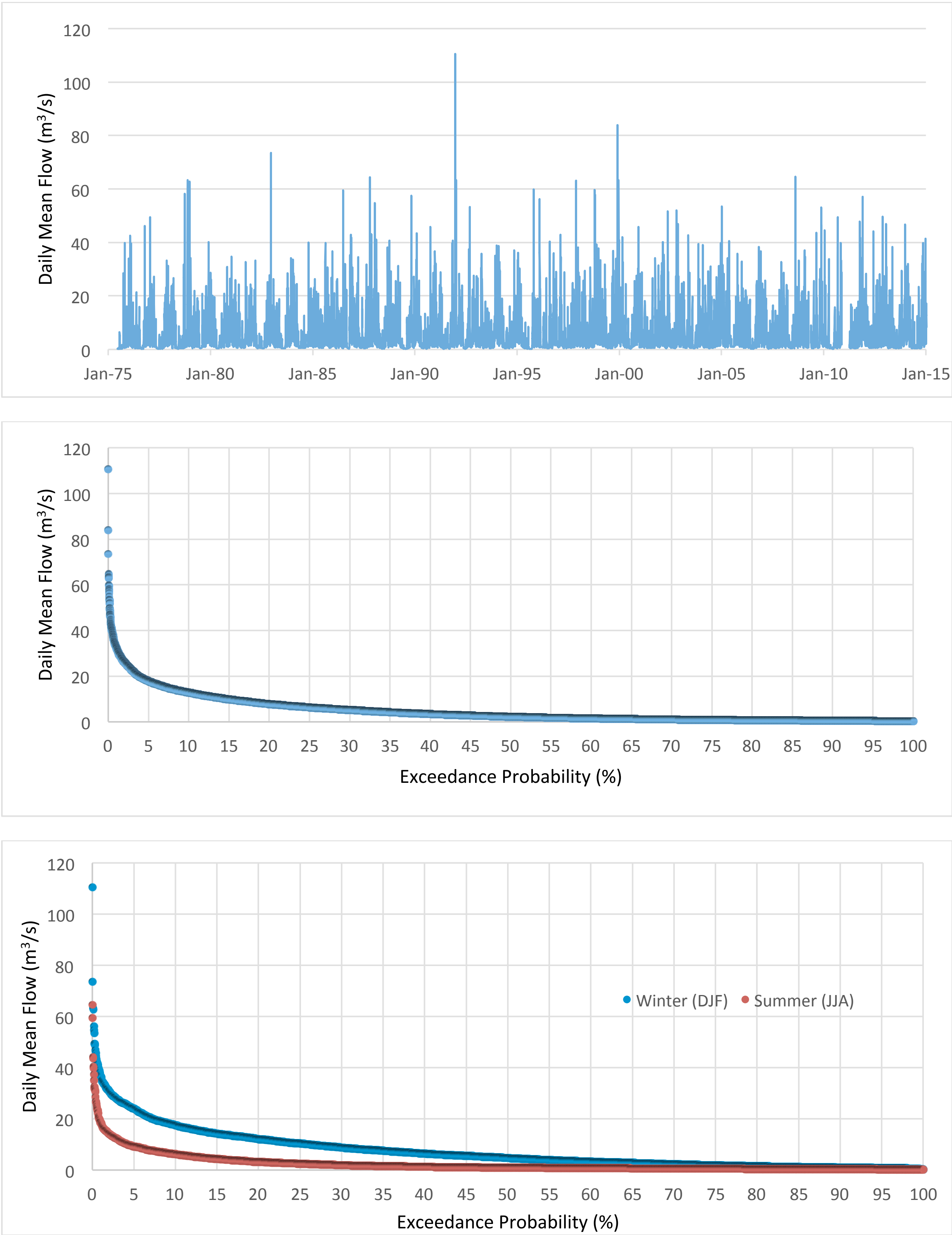
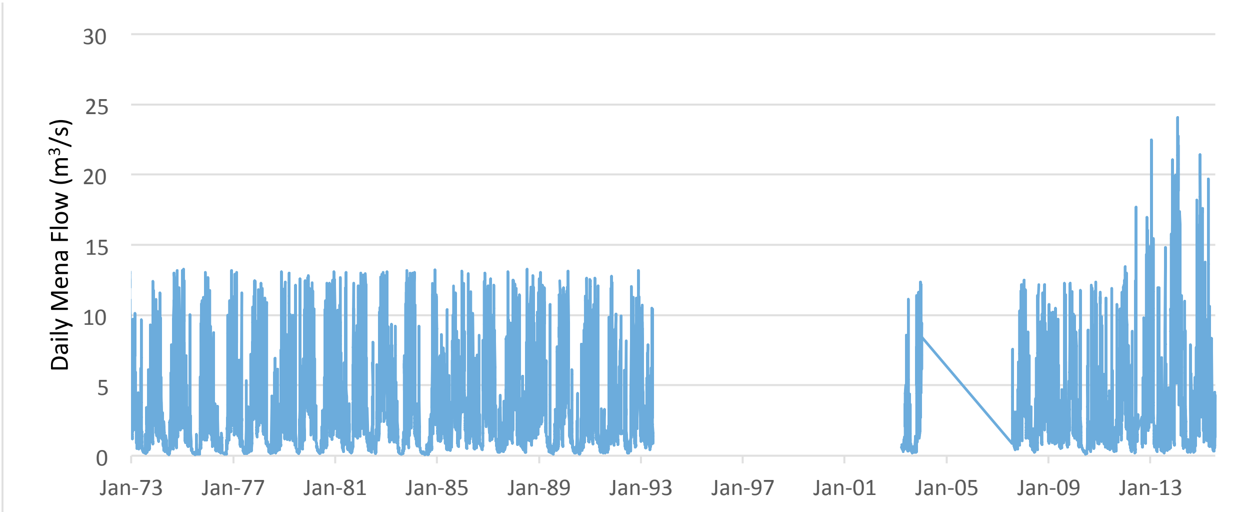
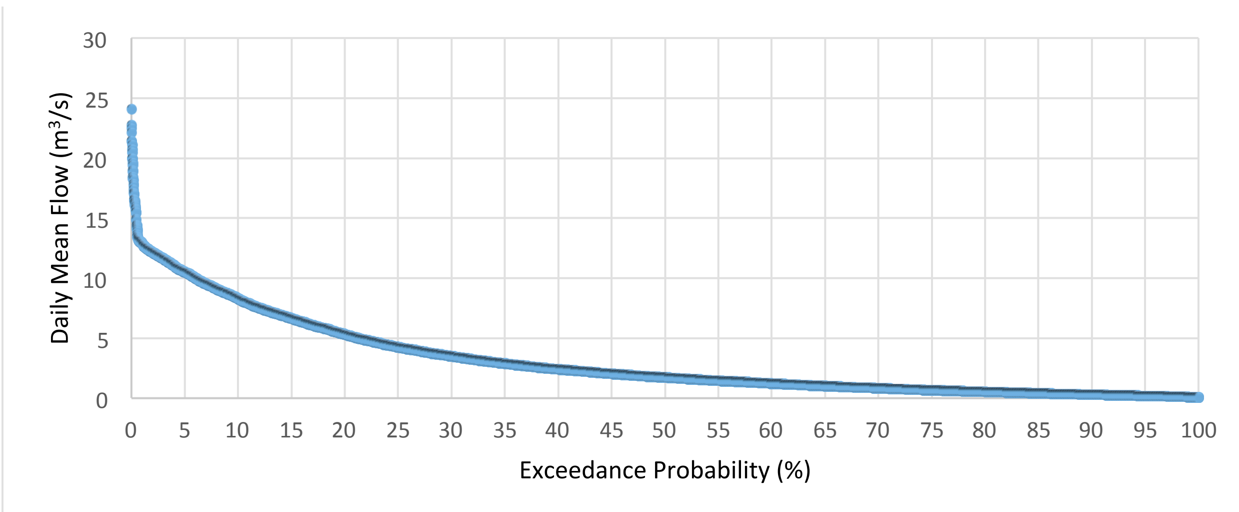


Figure B.7. Hydrograph and flow duration curve – Dowra (26029).





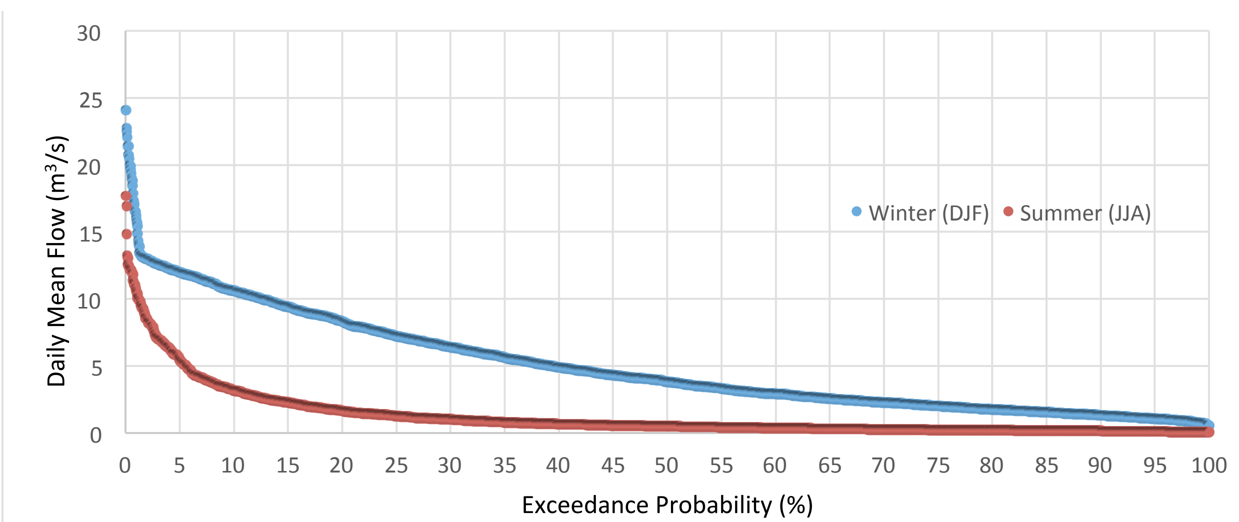


Figure B.8. Hydrograph and flow duration curve – Doonbeg (28002).

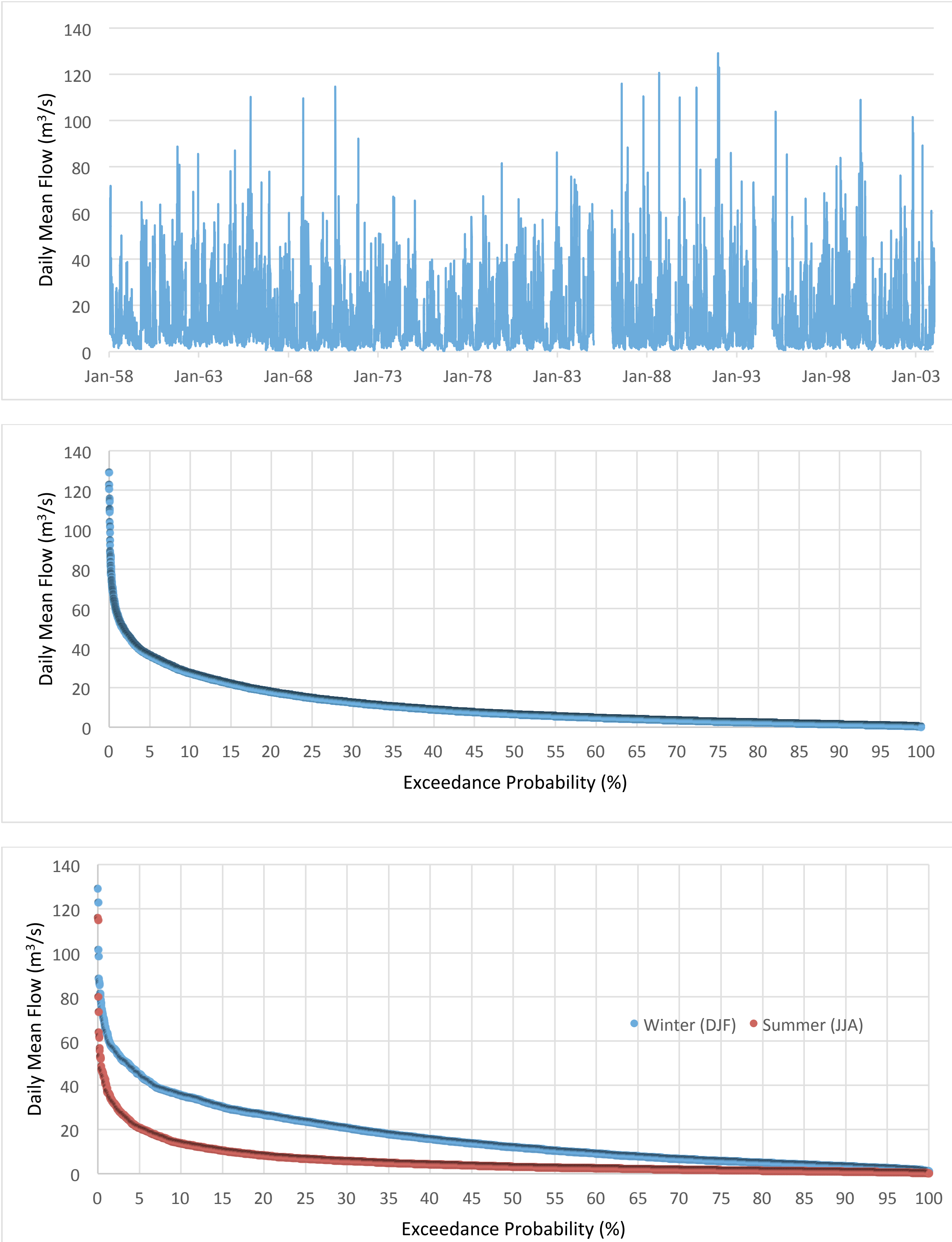
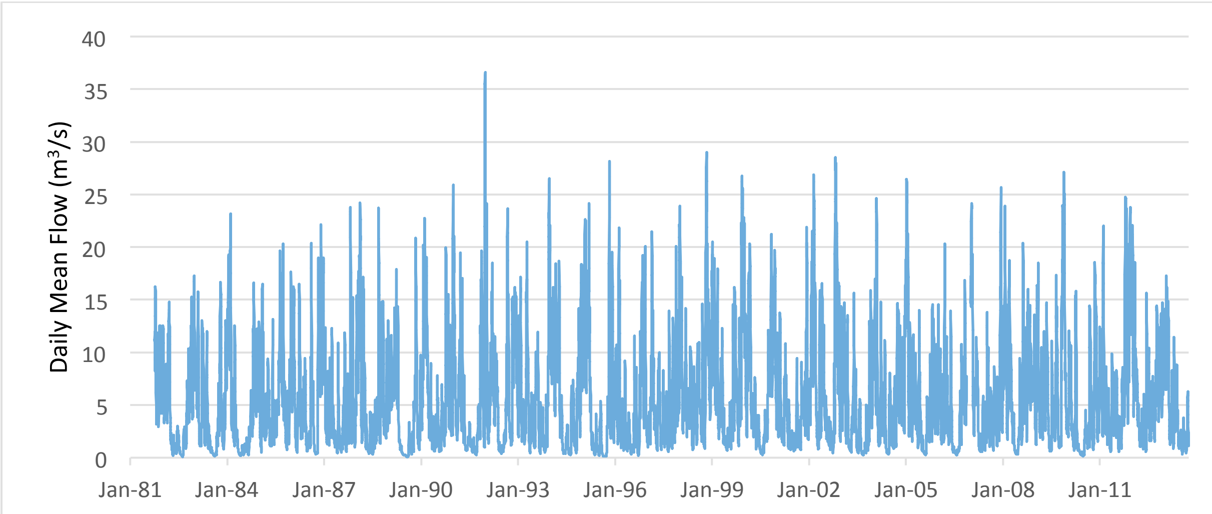
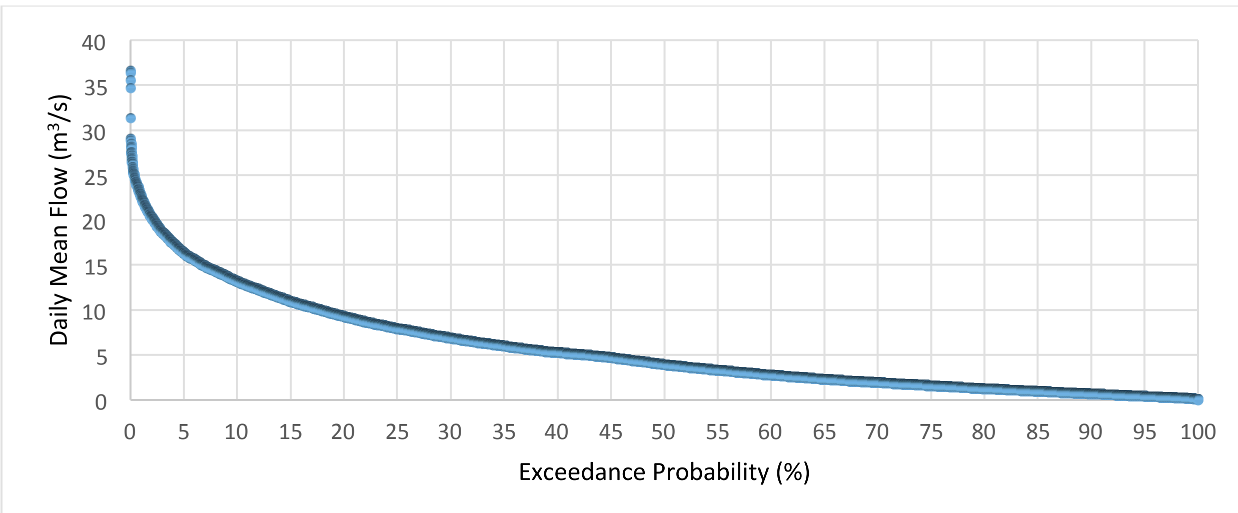


Figure B.9. Hydrograph and flow duration curve – Dromahair (35011).





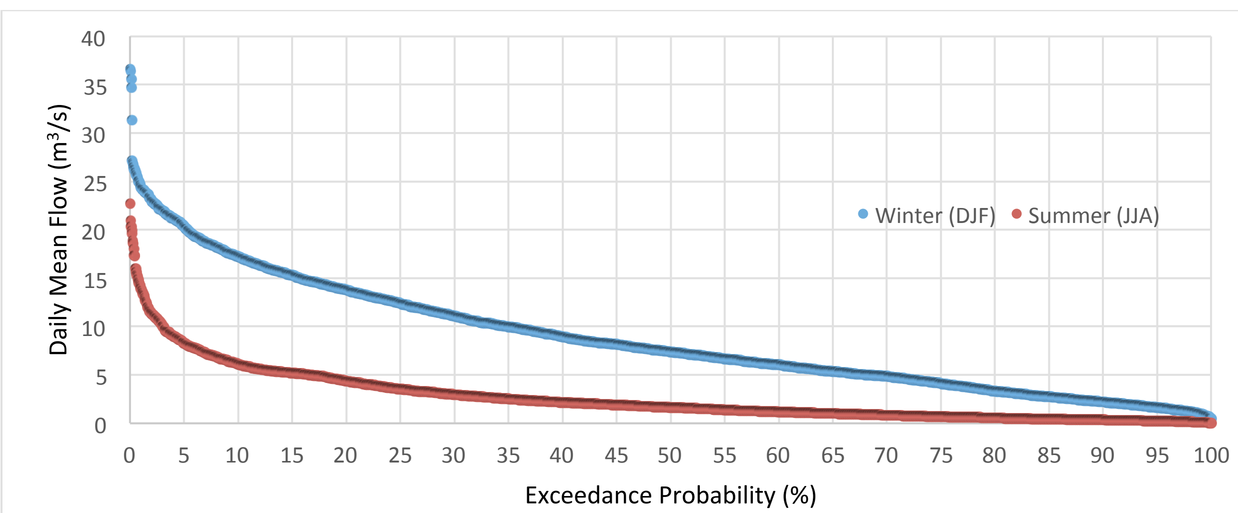
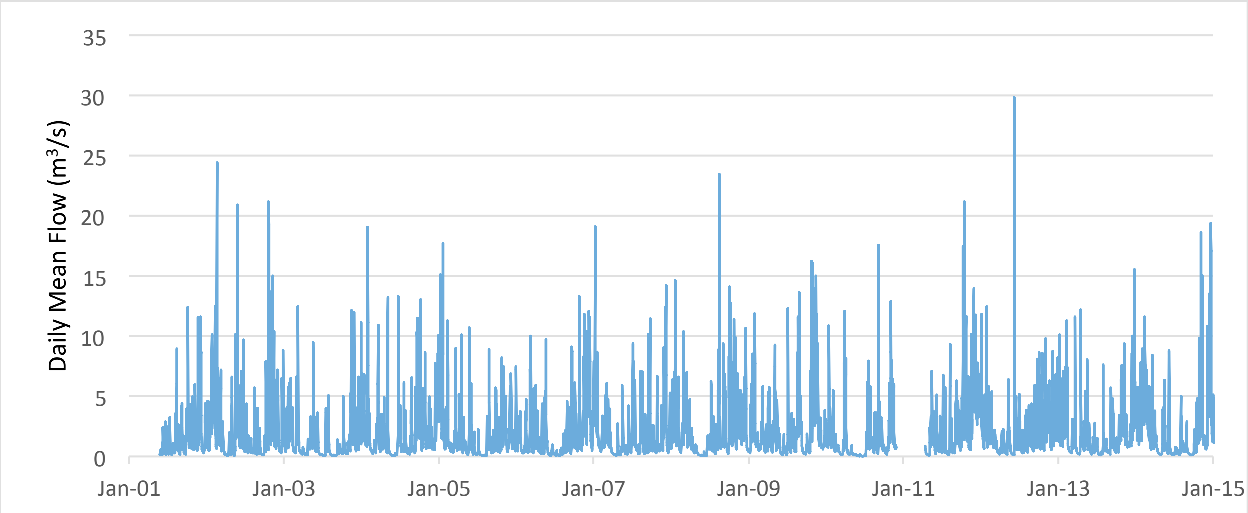
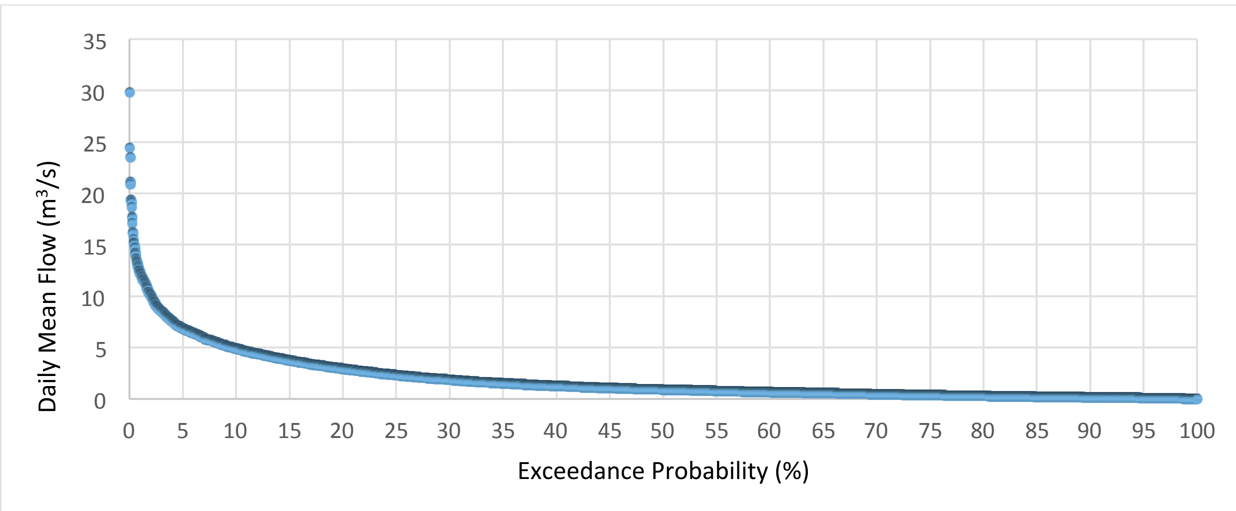


Figure B.10. Hydrograph and flow duration curve – Drumrainey Bridge (236007).





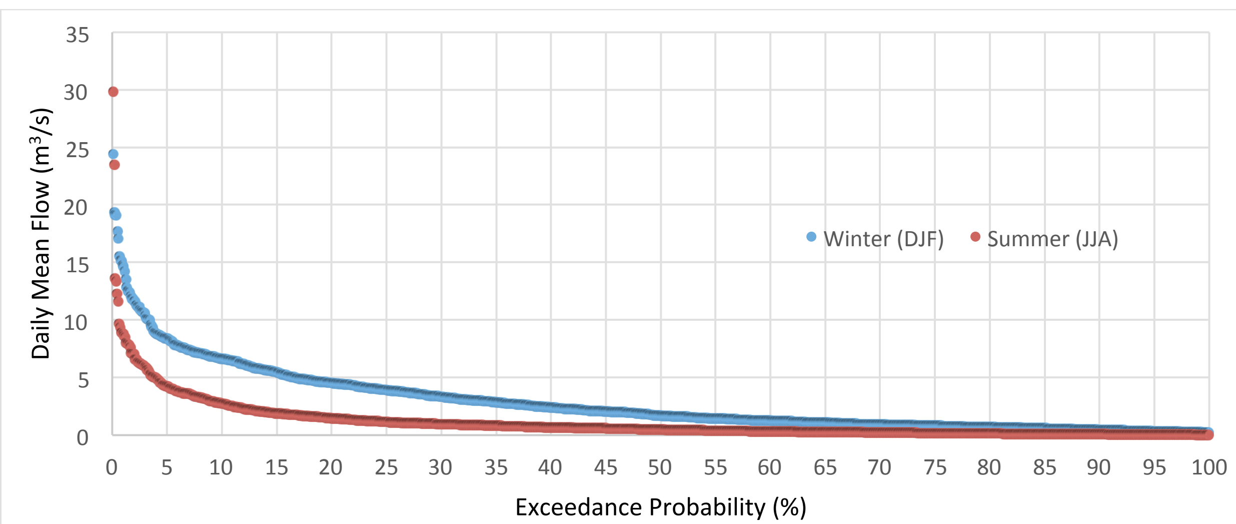


Figure B.11. Hydrograph and flow duration curve – Garrison (235050).

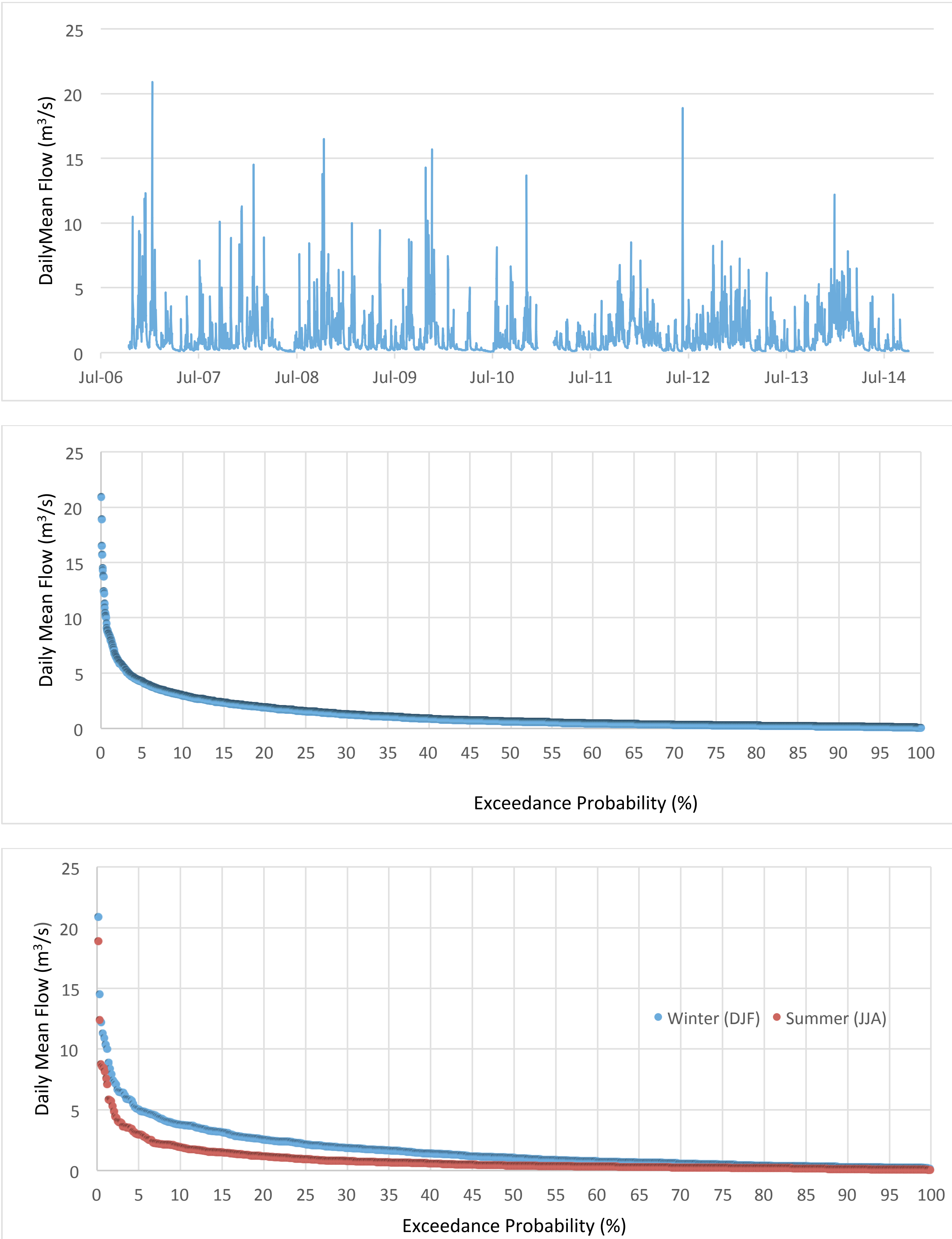


Figure B.12. Hydrograph and flow duration curve – Glenaniff Bridge (35054).

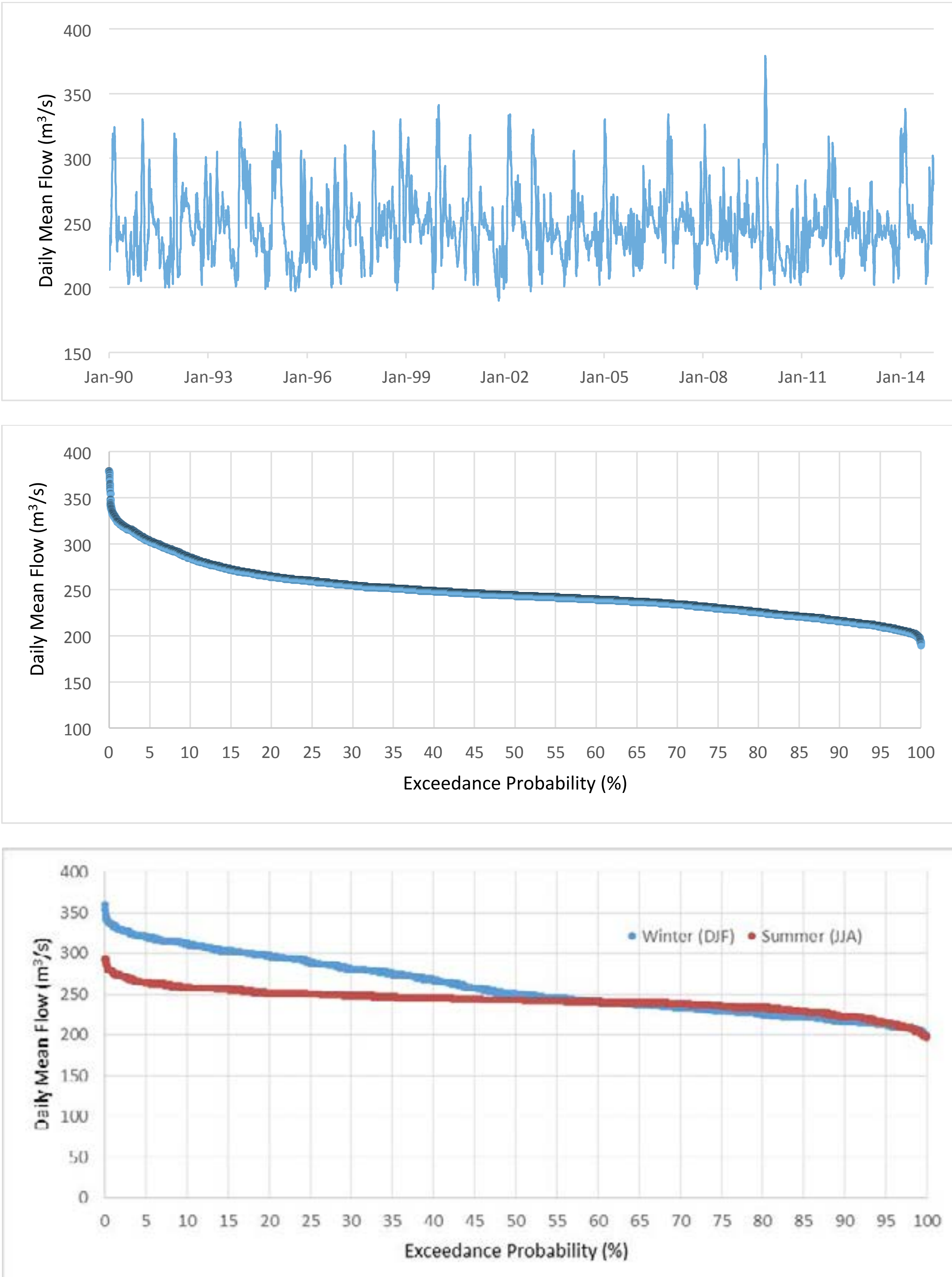


Figure B.13. Hydrograph and flow duration curve – Killyhevlin (236006).

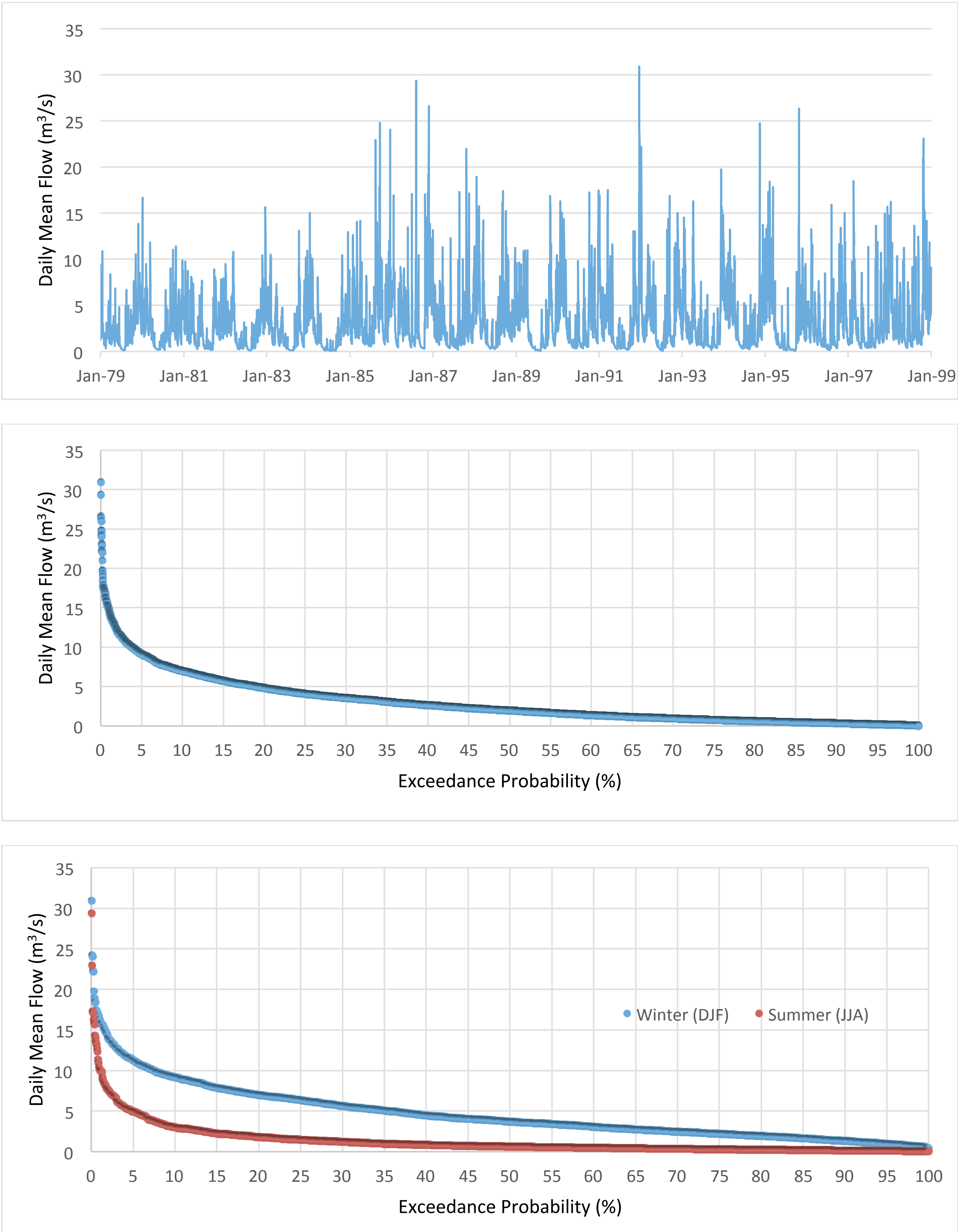
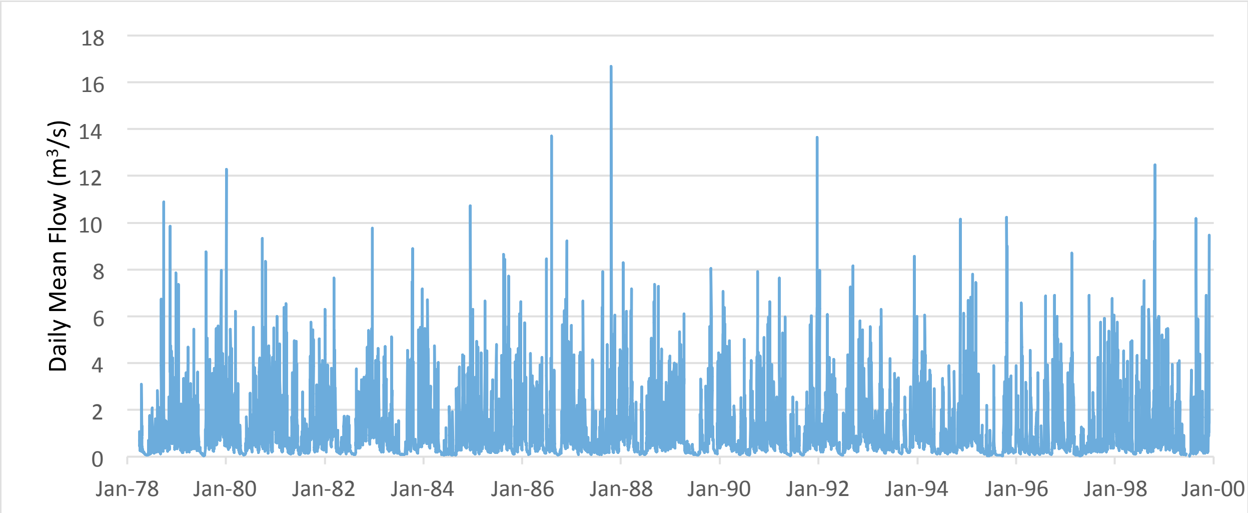
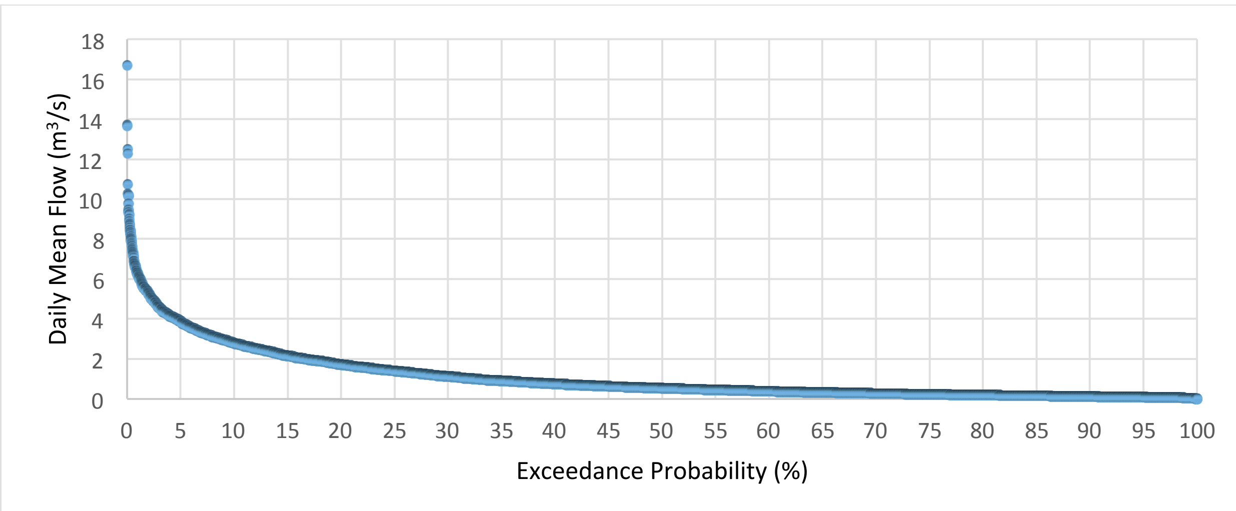


Figure B.14. Hydrograph and flow duration curve – Killywillin (36020).





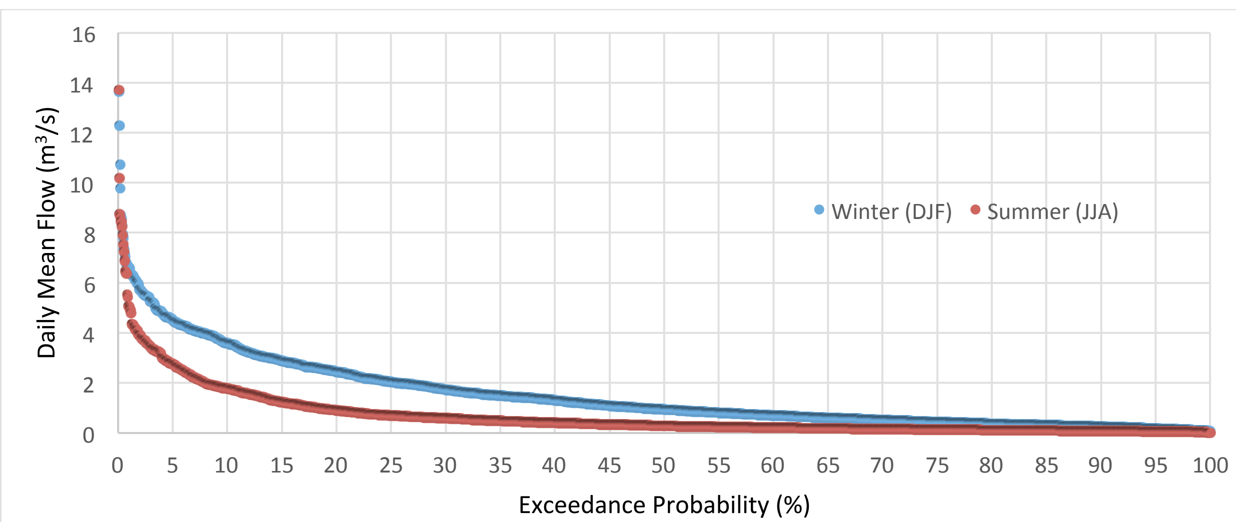
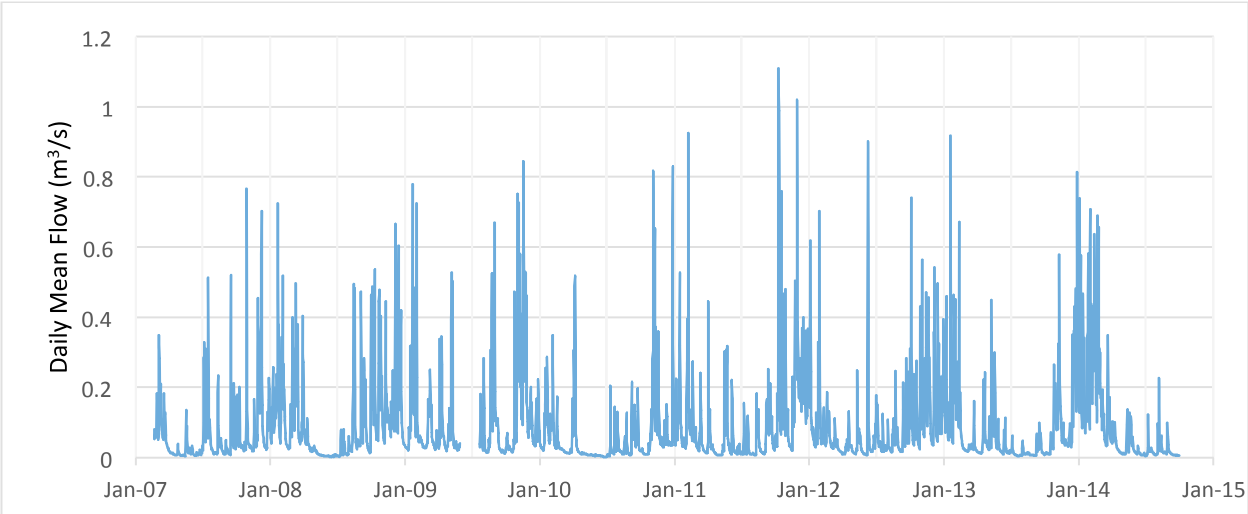
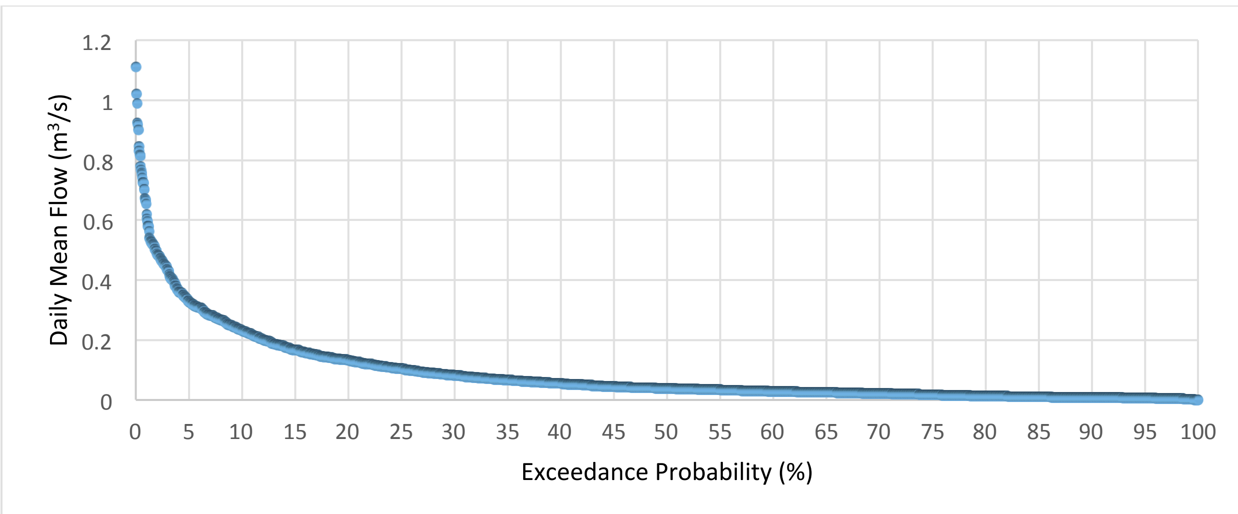


Figure B.15. Hydrograph and flow duration curve – Kiltybardan (36021).





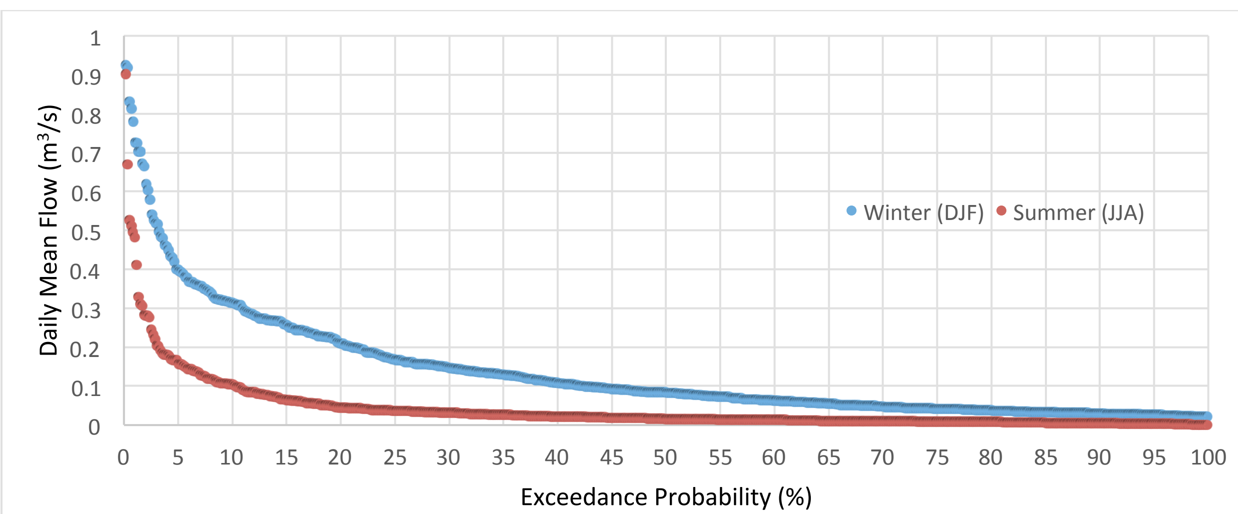


Figure B.16. Hydrograph and flow duration curve – Kinlough (35021).

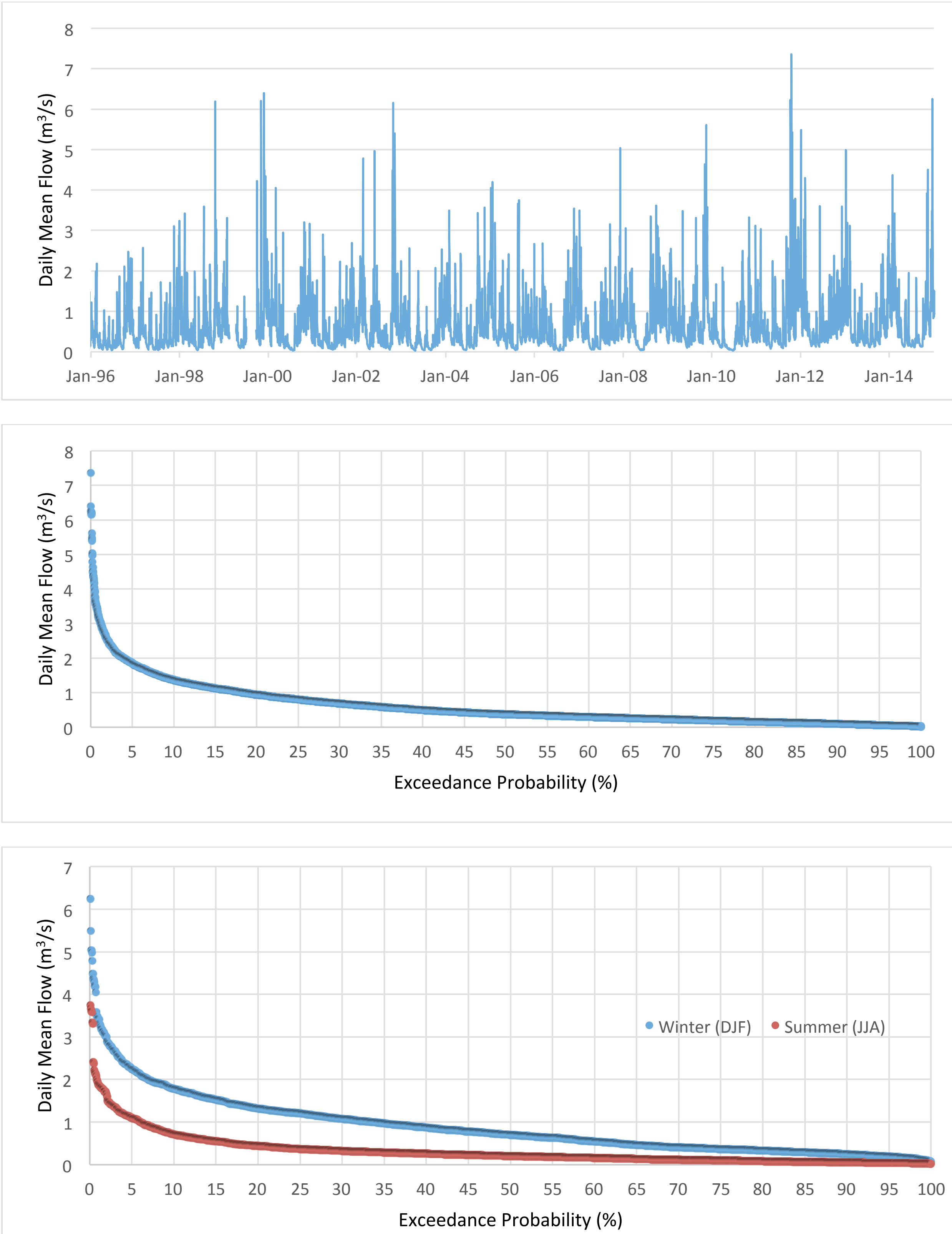


Figure B.17. Hydrograph and flow duration curve – Larkhill (Garvery) (236056).

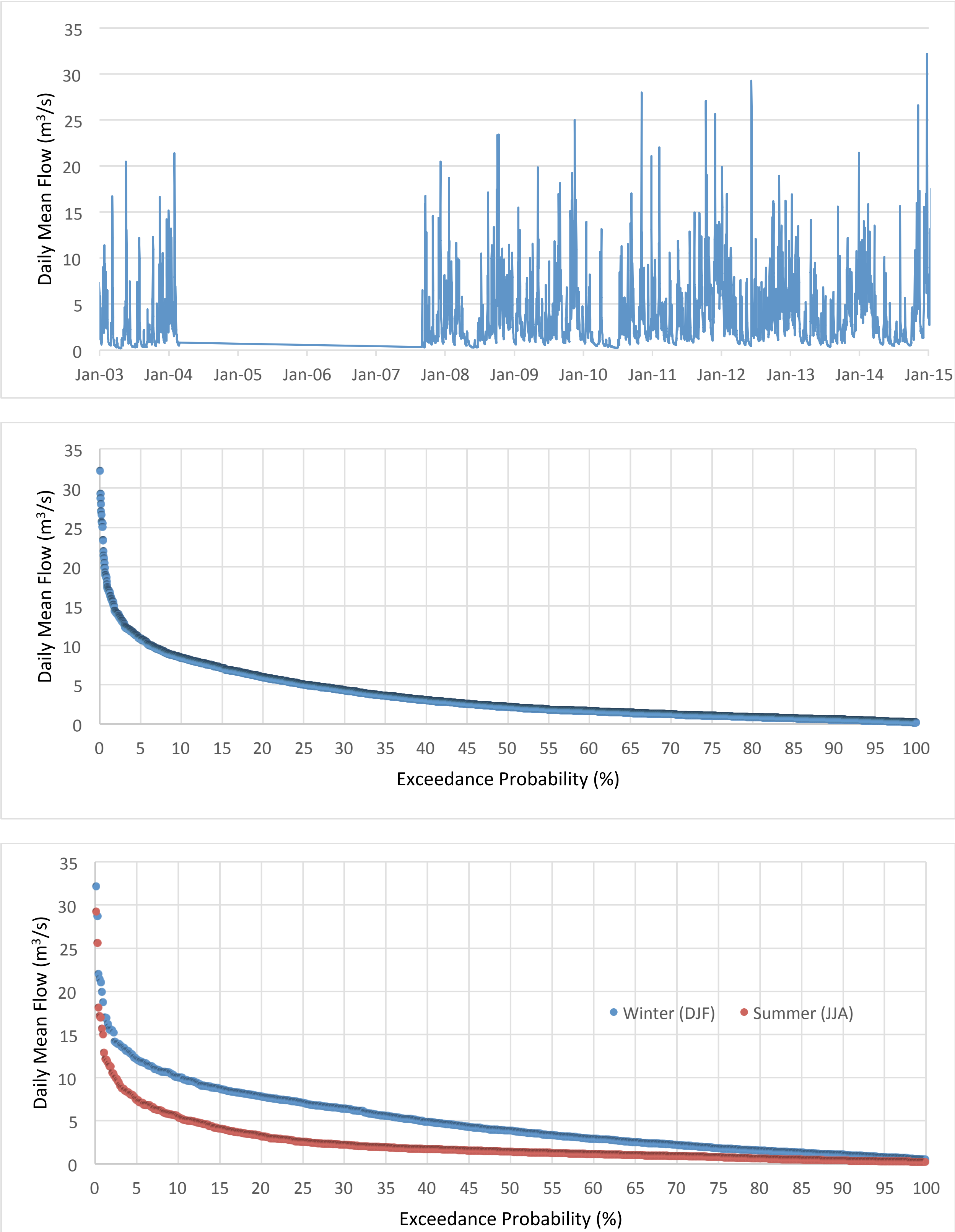


Figure B.18. Hydrograph and flow duration curve – New Br. Bonet (Manorhamilton) (35028).

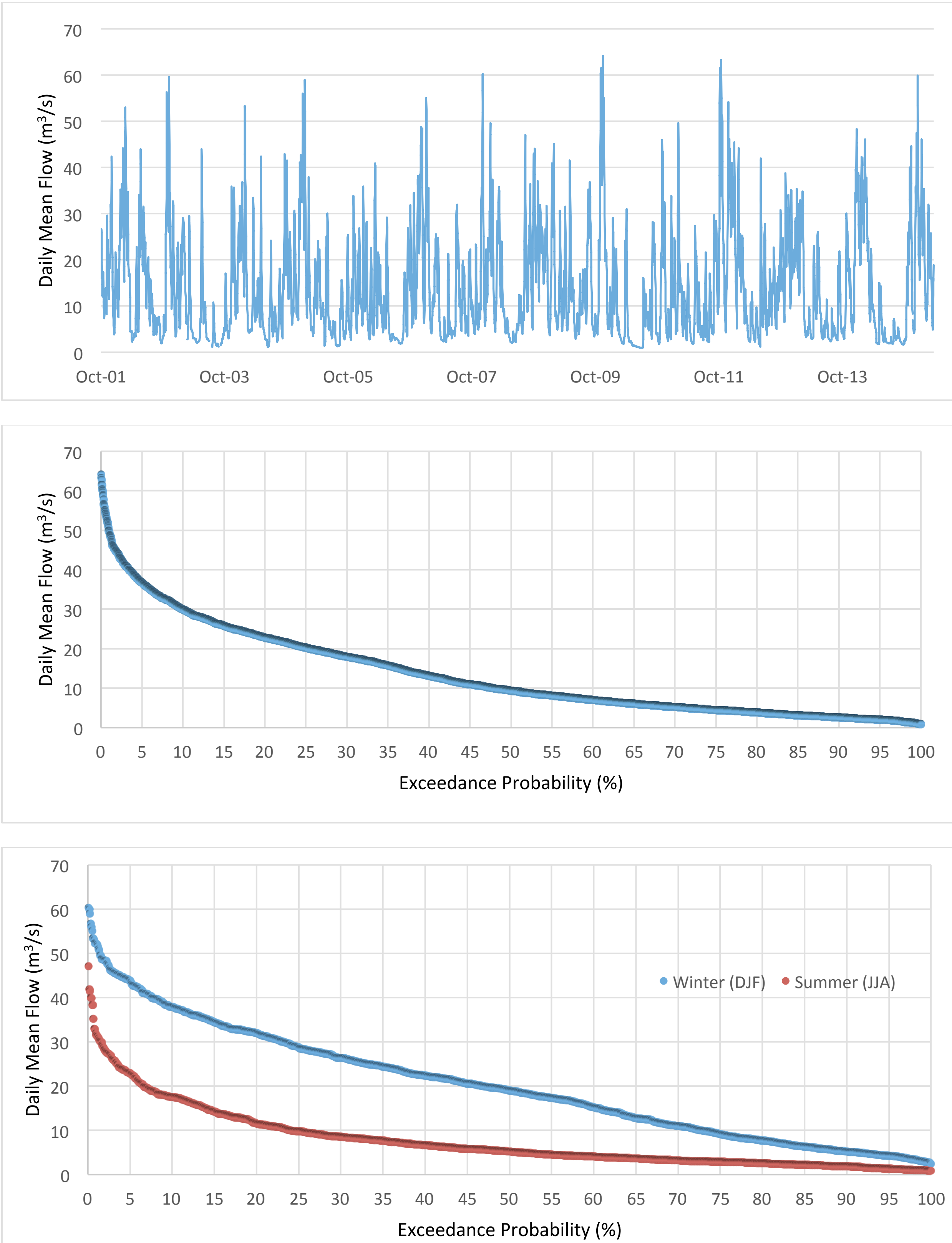


Figure B.19. Hydrograph and flow duration curve – New Br. Garravogue (35012).

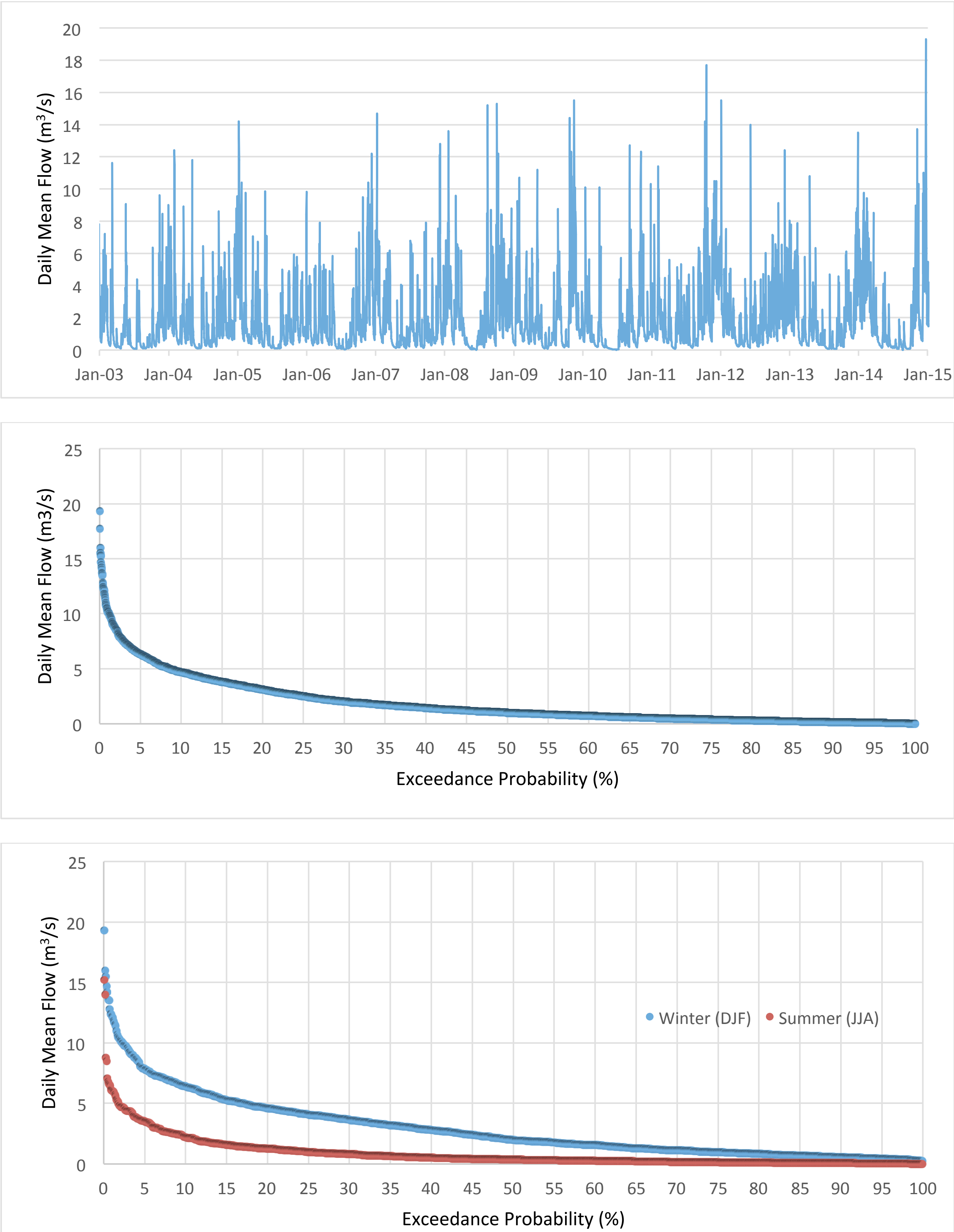


Figure B.20. Hydrograph and flow duration curve – Rockstown (County River) (235052).

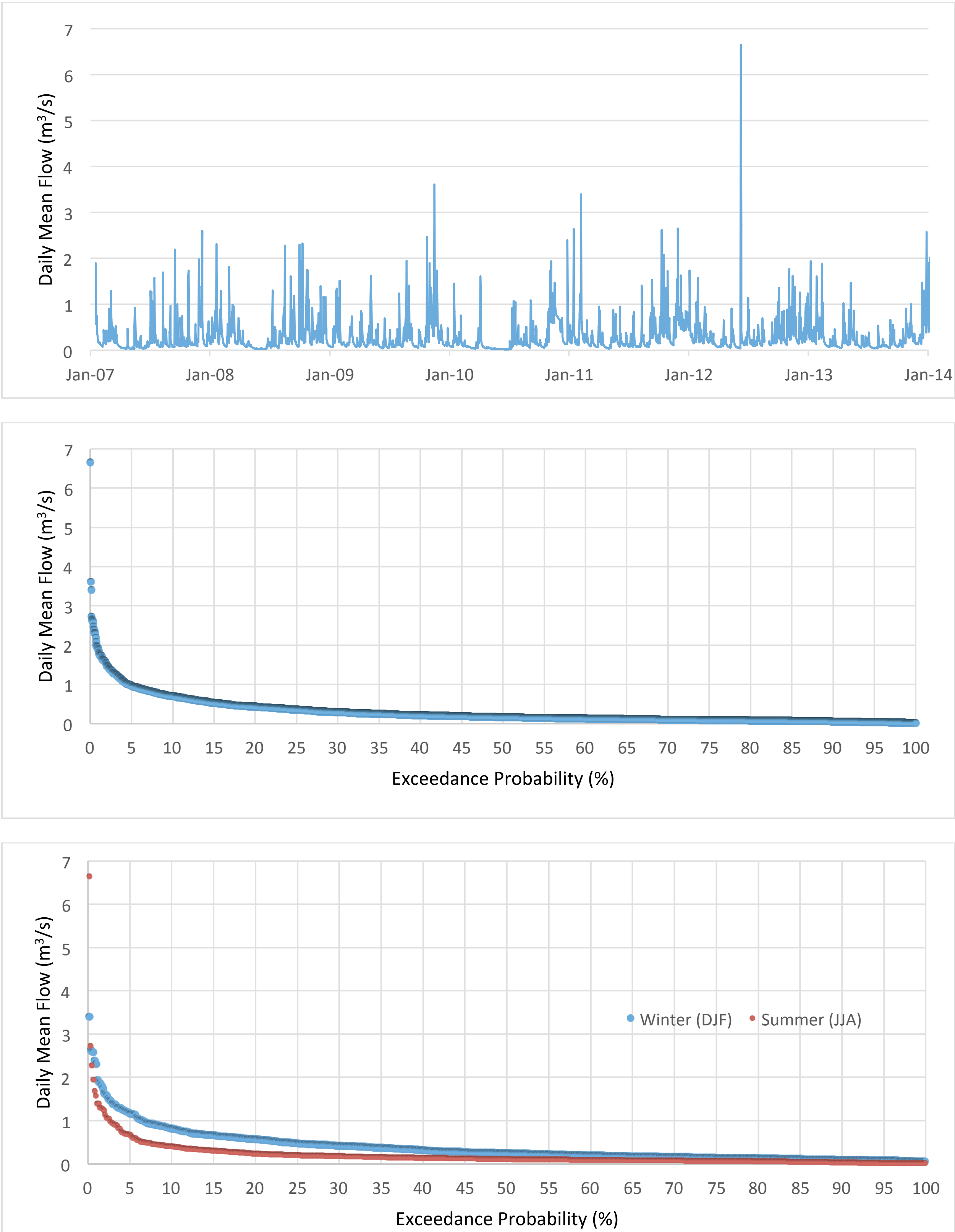
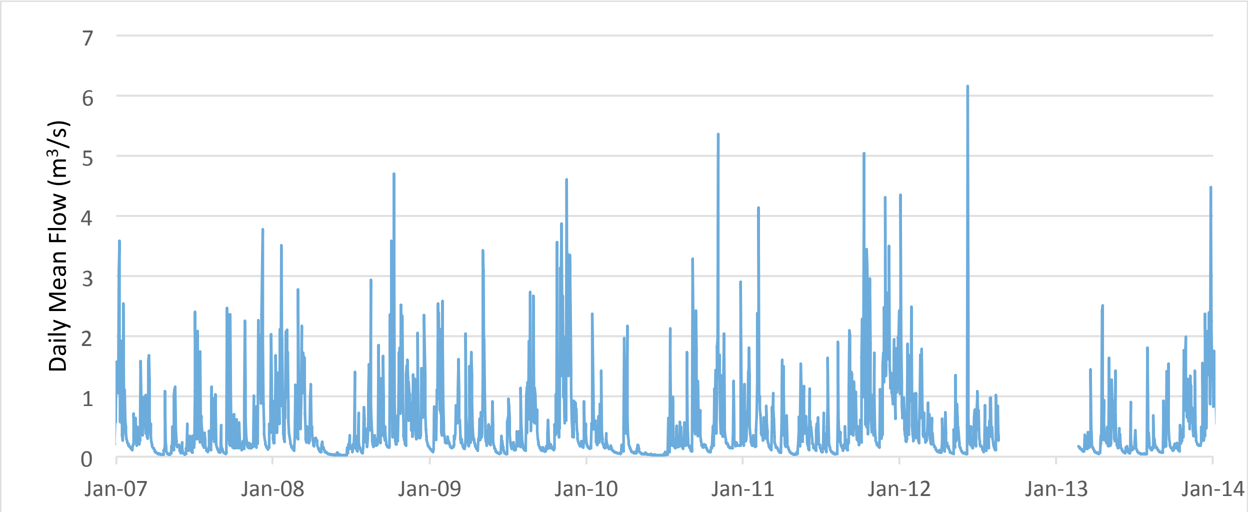
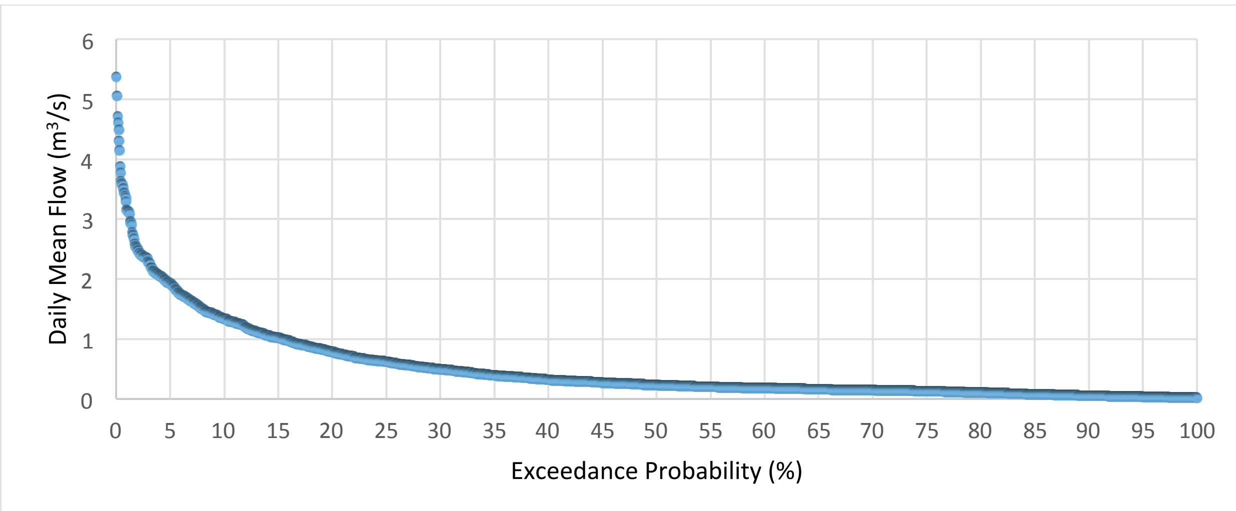


Figure B.21. Hydrograph and flow duration curve – Stracummer (35052).





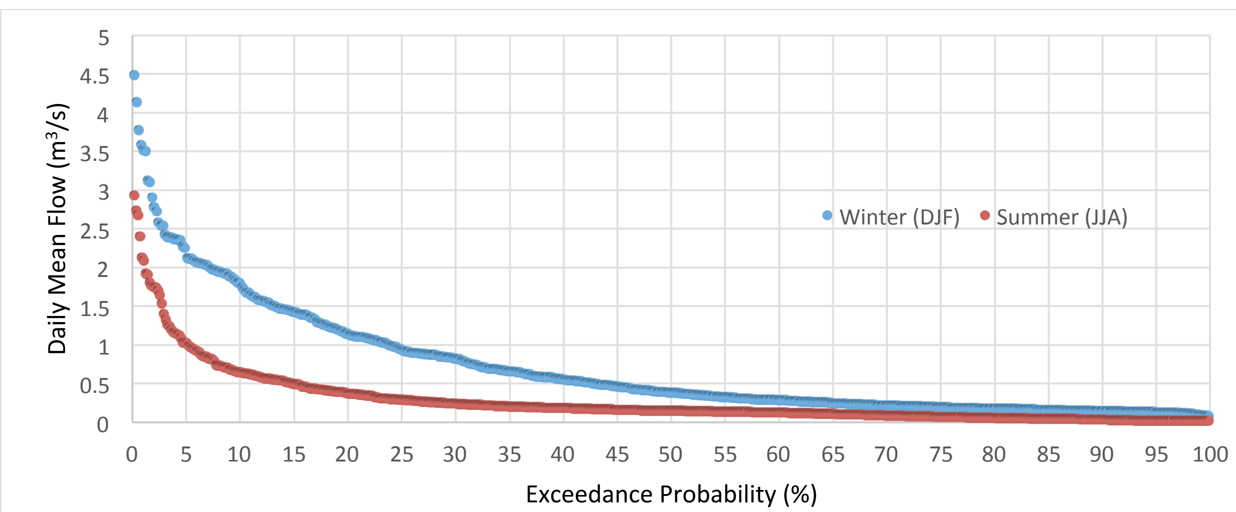
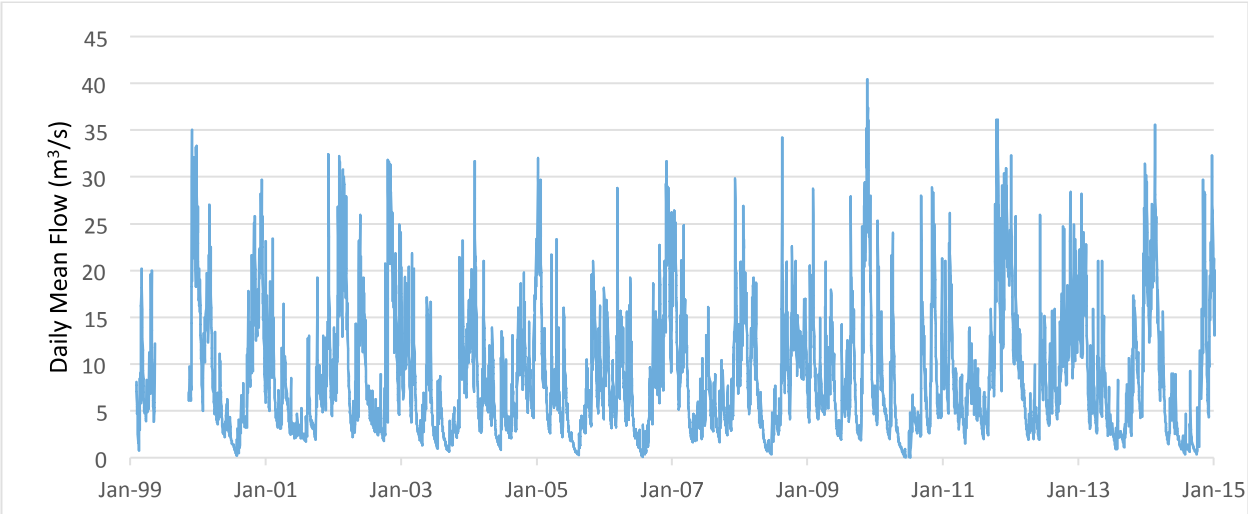
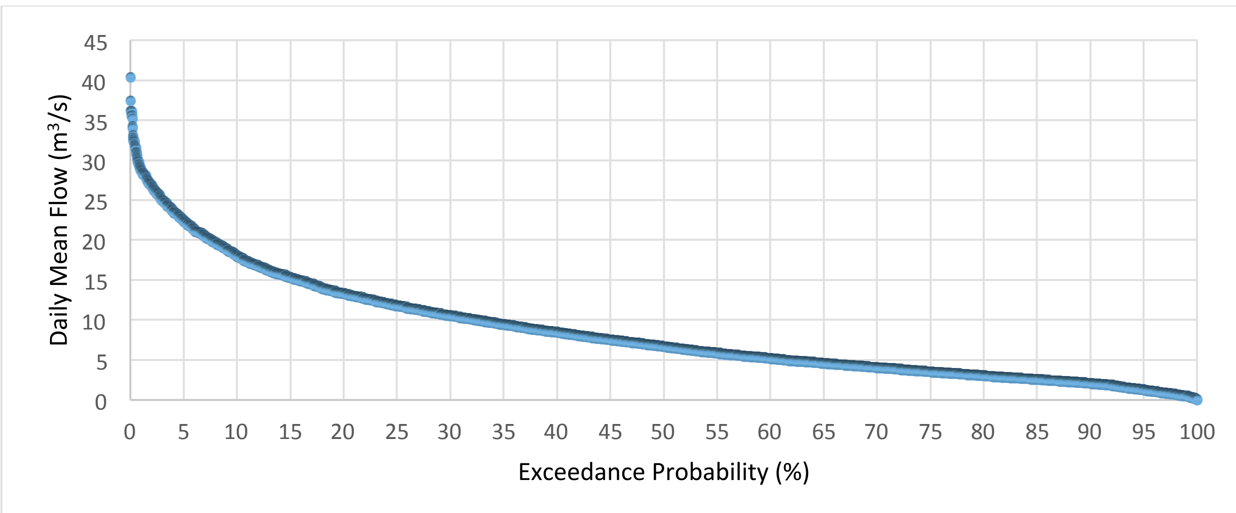


Figure B.22. Hydrograph and flow duration curve – Sraud (35055).





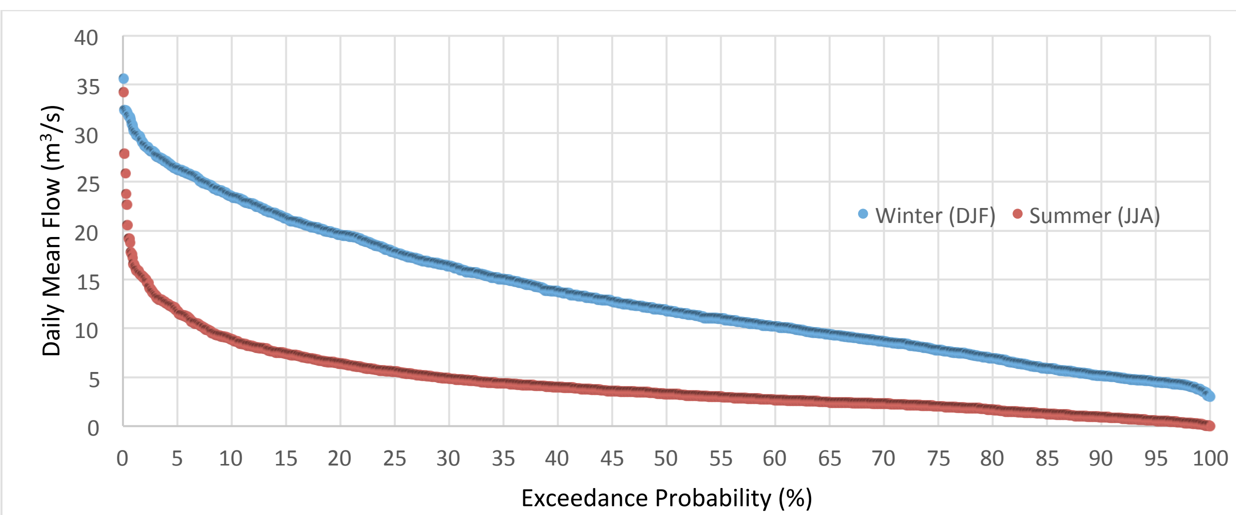


Figure B.23. Hydrograph and flow duration curve – Tilery Bridge (236058).

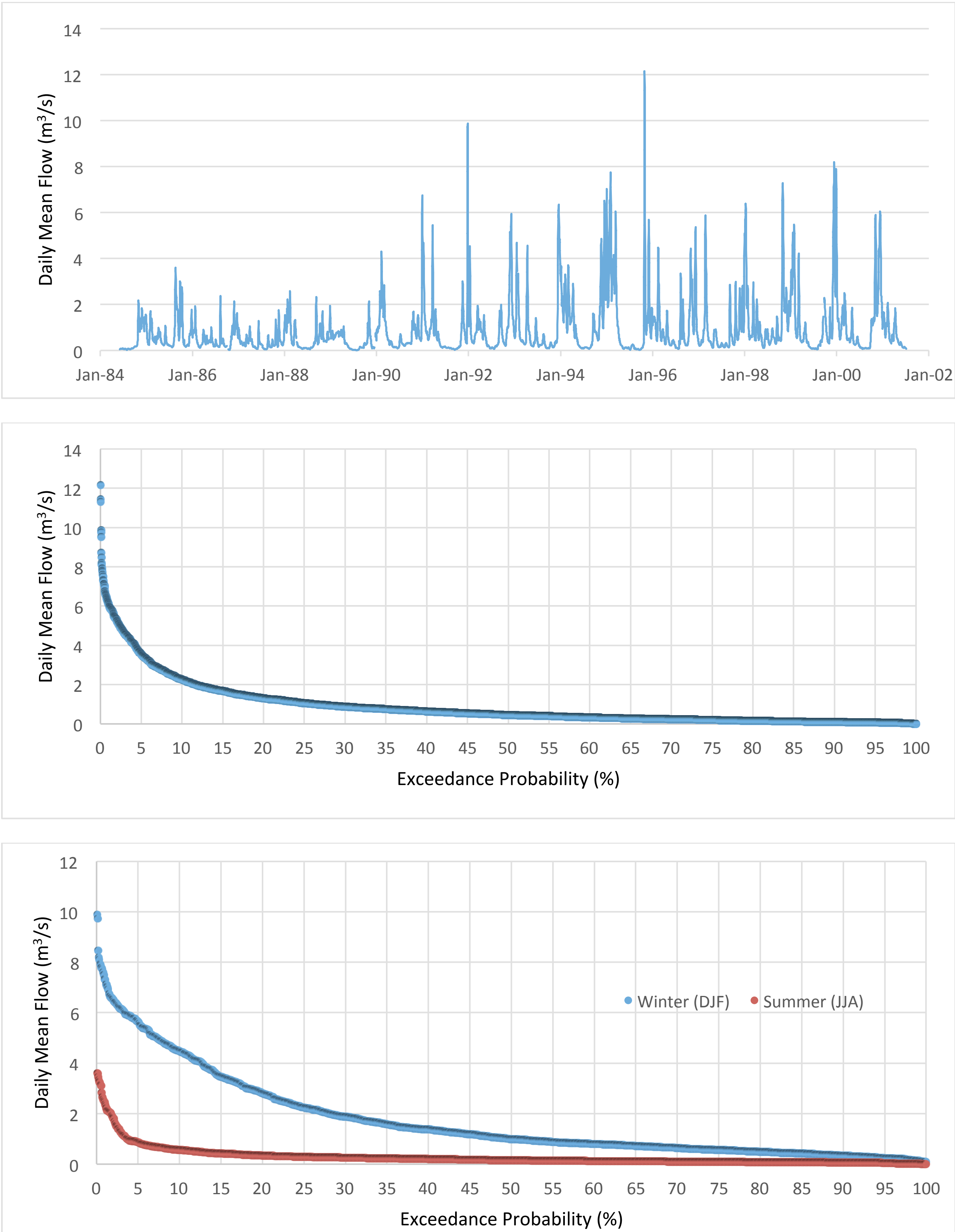


Figure B.24. Hydrograph and flow duration curve – Tomkinroad Bridge (36029).

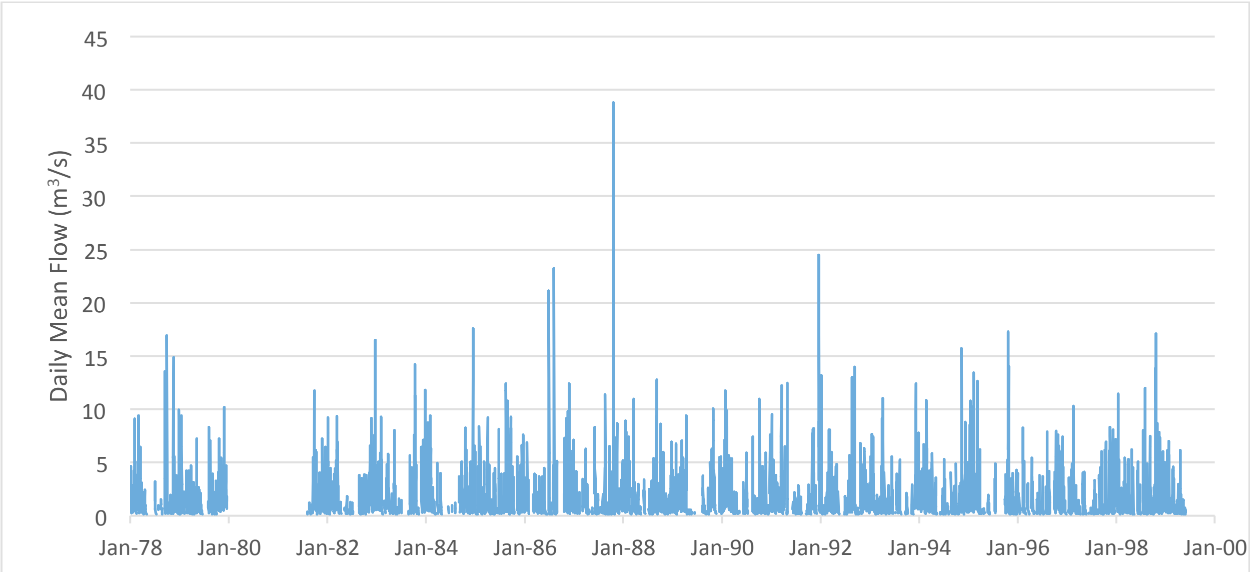


Figure B.25. Hydrograph – Aghacashlaun (36022).

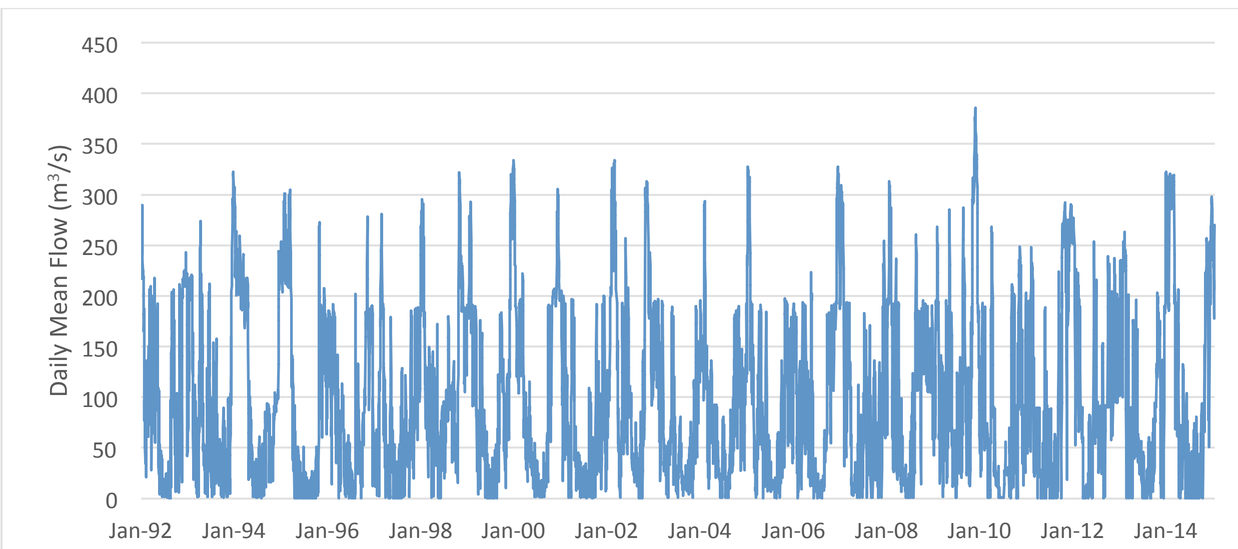


Figure B.26. Hydrograph – Cathleen Falls PS (36092).

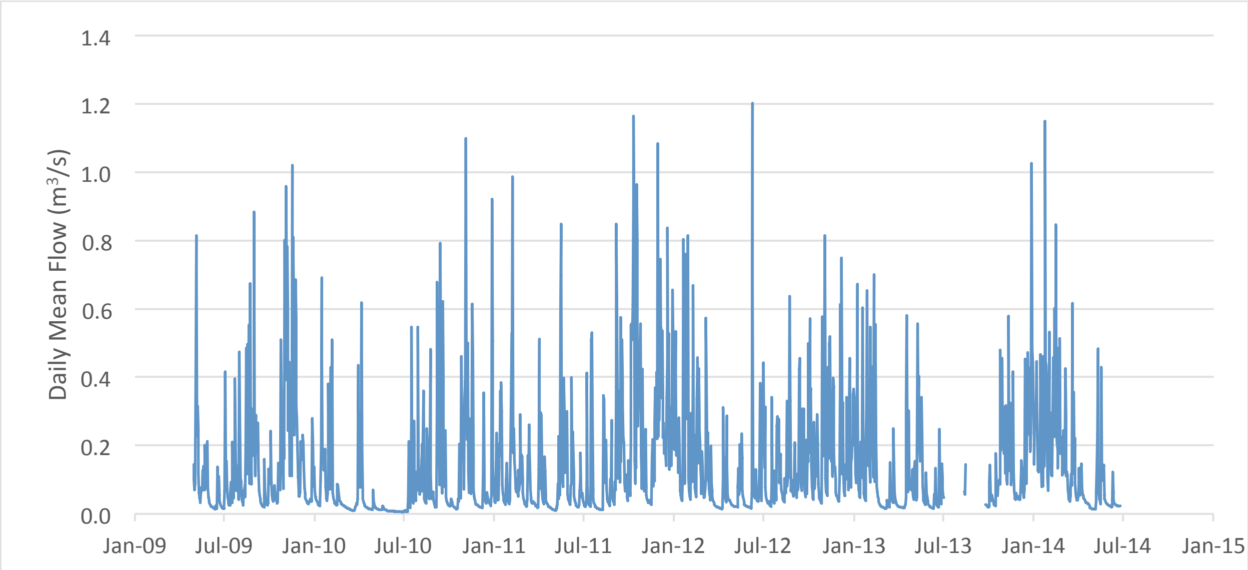


Figure B.27. Hydrograph – Manorhamilton Spring (35056).

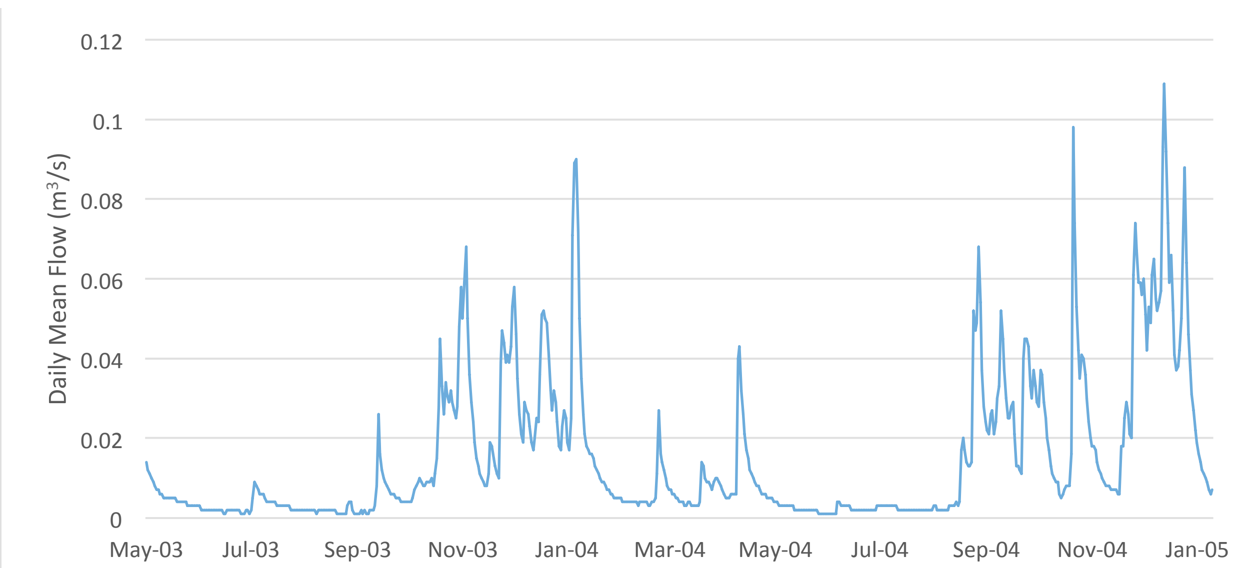


Figure B.28. Hydrograph – Parkhill (36131).